CARBON AND ENERGY BALANCES FOR A RANGE OF BIOFUELS OPTIONS

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EXECUTIVE SUMMARY

1. This is the Final Report on the project entitled "Carbon and Energy Balances for a Range of Biofuels Options" which has been undertaken for the Department of Trade and Industry Renewable Energy Programme, under Contract No. B/B6/000784/00/00, by the Resources Research Unit of Sheffield Hallam University and Forest Research. This work is set within the context of the establishment and emergence of a variety of biofuel technologies which use biomass to provide commercial sources of energy whilst offering significant potential benefits, in terms of savings in fossil fuel resource depletion and greenhouse gas emissions. It is well-known that all technologies, including biofuel options, involve the use of fossil fuels in their production and operation, resulting in associated greenhouse gas emissions. Hence, the actual benefits realised by biofuel technologies depend, crucially, on their energy and carbon balances which indicate the magnitude of fossil fuel inputs (and related greenhouse gas emissions) relative to subsequent fossil fuel savings (and avoided greenhouse gas emissions) resulting from their use as alternatives to conventional sources of energy. A considerable number of studies have been conducted for evaluating such energy and carbon balances of a range of biofuel options. However, these studies have been performed in various ways and are presented in different degrees of transparency. Consequently, a consistent approach is needed to provide a consistent, coherent and comprehensive assessment and comparison of the energy and carbon balances for a range of important biofuel options in the United Kingdom.

2. The particular aims of this project were to produce a set of baseline energy and carbon balances for a range of electricity, heat and transport fuel production systems based on biomass feedstocks. The specific objectives were:

- to agree the selection of up to 15 biofuel technologies for assessment
- to collate existing information on these technologies,
- to produce a series of flow charts representing these technologies,
- to divide the technologies into relevant modules,
- to review the collated information for establishing base case energy and carbon requirements for each module within each technology,
- to identify any significant emissions of greenhouse gases other than carbon dioxide for each module,
- to estimate such emissions where relevant data exist, and
- to specify values which are uncertain and the need for additional information.

3. The process of selecting biofuel technologies was based on consultation with scoping advisors. The resulting list of 18 separate biofuel technologies consisted of the following:

- biodiesel from oilseed rape,
- biodiesel from recycled vegetable oil,
- combined heat and power (large scale with an industrial load) by combustion of wood chip from forestry residues (large scale),
- combined heat and power (small scale) by gasification of wood chip from short rotation coppice,
- electricity (large scale) by combustion of miscanthus
- electricity (large scale) by combustion of straw,
- electricity by combustion of wood chip from forestry residues (large scale),
- electricity by combustion of wood chip from short rotation coppice,

- electricity by gasification of wood chip from forestry residues (large scale),
- electricity by gasification of wood chip from short rotation coppice,
- electricity by pyrolysis of wood chip from forestry residues (large scale),
- electricity by pyrolysis of wood chip from short rotation coppice,
- ethanol from lignocellulosics,
- ethanol from sugar beet,
- ethanol from wheat,
- heat (small scale) by combustion of wood chip from forestry residues (large scale),
- heat (small scale) by combustion of wood chip from woodland residues (small scale), and
- rapeseed oil from oilseed rape.

4. Application of a modular structure for describing biofuel technologies determines that 9 biomass provision modules and 12 biomass processing modules were required to evaluate baseline carbon and energy balances for 18 selected biofuel technologies. The results of reviewing 43 existing studies on these selected biofuel technologies are presented. Using the concise format of the review summaries, provided in Appendix A, the main features of these studies were identified. These consist of their coverage (in terms of estimates of energy inputs, carbon dioxide, methane, nitrous oxide and total greenhouse gas emissions), transparency (in relation to methods and details of calculation) and relevance (as regards the countries where the results are applicable). This review process enabled the most suitable existing studies to be selected for the preparation of baseline energy and carbon balances.

5. Key details for each of the selected biofuel technologies have been summarised. Flow charts were formulated to represent the essential stages of the production of biomass and its conversion into relevant biofuels, as well as the prominent inputs and outputs for each process chain. Estimates, qualified with indications of uncertainty, for primary energy inputs and carbon dioxide, methane, nitrous oxide and total greenhouse gas outputs were derived and recorded systematically on spreadsheets. Notes provide detailed information on methods of calculation, any necessary modifications and original sources of data. Flow charts, spreadsheets and notes for each selected biofuel technology are presented in Appendices B to T.

6. Specific results were produced, in the form of energy requirements (primary energy input per delivered energy output), carbon requirements (carbon dioxide outputs per delivered energy output), methane requirements (methane output per delivered energy output), nitrous oxide requirements (nitrous oxide output per delivered energy output) and total greenhouse gas requirements (equivalent carbon dioxide output per delivered energy output). Where relevant, results are quoted in terms of the net calorific value of the biofuel under consideration. These results are summarised in Table I. Comparison with a sample of reference results for conventional sources of energy, in the form of ultra low sulphur diesel, unleaded petrol and fuel oil obtained from crude oil, average grid electricity supplies, industrial oil-fired combined heat and power and heat from a small-scale oil-fired boiler, is provided by Table II.

Table I Summary of Energy, Carbon, Methane, Nitrous Oxide and Total Greenhouse Gas Requirements for Selected Biofuel Technologies

Selected Biofuel Technology	Energy Requirement (MJ/MJ)	Carbon Requirement (kg CO_2/MJ)	Methane Requirement (g CH_4/MJ)	Nitrous Oxide Requirement (g N_2O/MJ)	Total Greenhouse Gas Requirement (kg eq CO_2/MJ)
Biodiesel from oilseed rape	0.437 ± 0.024(a)	0.025 ± 0.001(a)	0.028 ± 0.002(a)	0.048 ± 0.006(a)	0.041 ± 0.002(a)
Biodiesel from recycled vegetable oil	0.188 ± 0.018(a)	0.013 ± 0.002(a)	0.007 ± 0.001(a)	-	0.013 ± 0.002(a)
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.139 ± 0.012(b)	0.007 ± 0.001(b)	0.002(b)	0.005(b)	0.008 ± 0.002(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	0.102 ± 0.019(b)	0.005 ± 0.001(b)	0.001(b)	-	0.005 ± 0.001(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	0.092 ± 0.016(b)	0.004 ± 0.001(b)	-	-	0.004 ± 0.001(b)
Electricity (large scale) by combustion of miscanthus	0.272 ± 0.019	0.018 ± 0.001	0.008	0.021	0.026 ± 0.001
Electricity (large scale) by combustion of straw	0.607 ± 0.038	0.029 ± 0.002	0.025 ± 0.003	0.111 ± 0.011	0.066 ± 0.004
Electricity by combustion of wood chip from forestry residues (large scale)	0.309 ± 0.023	0.016 ± 0.001	0.004	0.019	0.022 ± 0.001
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.381 ± 0.056	0.018 ± 0.003	0.004	0.025 ± 0.003	0.025 ± 0.003
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.352 ± 0.048	0.016 ± 0.002	0.003	0.023 ± 0.003	0.023 ± 0.003
Electricity by gasification of wood chip from forestry residues (large scale)	0.133 ± 0.009	0.007	0.003	-	0.007
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.169 ± 0.027	0.008 ± 0.001	0.003	0.001	0.008 ± 0.001
Electricity by gasification of wood chip from short rotation coppice (Option B)	0.154 ± 0.023	0.007 ± 0.001	0.003	-	0.007 ± 0.001
Electricity by pyrolysis of wood chip from forestry residues (large scale)	0.284 ± 0.022	0.014 ± 0.001	0.014 ± 0.002	-	0.014 ± 0.001
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.331 ± 0.040	0.016 ± 0.002	0.014 ± 0.002	0.001	0.016 ± 0.002
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.312 ± 0.035	0.014 ± 0.002	0.014 ± 0.002	0.001	0.015 ± 0.002
Ethanol from lignocellulosics (wheat straw)	- 0.028 ± 0.037(a)	0 ± 0.002(a)	- 0.024 ± 0.005(a)	0.043 ± 0.005(a)	0.013 ± 0.002(a)
Ethanol from sugar beet	0.496 ± 0.044(a)	0.034 ± 0.003(a)	0.013 ± 0.001(a)	0.018 ± 0.002(a)	0.040 ± 0.003(a)
Ethanol from wheat	0.464 ± 0.032(a)	0.024 ± 0.002(a)	0.028 ± 0.003(a)	0.012 ± 0.001(a)	0.029 ± 0.002(a)
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.100 ± 0.006	0.005	0.017	0.005	0.007
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.092 ± 0.006	0.005	0.017	0.005	0.007
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.094 ± 0.006	0.005	0.017	0.005	0.007
Rapeseed Oil from oilseed rape	0.291 ± 0.018(a)	0.015 ± 0.001(a)	0.020 ± 0.002(a)	0.046 ± 0.006(a)	0.031 ± 0.002(a)

Notes

(a) Based on the net calorific value of the biofuel.

(b) Per unit of electricity or heat.

Table II Reference Results for a Relevant Sample of Conventional Sources of Energy

Conventional Energy Supply	Energy Requirement (MJ/MJ)	Carbon Requirement (kg CO_2/MJ)	Methane Requirement (g CH_4/MJ)	Nitrous Oxide Requirement (g N_2O/MJ)	Total Greenhouse Gas Requirement (kg eq CO_2/MJ)
Ultra Low Sulphur Diesel from Crude Oil(a)	1.26	0.087	0.025(b)	0.000075(b)	0.087(b)
Unleaded Petrol from Crude Oil(a)	1.19	0.081	0.022(b)	0.000028(b)	0.081(b)
Fuel Oil from Crude Oil(a)	1.19	0.087	0.022(b)	0.000028(b)	0.087(b)
Electricity from UK Grid Supplies in 1996	3.08	0.150	0.404	0.006	0.162
Industrial Combined Heat and Power(c)	1.38	0.100	0.027	0.001	0.101
Heat from Small-Scale Oil-Fired Boiler	1.45	0.104	0.029	0.001	0.105

Notes

(a) Based on the net calorific value of the fuel.

(b) Excluding direct CH_4 and N_2O emissions during combustion due to variations in vehicle and equipment performance.

(c) Per unit of electricity or heat.

7. The conclusions of this work can be summarised as follows:

   - there is a substantial collection of existing studies on the energy inputs and greenhouse gas outputs of a range of biofuel technologies which could be potentially important in the United Kingdom,
   - although these studies vary in relevance, detail and transparency, it was possible to identify those which could provide a suitable basis for deriving baseline energy and carbon balances for selected biofuel technologies,
   - complete estimates of primary energy inputs and carbon dioxide, methane, nitrous oxide and total greenhouse gas outputs, qualified by indications of uncertainty, were calculated for selected biofuel technologies,
   - these estimates were recorded in spreadsheets, supported by flow charts and detailed notes to provide a high degree of standardisation and transparency,
   - results were derived in the form of energy, carbon dioxide, methane, nitrous oxide and total greenhouse gas requirements, and
   - these baseline results demonstrate that all the biofuel technologies considered achieve, in varying degrees, positive energy and greenhouse gas benefits which would offer savings in the consumption of fossil fuel resources and associated emissions of greenhouse gases.

8. As part of recommendations for further work, the following additional data requirements were identified:

   - agricultural activity data for estimating the primary energy inputs and greenhouse gas outputs of the manufacture, repair and maintenance for agricultural machinery used in the production of oilseed rape, miscanthus, sugar beet and wheat,
   - agreed evaluation of the effect of removing straw from fields for fuel use on

fertiliser use and yields for subsequent crops,

- direct methane and nitrous oxide emissions from the operation of a combined heat and power plant based on the gasification of wood chips, power only plants based on the combustion, gasification and pyrolysis of wood chips, and an ethanol plant based on lignocellulosics (straw),
- physical inventories of plant components for calculation of the primary energy inputs to the construction of a combined heat and power plant based on the combustion of wood chips, power only plants based on the combustion of miscanthus, straw and wood chips, and ethanol plants based on lignocellulosics (straw), sugar beet and wheat,
- direct methane and nitrous oxide emissions factors for the combustion of liquid biofuels and their equivalents, such as diesel oil, petrol and fuel oil derived from crude oil, on an agreed and comparable basis, and
- a set of equivalent reference results for conventional fuels, electricity and heat supplies for consistent and comprehensive comparison with results for biofuel technologies.

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CONTENTS

1. INTRODUCTION

1.1 Context

There is a variety of established and emerging **biofuel technologies** which use biomass to provide commercial sources of energy in the form of electricity, heat and/or transport fuels. Such biofuels can offer significant benefits, in the form of reductions in fossil fuel resource depletion and carbon dioxide and other greenhouse gas emissions which are implicated in global climate change. However, all technologies, including biofuel options, have some associated consumption of fossil fuels and emissions of greenhouse gases, directly and/or indirectly. Hence, the actual benefits which can, in practice, be realised by biofuels depend, crucially, on their **energy and carbon balances** which indicate the magnitude of fossil fuel inputs (and related greenhouse gas emissions) relative to subsequent fossil fuel savings (and avoided greenhouse gas emissions) resulting from their use as alternatives to current commercial sources of energy. A considerable number of studies have been conducted for evaluating such energy and carbon balances of a range of biofuel options. However, these studies have been performed in various ways, to achieve diverse objectives and are presented in different degrees of transparency. Nevertheless, given the appropriate approach, these existing studies present the opportunity to formulate a consistent, coherent and comprehensive assessment and comparison of the energy and carbon balances for a range of important biofuel options in the United Kingdom (UK).

1.2 Aims and Objectives

The aims of this project are to produce a set of baseline energy and carbon balances for a range of electricity, heat and transport fuel production systems which are based on biomass feedstocks. The resulting objectives are as follows:

- to agree the selection of up to 15 biofuel technologies which will be assessed,
- to collate existing information on these technologies,
- to produce a series of flow charts representing these technologies,
- to divide the technologies into relevant modules,
- to review the collated information for establishing base case energy and carbon requirements for each module within each technology,
- to identify any significant emissions of greenhouse gases other than carbon dioxide for each module,
- to estimate such emissions where relevant data exist, and
- to specify values which are uncertain and the need for additional information.

1.3 Time Schedule

The agreed start date for this project was 17 January 2002 with an end date of 17 November 2002, subsequently revised to 31 January 2003. During this period, the work programme was arranged into a series of tasks with actual durations as indicated below.

Activity	Month												
	01/02	02/02	03/02	04/02	05/02	06/02	07/02	08/02	09/02	10/02	11/02	12/02	01/03
A. Selection of Technologies		X	X	X	X	X							
B. Review of Data			X	X	X	X	X	X					
C. Preparation of Flow Charts				X	X	X	X	X	X	X	X	X	
D. Finalisation of Flow Charts							X	X	X	X	X	X	
E. Project Management		X	X	X	X	X	X	X	X	X	X	X	X
Meetings		KO		P1					P2				
Deliverables				MR						IR		DR	FR

The Kick-Off Meeting (KO) was held on 27 February 2002. The Selection of Technologies (Task A) commenced in January 2002 and was completed in June 2002. The Management Report (MR) was submitted in April 2002 (Ref. 1) and the first Progress Meeting (P1) was held on 23 April 2002. The Review of Data (Task B) was conducted between March and August 2002, and the Preparation of Flow Charts (Task C) was undertaken between March and December 2002. The second Progress Meeting (P2) was held on 17 September 2002. The Interim Report (IR) was submitted in October 2002 (Ref. 2). The Finalisation of Flow Charts (Task D) and the Draft Final Report (DR) were completed by 7 January 2003. The Final Report was submitted on 31 January 2003.

1.4 Structure of the Report

The general process of selecting the biofuel technologies for investigation and subsequent preparation of energy and carbon balances is outlined in Section 2 which also includes an introduction to the modular approach adopted here. The basis and conclusions of the review of existing studies are described in Section 3. The main results are presented in Section 4 which specifies the main features of the flow charts and spreadsheets for the energy and carbon balances and provides the key details for the selected biofuel technologies. Results in the form of energy, carbon, methane, nitrous oxide and total greenhouse gas requirements are summarised in Section 5. Appendix A contains the individual reviews of existing studies and the full flow charts and spreadsheets for all the selected biofuel technologies are presented in Appendices B to T.

2. SELECTION OF TECHNOLOGIES

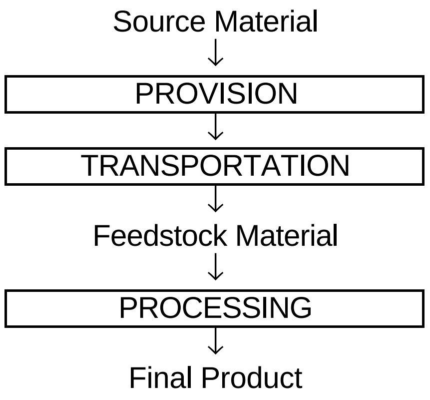
The process of selecting the biofuel technologies for preparation of energy and carbon balances involved formulating an initial list which was circulated amongst an agreed group of scoping advisors for their comments. This group of scoping advisors reflected a range of different perspectives and interests in biofuel technologies. Few restrictions were placed on subsequent feedback. However, it was suggested that consideration be given to those technologies which might be expected to be particularly relevant to the UK in the foreseeable future. Although diverse opinions were expressed, a degree of consensus was apparent. The continuous emergence of new biofuel technologies was recognised. Hence, it was agreed to include bioethanol production from lignocellulosics. It was also suggested that gasification and Fischer Tropsch synthesis of alkanes, methanol and ethers might be considered. Unfortunately, investigation of possible sources of information demonstrated that no relevant published studies on these processes were, in fact available. Hence, these biofuel technologies could not be considered here. The selected list of biofuel technologies is summarised in Table 1.

In total, 18 biofuel technologies are represented in Table 1. From closer examination, it will be noted that some of these technologies share certain common features. This can be demonstrated by considering the general modular structure, shown in Figure 1, which can be used to represent biofuel technologies. In effect, this results in a structure composed of three major **modules**, representing the **provision**, **transportation** and **processing** of any given biofuel. Transportation is a fairly common activity involved in most biofuel technologies. Hence, the most definitive modules for a biofuel technology concern provision and processing. A number of selected biofuel technologies listed in Table 1 incorporate common modules. For example, the provision module for both biodiesel and rapeseed oil consists of the cultivation and harvesting of oilseed rape. Furthermore, the same three processing modules are used to generate electricity by combustion, gasification and pyrolysis, respectively, of wood chip regardless of the original source, or provision module.

Table 1 List of Selected Biofuel Technologies

Biodiesel from oilseed rape **Biodiesel** from recycled vegetable oil
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues (large scale) **Combined Heat and Power** (small scale) by gasification of wood chip from short rotation coppice
Electricity (large scale) by combustion of miscanthus **Electricity** (large scale) by combustion of straw **Electricity** by combustion of wood chip from forestry residues (large scale) **Electricity** by combustion of wood chip from short rotation coppice **Electricity** by gasification of wood chip from forestry residues (large scale) **Electricity** by gasification of wood chip from short rotation coppice **Electricity** by pyrolysis of wood chip from forestry residues (large scale) **Electricity** by pyrolysis of wood chip from short rotation coppice
Ethanol from lignocellulosics **Ethanol** from sugar beet **Ethanol** from wheat
Heat (small scale) by combustion of wood chip from forestry residues (large scale) **Heat** (small scale) by combustion of wood chip from woodland management
Rapeseed Oil from oilseed rape

Figure 1 General Modular Structure for Biofuel Technologies



Consequently, as demonstrated in Tables 2 and 3, it can be established that it is necessary to examine 9 separate provision modules and 12 separate processing modules in this project. In practice, there are some common elements of processing for the production of biodiesel from oilseed rape and from recycled vegetable oil, and for the production of rapeseed oil from oilseed rape. In general, the list of selected biofuel technologies, represented in Table 1, was considered to be reasonable and relevant. It should be noted that this rather detailed discussion of selected biofuel technologies and their component modules is important since it influences aspects of the subsequent review of data and, crucially, underpins the formulation of draft flow charts.

Table 2 Specification of Selected Provision Modules

Source Material	Provision Activities
Lignocellulosics	Collection and preparation prior to processing
Miscanthus	Cultivation, harvesting and baling
Oilseed Rape	Cultivation and harvesting
Straw	Collection and baling
Sugar Beet	Cultivation and harvesting
Wheat	Cultivation and harvesting
Wood Chip from Forestry Residues	Collection and chipping (large scale)
Wood Chip from Woodland Residues	Collection and chipping (small scale)
Wood Chip from Short Rotation Coppice	Cultivation, harvesting and chipping

Table 3 Specification of Selected Processing Modules

Process Activities	Final Product
Oilseed milling, refining and esterification	Biodiesel
Recycled vegetable oil refining and esterification	Biodiesel
Combustion of miscanthus and straw and electricity generation	Electricity
Combustion of wood chip and electricity generation	Electricity
Gasification of wood chip and electricity generation	Electricity
Pyrolysis of wood chip and electricity generation	Electricity
Conversion of lignocellulosics to sugars and fermentation	Ethanol
Conversion of sugar beet or wheat to sugars and fermentation	Ethanol
Combustion of wood chip (small scale)	Heat
Combustion of wood chip (large scale) in CHP plant	Heat and electricity
Gasification of wood chip (small scale) in CHP plant	Heat and electricity
Oilseed milling and refining	Rapeseed Oil

3. REVIEW OF DATA

The basis of the preparation of a set of baseline energy and carbon balances rests on the existence of established work on the selected biofuel technologies and availability of studies in an accessible format, such as a contract report, a journal paper or a book. A literature search was conducted to identify and obtain copies of such studies. By necessity, the literature search was fairly wide and had to include studies which addressed a complete relevant biofuel technology or one element of such a technology. In many instances, principal sources were based on **life cycle assessment** which is an established technique for quantifying the total environmental impacts of the provision of a product or service from original resources to final disposal, or so-called "cradle-to-grave". In total, 43 studies were identified and these were subjected to a systematic review. Review summaries are presented in Appendix A. These summaries provide the year of publication, the short list of authors, the type of publication, the full reference, brief descriptions of the systems considered and processes included, the major strengths and weaknesses, and key citations. Particular attention focused on the nature of the results provided by each study and the transparency of each study. In general, results were characterised in terms of estimates of energy inputs (usually in the form of primary energy or fossil fuel energy), emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG), and total greenhouse gas emissions (normally expressed in terms of equivalent CO_2). In the case of total greenhouse gas emissions, it should be noted that some studies may only present results in this aggregated format which prevents access to estimates of individual greenhouse gases. This can create problems for comparison between studies.

The most important concern which determines the relevance of any given study to this project is its transparency. Ideally, studies were needed which explain, clearly, the systems considered and the processes included in the analysis. Most specifically, all major assumptions and key parameters should be stated. A study would be regarded as being completely transparent if the information which it contains could be adopted with confidence and modified, if necessary, to calculate new results which reflect representative circumstances in the UK. Of specific concern in the matter of transparency are the **allocation procedures** which partition primary energy inputs and greenhouse gas outputs between different co-products. Numerous biofuel technologies have diverse main products, co-products, by-products and waste products. Suitable allocation procedures need to be established and applied to produce meaningful results in such circumstances. The choice and justification of allocation procedures is a major issue for life cycle assessment (Ref. 3), especially since they can have a significant influence on subsequent results. Existing studies adopt a range of allocation procedures which may or may not be appropriate for this project. For example, although a variety of allocation procedures may be used, the preferred choice is normally **substitution** which involves applying effective input and output "credits" for by-products based on the results of the life cycle assessment of their main means of production. However, this approach cannot be used when such a product is only ever obtained as a by-product. In such instances, which occur frequently with biofuel technologies, an alternative allocation procedure, usually based on comparative economic value, must be adopted. Hence, the ability to identify the actual allocation procedure used in a study and, if necessary, modify it to derive relevant results is a prominent consideration.

As a consequence of this and other considerations, it can be seen that completely transparent studies are very important for this project. In contrast, inability to access basic data, assumptions and parameters suggests a complete lack of transparency which means that such a study would be of little value to this project. Obviously, degrees of transparency exist and any study which falls between these extremes is referred to here, for convenience, as having partial transparency. Another consideration which needed to be taken into account in the review was the relevance of the study to this project. Although the evaluation of relevance can depend on numerous factors, the country to which a study refers can be a particular concern. This consideration can have a particular influence on the relevance of data and results for the provision of the biomass rather than its processing. For example, some studies may not be relevant because assumed growing conditions do not reflect actual circumstances and/or practice in the UK.

The main features of the review summaries in Appendix A are presented here in Tables 4 to 16 which indicate the nature of the results (energy, CO_2, other GHG, and total GHG; ✓ = result presented, **X** = result not presented), their general transparency (✓ = transparent, **X** = not transparent), and their country of relevance.

In some instances, studies coincide exactly with the biofuel technologies selected in Table 1. In other cases, only specific modules are addressed by the studies which were reviewed. Studies addressing the complete aspects of producing biodiesel from oilseed rape are examined in Table 4. As indicated in Table 5, only one study, which concerns a range of alternative fuels for heavy road vehicles, specifically considers the production of biodiesel from recycled vegetable oil. However, it should be noted that data for esterification, available in the more transparent studies in Table 4 are relevant to this particular biofuel technology. Two different biofuel technologies are represented by the studies shown in Table 6. These refer to the production of combined heat and power from wood chip using combustion and gasification technologies. Table 7 includes studies on the cultivation and harvesting of miscanthus but not its eventual use as a fuel for large scale electricity generation by combustion. The two studies given in Table 8 relate to the large scale generation of electricity from straw by combustion. As shown in Table 9, numerous studies are available on the production of wood chip from forestry residues. Similarly, a range of studies were identified for the production of wood chip from short rotation coppice, as illustrated by Table 10. However, it should be noted that no studies were identified for the production of wood chip specifically from the small scale management of woodland. A number of different technologies are incorporated in Table 11 which concerns studies on the generation of electricity from wood chip. These include combustion and gasification but not pyrolysis. Although a few studies on the production of ethanol from lignocellulosics are indicated in Table 12, these cover different technologies at different stages of development and, it should be noted, they generally lack transparency. Apart from one particular instance in each case, this is also a problem for the studies on the production of ethanol from sugar beet and wheat shown in Tables 13 and 14, respectively. Small scale heating by combustion of wood chip from various sources is included in the studies specified in Table 15. As rapeseed oil manufacture is part of production of biodiesel from oilseed rape, the studies included in Table 4 are assumed to be relevant to this biofuel technology, as indicated in Table 16, provided they are sufficiently transparent.

Table 4 Review of Studies on Biodiesel Production from Oilseed Rape

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Culshaw & Butler, 1992	✓	✓	X	X	Partial	UK
IEA, 1994	X	X	X	✓	X	UK & USA
Gustavsson et al, 1995	X	✓	X	X	X	Sweden
Gover et al, 1996	✓	✓	✓	✓	Partial	UK
Spirinckx & Ceuterick, 1996	✓	X	X	✓	Partial	Belgium
Kaltschmitt & Reinhardt, 1997	✓	✓	✓	✓	✓	Germany
ECOTEC, 1999	X	✓	✓	✓	X	UK
ECOTEC, 2000	✓	✓	✓	✓	X	UK
Richards, 2000	✓	✓	✓	X	X	UK
ECOTEC, 2001	X	X	X	✓	X	UK
Beer et al, 2002	✓	✓	X	✓	X	Australia
Grover, 2002	✓	✓	✓	✓	Partial	UK

Table 5 Review of Studies on Biodiesel Production from Recycled Vegetable Oil

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Beer et al, 2002	✓	✓	X	✓	Partial	Australia

Table 6 Review of Studies on Combined Heat and Power Production from Wood Chip

Study	Results				Transparency	Country
	Energy	CO$_2$	Other GHG	Total GHG		
Hanegraaf et al, 1998	✓	✓	✓	✓	Partial	Netherlands & EU
Jungmeier et al, 1998	✓	✓	✓	✓	Partial	Austria

Table 7 Review of Studies on Miscanthus Production

Study	Results				Transparency	Country
	Energy	CO$_2$	Other GHG	Total GHG		
Kaltschmitt & Reinhardt, 1997	✓	✓	✓	✓	✓	Germany
Bullard & Metcalfe, 2001	✓	✓	**X**	**X**	Partial	UK

Table 8 Review of Studies on Electricity Generation by Combustion of Straw

Study	Results				Transparency	Country
	Energy	CO$_2$	Other GHG	Total GHG		
Grant et al, 1995	✓	✓	**X**	**X**	✓	UK
Gustavsson et al, 1995	**X**	✓	**X**	**X**	**X**	Sweden

Table 9 Review of Studies on Wood Chip from Forestry Residues

Study	Results				Transparency	Country
	Energy	CO$_2$	Other GHG	Total GHG		
Herendeen & Brown, 1987	✓	**X**	**X**	**X**	**X**	USA
Turhollow & Perlack, 1991	✓	✓	**X**	**X**	Partial	USA
Börjesson et al, 1996	✓	**X**	**X**	**X**	Partial	Sweden
Boman & Turnbull, 1997	✓	✓	**X**	**X**	Partial	Sweden & USA
Kaltschmitt & Reinhardt, 1997	✓	✓	✓	✓	✓	Germany
Hektor, 1998	✓	✓	**X**	**X**	**X**	Sweden
Jungmeier et al, 1998	✓	✓	✓	✓	Partial	Austria
Korpilahti, 1998	✓	✓	**X**	**X**	Partial	Finland
Schwaiger & Schlamadinger, 1998	**X**	✓	✓	✓	Partial	Austria
Hartmann & Kaltschmitt, 1999	**X**	✓	✓	✓	**X**	Germany
Jungmeier, 2000	**X**	✓	✓	✓	**X**	Austria
Matthews & Mortimer, 2000	✓	✓	**X**	**X**	✓	UK

Table 10 Review of Studies on Wood Chip Production from Short Rotation Coppice

Study	Results				Transparency	Country
	Energy	CO$_2$	Other GHG	Total GHG		
Matthews et al, 1994	✓	✓	**X**	**X**	✓	UK
Börjesson et al, 1996	✓	**X**	**X**	**X**	Partial	Sweden
Boman & Turnbull, 1997	✓	✓	**X**	**X**	Partial	Sweden & USA
Mann & Spath, 1997	✓	✓	✓	✓	Partial	USA
Dubuisson & Sintzoff, 1998	✓	✓	**X**	**X**	✓	Belgium
Hanegraaf et al, 1998	✓	✓	✓	✓	Partial	Netherlands & EU
Hektor, 1998	✓	✓	**X**	**X**	**X**	Sweden
Jungmeier et al, 1998	✓	✓	✓	✓	Partial	Austria
Schwaiger & Schlamadinger, 1998	**X**	✓	✓	✓	Partial	Austria
Tahara et al, 1999	**X**	✓	**X**	**X**	**X**	USA, Indonesia & Brazil
Jungmeier, 2000	**X**	✓	✓	✓	**X**	Austria
Matthews & Mortimer, 2000	✓	✓	**X**	**X**	✓	UK

Table 11 Review of Studies on Electricity Generation from Wood Chip

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
IEA, 1994	X	X	X	✓	X	UK & USA
Gustavsson et al, 1995	X	✓	X	X	X	Sweden
Boman & Turnbull, 1997	✓	✓	X	X	Partial	Sweden & USA
Mann & Spath, 1997	✓	✓	✓	✓	Partial	USA
Hanegraaf et al, 1998	✓	✓	✓	✓	Partial	Netherlands & EU
Jungmeier et al, 1998	✓	✓	✓	✓	Partial	Austria
Hartmann & Kaltschmitt, 1999	X	✓	✓	✓	X	Germany
Tahara et al, 1999	X	✓	X	X	X	USA, Indonesia & Brazil
Matthews & Mortimer, 2000	✓	✓	X	X	✓	UK

Table 12 Review of Studies on Ethanol Production from Lignocellulosics

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Ferchak & Pye, 1981	✓	X	X	X	X	USA
Marrow et al, 1990	✓	X	X	X	X	UK
Born, 1994	X	✓	X	X	X	Germany
Wyman, 1994	✓	✓	X	X	X	USA
O'Connor et al, 1999	X	✓	✓	✓	X	Canada
Wang et al, 1999	✓	✓	✓	✓	X	USA

Table 13 Review of Studies on Ethanol Production from Sugar Beet

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Marrow et al, 1987	✓	X	X	X	X	UK
Born, 1994	X	✓	X	X	X	Germany
IEA, 1994	X	X	X	✓	X	UK & USA
Kaltschmitt & Reinhardt, 1997	✓	✓	✓	✓	✓	Germany

Table 14 Review of Studies on Ethanol Production from Wheat

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Marrow et al, 1987	✓	X	X	X	X	UK
Marrow et al, 1990	✓	X	X	X	X	UK
Batchelor et al, 1994	✓	✓	✓	✓	X	UK
Born, 1994	X	✓	X	X	X	Germany
IEA, 1994	X	X	X	✓	X	UK & USA
Gustavsson et al, 1995	X	✓	X	X	X	Sweden
Gover et al, 1996	✓	✓	✓	✓	Partial	UK

Table 15 Review of Studies on Heat Production from Combustion of Wood Chip

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Schwaiger & Schlamadinger, 1998	X	✓	✓	✓	Partial	Austria
Jungmeier, 2000	X	✓	✓	✓	X	Austria

Table 16 Review of Studies on Rapeseed Oil Production from Oilseed Rape

Study	Results				Transparency	Country
	Energy	CO_2	Other GHG	Total GHG		
Culshaw & Butler, 1992	✓	✓	X	X	Partial	UK
IEA, 1994	X	X	X	✓	X	UK & USA
Gustavsson et al, 1995	X	✓	X	X	X	Sweden
Gover et al, 1996	✓	✓	✓	✓	Partial	UK
Spirinckx & Ceuterick, 1996	✓	X	X	✓	Partial	Belgium
Kaltschmitt & Reinhardt, 1997	✓	✓	✓	✓	✓	Germany
ECOTEC, 1999	X	✓	✓	✓	X	UK
ECOTEC, 2000	✓	✓	✓	✓	X	UK
Richards, 2000	✓	✓	✓	X	X	UK
ECOTEC, 2001	X	X	X	✓	X	UK
Beer et al, 2002	✓	✓	X	✓	X	Australia
Grover, 2002	✓	✓	✓	✓	Partial	UK

The results of the reviews given in Tables 4 to 16 can be used to establish the basis for the preparation of the draft flow charts and the baseline carbon and energy balances for the selected technologies. Occasionally, a specific study may provide the entire basis for such work. However, in most circumstances, it will be necessary to modify the original study for the purposes of this project, to combine information from different studies, or to add information from other sources or from new work. For example, appropriate studies can be identified for results on wood chip production from forestry residues, but these have to be used in conjunction with other information on small scale wood-fired boilers to derive baseline results for the biofuel technology described as “heat (small scale) by combustion of wood chip from forestry residue (large scale)”. The type of additional information required included the specified biofuel consumption of the conversion plant per unit of output. Such information was obtained, directly or indirectly, from manufacturers, suppliers and developers. In a number of instances, estimates of primary energy inputs and associated CO_2 emissions of the manufacture of the conversion plant were derived from previous work (Ref. 4), supplemented to reflect other GHG outputs and, where necessary, modified to represent other types of conversion plant.

The basis for subsequent work on each of the selected biofuel technologies is summarised in Table 17 which indicates the main studies used in the calculation of the energy and carbon balances. Additional notes are provided in Table 17 on the need to modify existing work to UK conditions, and to add further information and new work where necessary. With many of the selected biofuel technologies, it was apparent that a sound basis of existing studies was established. However, in a few instances, concern over the availability of suitable results from existing studies was noted. In particular, the biofuel technologies which were affected by this concern consist of the production of biodiesel from recycled vegetable oil, the generation of electricity by pyrolysis of wood chips, and the production of ethanol from lignocellulosics. In these cases, it was necessary to combine additional information from other sources to obtain the results required.

Table 17 Basis for Evaluating Baseline Results for Selected Biofuel Technologies

Selected Biofuel Technology	Basis for Energy and Carbon Balances
Biodiesel from oilseed rape	Kaltschmitt & Reinhardt, 1997, modified to UK conditions.
Biodiesel from recycled vegetable oil	Kaltschmitt & Reinhardt, 1997, combined with Beer et al, 2002, modified to UK conditions.
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	Matthews & Mortimer, 2000, combined with Kaltschmitt & Reinhardt, 1997, and added to Hanegraaf et al, 1998, and Jungmeier et al, 1998.
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice	Matthews & Mortimer, 2000, combined with Kaltschmitt & Reinhardt, 1997, and used with necessary data on gasification CHP plant operation and emissions.
Electricity (large scale) by combustion of miscanthus	Kaltschmitt & Reinhardt, 1997, modified with Bullard & Metcalfe, 2001, and added to Grant et al, 1996 with necessary data on combustion electricity plant operation and emissions.
Electricity (large scale) by combustion of straw	Grant et al, 1995, combined with necessary data on other GHG emissions.
Electricity by combustion of wood chip from forestry residues (large scale)	Matthews & Mortimer, 2000, combined with Kaltschmitt & Reinhardt, 1997, and added to necessary data on combustion electricity plant operation and emissions.
Electricity by combustion of wood chip from short rotation coppice	Matthews & Mortimer, 2000, combined with Jungmeier, 2000, and added to necessary data on combustion electricity plant operation and emissions.
Electricity by gasification of wood chip from forestry residues (large scale)	Matthews & Mortimer, 2000, combined with Kaltschmitt & Reinhardt, 1997, and added to necessary data on other GHG emissions from gasification electricity plant.
Electricity by gasification of wood chip from short rotation coppice	Matthews & Reinhardt, 2000, combined with Jungmeier, 2000, and added to necessary data on other GHG emissions from gasification electricity plant.
Electricity by pyrolysis of wood chip from forestry residues (large scale)	Matthews & Reinhardt, 2000, combined with Kaltschmitt & Reinhardt, 1997, and added to necessary data on pyrolysis electricity plant operation and emissions.
Electricity by pyrolysis of wood chip from short rotation coppice	Matthews & Reinhardt, 2000, combined with Jungmeier, 2000, and added to necessary data on pyrolysis electricity plant operation and emissions.
Ethanol from lignocellulosics (wheat straw)	O'Connor et al, 1999, combined with Wyman, 1994.
Ethanol from sugar beet	Kaltschmitt & Reinhardt, 1997, modified to UK conditions.
Ethanol from wheat	Gover et al, 1996.
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	Matthews & Mortimer, 2000, combined with Jungmeier, 2000, and added to Schwaiger & Schlamadinger, 1998, with any necessary data on combustion heat plant operation and emissions.
Heat (small scale) by combustion of wood chip from woodland management	Matthews & Mortimer, 2000, combined with Jungmeier, 2000, modified to UK woodland management, and added to Schwaiger & Schlamadinger, 1998, with any necessary data on combustion heat plant operation and emissions.
Rapeseed Oil from oilseed rape	Kaltschmitt & Reinhardt 1997 adjusted to rapeseed oil production and modified to UK conditions.

4. RESULTS

4.1 Flow Charts

The essential stages of production of biomass into suitable biofuels and the prominent inputs and outputs are summarised by means of **flow charts**. Draft flow charts were originally submitted for consideration in the Interim Report (Ref. 2). The organisation of these draft flow charts was simplified for clarity. In particular, flow charts were assembled for various means of producing dried wood chip and separate flow charts were presented for the use of this biomass feedstock to generate electricity only (by combustion, gasification and pyrolysis), combined heat and power (by combustion and gasification), and heat only (by combustion). Two options were given for the production of dried wood chip from both forestry residues and the management of small scale woodland, respectively. The **end points** of both the draft and final flow charts are, effectively, forms of delivered energy such as electricity, heat or liquid fuels, normalised to a single unit of physical measurement. The choice of such end points is appropriate for at least two important reasons. First, it enables subsequent results to be used in a variety of different ways depending on specific purposes. In particular, delivered energy end points are commonplace in existing studies since they assist the flexible use of results and avoid the complexities of adding further assumptions about the specific subsequent applications of delivered energy. Second, the essentially diverse options for delivered energy use mean that an impossibly large number of combinations arise which cannot be accommodated within the constraints of this work.

These consideration affect the flow charts for liquid biofuels for transport applications, in particular, as it is not meaningful to consider their subsequent use here. In order to do this, it would be necessary to adopt an agreed set of **vehicle performance factors** such as "kilometres travelled per kilogram of biofuel consumed". Although vehicle performance factors are available and can be readily applied to the results of this work, it is well-known that such factors depend on a variety of considerations, including type and age of vehicle, driving conditions, etc. Despite numerous trials and tests, it is apparent that there are no widely-accepted, standard performance factors for all the liquid biofuels addressed here. Indeed, there is much disagreement about the interpretation and comparison of currently published performance factors. This might not seem surprising for such relatively new transport fuels. Hence, there is not a sound basis for formulating flow charts and subsequent spreadsheets which have "kilometres travelled" as end points. It is, however, recognised that results provided in such format would be extremely useful. Hence, **biofuel specification** are provided in the relevant spreadsheets as means of converting results into "per litre" and "per unit of delivered energy" so that they can be combined with vehicle performance factors chosen independently by subsequent users.

4.2 Spreadsheets

Detailed summaries and means of presentation of the energy inputs and GHG outputs for selected biofuel technologies are provided in the form of **spreadsheets**. These spreadsheets were modified from earlier versions (Ref. 2) in order to accommodate the specification of all GHG emissions. Due to the resulting size of a single, combined spreadsheet for each biofuel technology, individual spreadsheets are presented for primary energy inputs, CO_2 outputs, methane (CH_4) outputs, nitrous oxide (N_2O) outputs, and total GHG outputs given in terms of equivalent CO_2. This conversion was achieved using quoted values of **global warming potential** which relate other greenhouse gases to an equivalent amount of CO_2. The global warming potential for 1 kg of CH_4 is 24.5 kg eq CO_2 and a global warming potential for 1 kg of N_2O is 320 kg eq CO_2. It should be noted that other possible values of global warming potential, which are based on relative GHG lifetimes, can be substituted for those adopted here. In particular, the direct global warming potentials for CO_2, CH_4 and N_2O over periods of 20, 100 and 200 years (Ref. 5) are summarised in Table 18.

Table 18 Direct Global Warming Potentials over Specified Lifetimes

Gas	Units	Direct Global Warming Potentials		
		20 years	100 years	200 years
CO_2	kg eq CO_2/kg CO_2	1	1	1
CH_4	kg eq CO_2/kg CH_4	62	23	7
N_2O	kg eq CO_2/kg N_2O	275	296	156

In keeping with agreed international standards for reporting the results life cycle assessment studies, specifically ISO 14041 (Ref. 3), basic assumptions are specified at the beginning of each spreadsheet. The first of these assumptions is the **functional unit** which provides a clear definition of the product or service under consideration. The use of this term in life cycle assessment is very important since it enables results for alternative products or services to be compared in a meaningful manner. Indeed, use of the term recognises that alternatives must be compared on the basis of the equivalent function which they perform or provide. The next basic assumption is the **unit of measurement** which specifies quantity of the end point of the biofuel technology. Typically, the flow charts and spreadsheets are normalised to 1 tonne of biofuel or 1 GJ (1 gigajoule or 10^9 joules) of electricity and/or heat. The **relevant location and period** for the calculations are indicated on the spreadsheets because both these assumptions can, in certain cases, significantly affect results. For example, biomass cultivation methods, inputs and yields can vary considerably between different countries and the primary energy inputs and GHG outputs for the production of agrochemicals, especially nitrogen fertiliser, and the generation of electricity, in particular, can change substantially over time. Finally, the **allocation procedure** applied to the partitioning of primary energy inputs and GHG outputs between the main, co-, by- and waste production of specific biofuel technologies are summarised in each spreadsheet.

It should be noted that the allocation procedures adopted here depend on the particular circumstances for each biofuel technology under consideration. Typically, substitution is preferred when credits are applied for the primary energy inputs and GHG outputs of a co-product based on its main means of production. For example, credits for the co-production of electricity by certain biofuel technologies are derived from the generation of average electricity available in the UK. However, many of the co-products of biofuel technologies have no separate main means of production. In these cases, allocation is based on the relative economic values of the main and co-product. For example, rape meal derived as a co-product from the production of biodiesel from oilseed rape is an animal feed. It is not produced by any other means as a main product. Even though it can be substituted by soya meal, this animal feed is also a co-product of soya oil production. Hence, a simple substitute cannot be identified and, consequently, it is necessary to adopt another allocation procedure. In some studies, mass or energy content of co-products has been chosen as a basis for allocation. However, the basis for using mass only seems to arise because both main and co-products can be weighed, and the use of energy content would only be relevant if both main and co-products are actually burned as fuels. In the absence of a physical basis for partitioning, it becomes necessary to use an allocation procedure based on the relative economic value of main and co-products. This is the case despite subsequent concerns about the effect of variations in the prices of the main and co-products which are, effectively, incorporated into the allocation procedure calculations.

The **primary energy inputs** reported in the appropriate spreadsheet represents the amount of energy available in resources in their natural state, such as coal, natural gas and oil deposits in the ground. As such, it is an indicator of energy resource availability and fossil fuel depletion. The total amount of primary energy consists of the sum of the **direct energy** due to the consumption of fuels and electricity in specific stages of the biofuel technology, the **indirect energy** associated with the provision of materials, equipment, fuels, electricity, etc., used in these stages of biofuel production, and the energy contained in any **feedstocks**, such as chemicals, especially nitrogen fertiliser, and materials, such as plastics, derived from fossil fuels. Although the energy within a feedstock is not necessarily released, it amounts to a reduction in fossil fuel resources and, as such, must be included in these calculations.

The **GHG emissions** recorded in the remaining spreadsheets equal the **direct GHG emissions** from the combustion of fuels and the **indirect GHG emissions** due to the production of these fuels, the generation of electricity and the manufacture of materials, equipment, etc. In addition to GHG emissions from the direct or indirect combustion of fossil fuels, other sources of GHG outputs, particularly CO_2 emissions, such as the manufacture of cement and nitrogen fertiliser, must be taken into account. Although not presented separately, the issue of feedstocks must be treated carefully in GHG calculations. This issue is more complicated than in primary energy calculations. Whether any CO_2 emissions arise from feedstocks which store carbon originally derived from fossil fuels depends on the ultimate fate of this carbon. If the carbon always remains stored in the feedstock, then it is excluded from calculations. However, if the feedstock is eventually burnt or decomposes naturally, the CO_2 released must be included. Additionally, the carbon in fossil fuels used as feedstocks in chemical processes may be released as CO_2 emissions as a result of chemical reactions. This is an important consideration for the production of nitrogen fertiliser from natural gas. Similarly, direct N_2O emissions from the application of nitrogen fertiliser to cultivated land are also taken into account in calculations.

The contributions to primary energy inputs and GHG outputs for each stage of production represented in the relevant flow chart are summarised in the spreadsheets for each biofuel technology. Basic results for these contributions are initially specified by an appropriate unit of production (recorded in *italics*). For example, results for contributions to cultivation and harvesting are initially presented "per hectare of land used per year" (ha.a). These are then adjusted, by accounting for production ratios, reflected in the flow charts, and any allocation procedures, to provide results specified by the final unit of output of the relevant biofuel (reported in **bold**). Total values of direct, indirect and feedstock inputs and outputs for all contributions at each and all stages of the biofuel technology are summarised within the spreadsheets. Both typical values and ranges of results are provided. The ranges are based on specified levels of uncertainty for individual inputs or outputs with final results derived using a standard propagation of errors routine (Ref. 4). Supplementary information is incorporated into the spreadsheets. As mentioned previously, biofuel specifications, such as the density, and gross and net calorific values of the relevant biofuel, are summarised, where necessary. Abbreviations for the units of measurement adopted in the spreadsheets are explained. Detailed notes on the essential data used in the calculation of specific inputs and outputs are provided, and appropriate references are specified. It should be noted that results for primary energy inputs, in MJ, and CO_2 and total GHG outputs, in kg, are quoted in whole numbers, whilst results for CH_4 and N_2O outputs, in kg, are quoted to the third decimal place. Results with lower values than these are not recorded (indicated by "-" in the spreadsheets).

4.3 Key Details of Biofuel Technologies

The final flow charts and spreadsheets for each of the selected biofuel technologies are presented in Appendices B to T. Consultation over the basic aspects of these flow charts and spreadsheets has been conducted with technical advisors. Although all relevant information is reported in these flow charts and spreadsheets, key details of each biofuel technology are summarised here. All results refer to biofuel technologies in the UK even though some are based on studies prepared on processes in different countries. In many instances, the year to which the original existing study refers determines the relevant year of the results. However, for those biofuel technologies which are particularly affected by the manufacture of nitrogen fertiliser and the generation of electricity, the relevant year is 1996 for which detailed emissions data for the European Union (Ref. 6) and the UK (Ref. 7), respectively, are available. The coverage, content and compatibility of spreadsheets for individual biofuel technologies depend crucially on the existing studies which form the original sources for this work. Certain important modifications have been incorporated to ensure that results are compatible and appropriate to the application of biofuels technologies in the UK. However, imposition of consistency does not extend to all the parameters and assumptions adopted in the exist studies. For example, no attempt has been made to apply fixed load factors or lifetimes to results for similar biofuel technologies. Instead, the results reflect the original data although, given the transparency of the spreadsheets, it is possible to alter these parameters and assumptions independently.

4.3.1 Biodiesel from Oilseed Rape

The final flow chart and spreadsheets for the production of biodiesel from oilseed rape are provided in Appendix B. Production using solvent extraction is assumed to be the most relevant form of this biofuel technology for the UK. The results are based on a biodiesel production plant of 40,000 tonnes per year. A German study (Ref. 8) is the source of the most prominent data which was adjusted, where appropriate, to current conditions in the UK. A reference system based on fallow set-aside is incorporated into the calculations. Primary energy inputs and GHG outputs for the manufacture, maintenance and repair of agricultural machinery are not included. The primary energy inputs and GHG outputs for plant construction, maintenance and decommissioning are based on a physical inventory for biodiesel plant with mechanical extraction which was assumed to be similar to a plant with solvent extraction (Ref. 4). Allocation by market prices is adopted for partitioning between rape straw and raw rapeseed, rape meal and crude rapeseed oil, and crude glycerine and biodiesel.

4.3.2 Biodiesel from Recycled Vegetable Oil

Appendix C contains the final flow chart and spreadsheets for the production of biodiesel from recycled vegetable oil. Current practice in the UK is used as the basis for deriving results (Ref. 9) supplemented with data on esterification from a German study (Ref. 8). Production of the original vegetable is excluded from the calculations since the primary energy inputs and GHG outputs for this should already be allocated fully to this main product and its principal uses. Similarly, recycled vegetable oil collection and transport to the processing plant are excluded because such activities are necessary for the alternative treatment of such oil as a waste product for disposal. The primary energy input and GHG outputs of plant construction are based on a physical inventory of the relevant elements of a biodiesel plant (Ref. 4). Allocation by market prices is adopted for partitioning between crude glycerine and biodiesel.

4.3.3 Wood Chips from Forest Residues

The final flow chart and spreadsheets for the large-scale production of wood chips from forestry residues are presented in Appendix D. Results are based on typical practice in the UK (Refs. 10 and 11) supplemented with other relevant data where necessary (Refs. 4, 7 and 8). The effective reference system adopted assumes that the land is allowed to return to its original wilderness state with no energy inputs and associated GHG outputs. The primary energy inputs and GHG outputs of machinery manufacture, maintenance and repair are included. Allocation between small roundwood, saw logs and forest residues is based on relative prices.

4.3.4 Wood Chips from Woodland Management

Final flow charts and spreadsheets for small-scale production of wood chips from broadleaf and coniferous woodland, referred to as Options A and B, are given in Appendices E and F, respectively. Results are based on typical practice in the recovery of saw logs and wood fuel from existing woodland in the UK (Refs. 10 and 11) modified with standard yield and other data accordingly. In relation to the reference system, the alternative is assumed to consist of no management of the woodland. The primary energy inputs and GHG outputs of machinery manufacture, maintenance and repair are included. Allocation between saw logs and wood fuel is based on relative prices.

4.3.5 Wood Chips from Short Rotation Coppice

Final flow charts and spreadsheets for production of wood chips from short rotation coppice by different means, referred to as Options A and B, are given in Appendices G and H, respectively. In Option A, combined harvesting and chipping is assumed, whilst in Option B stick harvesting and baling is used with transport to the point of use where chipping occurs. Typical practice in the UK is used as a basis for the results (Refs. 10 and 11) with data supplemented by relevant information where necessary (Refs. 4, 7 and 8). The reference system assumed is fallow set-aside. The primary energy inputs and GHG outputs for the manufacture, maintenance and repair of machinery is included. No allocation is necessary as wood chips are the only product of short rotation coppice production.

4.3.6 Combined Heat and Power Generation by Combustion of Wood Chips

Appendix I contains the final flow chart and spreadsheet for combined heat and power generation by combustion of wood chips. A simulated wood-fired combined heat and power plant, consuming 32,086 oven dried tonnes (25% moisture content) of wood chip per year, is based on the Masnedø co-fired (straw and wood) combined heat and power plant in Denmark which has a net electrical output rating of 8.2 MW and a heat output rating 20.8 MW of steam at 522°C and 92 bar, and a 55% load factor (Ref. 12). No distinction is made between the electricity or steam output here so that the results refer to the generation of 1 GJ of either electricity or steam. Due to the lack of a physical inventory of plant components, it was necessary to use cost data to derive approximate results for the primary energy inputs and GHG outputs of plant construction, maintenance and decommissioning (Ref. 13). It should be noted that this approach often leads to over-estimates of primary energy inputs and GHG outputs. Direct CH_4 and N_2O outputs from the combustion of wood chips in the combined heat and power plant are included. The primary energy input and GHG outputs of any start-up fuel are not included since this was not specified.

4.3.7 Combined Heat and Power Generation by Gasification of Wood Chips

The final flow chart and spreadsheets for combined heat and power generation by gasification of wood chips are provided in Appendix J. The basis of the calculations is a modular wood gasification combined heat and power plant, consuming 17,518 tonnes of wood chip (37% moisture content) per year, with a net electrical output rating of 2.50 MW and a heat output rating of 6.21 MW of hot water at 90°C, and 55% load factor (Ref. 14). The primary energy input and GHG outputs of plant construction are based on a physical inventory of modular wood gasification combined heat and power plant (Ref. 4). Neither direct CH_4 and N_2O outputs from the gasification of wood chips in the combined heat and power plant nor the primary energy input and GHG outputs of any start-up fuel are included because of lack of specified operating data.

4.3.8 Electricity Generation by Combustion of Wood Chips

Appendix K contains the final flow chart and spreadsheets for electricity generation by combustion of wood chips. As no specific data were available, calculations assume a simulated wood-fired power only plant, consuming 132,808 oven dried tonnes (25% moisture content) of wood chip per year, based on an equivalent straw-fired power only plant with a net electrical output rating of 20.00 MW and a load factor of 65% (Ref. 13). Due to the lack of a physical inventory of such a plant, it was necessary to use cost data to derive approximate results for the primary energy inputs and GHG outputs of plant construction, maintenance and decommissioning (Ref. 13). As noted previously, this approach often leads to over-estimates of primary energy inputs and GHG outputs. Additionally, direct CH_4 and N_2O outputs from the combustion of wood chips in the power only plant are not included due to lack of relevant data. Similarly, the primary energy input and GHG outputs of any start-up fuel are not included since this was not specified.

4.3.9 Electricity Generation by Gasification of Wood Chips

The final flow chart and spreadsheets for electricity generation by gasification of wood chips are presented in Appendix L. A large-scale wood gasification power only plant, consuming 129,080 oven dried tonnes (25% moisture content) of wood chip per year, with a net electrical output rating of 30.00 MW and a load factor of 85%, is based on extrapolation from a smaller demonstration plant (Ref. 4). The primary energy input and GHG outputs of plant construction were derived from a detailed physical inventory of plant components. No direct CH_4 and N_2O outputs from the gasification of wood chips in the power only plant are included due to lack of relevant data. However, the primary energy input and GHG outputs of natural gas used as a start-up fuel are included.

4.3.10 Electricity Generation by Pyrolysis of Wood Chips

The final flow chart and spreadsheets for electricity generation by pyrolysis of wood chips are provided in Appendix M. A large-scale wood pyrolysis power only plant, consuming 119,774 oven dried tonnes (25% moisture content) of wood chip per year, with a net electrical output rating of 20.00 MW and a load factor of 90%, is based on extrapolation from a smaller demonstration plant (Ref. 15). The primary energy input and GHG outputs of plant construction were derived from a detailed physical inventory of plant components. No direct CH_4 and N_2O outputs from the pyrolysis of wood chips in the power only plant are included due to lack of relevant data. However, the primary energy input and GHG outputs of natural gas used as a pyrolysis process fuel are included.

4.3.11 Electricity Generation by Combustion of Miscanthus

Appendix N contains the final flow chart and spreadsheets for large-scale electricity generation by combustion of miscanthus. Current practice for the cultivation of miscanthus in the UK is assumed, with a 1 year period for establishment and a 19 year production period (Ref. 16). No reference system of alternative land use was adopted and the primary energy input and GHG outputs of agricultural machinery manufacture, maintenance and repair are not included. A large-scale miscanthus-fired power only plant, consuming 121,350 tonnes of miscanthus fuel feed (25% moisture content) per year, is based on a similar straw-fired power only plant with a net electrical output rating of 20.00 MW and a load factor of 65% (Ref. 13). Due to the lack of a physical inventory of plant components, it was necessary to use cost data to derive approximate results for the primary energy inputs and GHG outputs of plant construction, maintenance and decommissioning (Ref. 13). As stated previously, it is likely that this approach leads to over-estimates of primary energy input and GHG outputs. Direct CH_4 and N_2O outputs from the combustion of wood chips in the combined heat and power plant are included. The primary energy input and GHG outputs of any start-up fuel are not included since this was not specified.

4.3.12 Electricity Generation by Combustion of Straw

Appendix O contains the final flow chart and spreadsheets for large-scale electricity generation by combustion of wheat straw. The average yield of wheat straw is based on data for the East Anglia region of the UK (Ref. 13). Primary energy inputs and GHG outputs for replacement fertilisers were derived from Canadian data adjusted to this average yield (Ref. 17). Since wheat straw is treated as a waste product, the primary energy inputs and GHG outputs of wheat grain cultivation and harvesting are not taken into account. However, a reference system, based on straw ploughing as the main current alternative, is incorporated into the calculations. Additionally, the primary energy inputs and GHG outputs of manufacture, maintenance and repair of agricultural machinery are included. Electricity is produced from a straw-fired power only plant with a net electrical output rating of 20.00 MW and a load factor of 65%, consuming 112,741 tonnes of straw fuel feed (15% moisture content) per year (Ref. 13). Due to the lack of a physical inventory of plant components, it was necessary to use cost data to derive approximate results for the primary energy inputs and GHG outputs of plant construction, maintenance and decommissioning (Ref. 13). Subsequent over-estimation of primary energy input and GHG outputs should be noted. Direct CH_4 and N_2O outputs from the combustion of wheat straw in the power only plant are included. The primary energy input and GHG outputs of any start-up fuel are not included since this was not specified.

4.3.13 Ethanol from Lignocellulosics (Wheat Straw)

The final flow chart and spreadsheets for the production of ethanol from lignocellulosics in the form of wheat straw are given in Appendix P. As in Section 4.3.12, the average yield of wheat straw is based on data for the East Anglia region of the UK (Ref. 13). Primary energy inputs and GHG outputs for replacement fertilisers were derived from Canadian data adjusted to this average yield (Ref. 17). Since wheat straw is treated as a waste product, the primary energy inputs and GHG outputs of wheat grain cultivation and harvesting are not taken into account. However, a reference system, based on straw ploughing as the main current alternative, is incorporated into the calculations. Additionally, the primary energy inputs and GHG outputs of manufacture, maintenance and repair of agricultural machinery are included. Based on extrapolation from pilot plant data, it is assumed that lignin and unfermentables are used to provide all the heat and electricity in the ethanol conversion process (Ref. 17). As a result, the ethanol plant is assumed to be self-sufficient in energy and, indeed, provides a surplus of electricity, for which credits arise in the form of primary energy and GHG savings due to the displacement of grid electricity in the UK in 1996 (Ref. 7). There are also credits for acetic acid produced as a by-product with primary energy and GHG savings based on the main production route for this particular chemical. The conversion plant is taken as having a rated capacity of 40,000 tonnes of ethanol per year, and primary energy inputs and GHG outputs for plant construction, maintenance and decommissioning are based on similarities with a biodiesel plant of the same output capacity and on a physical inventory of components (Ref. 4).

4.3.14 Ethanol from Sugar Beet

The final flow chart and spreadsheets for the production of ethanol from sugar beet are presented in Appendix Q. Sugar beet yields, fertiliser application rates and other prominent considerations are adapted to UK conditions from a German study (Ref. 8). A reference system, based on fallow set-aside, is applied but the primary energy inputs and GHG outputs of manufacture, maintenance and repair of agricultural machinery are not included. The ethanol conversion plant uses a heavy fuel oil-fired combined heat and power plant to provide all its steam, hot water and electricity requirements (Ref. 8). The conversion plant is taken as having a rated capacity of 40,000 tonnes of ethanol per year, and primary energy inputs and GHG outputs for plant construction, maintenance and decommissioning are based on similarities with a biodiesel plant of the same output capacity and a physical inventory of components (Ref. 4). Allocation of primary energy inputs and GHG outputs is based on the effective prices of pulp for animal feed and raw juice.

4.3.15 Ethanol from Wheat

The final flow chart and spreadsheets for the production of ethanol from wheat grain are provided in Appendix R. Wheat grain yields and fertiliser application rates for the UK in 1996 are used as a basis for results (Ref. 18). A reference system, based on fallow set-aside, is applied but the primary energy inputs and GHG outputs of manufacture, maintenance and repair of agricultural machinery are not included. It is assumed that the ethanol conversion plant uses steam and hot water provided by a natural gas-fired boiler and electricity imported from the grid with a primary energy input and GHG outputs for the UK in 1996 (Ref. 7). The conversion plant is taken as having a rated capacity of 40,000 tonnes of ethanol per year, and primary energy inputs and GHG outputs for plant construction, maintenance and decommissioning are based on similarities with a biodiesel plant of the same output capacity and a physical inventory of plant components (Ref. 4). Allocation of relevant primary energy inputs and GHG outputs between wheat straw and wheat grain, bran and course powder flour, and animal feed and ethanol is based on market prices.

4.3.16 Heat by Combustion of Wood Chips

Appendix S contains the final flow chart and spreadsheet for the small-scale production of heat by combustion of wood chips. Results are based on a wood-fired boiler with a net heat output of 50 kW and a load factor of 50% which consumes 89 tonnes of oven dried wood chips (25% moisture content) per year. The primary energy input and GHG output of plant construction are derived from a physical inventory of plant components (Ref. 4). Direct CH_4 and N_2O emissions from wood chip combustion are included.

4.3.17 Rapeseed Oil from Oilseed Rape

Appendix T presents the final flow chart and spreadsheets for the production of rapeseed oil from oilseed rape. A German study (Ref. 8) is the source of the most prominent data for this biofuel technology which was adjusted to UK conditions in 1996. A reference system, based on fallow set-aside, is applied to the cultivation and harvesting of oilseed rape. Primary energy inputs and GHG outputs for the manufacture, maintenance and repair of agricultural machinery are not included in the calculations. The primary energy input and GHG outputs for plant construction, maintenance and decommissioning are based on the physical inventory for an oilseed mill with a rated capacity of 42,080 tonnes per year (Ref. 4). Allocation by market prices is adopted for partitioning between rape straw and raw rapeseed, and rape meal and crude rapeseed oil.

5. SUMMARY OF RESULTS

For convenience, standard results can be summarised for the selected biofuel technologies. In terms of indicators of fossil fuel depletion, the principal result consists of the **energy requirement** which is the total primary energy input to the biofuel technology divided by its specified energy output, measured in MJ/MJ. For liquid biofuels, the energy output is measured in terms of net calorific value (heat of combustion excluding the latent heat in combustion products). For biofuel-fired combined heat and power plants, the energy output is given in either a unit of heat or electricity, with no distinction between these forms of energy. It should be noted that the energy requirement is the inverse of the energy ratio which is sometimes quoted in other energy and carbon balance studies. The energy requirements for the selected biofuel technologies are presented in Table 19. A major indicator of emissions is the **carbon requirement** which is the total CO_2 emissions from a biofuel technology, excluding those captured by the cultivation of the original source of biomass, divided by its specified energy output, measured in kg CO_2/MJ. The carbon requirements for the selected biofuel technologies are illustrated in Table 20. Other indicators of emissions are the **methane requirement** and the **nitrous oxide requirement** which are the total CH_4 and N_2O emissions, respectively, from a biofuel technology divided by its specified energy output, measured in kg CH_4/MJ and kg N_2O/MJ, respectively. The methane and nitrous oxide requirements of the selected biofuel technologies are given in Tables 21 and 22, respectively. The **total greenhouse gas requirement** equals the sum of all CO_2, CH_4 and N_2O emissions from the biofuel technology, excluding any CO_2 captured by the cultivation of the original source of biomass, divided by its specified energy output, measured in kg eq CO_2/MJ. The total greenhouse gas requirements for the selected biofuel technologies are displayed in Table 23.

It is possible to compare these results with those for a selection of conventional fuels, electricity and heat supplies. Some relevant results, for ultra low sulphur diesel, unleaded petrol and fuel oil from crude oil, average UK electricity supplies, and oil-fired combined heat and power generation and small-scale heat production, are provided in Table 24. For consistency, results for conventional liquid fuels are specified per unit of energy output measured in terms of net calorific value. Complete nergy, carbon, methane, nitrous oxide and total GHG requirements are presented for examples of conventional electricity and heat supply which can be compared with results for those biofuel technologies which produce electricity and/or heat. However, only methane, nitrous oxide and GHG requirements quoted for liquid fuels, consisting of ultra low sulphur diesel, unleaded petrol and fuel oil from crude oil, exclude direct CH_4 and N_2O emissions. The reason for this is that these emissions from these fuels and their equivalent liquid biofuels, such as biodiesel, ethanol and rapeseed oil, depend on the performance of the vehicles and equipment in which these fuels are used. Currently, no evidence could be found of agreed consensus over consistent and comparable performance data which would provide a basis for standard estimates of such emissions. It should be noted that comparison of total carbon dioxide outputs is possible because of the combustion of liquid biofuels is, in effect, treat as "carbon neutral" in terms of the carbon dioxide emitted and subsequently absorbed by growing biomass. For complete and extensive comparison, it can be seen that a comprehensive and transparent set of reference energy, carbon, methane, nitrous oxide and total GHG requirements for conventional fuels, electricity and heat supplies is needed.

Some summary details can be provided for the results presented in Table 24. In particular, ultra low sulphur diesel is produced in the UK using hydro-cracking with gas oil, electricity and steam generated from a natural gas-fired boiler (Ref. 6). Conventional production is assumed for unleaded petrol and fuel oil derived from a UK refinery using crude oil obtained from the North Sea (Ref. 7). The results for these liquid fuels are quoted in terms of net calorific values. Electricity is based on average supplies available from the national grid in the UK in 1996, thereby reflecting the particular mix of fossil fuel, nuclear and renewable generation in that given year (Ref. 7). An oil-fired industrial combined heat and power station with an overall thermal efficiency of 85%, with 70% heat production and 15% electricity generation, is taken to be equivalent to the Masnedø co-fired (straw and wood) combined heat and power plant in Denmark (Ref. 12). These results are presented in terms of one unit of heat or electricity produced by this technology. Heat is assumed to be provided by a small-scale oil-fired boiler with a typical thermal efficiency of 80%.

Table 19 Summary of Energy Requirements for Selected Biofuel Technologies

Selected Biofuel Technology	Energy Requirement (MJ/MJ)
Biodiesel from oilseed rape	0.437 ± 0.024(a)
Biodiesel from recycled vegetable oil	0.188 ± 0.018(a)
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.139 ± 0.012(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	0.102 ± 0.019(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	0.092 ± 0.016(b)
Electricity (large scale) by combustion of miscanthus	0.272 ± 0.019
Electricity (large scale) by combustion of straw	0.607 ± 0.038
Electricity by combustion of wood chip from forestry residues (large scale)	0.309 ± 0.023
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.381 ± 0.056
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.352 ± 0.048
Electricity by gasification of wood chip from forestry residues (large scale)	0.133 ± 0.009
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.169 ± 0.027
Electricity by gasification of wood chip from short rotation coppice (Option B)	0.154 ± 0.023
Electricity by pyrolysis of wood chip from forestry residues (large scale)	0.284 ± 0.022
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.331 ± 0.040
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.312 ± 0.035
Ethanol from lignocellulosics (wheat straw)	- 0.028 ± 0.037(a)
Ethanol from sugar beet	0.496 ± 0.044(a)
Ethanol from wheat	0.464 ± 0.032(a)
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.100 ± 0.006
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.092 ± 0.006
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.094 ± 0.006
Rapeseed Oil from oilseed rape	0.291 ± 0.018(a)

Table 20 Summary of Carbon Requirements for Selected Biofuel Technologies

Selected Biofuel Technology	Carbon Requirement (kg CO_2/MJ)
Biodiesel from oilseed rape	0.025 ± 0.001(a)
Biodiesel from recycled vegetable oil	0.013 ± 0.002(a)
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.007 ± 0.001(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	0.005 ± 0.001(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	0.004 ± 0.001(b)
Electricity (large scale) by combustion of miscanthus	0.018 ± 0.001
Electricity (large scale) by combustion of straw	0.029 ± 0.002
Electricity by combustion of wood chip from forestry residues (large scale)	0.016 ± 0.001
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.018 ± 0.003
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.016 ± 0.002
Electricity by gasification of wood chip from forestry residues (large scale)	0.007
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.008 ± 0.001
Electricity by gasification of wood chip from short rotation coppice (Option B)	0.007 ± 0.001
Electricity by pyrolysis of wood chip from forestry residues (large scale)	0.014 ± 0.001
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.016 ± 0.002
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.014 ± 0.002
Ethanol from lignocellulosics (wheat straw)	0 ± 0.002(a)
Ethanol from sugar beet	0.034 ± 0.003(a)
Ethanol from wheat	0.024 ± 0.002(a)
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.005
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.005
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.005
Rapeseed Oil from oilseed rape	0.015 ± 0.001(a)

Notes

(a) Based on the net calorific value of the biofuel.

(b) Per unit of electricity or heat.

Table 21 Summary of Methane Requirements for Selected Biofuel Technologies

Selected Biofuel Technology	Methane Requirement (g CH_4/MJ)
Biodiesel from oilseed rape	0.028 ± 0.002(a)
Biodiesel from recycled vegetable oil	0.007 ± 0.001(a)
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.002(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	0.001(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	-
Electricity (large scale) by combustion of miscanthus	0.008
Electricity (large scale) by combustion of straw	0.025 ± 0.003
Electricity by combustion of wood chip from forestry residues (large scale)	0.004
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.004
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.003
Electricity by gasification of wood chip from forestry residues (large scale)	0.003
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.003
Electricity by gasification of wood chip from short rotation coppice (Option B)	0.003
Electricity by pyrolysis of wood chip from forestry residues (large scale)	0.014 ± 0.002
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.014 ± 0.002
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.014 ± 0.002
Ethanol from lignocellulosics (wheat straw)	- 0.024 ± 0.005(a)
Ethanol from sugar beet	0.013 ± 0.001(a)
Ethanol from wheat	0.028 ± 0.003(a)
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.017
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.017
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.017
Rapeseed Oil from oilseed rape	0.020 ± 0.002(a)

Table 22 Summary of Nitrous Oxide Requirements for Selected Biofuel Technologies

Selected Biofuel Technology	Nitrous Oxide Requirement (g N_2O/MJ)
Biodiesel from oilseed rape	0.048 ± 0.006(a)
Biodiesel from recycled vegetable oil	-
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.005(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	-
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	-
Electricity (large scale) by combustion of miscanthus	0.021
Electricity (large scale) by combustion of straw	0.111 ± 0.011
Electricity by combustion of wood chip from forestry residues (large scale)	0.019
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.025 ± 0.003
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.023 ± 0.003
Electricity by gasification of wood chip from forestry residues (large scale)	-
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.001
Electricity by gasification of wood chip from short rotation coppice (Option B)	-
Electricity by pyrolysis of wood chip from forestry residues (large scale)	-
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.001
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.001
Ethanol from lignocellulosics (wheat straw)	0.043 ± 0.005(a)
Ethanol from sugar beet	0.018 ± 0.002(a)
Ethanol from wheat	0.012 ± 0.001(a)
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.005
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.005
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.005
Rapeseed Oil from oilseed rape	0.046 ± 0.006(a)

Notes

(a) Based on the net calorific value of the biofuel.

(b) Per unit of electricity or heat.

Table 23 Summary of Total Greenhouse Gas Requirements for Selected Biofuel Technologies

Selected Biofuel Technology	Total Greenhouse Gas Requirement (kg eq CO_2/MJ)
Biodiesel from oilseed rape	0.041 ± 0.002(a)
Biodiesel from recycled vegetable oil	0.013 ± 0.002(a)
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.008 ± 0.002(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	0.005 ± 0.001(b)
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	0.004 ± 0.001(b)
Electricity (large scale) by combustion of miscanthus	0.026 ± 0.001
Electricity (large scale) by combustion of straw	0.066 ± 0.004
Electricity by combustion of wood chip from forestry residues (large scale)	0.022 ± 0.001
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.025 ± 0.003
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.023 ± 0.003
Electricity by gasification of wood chip from forestry residues (large scale)	0.007
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.008 ± 0.001
Electricity by gasification of wood chip from short rotation coppice (Option B)	0.007 ± 0.001
Electricity by pyrolysis of wood chip from forestry residues (large scale)	0.014 ± 0.001
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.016 ± 0.002
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.015 ± 0.002
Ethanol from lignocellulosics (wheat straw)	0.013 ± 0.002(a)
Ethanol from sugar beet	0.040 ± 0.003(a)
Ethanol from wheat	0.029 ± 0.002(a)
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.007
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.007
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.007
Rapeseed Oil from oilseed rape	0.031 ± 0.002(a)

Notes

(a) Based on the net calorific value of the biofuel.

(b) Per unit of electricity or heat.

Table 24 Reference Results for a Sample of Conventional Sources of Energy

Conventional Energy Supply	Energy Requirement (MJ/MJ)	Carbon Requirement (kg CO_2/MJ)	Methane Requirement (g CH_4/MJ)	Nitrous Oxide Requirement (g N_2O/MJ)	Total Greenhouse Gas Requirement (kg eq CO_2/MJ)
Ultra Low Sulphur Diesel from Crude Oil(a)	1.26	0.087	0.025(b)	0.000075(b)	0.087(b)
Unleaded Petrol from Crude Oil(a)	1.19	0.081	0.022(b)	0.000028(b)	0.081(b)
Fuel Oil from Crude Oil(a)	1.19	0.087	0.022(b)	0.000028(b)	0.087(b)
Electricity from UK Grid Supplies in 1996	3.08	0.150	0.404	0.006	0.162
Industrial Combined Heat and Power(c)	1.38	0.100	0.027	0.001	0.101
Heat from Small-Scale Oil-Fired Boiler	1.45	0.104	0.029	0.001	0.105

Notes

(a) Based on the net calorific value of the fuel.

(b) Excluding direct CH_4 and N_2O emissions during combustion due to variations in vehicle and equipment performance.

(c) Per unit of electricity or heat.

6. CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this work can be summarised as follows:

- there is a substantial collection of existing studies on the energy inputs and GHG outputs of a range of biofuel technologies which could be potentially important in the United Kingdom,

- although these studies vary in relevance, detail and transparency, it was possible to identify those which could provide a suitable basis for deriving baseline energy and carbon balances for selected biofuel technologies,

- complete estimates of primary energy inputs and CO_2, CH_4, N_2O and total GHG outputs, qualified by indications of uncertainty, have been calculated for selected biofuel technologies,

- these estimates have been recorded in spreadsheets, supported by flow charts and detailed notes to provide a high degree of standardisation and transparency,

- results have been derived in the form of energy, CO_2, CH_4, N_2O and total GHG requirements, and

- these baseline results demonstrate that all the biofuel technologies considered achieve, in varying degrees, positive energy and GHG benefits which would offer savings in the consumption of fossil fuel resources and associated GHG emissions.

The spreadsheets assembled here are based on existing studies, modified, where necessary, to apply to UK conditions and extended, where possible, to include important aspects, such as CH_4 and N_2O emissions which enable estimates to be derived for total GHG outputs. However, as noted in detail in Sections 4.3.1 to 4.3.17, the coverage of individual spreadsheets is affected by limitations in the original studies, resulting mainly from a lack of specific data. On this basis, it has been possible to recommend further work based on the following additional data requirements which, if fulfilled, would provide a consistent and comparable series of spreadsheets for the selected biofuel technologies:

- agricultural activity data for estimating the primary energy inputs and GHG outputs of the manufacture, repair and maintenance for agricultural machinery used in the production of oilseed rape, miscanthus, sugar beet and wheat,

- agreed evaluation of the effect of removing straw from fields for fuel use on fertiliser use and yields for subsequent crops,

- direct CH_4 and N_2O emissions from the operation of a combined heat and power plant based on the gasification of wood chips, power only plants based on the combustion, gasification and pyrolysis of wood chips, and an ethanol plant based on lignocellulosics (straw),

- start-up fuel data for combined heat and power plants based on the combustion and gasification of wood chips, and power only plants based on the combustion of miscanthus, straw and wood chips, and

- physical inventories of plant components for calculation of the primary energy inputs to the construction of a combined heat and power plant based on the combustion of wood chips, power only plants based on the combustion of miscanthus, straw and wood chips, and ethanol plants based on lignocellulosics (straw), sugar beet and wheat.

- direct CH_4 and N_2O emissions factors for the combustion of liquid biofuels and their equivalents, such as diesel oil, petrol and fuel oil derived from crude oil, on an agreed and comparable basis, and

- a set of equivalent reference results for conventional fuels, electricity and heat supplies for consistent and comprehensive comparison with results for biofuel technologies.

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8. "Nachwachsende Energieträger – Grundlagen, Verfaben, Ökologische Bilanzierung" (Renewable Energy Sources, Basis, Processes and Ecological Balance) by M. Kaltschmitt and G. A. Reinhardt (eds), Vieweg, Braunschweig/Weisbaden, Germany,1997.

9. Personal communication, Envirodiesel Ltd., 20 December 2002.

10. “Modelling of Carbon and Energy Budgets of Wood Fuel Coppice Systems” by R. Matthews, R. Robinson, S. Abbott and N. Fearis, ETSU B/W5/00337/REP, Energy Technology Support Unit, Harwell, United Kingdom, 1994.

11. “Estimation of Carbon Dioxide and Energy Budgets of Wood-fired Electricity Generation Systems” by R. Matthews and N. D. Mortimer, ETSU Report B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

12. "CHP- and Power Plants" in 'Straw for Energy Production', pp. 34 – 42.

13. "Energy and Carbon Analysis of Using Straw as a Fuel" by J. F. Grant, R. Hetherington, R. E. Horne and N. D. Mortimer, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom, 1995.

14. "Design of a 2.5 MW(e) Biomass Gasification Power Generation Module" by R. McLellan, Wellman Process Engineering Ltd., ETSU B/T1/00569, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

15. "Fast Pyrolysis of Biomass for Green Power Generation" by R. Thamburaij, Orenda Aerospace Corporation, and Dynamotive Energy Systems Corporation, First World Conference and Exhibition on Biomass for Energy and Industry, Seville, Spain, 2000.

16. "Estimating the Energy Requirements and CO_2 Emissions from Production of the Perennial Grasses Miscanthus, Switchgrass and Reed Canary Grass" by M. Bullard and P. Metcalfe, Report ETSU B/U1/00645, Energy Technology Support Unit, Harwell, United Kingdom, 2001.

17. "Assessment of Net Emissions of Greenhouse Gases from Ethanol-Blended Gasolines in Canada: Lignocellulosic Feedstocks" R-2000-2, Levelton Engineering Ltd., Richmond, Canada, December 1998.

18. "Alternative Road Transport Fuels – A Preliminary Life-Cycle Study for the UK" by M. P. Gover, S. A. Collings, G. S. Hitchcock, D. P. Moon and G. T. Williams, Report R92, Volume 2, Energy Technology Support Unit, Harwell, United Kingdom, March 1996.

APPENDIX A: Review Summaries

The following summaries are based on reviews of relevant studies of the evaluation of energy inputs, and carbon dioxide and other greenhouse gas emissions associated with selected biofuel technologies. A concise format has been used to present the findings of these reviews, consisting of the following aspects:

- Year of Publication
- Author(s)
- Full Reference
- System Considered
- Processes Included
- Strengths
- Weaknesses
- Key Citations

The review summaries are organised first in order of the year of publication of the study and then by alphabetical order of the first author of the study.

Year of Publication: 1981

Authors: Ferchack and Pye

Publication Type: Journal Paper

Full Reference:

Ferchack, J. D. and Pye, E. K. (1981), Utilization of Biomass in the US for the Production of Ethanol Fuel as a Gasoline Replacement - II Energy Requirements with Emphasis on Lignocellulosic Conversion. *Solar Energy*, 26, 17-25.

Systems Considered:

Calculations and comparisons of energy requirements of ethanol produced from corn, molasses and lignocellulosic substrate (wood – short rotation and long rotation options).

Processes Included:

Establishment; management (includes irrigation and herbicides); harvesting; processing; conversion.

Strengths:

Methods of calculation simple and fairly transparent

Weaknesses:

Relies heavily on summary estimates from earlier studies. Estimated energy inputs to conversion of wood to ethanol speculative. Study is dated.

Key Citations:

1. Ferchak, J. D. and Pye, E. K. (1981), Utilization of Biomass in the U.S. for the Production of Ethanol fuel as a Gasoline Replacement – I Terrestrial Resource Potential. *Solar Energy*, 26, 9-16.
2. Pimental, D. *et al*. (1973), Food Production and the Energy Crisis. *Science*, 195, 443-449.

Year of Publication: 1987

Authors: Herendeen and Brown

Publication Type: Journal Paper

Full Reference:

Herendeen, R. and Brown, S. (1987), A Comparative Analysis of Net Energy from Woody Biomass. *Energy*, 12, 75-84.

Systems Considered:

Review and calculations of energy balances of production of sawn timber from long rotation forests ('hardwoods', loblolly pine) and wood biomass production from short rotation forest systems (olive, sycamore, poplar, eucalyptus).

Processes Included:

Crop establishment and management, harvesting, basic processing, drying and transport.

Strengths:

Energy and carbon balances have been calculated in a consistent manner. The basis of calculations is fairly transparent.

Weaknesses:

Relies heavily on the validity of the underlying data sources (notably Blankenhorn et al, see below). Precise details of assumptions about crop establishment and management are not specified, nor is the basis of calculations. Unclear what is assumed about energy inputs associated with biomass storage. Assumptions about energy inputs to drying and irrigation speculative at best. Study now rather dated, particularly in terms of reliance on source data. Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. Blankenhorn, P. R., Bowersox, T. W. and Murphey, W. K. (1978), *TAPPI*, 61, 57-.
2. Rose, D., Ferguson, K., Lothner, D. C. and Zavitkovski, J. (1981), An Economic and Energy Analysis of Poplar Intensive Cultures in the Lake States, USDA Forest Service Research Paper NC-196. North Central Forest Experimental Station, St. Paul, Minnesota.
3. Wang, F. C., Richardson, J., Ewel, K. C. and Sullivan, E. T. (1981), in Mitsch, W. J., Bosserman, R. W. and Klopatek, J. M. (eds.) Energy and Ecological Modelling. Elsevier: New York, 673-.
4. White, T. A., Rolfe, G. L. and Bluhm, D. R. (1981), Update 81: a Research Report of the Dixon Springs Agriculture Center. Illinois Experimental Station: Urbana, Illinois.
5. Zavitkovski, J. (1979), *Forest Science*, 25, 383-.

Year of Publication: 1987

Authors: Marrow et al

Publication Type: Contract Report

Full Reference:

Marrow, J. E., Coombs, J. and Lees, E. W. (1987),
An Assessment of Bio-Ethanol as a Transport Fuel in the UK, Volume 1

Systems Considered:

Technology review and economic and market analysis of ethanol production from wheat and sugar beet. Material and energy balance.

Processes Included:

Crop planting; harvesting; storage; transport and processing.

Strengths:

Very through review of technologies and potential for ethanol production using different raw materials in the United Kingdom - comparisons with Europe and US.

Weaknesses:

Very brief mentioning for emissions produced during production and combustion.
Calculations for energy inputs is not transparent and does not cover many aspects.
Most of the data could be outdated due to developments in this field.

Key Citations:

1. Fuel Ethanol and Agriculture: An Economic Assessment, US Department of Agriculture.
2. Langley, K. F. (1987), A Ranking of Synthetic Fuel Options for Road Transport Applications in the UK, ETSU R-33, Harwell, United Kingdom.
3. EC Council Directive on the Use of Oxygenates in Petrol, 1985.

Year of Publication: 1990

Authors: Marrow et al

Publication Type: Contract Report

Full Reference:

Marrow, J. E., Coombs, J. and Lees, E. W. (1990), An Assessment of Bio-Ethanol as a Transport Fuel in the UK, Volume 2.

Systems Considered:

Technology review and economic and market analysis of ethanol production from wheat, wood and other lignocellulosic wastes and residues. Process flow sheets and energy balance.

Processes Included:

Crop planting, harvesting, storage, transport and processing

Strengths:

Very through review of technologies and potential for ethanol production using wood and other lignocellulosic wastes and residues in the United Kingdom. Very detailed cost analysis using different scenarios.

Weaknesses:

Emissions produced during production and combustion are not covered.
Calculations for energy inputs is not transparent and does not cover many aspects.
Cost data and most of the processing data could be outdated due to developments in this field.

Key Citations:

1. Home Grown Cereals Authority (1987), *HGCA Weekly Digest*, 13, 34.
2. Forestry Commission (1987), *Forestry Facts and Figures*, 1986-1987.
3. Clegg, J.M. et al (1985), The Acquisition and Utilisation of Straw as a Fuel, ETSU - B – 1115, Harwell, United Kingdom.
4. Mitchell, C.P. et al (1987), Growing Wood for Energy in Great Britain, ETSU-B-1102, Harwell, United Kingdom.

Year of Publication: 1991

Authors: Turhollow and Perlack

Publication Type: Journal Paper

Full Reference:
Turhollow, A. F. and Perlack, R. D (1991), Emissions of CO_2 from Energy Crop Production, *Biomass and Bioenergy*, 1, 129-135.

Systems Considered:
Calculations of energy requirements and carbon dioxide emissions factors for selected biomass production systems in the USA including poplar (wood), sorghum and switchgrass.

Processes Included:
Crop establishment and management, harvesting, basic processing and transport.

Strengths:
Energy and carbon balances have been calculated in a consistent manner for the three crops considered. The basis of calculations is fairly transparent.

Weaknesses:
Relies heavily on the validity of the underlying data sources (Pimentel, see below). Precise details of assumptions about crop establishment and management are not specified, nor is the basis of calculations. Unclear what is assumed about energy inputs associated with biomass storage. Does not include indirect energy inputs to equipment and machinery manufacture. Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. Marland, G. and Turhollow, A. F. (1990), CO_2 Emissions from Production and Combustion of Fuel Ethanol from Corn, ORNL/TM-11180, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.
2. Pimentel, D. (1980), Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, Florida, USA.
3. Blankenhorn, P. R., Bowersox, T. W., Strauss, C. H., Stover, L. R. and Grado, S. C. (1985), Net Financial and Energy Analyses for Producing Populus Hybrid under Four Management Strategies, ORNL/Sub/779-07928/1, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Year of Publication: 1992

Authors: Culshaw and Butler

Publication Type: Contract Report

Full Reference:

Culshaw, F., and Butler, C. (1992), A Review of the Potential of Biodiesel as a Transport Fuel, Report R71, Energy Technology Support Unit, Harwell, United Kingdom.

Systems Considered:

Calculation of primary energy inputs and carbon dioxide emissions of biodiesel production from oilseed rape.

Processes Included:

Complete process chain including cultivation, transportation, drying, storage, mechanical extraction, esterification and distribution.

Strengths:

Sources of data, assumptions and calculations are relatively transparent. The allocation procedures are explained. Complete details are provided for the derivation of primary energy inputs.

Weaknesses:

Flow charts for each process chain are not provided although related data are incorporated in the text. Only partial details are provided for the calculation of carbon dioxide emissions. No other greenhouse gas emissions are considered. The basis for the assumed primary energy inputs and carbon dioxide emissions for the manufacture of nitrogen fertiliser is not explained. The allocation procedure adopted for the main results is based on the calorific values of all co-products (rape straw, rape meal and glycerine) although none of these are used as a fuel currently.

Key Citations:

1. Boustead, I., and Hancock, G. (1979), Handbook of Industrial Energy Analysis, Ellis Horwood, Chichester, United Kingdom.
2. Anon (1981), The Fertiliser Industry, Energy Audit Series No. 13, Department of Trade and Industry, London, United Kingdom.
3. Michaelis, L. (1992), Personal Communication, Strategic Studies Department, Energy Technology Support Unit, Harwell, United Kingdom.
4. Mortimer, N. D. (1992), Personal Communication, Resources Research Unit, Sheffield Hallam University, Sheffield, United Kingdom.

Year of Publication: 1992

Authors: Ellington and Meo

Publication Type: Journal Paper

Full Reference:
Ellington, R. T. and Meo, M. (1992), Calculating the Net Greenhouse Warming Effect of Renewable Energy Resources: Methanol from Biomass. *Journal of Environmental Systems*, 20, 287-301.

Systems Considered:
Calculations of greenhouse gas emissions factors for methanol production from short rotation biomass forest systems, with conversion to methanol based on gasification.

Processes Included:
Crop establishment and management, harvesting, basic and advanced processing, transport; storage and conversion.

Strengths:
Analysis over complete life cycle.

Weaknesses:
The basis of calculations is not completely clear from this summary report. Use of warming potentials rather than simple emissions complicates interpretation of results.

Key Citations:

1. Ellington, R. T., and Meo, M. (1991), Greenhouse Gases, Utilities and Climate Policy, Performance and Waste Management Association, Vancouver, Canada.
2. Ellington, R. T., Meo, M. and Baugh, D. (1991), The Total Greenhouse Warming Effect of Technical Systems: Analysis for Decision Making. *Journal of Air and Waste Management*.

Year of Publication: 1993

Authors: Ellington et al

Publication Type: Journal Paper

Full Reference:

Ellington, R. T., Meo, M. and El-Sayad, D. A. (1993), Net Greenhouse Warming Forcing of Methanol Produced from Biomass. *Biomass and Bioenergy*, 4, 405-418.

Systems Considered:

Life cycle analysis of production of methanol from woody biomass (short rotation forestry) including energy balance and greenhouse gas emission factors.

Processes Included:

Crop establishment and management, harvesting, basic and advanced processing, transport, storage and conversion.

Strengths:

Analysis over complete life cycle. Very thorough in most but not all aspects.

Weaknesses:

Controversial assumptions about attributable energy inputs (for example, energy inputs to an on-farm shop) and allocation to co-products. Analysis seems to be purposefully pessimistic. Use of warming potentials rather than simple emissions complicates interpretation of results.

Key Citation:

1. Ellington, R. T., Meo, M. and El-Sayad, D. A. (1991), Methanol from Biomass as an Alternative Transportation Fuel – Examination of System-wide Energy, Emissions and Costs, Final Project Report, University of Oklahoma, Norman, Oklahoma, USA.

Year of Publication: 1993

Authors: Wintzer et al

Publication Type: Book

Full Reference:
Wintzer, D., Furniss, B., Klein-Veilhauer, S., Leible, L., Niele, E., Rosch, Ch., and Tangen, H. (1993), Technical Process Assessment of Renewable Energy Raw Materials, Division for Applied Systems Analysis, Nuclear Research Centre, Kahlsruhe, Germany.

Systems Considered:
Production and uses of several biofuels (rapeseed oil, rape methyl ester, ethanol from sugar beet, wheat, maize and potatoes, wood chips, miscanthus and hay). Calculations of costs, energy inputs, carbon and nitrous oxide emissions for the cultivation process.

Processes Included:
Cultivation, fertiliser and pesticide inputs, drying, processing and end uses. Calculates the cost for carbon dioxide abatement. Looks into several end uses for each biofuel.

Strengths:
Detailed calculations for cultivation costs, yields and energy inputs when using different fertiliser inputs (including organic).

Weaknesses:
Very brief data for the manufacturing process. Calculations for energy inputs and emissions are not always transparent. No complete calculations for greenhouse gas emissions for all the biofuels considered.

Key Citations:

1. Bassam et al, Dambroth, M., and Jacks, I., (1992), Die Nutzung von Miscanthus sinensis als Energie und Industriegrundstoff, Landbauforschung Volkenrode, 42, 3, Germany
2. Federal Ministry of Food, Agriculture and Forestry (1990), 1988/90 Statistical Yearbook for Food, Agriculture and Forestry, Germany.
3. Davidson, E. A., (1992), Sources of Nitric and Nitrous Oxide following Wetting or Dry Soil, Journal of Soil Science Society of America, 56, 1, 95-102, United States of America.
4. Birnbaum, K. U., and Wagner, H. J., (1991) Einheitliche Berechnung von CO_2-Emissionen, Energiewirtschafliche Tagesfragen, 42, 1/2, 78-80, Germany.

Year of Publication: 1994

Authors: Batchelor et al

Publication Type: Contract Report

Full Reference:

Batchelor, S., Booth, E. J., Walker, K. C., and Cook, P., (1994), The Potential for Bioethanol Production from Wheat in the UK, The Scottish Agricultural College, HGCA, Project No. 0015/1/93

Systems Considered:

Review of ethanol production from wheat compared to other sources, energy and material balance, its uses, cost and market.

Processes Included:

Cultivation, fertiliser and pesticide production, and processing technology.

Strengths:

Comparisons with other sources (mineral, starches, sugar-based and lignocellulosics. Looks in detail in the different uses of ethanol as fuel additive or oxygenating agent and by-products production and use.

Weaknesses:

Relies on the validity of underlying data. Very brief data for the manufacturing process. Calculations for energy inputs and emissions not transparent. Very brief discussion of some emissions. No further calculations of carbon dioxide or other greenhouse gas emissions.

Key Citations:

1. Anon, Substitute Fuels for Road Transport. OECD/IEA, Paris, France.
2. Anon, Prospects for Alternative Uses of Cereals and Other Crops, Agra Europe, London, United Kingdom.
3. Bockman, O. C., Kaarstad, O., Lie, O. H., and Richards, I. (1990), Agriculture and Fertilisers, A Report from Norsk Hydro a.s., Norway.
4. Marrow, J. E., Coombs, J., and Lees E. W. (1990), An Assessment of Bio-Ethanol as a Transport Fuel in the UK. Volumes 1 and 2, HMSO, London, United Kingdom.
5. ADAS

Year of Publication: 1994

Author: Born

Publication Type: Journal Paper

Full Reference:
Born, P., (1992), CO_2-neutrale Energieträger aus Biomasse? (CO_2-neutral Energy Carriers from Biomass?) *Brennstoff Wärme Kraft* (*BWK)*, 44, 271-274.

Systems Considered:
Production of raw biomass and conversion to ethanol (wood, sugar beet/cane, grain and others).

Processes Included:
Summary results only presented.

Strengths: Relatively up-to-date study with consistent calculations.

Weaknesses:
Too abbreviated to evaluate thoroughness of calculations. Need to check out reference to study by Born (see below).

Key Citation:

1. Born, P. (1991), Die Beurtielung Ausgewahlter Verfharen der Biomassenkonversion bei den Unterschiedlichen Industrialisierungsgraden in Indien und der Bundesrepublik Deutschland - Eine Analyse unter Einbeziehung des kumulierten Energie und Arbeitszeitaufwands sowie der Kohlendioxidemissionen. VDI-Fortschrittberichte, Reihe 6, Nr. 265. VDI-Verlag: Dusseldorf, Germany.

Year of Publication: 1994

Author: Matthews

Publication Type: Contract Report

Full Reference:

Matthews, R. W., Robinson, R. L., Abbott, S. R. and Fearis, N. (1994), Modelling of Carbon and Energy Budgets of Wood Fuel Coppice Systems, ETSU Report ETSU B/W5/00337/REP, Energy Technology Support Unit, Harwell, United Kingdom.

Systems Considered:

Calculations of energy requirements and carbon dioxide emissions factors (as carbon) for wood biomass production from short rotation forest systems based on poplar and willow in the United Kingdom.

Processes Included:

Crop establishment and management, harvesting, basic processing, transport and storage.

Strengths:

The basis of calculations is transparent. Energy and carbon balances have been calculated in a consistent manner for the three crops considered. Sensitivity of results to assumptions and estimates is considered.

Weaknesses:

Relies heavily on the validity of the underlying data sources. Some assumptions require validation (for example, conversion of work rates of machinery to fuel consumption). Results very sensitive to assumptions about energy inputs associated with biomass storage. Drying of biomass not considered. Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. Hutchinson, P. (1993), Farm Machinery Costs, Agro Business Consultants Ltd: Twyford, United Kingdom.
2. Mortimer, N. D. (1981), The Use of Energy Intensity Multipliers, Report 22, Energy Workshop, University of Sunderland, United Kingdom.
3. Nix, J. (1991), Farm Management Pocketbook, Wye College, University of London, United Kingdom.

Year of Publication: 1994

Author: Wyman

Publication Type: Journal Paper

Full Reference:

Wyman, C. E. (1994), Alternative Fuels from Biomass and their Impact on Carbon Dioxide Accumulation, *Applied Biochemistry and Biotechnology*, 44-46, 897-915.

Systems Considered:

Consideration of methods of conversion of lignocellulosic biomass (wood) into potential transportation fuels including: ethanol from fermentation; methanol from gasification; methane from anaerobic digestion; MTBE from paralysis. Energy and carbon dioxide balances estimated for ethanol production only.

Processes Included:

Establishment; management, harvesting, transport, processing and conversion (only briefly summarised in paper).

Strengths:

Relatively up-to-date study by experts familiar with conversion technologies.

Weaknesses:

Summary information only. Need to refer to Lynd et al and possibly follow-up references to establish whether a more full account is available. Seems that biomass production is represented fairly crudely, but this may not be a problem. Results sensitive to assumptions about allocation of energy inputs to co-products and to assumptions about internal use of energy.

Key citation:

1. Lynd, L. R., Cushman, J. H., Nichols, R. J. and Wyman, C. E. (1991) *Science*, 251, 1318.

Year of Publication: 1994

Author: International Energy Agency

Publication Type: Book

Full Reference:
International Energy Agency (1994), Biofuels, OECD/IEA, Paris, France.

Systems Considered:
Review and comparison of biomass-based biofuel production systems including: ethanol from maize, wheat, and sugar beet; rape methyl ester from rapeseed; electricity from wood; and methanol from wood.

Processes Included:
Crop establishment and management, harvesting, basic and advanced processing, transport, storage and conversion.

Strengths:
Calculations based on a common, simple spreadsheet model. Factors used in the model are documented in full.

Weaknesses:
Not enough information provided about details of calculations. Relies heavily on data from other studies. Not at all clear how to check data and calculations, and, generally, confirm validity of results.

Key citations:
None.

Year of Publication: 1995

Authors: Grant et al

Publication Type: Contract Report

Full Reference:

Grant, J. F., Hetherington, R., Horne, R. E., and Mortimer, N. D., (1995), Energy and Carbon Analysis of Using Straw as a Fuel, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom.

Systems Considered:

Calculation of primary energy inputs and carbon dioxide emissions of using straw for generating heat and/or electricity.

Processes Included:

Process chain from waste straw after cereal cultivation through to eventual utilisation in a heat only, electricity or combined heat and power plant.

Strengths:

Good level of detail and transparency with flow chart presented. Sensitivity analysis conducted on key parameters.

Weaknesses:

Issue of primary energy inputs and carbon dioxide emissions of cereal production prior to straw recovery not addressed and resulting allocation procedures not explored. Relatively approximate means used to estimate the primary energy inputs and carbon dioxide emissions of constructing and maintaining straw utilisation plant. Other greenhouse gas emissions not determined.

Key Citations:

1. Prew, R. D., and Smith, B. D. (1988), Changing Straw Disposal Practices, *HGCA Research Review No. 11*, Home-Grown Cereals Authority, London, United Kingdom.
2. Nikolaisen, L, (1992), Straw for Energy Production: Technology – Environment – Economy, The Centre of Biomass Technology, Aarhus, Denmark.
3. Nix, J. (1993), Farm Management Pocketbook, Wye College, University of London, London, United Kingdom.
4. Hetherington, R. (1994), An Input-Output Assessment of Carbon Dioxide Release within the United Kingdom, Working Paper No. 3, Resources Research Unit, Sheffield Hallam University, Sheffield, United Kingdom.

Year of Publication: 1995

Authors: Gustavsson et al.

Publication Type: Journal Paper

Full Reference:

Gustavsson, L., Börjesson, P., Johansson, B., and Svenningsson, P. (1995), Reducing CO_2 Emissions by Substituting Biomass for Fossil Fuels, *Energy*, 20, 1097-1113.

Systems Considered:

Review of options for reducing CO_2 emissions using biomass – based electricity generation and transport fuel production (includes wood, rape seed, straw, wheat, grain, reed canary grass, lucerne.)

Processes Included:

Not clear from review paper.

Strengths:

Thorough review.

Weaknesses:

Relies heavily on the validity of estimates obtained from underlying references. Not clear how references have been used to derive estimates.

Key Citations:

Detailed consideration of obscure Swedish reports.

Year of Publication: 1996

Author: Börjesson

Publication Type: Journal Paper

Full Reference:

Börjesson, P. I. I. (1996), Energy Analysis of Biomass Production and Transportation, *Biomass and Bioenergy*, 11, 305-318.

Systems Considered:

Review and calculations of net energy yield of a range of biomass-based energy carriers including willow (short rotation biomass forests), logging residues (from long rotation forests) and a number of non-woody forms of biomass. Particular emphasis placed on likely impact on energy inputs due to transportation resulting from increased dependence on biomass. Swedish context.

Processes Included:

Crop establishment and maintenance, harvesting, basic processing and transport.

Strengths:

Thorough and consistent analysis for a range of raw biomass energy sources. Methods used in calculations fairly transparent.

Weaknesses:

Quite a lot of reliance of broad-brush summary results (emissions factors, energy requirements, national statistics, for example, for fuel consumption by vehicle fleets) from other studies, therefore strong dependence on previous published results.

Key Citation:

1. Pimentel, D. (1980), Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, Florida, USA.

Year of Publication: 1996

Authors: Gover et al

Publication Type: Contract Report

Full Reference:

Gover, M. P., Collins, S. A., Hitchcock, G. S., Moon, D. P. and Wilkins, G. T., (1996), Alternative Road Transport Fuels – A Preliminary Life Cycle Study for the UK, Report R92, Energy Technology Support Unit, Harwell, United Kingdom.

Systems Considered:

Comparative assessment of the primary energy inputs and emissions, including greenhouse gases, carbon dioxide, methane (as hydrocarbons) and nitrous oxide, as well as carbon monoxide, sulphur dioxide and particulates, for a range of road transport fuels, including biodiesel from oilseed rape and bioethanol from wheat.

Processes Included:

Complete process chain, including cultivation, preparation, processing (esterification for biodiesel and fermentation for bioethanol) and distribution.

Strengths:

Good explanation of the basis of the assessment is provided. Important sources of data, assumptions and calculations are transparent. Results are presented a detailed and clear manner. Effects of certain key factors, especially allocation procedures, are demonstrated. Different allocation procedures are investigated for biodiesel (co-products = rape straw, rape meal and glycerine) and bioethanol (co-products = wheat straw, wheat bran, distillers' dark grains and industrial carbon dioxide).

Weaknesses:

Flow charts for each process chain are not provided although related data are incorporated in the text. A variety of allocation procedures, especially those based on calorific value and substitution, are examined and subsequent results are presented. However, allocation by price, consistent with the associated economic assessment, is not considered. In general, this work updates that in an earlier ETSU report (Culshaw and Butler, 1992). Hence, it may be affected by some of the weaknesses of the earlier work. However, more realistic and transparent energy consumption and carbon dioxide emissions data for nitrogen fertiliser production are used. In contrast, a controversially-high value for the energy consumption of mechanical extraction of rapeseed is assumed.

Key Citations:

1. Culshaw, F., and Butler, C. (1992), A Review of the Potential of Biodiesel as a Transport Fuel, Report R71, Energy Technology Support Unit, Harwell, United Kingdom.
2. ADAS Silsoe (1993), Energy Input/Output Ratios in Biofuel Crop Production – Biofuel Study, Report ETSU/5A/1329/33, Energy Technology Support Unit, Harwell, United Kingdom.
3. ERL (1990), Study of the Environmental Impacts of Large-Scale Bioethanol Production in Europe, ERL, London, United Kingdom.

Year of Publication: 1996

Authors: Spirinckx and Ceuterick

Publication Type: Contract Report

Full Reference:

Spirinckx, C., and Ceuterick, D., (1996), Comparative Life-Cycle Assessment of Diesel and Biodiesel, Flemish Institute for Technological Research, Mol, Belgium.

Systems Considered:

Calculation of primary energy inputs and total greenhouse gas emissions for biodiesel production from oilseed rape.

Processes Included:

Complete process chain including cultivation, transportation, drying, storage, solvent extraction, esterification and distribution.

Strengths:

Adoption of International Standard ISO 14040 series on life cycle assessment ensures clarity with definition of goal, scope, functional unit and system boundaries. A range of different allocation procedures (calorific value, mass and price) are considered and their effects on results are demonstrated. Results are presented in considerable detail.

Weaknesses:

General lack of transparency over certain key assumptions, especially concerning nitrogen fertiliser. Estimates of carbon dioxide emissions are subsumed within total greenhouse gas emissions. Results reflect processing with hexane for solvent extraction of rapeseed oil which is common in Belgium rather than mechanical extraction which is currently used in the United Kingdom. The main results are based on a mixture of allocation procedures (mass for raw rapeseed and rape straw, price for rapeseed oil and rape meal, and biodiesel and glycerine).

Key Citations:

1. Consoli, F., Allen, D., Boustead, I., Fava, J., Franklin, W., Jensen, A. A., De Oude, N., Parrish, R., Perriman, R., Postethwaite, D., Quay, B., Seguin, J., and Veigon, B. (eds) (1993), Guidelines for Life Cycle Assessment: A Code of Practice, Report from the Workshop of the Society of Environmental Toxicology and Chemistry, Brussels, Belgium.
2. Lindfors, L. G., Christiansen, K., Hoffman, L., Virtanen, Y., Juntilla, V., Hanssen, O. J., Ronning, A., Ekvall, T., and Finnveden, G. (1995), Nordic Guidelines on Life Cycle Assessment, Nordic Council of Ministers, Copenhagen, Denmark.

Year of Publication: 1997

Authors: Boman and Turnbull

Publication Type: Journal Paper

Full Reference:

Boman, U. R. and Turnbull, J. H. (1997), Integrated Biomass Energy Systems and Emissions of Carbon Dioxide, *Biomass and Bioenergy*, 13, 333-343.

Systems Considered:

Review and calculations of energy balances and emissions of carbon dioxide resulting from electricity production from short rotation forest systems (poplar, willow), residues from long rotation forest systems, and energy crops (alfalfa, reed canary grass and switchgrass).

Processes Included:

Crop establishment and management, harvesting, basic processing, drying (in some cases) and transport.

Strengths:

The basis of calculations is fairly transparent.

Weaknesses:

Energy and carbon balances have not been calculated entirely consistently for the crops considered. Relies very heavily on the validity of the underlying studies (Börjesson, Bränström-Norberg et al, Northern States Power, Turhollow and Perlack, see below). Precise details of assumptions about crop establishment and management are not specified, nor is the basis of calculations. Unclear what is assumed about energy inputs associated with biomass storage. Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. Börjesson, P. (1994), Energy Analysis of Biomass Production in Swedish Agriculture and Forestry - Today and around 2015, IMES/EESS Report 17, Lund University, Sweden.
2. Bränström-Norberg, B.-M., Rosén-Lidholm, S. and Ternström, C. (1994), Analysis of Environmental Consequences for a Co-generation Power Station Burning Willows - Comparison with Forest Fuel and Coal, Research and Development Report UB 94/3. Vattenfall: Stockholm, Sweden.
3. Northern States Power, Sustainable Biomass Energy Production, Volume 1, Final Report to NSP, Minneapolis, USA.
4. Turhollow, A. F. and Perlack, R. D (1991), Emissions of CO_2 from Energy Crop Production, Biomass and Bioenergy, 1, 129-135.

Year of Publication: 1997

Authors: Kaltschmitt and Reinhardt

Publication Type: Book

Full reference:

Kaltschmitt, M., and Reinhardt, G. A., (1997), Renewable Energy Sources, Basis, Processes and Ecological Balance, Institut für Energie- und Umweltforschung Heidelberg GmbH, Germany.

Systems Considered:

Life cycle assessment calculations of several biofuels (wood residues, short rotation coppice, perennial grasses, cereals. ethanol from several sources, rapeseed oil and rape methyl ester).

Processes Included:

Crop planting, harvesting, storage, drying, transport, conversion and end use. Some general flowsheets are shown.

Strengths: Energy, carbon and other greenhouse gas balances have been calculated in a consistent manner for ethanol from sugar beet, rapeseed oil and rape methyl ester. Most of calculations are fairly transparent with very detailed calculations for the planting process (machinery, planting operations, fertiliser agrochemical and other process inputs) and conversion processes to ethanol, rapeseed oil and rape methyl ester. Life cycle assessment comparisons and sensitivity analysis.

Weaknesses:

Relies to some extent on the validity of the underlying data sources. For most of the biofuels, results for energy and carbon balances are presented on graphs without showing the break-up of the different processes.

Key Citations:

Extremely numerous.

Year of Publication: 1997

Authors: Mann and Spath

Publication Type: Contract Report

Full Reference:

Mann, M. K., and Spath, P. L., (1997), Life Cycle Assessment of a Biomass Gasification Combined-cycle System, Report NREL/TP-430-23076, National Renewable Energy Laboratory, Golden, Colorado, USA.

Systems Considered:

A fairly complete life cycle assessment of a projected biomass-fired integrated combined-cycle gasification plant in the midwest of the USA, including assessment of energy inputs and emissions per unit energy generated. Biomass was assumed to come from short rotation forests (poplar).

Processes Included:

Crop establishment and management, harvesting, processing, transport, storage, conversion, and power station construction and maintenance.

Strengths:

Based on the TEAM/DEAM software produced by Ecobalance Inc. Authors checked methodology and data sources against classic texts and found them to be consistent. Where reference is made to other sources of data, generally these are cross-checked or at least some effort made to validate results. For the most part, extremely thorough.

Weaknesses:

To some extent relies on software as black box. Slightly complicated by allowance for carbon sequestration attributable to establishment and maintenance of new forest areas, and introduction of the controversial concept of 'carbon closure'. Does not appear to have accounted for start-up fuel consumption.

Key Citations:

None.

Year of Publication: 1998

Authors: Dubuisson and Sintzoff

Publication Type: Journal Paper

Full Reference:

Dubuisson, X., and Sintzoff, I., (1998), Energy and CO_2 Balances in Different Power Generation Routes using Wood Fuel from Short Rotation Coppice, *Biomass and Bioenergy*, 15, 379-390.

Systems Considered:

Calculations of energy and carbon dioxide balances for wood fuel production from short rotation forests (poplar) in Belgium.

Processes Included:

Crop establishment and management, harvesting, basic processing, transport, storage and drying.

Strengths:

Repeats the methodology of Matthews et al (1994). The basis of calculations is transparent. Energy and carbon balances have been calculated in a consistent manner for the three crops considered. Sensitivity of results to assumptions and estimates is considered.

Weaknesses:

Relies heavily on the validity of methodology of Matthews et al (1994) and the underlying data sources. Some assumptions require validation (for example, conversion of work rates of machinery to fuel consumption). Assumes all carbon is emitted as carbon dioxide.

Key Citation:

1. Matthews ,R. W., Robinson, R. L., Abbott, S. R. and Fearis, N. (1994), Modelling of Carbon and Energy Budgets of Wood Fuel Coppice Systems, ETSU Report ETSU B/W5/00337/REP, Energy Technology Support Unit, Harwell, United Kingdom.

Year of Publication: 1998

Authors: Hanegraaf et al.

Publication Type: Journal Paper

Full Reference:

Hanegraaf, M. C., Biewinga, E. E. and van der Bijl, G. (1998), Assessing the Ecological and Economic Sustainability of Energy Crops, *Biomass and Bioenergy*, 15, 345-355.

Systems Considered:

Life cycle assessment of a wide range of biomass-based energy carriers in the Netherlands and rest of the European Union, including short rotation forestry systems (poplar, willow and eucalyptus) and a number of non-woody crops. Emphasis on gasification for electricity or combined heat and power, but with some consideration of liquid transport fuels.

Processes Included:

Establishment and management, harvesting, processing, transport, and conversion unit construction and maintenance. Only summary described so not possible to check details.

Strengths:

Extremely thorough and rigorous life cycle assessment approach. Results for a range of greenhouse gas emissions presented, also in terms of carbon dioxide equivalents.

Weaknesses:

Only summary results presented. Not possible to check calculations. Seems to rely heavily on results derived from other studies but not possible to determine this from information available.

Key Citation:

1. van der Bijl, G. and Beiwinga, E. E. (1996), Environmental Impact of Biomass for Energy, *Proceedings of a Conference organised as part of AIR 3-94-2455*, Noordwijkkerhout, Netherlands, Centre for Agriculture and Environment, Utrecht, Netherlands.

Year of Publication: 1998

Author: Hektor

Publication Type: Journal Paper

Full Reference:

Hektor, B., (1998), Cost Effectiveness of Measures for the Reduction of Net Accumulation of Carbon Dioxide in the Atmosphere, *Biomass and Bioenergy*, 15, 299-309.

Systems Considered:

Calculations of energy requirements and carbon dioxide emissions factors for biomass production systems for district heat generation plants in Sweden based on long rotation forests (residues from conventional production and waste from the wood processing industry) or based on short rotation biomass forests.

Processes Included:

Harvesting, basic processing and transport.

Strengths:

Thorough treatment.

Weaknesses:

For some systems, analysis only considers part of production process. Methods of calculation not transparent. Depends critically on cited literature (see below). Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. Hektor, B., (1994), Utilisation of Biofuels from Agriculture and Forestry for Cost Effective Reduction of CO_2 Emissions, Department of SIMS Paper 48, Swedish University of Agricultural Sciences, Sweden.
2. Hillebrand, K., (1993), Three Greenhouse Effects of Peat Production and Use Compared with Coal, Oil, Natural Gas and Wood, VTT Research Note 1494, VTT, Espoo, Finland.
3. Setzmanm, E., et al (1993), Environment Impact Analysis: from Cradle to Grave - Case Study of the VEGA Project, Vattenfal U(B), 19, Sweden.

Year of Publication: 1998

Authors: Jungmeier et al

Publication Type: Journal Paper

Full Reference:
Jungmeier, G., Resch, G. and Spitzer, J. (1998), Environmental Burdens over the Entire Life Cycle of a Biomass CHP Plant, *Biomass and Bioenerg*y, 15, 311-323.

Systems Considered:
Calculations of environmental impacts of combined heat and power generation in Austria based on wood biomass production systems (residues from conventional long rotation forests).

Processes Included:
Establishment and management (not clear how fully this is represented), harvesting, processing, transport, storage, conversion, and power station construction and maintenance.

Strengths:
Thorough (minor omissions). Analysis of a working plant. Estimates of emissions factors for all key greenhouse gases.

Weaknesses:
Relies on validity of methodology and, in particular, of parameter estimates assumed in model. Does not consider energy inputs to forest management in full although this is not an essential problem. Methods of calculation are not transparent. Evaluation of start-up fuel is unclear.

Key Citations:

1. European Commission (1995), EUR 16520 EN – ExternE Externalities of Energy - 1: Summary, Office for Official Publications of the European Communities, Luxembourg.
2. European Commission (1995), EUR 16520 EN – ExternE Externalities of Energy - 2: Methodology. Office for Official Publications of the European Communities, Luxembourg.
3. Resch, G. (1997), Life Cycle Inventory of a Biomass-fired Combined Heat and Power Plant, Technical University of Graz, 80, Austria.

Year of Publication: 1998
Author: Korpilahti
Publication Type: Journal Paper
Full Reference: Korpilahti, A., (1998), Finnish Forest Energy Systems and CO_2 Consequences, *Biomass and Bioenergy*, 15, 293-297.
Systems Considered: Calculations of energy requirements and carbon dioxide emissions factors for biomass production systems in Finland based on long rotation forests (residues from conventional production and integrated production).
Processes Included: Harvesting, basic processing and transport.
Strengths: Based on direct observations and reliable estimates.
Weaknesses: Analysis only considers part of production process. Methods of calculation not always completely transparent. Assumes all carbon is emitted as carbon dioxide.
Key Citations: None.

Year of Publication: 1998

Authors: Schwaiger and Schlamadinger

Publication Type: Journal Paper

Full Reference:

Schwaiger, H., and Schlamadinger, B., (1998), The Potential of Fuelwood to Reduce Greenhouse Gas Emissions in Europe, *Biomass and Bioenergy*, 15, 369-377.

Systems Considered:

Review of potential of increasing fuelwood supply and consumption in selected European countries with projected reductions in carbon dioxide emissions.

Processes Included:

Production, transport and conversion.

Strengths:

Variety of fuelwood types covered. Consistent calculations; carbon dioxide and other greenhouse gas emissions considered. Simple methodology has advantage of robustness.

Weaknesses:

Heavily reliant on statistics from other countries and grey literature. Analysis is broad.

Key Citations:

1. European Commission (1995), ExternE: Externalities of Energy, 1-6, Luxembourg.
2. Four obscure grey-literature reports.

Year of Publication: 1999

Author: ECOTEC Research and Consulting Ltd

Publication Type: Contract Report

Full Reference:
ECOTEC (1999), Financial and Environmental Impact of Biodiesel as an Alternative to Fossil Diesel in the UK, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.

Systems Considered:
Calculation of total greenhouse gas emissions, as well as carbon dioxide, methane, sulphur dioxide, oxides of nitrogen, volatile organic compounds and black smoke, for the production of biodiesel from oilseed rape.

Processes Included:
Complete process chain including cultivation, transportation, drying, storage, mechanical extraction, esterification and distribution.

Strengths:
Updating of earlier ETSU reports (Culshaw and Butler, 1992, and Gover et al, 1996) with the addition of new data from the British Association for Bio Fuels and Oils and an oilseed milling company, Cargill plc.

Weaknesses:
A general lack of transparency and detail with the sources of data, assumptions and methods of calculation. In particular, data used for nitrogen fertiliser is obscure, the allocation procedure is not explicit, estimated carbon dioxide emissions are subsumed within total greenhouse gas emissions and final results are presented in terms of "per kilometre" without any information on the assumed performance of the vehicle using biodiesel.

Key Citations:

1. Gover, M. P., Collins, S. A., Hitchcock, G. S., Moon, D. P. and Wilkins, G. T., (1996), Alternative Road Transport Fuels – A Preliminary Life Cycle Study for the UK, Report R92, Energy Technology Support Unit, Harwell, United Kingdom.
2. Culshaw, F., and Butler, C. (1992), A Review of the Potential of Biodiesel as a Transport Fuel, Report R71, Energy Technology Support Unit, Harwell, United Kingdom.

Year of Publication: 1999

Authors: Hartmann and Kaltschmitt

Publication Type: Journal Paper

Full Reference:

Hartmann, D., and Kaltschmitt, M., (1999), Electricity Generation from Solid biomass via Co-combustion with Coal: Energy and Emission Balances from a German Case Study, *Biomass and Bioenergy*, 16, 397-406.

Systems Considered:

A fairly complete life cycle assessment of the potential to co-firing biomass in existing German coal-fired electricity generation stations.

Processes Included:

Collection, chipping and transport of wood chips from harvesting residues arising from long-rotation forest systems. (All energy inputs to forest establishment and management are ignored). Power station construction, maintenance and demolition.

Strengths:

Thorough life cycle assessment. Consideration of a range of greenhouse gases.

Weaknesses:

Details of calculations not presented, therefore difficult to evaluate. Probably need to check out the citation below. Complicated by co-firing scenario considered in the case study, making it difficult to assess the impact of biomass in isolation.

Key Citations:

1. Hartmann, D., and Kaltschmitt, M., (1998), From Cradle to Grave; Comparison of the Overall Emissions of Electricity Production from Renewable Energies, *Brennstoff Wärme Kraft*, 50, 56--61.

Year of Publication: 1999

Authors: O'Connor et al

Publication Type: Conference Paper

Full Reference:

O'Connor, D. V., Esteghlalian, A. R., Gregg, D. J., and Saddler, J. N., (2000), Full Fuel Cycle Analysis of Greenhouse Gas Emissions from Biomass-derived Ethanol Fuel in Canada in Robertson, K. A. and Schlamadinger, B., (eds.), Bioenergy for Mitigation of CO2 Emissions: The Power, Transportation and Industrial Sectors, *Proceedings of an IEA Bioenergy Task 25 Workshop*, 27-30 September 1999, Gatlinburg, Tennessee, USA. . IEA Bioenergy Task 25: Graz, Austria 9-26.

Systems Considered:

Assessment of the potential for producing ethanol from wood waste generated by forest industries in Canada. Production of ethanol from corn also considered.

Processes Included:

Production, processing, distribution and utilisation. Only summary. PowerPoint presentation available so not possible to assess in detail.

Strengths:

Based on an extended version of the model of Mark Delucchi.

Weaknesses:

To some extent uses model as black box. Relies heavily on estimates derived from other studies. Summary information only available, so impossible to assess in detail.

Key Citations:

None.

Year of Publication: 1999	
Authors: Tahara et al	
Publication Type: Conference Paper	
Full Reference: Tahara, K., Kojima, T., Inaba, A., and Yokayama, S., (1999), Life Cycle Assessment of Biomass Power Generation with Sustainable Forestry System, in Reimer, P., Eliasson, B., and Wokaun, A., (eds.) Greenhouse Gas Control Technologies, 1183-1185.	
Systems Considered: Calculations of carbon dioxide balances for electricity generation from wood grown in short rotation forest systems. Potential systems in USA, Indonesia and Brazil.	
Processes Included: Crop establishment and management, harvesting, basic processing, transport, storage and conversion (but details not clear).	
Strengths: Based on NIRE life cycle assessment software developed at the (Japanese) National Institute for Resources and Environment.	
Weaknesses: Summary report only. Details not clear.	
Key Citations: 1. Inaba, A., (1995), *Environmental Management*, 31. 2. Tahara, K., et al (1997), *Energy Conversion and Management*, 38, Supplement, S615-S620. 3. Yokayama, S., (1996), *Resource and Environment*, 5, 431-436.	

Year of Publication: 1999

Authors: Wang et al

Publication Type: Contract Report

Full Reference:

Wang, C., Saricks, C. L., and Santini, D. (1999), Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emission, Centre for Transportation Research, Argonne National Laboratory, prepared for US Department of Energy, Office of Transportation Technologies, USA.

Systems Considered:

Estimation of primary energy inputs and greenhouse emissions of using ethanol (from corn and lignocellulosics) blended with petrol in passenger cars. 10% and 85% blends with gasoline.

Processes Included:

Corn farming; fertiliser production; land use assumptions, storage; transport; processing; distribution and vehicle operation.

Strengths:

Good analysis of the life cycle energy input and greenhouse gas emissions when using different ethanol-petrol blends from different feedstocks. Some data on yields, fertiliser input and rate of ethanol recovery. Sensitivity analysis (market-based, and electricity credit-based methods).

Weaknesses:

Relies on the validity of underlying data. Calculations for energy inputs and emissions is not transparent. Analysis is based on corn production in USA conditions.

Key Citations:

1. Delucchi, M., (1998), Life Cycle Energy Use, Greenhouse Gas Emissions, and Air Pollution from the Use of Transportation Fuels and Electricity, Institute of Transportation Studies, University of California, United States of America,
2. Levelton Engineering Ltd, (1999), Assessment of Net Emissions of Greenhouse Gases from Ethanol Blends in Southern Ontario, United States of America.
3. Wang, M. Q., (1996), GREET 1.0: Transportation Fuel Cycle Model: Methodology, and Use, ANL/ESD-33, Centre for Transportation Research, Argonne National Laboratory, Argonne, Illinois, United States of America.
4. Wang, M. Q., Saricks, C. L., and Wu, M., (1997), Fuel-Cycle Fossil Energy Use Greenhouse Gas Emissions of Fuel Ethanol Produced from U.S. Midwest Corn, prepared for Illinois Department of Commerce and Community Affairs, Centre for Transportation Research, Argonne National Laboratory, Argonne, Illinois, United States of America.

Year of Publication: 2000

Author: ECOTEC Research and Consulting Ltd.

Publication Type: Contract Report

Full Reference:

ECOTEC (2000), Emissions from Liquid Biofuels, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.

Systems Considered:

Calculation of the primary energy inputs and total greenhouse gas emissions, as well as carbon dioxide, oxides of sulphur, oxides of nitrogen, volatile organic compounds and carbon monoxide, for biodiesel production from oilseed rape.

Processes Included:

Complete process chain including cultivation, transportation, drying, storage, mechanical extraction, esterification and distribution.

Strengths:

Updating of the earlier reports (Culshaw and Butler, 1992, Gover et al, 1996 and ECOTEC, 1999) with data from a more recent report (Richards, 2000).

Weaknesses:

General lack of transparency with key assumptions and calculations. Allocation procedures are not explicit. Incomplete coverage since the report mainly concentrates on higher oilseed rape yields, primary energy and emissions data for nitrogen fertiliser manufacture, and nitrous oxide emissions associated with nitrogen fertiliser.

Key Citations:

1. Gover, M. P., Collins, S. A., Hitchcock, G. S., Moon, D. P. and Wilkins, G. T., 1996, Alternative Road Transport Fuels – A Preliminary Life Cycle Study for the UK, Report R92, Energy Technology Support Unit, Harwell, United Kingdom.
2. ECOTEC (1999), Financial and Environmental Impact of Biodiesel as an Alternative to Fossil Diesel in the UK, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.
3. Richards, I. R. (2000), Energy Balances in the Growth of Oilseed Rape for Biodiesel and of Wheat for Bioethanol, Levington Agriculture Ltd., Ipswich, United Kingdom.

Year of Publication: 2000

Author: Jungmeier

Publication Type: Conference Paper

Full Reference:

Jungmeier, G., (2000), Greenhouse Gas Balance of Bioenergy Systems - a Comparison of Bioenergy with Fossil Fuel Systems, in: Robertson, K.A., and Schlamadinger, B., (eds.) Bioenergy for Mitigation of CO2 emissions: The Power, Transportation and Industrial Sectors, *Proceedings of an IEA Bioenergy Task 25 Workshop*, 27-30 September 1999, Gatlinburg, Tennessee, USA. IEA Bioenergy Task 25: Graz, Austria 9-26.

Systems Considered:

Review and calculations for wide range of potential bioenergy systems in Austria, including comparison with alternative systems based on fossil energy. Systems considered include domestic stoves and central heating, electricity and heat generation at various scales, liquid and gaseous fuels.

Processes Included:

Forest establishment and management, harvesting, transport, processing, conversion, and conversion unit construction and maintenance.

Strengths:

Consistent calculations based on the GEMIS model. Also based on classic methodology of Schlamadinger *et al*. (see below). Thorough.

Weaknesses:

Relies on derived data and assumptions embedded in the GEMIS model. Therefore not transparent and difficult to validate results. Summary report only.

Key Citations:

1. Jungmeier, G., Canella, L., and Spitzer, J., (1999), Treibhausgasbilanz der Bioenergie (Greenhouse Gas Balance of Bioenergy Systems), Joanneum Research Report, Graz, Austria.
2. GEMIS-A (1998), Global Emission Model of Integrated Systems – Austria, Austrian Environmental Agency, Vienna, Austria.
3. Schlamadinger, B., Apps, M., Bohlin, F., Gustavsson, L., Jungmeier, G., Marland, G., Pingoud, K. and Savolainen, I., (1997), Towards a Standard Methodology for Greenhouse Gas Balances of Bioenergy Systems in Comparison with Fossil Fuel Energy Systems, *Biomass and Bioenergy*, 13, 359-375.

Year of Publication: 2000

Author: Levelton Engineering Ltd

Publication Type: Contract Report

Full Reference:

Levelton Engineering Ltd Assessment of Net Emissions of Greenhouse Gases from Ethanol-Blended Gasolines in Canada: Lignocellulosic Feedstocks, prepared for Agriculture and Agri-Food Canada

Systems Considered:

A model of life cycle assessment of primary energy inputs and greenhouse emissions of ethanol production from corn, corn stover, switchgrass, wheat straw and hay - 10% and 85% blends with gasoline.

Processes Included:

Feedstock recovery; fertiliser production; land use assumptions, storage; transport; processing; distribution and vehicle operation.

Strengths:

Good review of the feedstock production and yields and land use impacts of the different feedstocks. Detailed data on yields, fertiliser input and rate of ethanol recovery. Data for greenhouse gas and tailpipe emissions.

Weaknesses:

Relies on the validity of underlying data. Very brief data for the conversion process. Calculations for energy inputs and emissions are not very transparent. Modelled on a demonstration plant since no commercial plant is available yet. Most of the data is based on Canadian conditions.

Key Citations:

1. Delucchi, M., (1998), Life Cycle Energy Use, Greenhouse Gas Emissions, and Air Pollution from the Use of Transportation Fuels and Electricity, Institute of Transportation Studies, University of California, USA.
2. Levelton Engineering Ltd., (1999), Assessment of Net Emissions of Greenhouse Gases from Ethanol Blends in Southern Ontario.
3. Wang, M.Q, (1999), Transportation Fuel Cycle Model: Methodology, Development, Use and Results, Greet 1.5, ANL/ESD-39, Vol 1 and 2, prepared for the Centre of Transportation Research, Energy System Division, Argonne National Laboratory, Argonne, Illinois, USA

Year of Publication: 2000

Authors: Matthews and Mortimer

Publication Type: Contract Report

Full Reference:

Matthews, R.W., and Mortimer, N.D., (2000), Estimation of Carbon Dioxide and Energy Budgets of Wood-fired Electricity Generation Systems, ETSU Report, ETSU B/U1/00601/05/REP, ETSU, Harwell, United Kingdom.

Systems Considered:

Calculations of energy requirements and carbon dioxide emissions factors for electricity generation (IGCC) systems fired by wood fuel from short rotation forests (poplar, willow) or residues from long rotation forests (spruce, pine) in the United Kingdom.

Processes Included:

Crop establishment and management, harvesting, processing, transport, storage (basic treatment), conversion, and power station construction and maintenance.

Strengths:

Energy and carbon balances have been calculated in a consistent manner for the systems considered. The basis of calculations is transparent.

Weaknesses:

Relies heavily on the validity of the underlying data sources. Some assumptions require validation (for example, transport distances, wood chip carrying capacities of lorries). Results very sensitive to assumptions about energy inputs associated with biomass chipping and storage. Drying of biomass assumed to take place as part of firing of power station. Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. Matthews, R. W., Robinson, R. L., Abbott, S. R. and Fearis, N., (1994), Modelling of Carbon and Energy Budgets of Wood Fuel Coppice Systems, ETSU Report ETSU B/W5/00337/REP, Energy Technology Support Unit, Harwell, United Kingdom.

Year of Publication: 2000

Author: Richards

Publication Type: Contract Report

Full Reference:

Richards, I. R., (2000), Energy Balances in the Growth of Oilseed Rape for Biodiesel and of Wheat for Bioethanol, Levington Agriculture Ltd., Ipswich, United Kingdom.

Systems Considered:

Calculation of primary energy inputs and carbon dioxide emissions, as well as ammonia, nitrous oxide and oxides of nitrogen, of biodiesel production from oilseed rape and of bioethanol production from wheat.

Processes Included:

Mainly oilseed rape and wheat cultivation although subsequent processing to biodiesel and bioethanol is taken into account by quoting information from elsewhere.

Strengths:

Detailed examination of cultivation practices, especially nitrogen fertiliser application rates and yields, and agricultural options, such as the ploughing in of straw and its use as a fuel for electricity generation.

Weaknesses:

Lack of clarity and transparency concerning the primary energy inputs and carbon dioxide and greenhouse gas emissions of nitrogen fertiliser manufacture. Uncritical use of data on subsequent biofuel processing from an earlier ECOTEC report (ECOTEC, 1999). Lack of transparency concerning allocation procedures.

Key Citations:

1. Nix, J., (1996), Farm Management Pocketbook, Wye College, University of London, London, United Kingdom.
2. Gover, M. P., Collins, S. A., Hitchcock, G. S., Moon, D. P. and Wilkins, G. T., (1996), Alternative Road Transport Fuels – A Preliminary Life Cycle Study for the UK, Report R92, Energy Technology Support Unit, Harwell, United Kingdom.
3. Anon (1997), EFMA Environmental Report for 1996, European Fertilizer Manufacturers' Association, Brussels, Belgium.
4. Laegrid, M., Bockman, O., and Kaarstad, O., (1999), Agriculture, Fertiliser and the Environment, CABI Publishing, Norsk Hydro, Norway.
5. ECOTEC (1999), Financial and Environmental Impact of Biodiesel as an Alternative to Fossil Diesel in the UK, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.

Year of Publication: 2000

Authors: Wihersaari and Palosauo

Publication Type: Contract Report (Summary)

Full Reference: Wihersaari, M., and Palosuo, T., (2002), Greenhouse Gas Emissions from Final Harvest Fuel Chips Production, VTT Energy Information Sheet, VTT Energy, Helsinki, Finland.

Systems Considered:

Wood chip production from final-harvest forest fellings (terrain chipping, roadside chipping, terminal chipping, loose residue chipping and bale chipping).

Processes Included:

Full process chain from forest to point of use considered, but biomass losses during any storage of chips not accounted for.

Strengths:

Up to date, covers systems that are highly relevant to the UK. Data likely to be transferable.

Weaknesses:

Summary results reported only. Will need to refer to the two cited reports, which are likely to be (very) Finnish.

Key Citations:

1. Wihersaari, M., and Palosuo, T., (2000), Puuenergia ja Kasvihuonekaasut, Osa 1: Päätehakkun Haketuotantoketjujen Kasvihuonekaasupäästöt, VTT Energien Raportteja 8/2000, Finland.
2. Wihersaari, M., and Palosuo, T., (2000), Puuenergia ja Kasvihuonekaasut. Osa 2: Hakkuutähteiden Energiakäytön Vaikutus Metsien Maaperän Hiilitaseeseen, VTT Energien Raportteja 9/2000, Finland.

Year of Publication: 2001

Authors: Bullard and Metcalfe

Publication Type: Contract Report

Full Reference:

Bullard, M., and Metcalfe, P., (2001), Estimating the Energy Requirements and CO_2 Emissions from the Perennial Grasses; Miscanthus, Switchgrass and Reed Canary Grass, ETSU B/U1/00645/REP, Energy Technology Support Unit, Harwell, United Kingdom.

Systems Considered:

Calculations of energy and carbon ratios for miscanthus, switchgrass and reed canary grass upon their delivery to the power station.

Processes Included:

Crop planting, harvesting, storage and transport.

Strengths:

Energy and carbon balances have been calculated in a consistent manner for the three crops considered. Most of calculations are fairly transparent with very detailed calculations for the planting process (machinery, planting operations, fertilisers and agrochemicals).

Weaknesses:

Relies heavily on the validity of the underlying data sources. Energy and carbon balances have been limited to cultivation operations and do not extend to conversion processes. Assumes all carbon is emitted as carbon dioxide.

Key Citations:

1. ADAS, several reports.
2. Kaltschmitt, M., and Reinhardt, G. A., (1996), LCA of Biofuels under Different Environmental Aspects, in Biomass for Energy and the Environment, Proceedings of the 9th European Bioenergy Conference.
3. Matthews, R. W., and Mortimer, N. D., (2000), Estimation of Carbon Dioxide and Energy Budgets of Wood Fired Electricity Generation Systems, ETSU Report, ETSU B/U1/00601/05/REP, ETSU, Harwell, United Kingdom.
4. Patyk, A., and Reinhardt, G., (1997), Energy and Material Flow Analysis of Fertiliser Production and Supply, 4th Symposium for Case Studies in LCA, Brussels.

Year of Publication: 2001

Author: ECOTEC Research and Consulting Ltd.

Publication Type: Contract Report

Full Reference:
ECOTEC (2001), Lifecycle Greenhouse Gas Assessment of RME – Comparative Emissions from Set-aside and Wheat, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.

Systems Considered:
Calculation of total greenhouse gas emissions for biodiesel.

Processes Included:
Complete process chain including cultivation, transportation, storage, mechanical extraction, esterification and distribution.

Strengths:
Updating of the earlier reports (Culshaw and Butler, 1992, Gover et al, 1996 and ECOTEC, 1999, ECOTEC, 2000, and Richards, 2000) with further consideration of the effects of choosing different reference systems (set-aside and wheat production).

Weaknesses:
General lack of transparency with assumptions and calculations. Source of data for maintenance of set-aside land is obscure. Estimates of carbon dioxide emissions are subsumed within total greenhouse gas emissions. Final results are presented in terms of "per kilometre" without any information on the assumed performance of the vehicle using biodiesel.

Key Citations:
1. ECOTEC (2000), Emissions from Liquid Biofuels, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.
2. Anon (2001a), Life Cycle Greenhouse gas Assessment of Rape Methyl Ester, Internal Paper, Department of Environment, Transport and the Regions, London, United Kingdom
3. Anon (2001b), DETR Lifecycle Greenhouse Gas Emissions of RME, Cargill plc, United Kingdom.

Year of Publication: 2002

Authors: Beer et al

Publication Type: Contract Report

Full Reference:

Beer, T., Grant, T., Morgan, G., Lapszewicz, J., Anyon, P., Edwards, J., Nelson, P., Watson, H., and Williams, D., (2002), Comparison of Transport Fuels – Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles, Commonwealth Scientific and Industrial Research Organisation, Aspendale, Australia.

Systems Considered:

Calculation of primary energy inputs and total greenhouse gas emissions, as well as non-methane hydrocarbons, oxides of nitrogen, carbon monoxide and particulates, for the production and use of a variety of heavy road vehicle transport fuels, including biodiesel and bioethanol.

Processes Included:

Complete process chains for the relevant transport fuel from resource to vehicle, including emissions from use in the vehicle.

Strengths:

Flow charts are given for the main methods of production. Consistent and comprehensive approach to reporting results with clear distinctions between urban (vehicle) emissions and total life cycle (production plus vehicle) emissions.

Weaknesses:

Flow charts do not contain all details on assumed quantities of raw materials, intermediate products, co-products, etc. There is considerable reliance on a variety of other studies, often modified to Australian conditions without clear explanation of the assumptions incorporated into modifications. Chosen production processes reflect Australian options (for example, bioethanol production from sugar cane) rather than European options (for example, bioethanol production from sugar beet). Despite quite extensive text, numerous essential data sources, assumptions and methods of calculations are unclear or, simply, confusing or contradictory. Allocation procedures are frequently discussed in considerable detail but those which have been adopted for particular results are sometimes not explicit. Estimates of carbon dioxide emissions from fuel production are subsumed within total greenhouse gas emissions. In general, it is not possible to use most of the results with confidence for other purposes.

Key Citations:

1. Eriksson, E., Blinge, M., and Lovgren, G., (1998), Life-Cycle Assessment of the Road Transport Sector, Science of the Total Environment, 190, 69 - 76
2. Spirinckx, C., and Ceuterick, D., (1996), Comparative Life-Cycle Assessment of Diesel and Biodiesel, Flemish Institute for Technological Research, Mol, Belgium.

Year of Publication: 2002

Author: Groves

Publication Type: Conference Paper

Full Reference:
Groves, A. P., (2002), Well to Wheel Assessment of Rapeseed Methyl Ester Biodiesel in the UK, Shell Global Solutions, F. O. Lichts Second World Biofuels Conference, 24 April 2002.

Systems Considered:
Calculation of primary energy inputs and carbon dioxide and total greenhouse gas emissions of producing biodiesel from oilseed rape and carbon dioxide emissions and total greenhouse gas emissions of use of biodiesel in a typical European passenger car.

Processes Included:
Process chain from raw materials through to final use.

Strengths:
Flow chart provided. Quite detailed and fairly transparent. Sensitivity analysis conducted.

Weaknesses:
Some details lacking, especially concerning the estimation of the primary energy inputs and carbon dioxide and greenhouse gas emissions associated with the manufacture of nitrogen fertiliser. In terms of emissions, mainly concentrates on carbon dioxide emissions but main results provided for total greenhouse gas emissions although only nitrous oxide from nitrogen fertiliser manufacture and use seems to have been calculated. Limited discussion of allocation procedures and the apparent choice of no allocation to co-products for the main results is not justified.

Key Citations:
1. ECOTEC (1999), Financial and Environmental Impact of Biodiesel as an Alternative to Fossil Diesel in the UK, ECOTEC Research and Consulting Ltd., Birmingham, United Kingdom.
2. Richards, I. R., (2000), Energy Balances in the Growth of Oilseed Rape for Biodiesel and of Wheat for Bioethanol, Levington Agriculture Ltd., Ipswich, United Kingdom.
3. Daugherty, E. C., (2001), Biomass Energy Systems Efficiency Analysed through LCA, MSc Thesis, University of Lund, Sweden.
4. Reinhardt, G, and Zemenek, G. (2001), Oekobilanz Bioenergietrager, Institute for Energy and Environmental Research, Heidelberg, Germany.

APPENDIX B: Production of Biodiesel from Oilseed Rape

Figure B. 1 Flow Chart for the Production of Biodiesel from Oilseed Rape

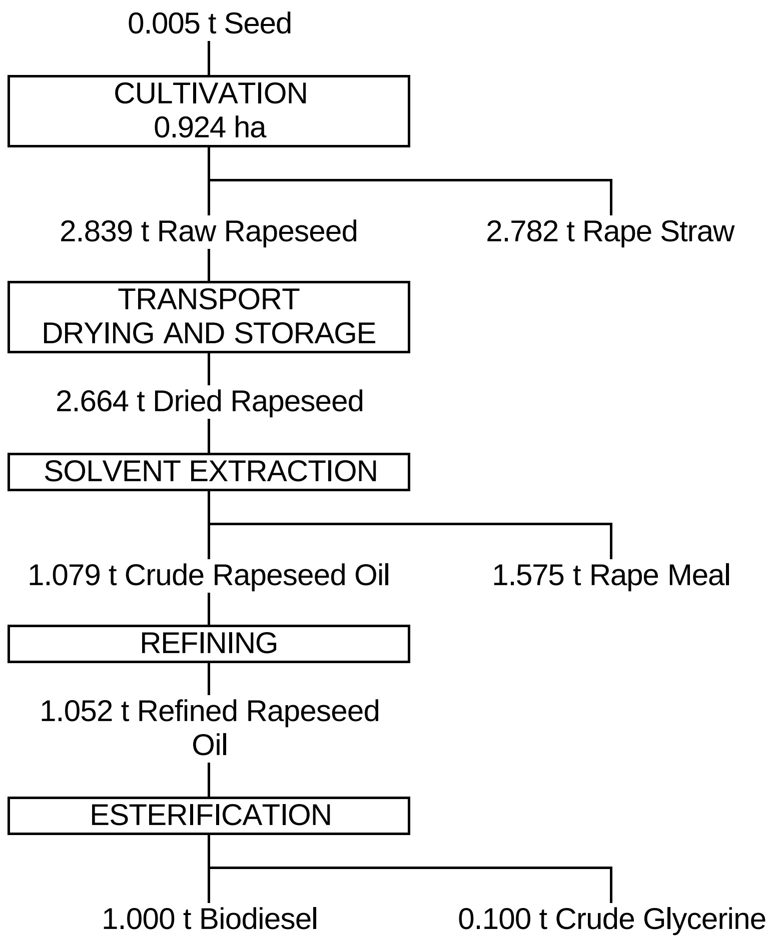

Table B1 Spreadsheet for Primary Energy Inputs to Biodiesel Production from Oilseed Rape Using Solvent Extraction

Functional Unit:	Biodiesel at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to biodiesel, 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to biodiesel, and 0.100 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 2) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 2), giving a 87% allocation to biodiesel.

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:										
- N Fertiliser	*ha.a*	-	-	*2,747*	*±1,097*	*5,213*	*±208*	*7,960*	*±1,117*	(a)
- Other Fertiliser	*ha.a*	-	-	*1,276*	*±191*	-	-	*1,276*	*±191*	(b)
- Pesticides	*ha.a*	-	-	*767*	*±115*	-	-	*767*	*±115*	(c)
- Seeds	*ha.a*	-	-	*39*	*±6*	-	-	*39*	*±6*	(d)
- Diesel Fuel	*ha.a*	*2,385*	*±377*	*262*	*±124*	-	-	*2,647*	*±397*	(e)
Reference System:										
- Diesel Fuel	*ha.a*	*- 922*	*±145*	*- 101*	*±49*	-	-	*-1,023*	*±153*	(f)
Sub-Totals	*ha.a*	*1,463*	*±404*	*4,990*	*±1,127*	*5,213*	*±208*	*11,666*	*±1,216*	
	t bd	**728**	**±201**	**2,484**	**±561**	**2,595**	**±104**	**5,807**	**±605**	(g)
Transport:										
- Diesel Fuel	*t ros*	*213*	*±8*	*74*	*±9*	-	-	*287*	*±12*	(h)
	t bd	**379**	**±14**	**132**	**±16**	**-**	**-**	**511**	**±22**	(i)
Drying:										
- Fuel Oil	*t dos*	*305*	*±48*	*34*	*±17*	-	-	*339*	*±51*	(j)
	t bd	**510**	**±81**	**56**	**±29**	**-**	**-**	**566**	**±85**	(k)
Storage:										
- Electricity	*t dos*	*42*	*±6*	*87*	*±9*	-	-	*129*	*±11*	(l)
	t bd	**70**	**±11**	**144**	**±14**	**-**	**-**	**214**	**±18**	(k)
Solvent Extraction:										
- Natural Gas	*t cro*	*2,237*	*±336*	*246*	*±111*	-	-	*2,483*	*±354*	(m)
- Electricity	*t cro*	*302*	*±45*	*629*	*±15*	-	-	*931*	*±47*	(n)
- Hexane	*t cro*	-	-	*129*	*±19*	-	-	*129*	*±19*	(o)
Sub-Totals	*t cro*	*2,539*	*±339*	*1,004*	*±114*	-	-	*3,543*	*±358*	
	t bd	**1,716**	**±229**	**678**	**±77**	**-**	**-**	**2,394**	**±242**	(p)
Refining:										
- Electricity	*t rro*	*11*	*±2*	*23*	*±5*	-	-	*34*	*±5*	(q)
- Natural Gas	*t rro*	*178*	*±27*	*20*	*±8*	-	-	*198*	*±28*	(r)
- Heavy Fuel Oil	*t rro*	*20*	*±3*	*3*	-	-	-	*23*	*±3*	(s)
- Light Fuel Oil	*t rro*	*152*	*±23*	*16*	*±7*	-	-	*168*	*±24*	(t)
- Phosph. Acid	*t rro*	-	-	*11*	*±2*	-	-	*11*	*±2*	(u)
- Smectite	*t rro*	-	-	*15*	*±2*	-	-	*15*	*±2*	(v)
Sub-Totals	*t rro*	*361*	*±36*	*88*	*±12*	-	-	*449*	*±37*	
	t bd	**330**	**±33**	**81**	**±11**	**-**	**-**	**411**	**±34**	(w)
Esterification:										
- Electricity	*t bd*	*83*	*±12*	*173*	*±76*	-	-	*256*	*±21*	(x)
- Natural Gas	*t bd*	*1,402*	*±210*	*154*	*±69*	-	-	*1,556*	*±221*	(y)
- Heavy Fuel Oil	*t bd*	*161*	*±24*	*18*	*±8*	-	-	*179*	*±25*	(z)
- Light Fuel Oil	*t bd*	*161*	*±24*	*18*	*±8*	-	-	*179*	*±25*	(aa)
- Caustic Soda	*t bd*	-	-	*238*	*±36*	-	-	*238*	*±36*	(bb)
- Methanol	*t bd*	-	-	*4,151*	*±623*	-	-	*4,151*	*±623*	(cc)
Sub-Totals	*t bd*	*1,809*	*±213*	*4,752*	*±633*	-	-	*6,559*	*±663*	
	t bd	**1,572**	**±185**	**4,134**	**±579**	**-**	**-**	**5,706**	**±607**	(dd)
Plant Construct.	**t bd**	**3**	**-**	**97**	**±18**	**-**	**-**	**100**	**±18**	(ee)
Plant Maintain.	**t bd**	**-**	**-**	**62**	**±11**	**-**	**-**	**62**	**±11**	(ff)
Distribution:										
- Diesel Fuel	**t bd**	**369**	**±14**	**129**	**±16**	**-**	**-**	**498**	**±21**	(gg)
Totals	**t bd**	**5,677**	**±368**	**7,997**	**±811**	**2,595**	**±104**	**16,269**	**±896**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil
t bd = tonne of biodiesel

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for ammonium nitrate (Ref. 4).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 5), and for lime of 18.9 kg CaO (Ref. 6), with total energy requirements for phosphate fertiliser of 15.8 MJ/kg P_2O_5 , for potash fertiliser of 9.3 MJ/ kg K_2O, and for lime of 2.1 MJ/kg CaO (Ref. 6).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 6).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total energy requirement of 7.8 MJ/kg of seed (Ref. 6).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.924 ha.a/t of biodiesel and allocation of 86% x 72% x 87% = 53.87% to biodiesel.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.839 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.664t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 6), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total energy requirement of 52.05 MJ/kg of hexane (Ref. 6).

(p) Crude rapeseed oil requirement of 1.079 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total energy requirement of 11.4 MJ/kg for phosphoric acid (Ref. 6).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total energy requirement of 2.55 MJ/kg for smectite (Ref. 6).

(w) Refined rapeseed oil requirement of 1.052 t/t of biodiesel and allocation of 87% to biodiesel.

(x) Electricity consumption of 23 kWh/t of biodiesel (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(y) Natural gas consumption of 1,402 MJ/t of biodiesel (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 9).

(z) Heavy fuel oil consumption of 161 MJ/t of biodiesel (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(aa) Light fuel oil consumption of 161 MJ/t of biodiesel (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(bb) Caustic soda (50% concentration) consumption of 12 kg/t of biodiesel and a total energy requirement of 19.87 MJ/kg of caustic soda (Ref. 6).

(cc) Methanol consumption of 109 kg/t of biodiesel and a total energy requirement of 38.08 MJ/kg of methanol (Ref. 6).

(dd) Allocation of 87% to biodiesel.

(ee) Primary energy input of 131,004 ± 23,909 GJ for construction of a biodiesel plant (Ref. 11) with a capacity of a 40,000 t/a and a 25 year life, assuming oil mill (assumed similar to solvent extraction plant) accounting for 72% of the primary energy input by weight and 72% contribution to biodiesel by price of co-products, and assuming refining and esterification plants accounting for 28% of the primary energy input by weight and 87% contribution to biodiesel by price of co-products.

(ff) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 11).

(gg) Average round trip distance of 450 km (Ref. 10) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 11).

References

1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

2. "The Cost of Production of Rape Methyl Ester (RME) Biodiesel" by P. Smith, Cargill plc, United Kingdom, January 2001.

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11. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

Table B2 Spreadsheet for Carbon Dioxide Outputs from Biodiesel Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Biodiesel at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to biodiesel, 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to biodiesel, and 0.100 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 2) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 2), giving a 87% allocation to biodiesel.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*373*	*±54*	*373*	*±54*	(a)
- Other Fertiliser	*ha.a*	-	-	*60*	*±9*	*60*	*±9*	(b)
- Pesticides	*ha.a*	-	-	*14*	*±2*	*14*	*±2*	(c)
- Seeds	*ha.a*	-	-	*2*	-	*2*	-	(d)
- Diesel Fuel	*ha.a*	*164*	*±25*	*19*	*±3*	*183*	*±25*	(e)
Reference System:								
- Diesel Fuel	*ha.a*	*- 64*	*±9*	*- 7*	*±1*	*- 71*	*±9*	(f)
Sub-Totals	*ha.a*	*100*	*±27*	*461*	*±55*	*561*	*±61*	
	t bd	**50**	**±13**	**229**	**±27**	**279**	**±30**	(g)
Transport:								
- Diesel Fuel	*t ros*	*15*	*±1*	*4*	-	*19*	*±1*	(h)
	t bd	**26**	**±1**	**7**	**±1**	**33**	**±1**	(i)
Drying:								
- Fuel Oil	*t dos*	*22*	*±3*	*2*	-	*24*	*±3*	(j)
	t bd	**37**	**±6**	**4**	**±1**	**41**	**±6**	(k)
Storage:								
- Electricity	*t dos*	-	-	*6*	*±1*	*6*	*±1*	(l)
	t bd	**-**	**-**	**17**	**±2**	**17**	**±2**	(k)
Solvent Extraction:								
- Natural Gas	*t cro*	*117*	*±18*	*4*	-	*121*	*±18*	(m)
- Electricity	*t cro*	-	-	*45*	*±7*	*45*	*±7*	(n)
- Hexane	*t cro*	-	-	*1*	-	*1*	-	(o)
Sub-Totals	*t cro*	*117*	*±18*	*50*	*±7*	*167*	*±19*	
	t bd	**79**	**±12**	**34**	**±5**	**113**	**±13**	(p)
Refining:								
- Electricity	*t rro*	-	-	*2*	-	*2*	-	(q)
- Natural Gas	*t rro*	*9*	*±1*	*1*	-	*10*	*±1*	(r)
- Heavy Fuel Oil	*t rro*	*2*	-	-	-	*2*	-	(s)
- Light Fuel Oil	*t rro*	*11*	*±2*	*1*	-	*12*	*±2*	(t)
- Phosph. Acid	*t rro*	-	-	*1*	-	*1*	-	(u)
- Smectite	*t rro*	-	-	*1*	-	*1*	-	(v)
Sub-Totals	*t rro*	*22*	*±2*	*6*	-	*28*	*±2*	
	t bd	**20**	**±2**	**6**	**-**	**26**	**±2**	(w)
Esterification:								
- Electricity	*t bd*	-	-	*12*	*±2*	*12*	*±2*	(x)
- Natural Gas	*t bd*	*73*	*±11*	*2*	-	*75*	*±11*	(y)
- Heavy Fuel Oil	*t bd*	*12*	*±2*	*1*	-	*13*	*±2*	(z)
- Light Fuel Oil	*t bd*	*12*	*±2*	*1*	-	*13*	*±2*	(aa)
- Caustic Soda	*t bd*	-	-	*13*	*±2*	*13*	*±2*	(bb)
- Methanol	*t bd*	-	-	*297*	*±45*	*297*	*±45*	(cc)
Sub-Totals	*t bd*	*97*	*±11*	*326*	*±45*	*423*	*±46*	
	t bd	**84**	**±10**	**284**	**±39**	**368**	**±40**	(dd)
Plant Construction	**t bd**	**-**	**-**	**5**	**±1**	**5**	**±1**	(ee)
Plant Maintenance	**t bd**	**-**	**-**	**2**	**-**	**2**	**-**	(ff)
Distribution:								
- Diesel Fuel	**t bd**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(gg)
Totals	**t bd**	**321**	**±21**	**595**	**±48**	**916**	**±52**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil
t bd = tonne of biodiesel

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 4).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 5), and for lime of 18.9 kg CaO (Ref. 6), with total carbon requirements for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 , for potash fertiliser of 0.453 kg CO_2/ kg K_2O, and for lime of 0.179 kg CO_2/kg CaO (Ref. 6).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 6).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total carbon requirement of 0.316 kg CO_2/kg of seed (Ref. 6).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 6), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.924 ha.a/t of biodiesel and allocation of 86% x 72% x 87% = 53.87% to biodiesel.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.839 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 6), and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.664t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 6), and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 6), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 6) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total carbon requirement of 0.543 kg CO_2/kg of hexane (Ref. 6).

(p) Crude rapeseed oil requirement of 1.079 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 6) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 6) and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 6) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 6) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total carbon requirement of 0.768 kg CO_2 /kg for phosphoric acid (Ref. 6).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total carbon requirement of 0.197 kg CO_2 /kg for smectite (Ref. 6).

(w) Refined rapeseed oil requirement of 1.052 t/t of biodiesel and allocation of 87% to biodiesel.

(x) Electricity consumption of 23 kWh/t of biodiesel (Ref. 6) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(y) Natural gas consumption of 1,402 MJ/t of biodiesel (Ref. 6) and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 9).

(z) Heavy fuel oil consumption of 161 MJ/t of biodiesel (Ref. 6) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(aa) Light fuel oil consumption of 161 MJ/t of biodiesel (Ref. 6) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(bb) Caustic soda (50% concentration) consumption of 12 kg/t of biodiesel and a total carbon requirement of 1.120 kg CO_2/kg of caustic soda (Ref. 6).

(cc) Methanol consumption of 109 kg/t of biodiesel and a total carbon requirement of 2.722 kg CO_2/kg of methanol (Ref. 6).

(dd) Allocation of 87% to biodiesel.

(ee) Carbon dioxide output of 6,287 ± 1,116 tonnes CO_2 from construction of a biodiesel plant (Ref. 11) with a capacity of a 40,000 t/a and a 25 year life, assuming oil mill (assumed similar to solvent extraction plant) accounting for 72% of the carbon dioxide output by weight and 72% contribution to biodiesel by price of co-products, and assuming refining and esterification plants accounting for 28% of the carbon dioxide output by weight and 87% contribution to biodiesel by price of co-products.

(ff) Carbon dioxide output for annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 11).

(gg) Average round trip distance of 450 km (Ref. 10) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 11).

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Table B3 Spreadsheet for Methane Outputs from Biodiesel Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Biodiesel at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to biodiesel, 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to biodiesel, and 0.100 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 2) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 2), giving a 87% allocation to biodiesel.

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*0.706*	*±0.118*	*0.706*	*±0.118*	(a)
- Other Fertiliser	*ha.a*	-	-	*0.002*	-	*0.002*	-	(b)
- Pesticides	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c)
- Seeds	*ha.a*	-	-	-	-	-	-	(d)
- Diesel Fuel	*ha.a*	*0.001*	-	*0.049*	*±0.007*	*0.050*	*±0.007*	(e)
Reference System:								
- Diesel Fuel	*ha.a*	*-0.001*	-	*-0.019*	*±0.003*	*-0.020*	*±0.003*	(f)
Sub-Totals	*ha.a*	-	-	*0.739*	*±0.118*	*0.739*	*±0.118*	
	t bd	**-**	**-**	**0.368**	**±0.059**	**0.368**	**±0.059**	(g)
Transport:								
- Diesel Fuel	*t ros*	-	-	*0.004*	*±0.001*	*0.004*	*±0.001*	(h)
	t bd	**-**	**-**	**0.008**	**±0.001**	**0.008**	**±0.001**	(i)
Drying:								
- Fuel Oil	*t dos*	*0.001*	-	*0.006*	*±0.001*	*0.007*	*±0.001*	(j)
	t bd	**0.001**	**-**	**0.010**	**±0.002**	**0.011**	**±0.002**	(k)
Storage:								
- Electricity	*t dos*	-	-	*0.017*	*±0.003*	*0.017*	*±0.003*	(l)
	t bd	**-**	**-**	**0.028**	**±0.004**	**0.028**	**±0.004**	(k)
Solvent Extraction:								
- Natural Gas	*t cro*	*0.008*	*±0.001*	*0.242*	*±0.036*	*0.250*	*±0.036*	(m)
- Electricity	*t cro*	-	-	*0.122*	*±0.018*	*0.122*	*±0.018*	(n)
- Hexane	*t cro*	-	-	*0.002*	-	*0.002*	-	(o)
Sub-Totals	*t cro*	*0.008*	*±0.001*	*0.366*	*±0.040*	*0.374*	*±0.040*	
	t bd	**0.005**	**±0.001**	**0.247**	**±0.027**	**0.252**	**±0.027**	(p)
Refining:								
- Electricity	*t rro*	-	-	*0.005*	*±0.001*	*0.005*	*±0.001*	(q)
- Natural Gas	*t rro*	*0.001*	-	*0.019*	*±0.003*	*0.020*	*±0.003*	(r)
- Heavy Fuel Oil	*t rro*	-	-	-	-	-	-	(s)
- Light Fuel Oil	*t rro*	-	-	*0.003*	*±0.001*	*0.003*	*±0.001*	(t)
- Phosph. Acid	*t rro*	-	-	*0.001*	-	*0.001*	-	(u)
- Smectite	*t rro*	-	-	-	-	-	-	(v)
Sub-Totals	*t rro*	*0.001*	-	*0.028*	*±0.003*	*0.029*	*±0.003*	
	t bd	**0.001**	**-**	**0.026**	**±0.003**	**0.027**	**±0.003**	(w)
Esterification:								
- Electricity	*t bd*	-	-	*0.033*	*±0.005*	*0.033*	*±0.005*	(x)
- Natural Gas	*t bd*	*0.005*	*±0.001*	*0.152*	*±0.023*	*0.157*	*±0.023*	(y)
- Heavy Fuel Oil	*t bd*	*0.001*	-	*0.003*	*±0.001*	*0.004*	*±0.001*	(z)
- Light Fuel Oil	*t bd*	*0.001*	-	*0.003*	*±0.001*	*0.004*	*±0.001*	(aa)
- Caustic Soda	*t bd*	-	-	*0.039*	*±0.006*	*0.039*	*±0.006*	(bb)
- Methanol	*t bd*	-	-	*0.142*	*±0.021*	*0.142*	*±0.021*	(cc)
Sub-Totals	*t bd*	*0.007*	*±0.001*	*0.372*	*±0.032*	*0.379*	*±0.032*	
	t bd	**0.006**	**±0.001**	**0.324**	**±0.028**	**0.330**	**±0.028**	(dd)
Plant Construction	**t bd**	**-**	**-**	**-**	**-**	**-**	**-**	(ee)
Plant Maintenance	**t bd**	**-**	**-**	**-**	**-**	**-**	**-**	(ff)
Distribution:								
- Diesel Fuel	**t bd**	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(gg)
Totals	**t bd**	**0.013**	**±0.001**	**1.019**	**±0.071**	**1.032**	**±0.071**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil
t bd = tonne of biodiesel

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a total methane requirement for ammonium nitrate of 3.6 x 10^{-3} ± 0.6 x 10^{-3} kg CH_4/kg N (Ref. 4).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 5), and for lime of 18.9 kg CaO (Ref. 6), with total methane requirements for phosphate fertiliser of 2.3 x 10^{-5} kg CH_4/kg P_2O_5 , for potash fertiliser of 2.1 x 10^{-5} kg CH_4/ kg K_2O, and for lime of 3.9 x 10^{-6} kg CH_4/kg CaO (Ref. 6).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 6).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total methane requirement of 0 kg CH_4/kg of seed (Ref. 6).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 6), and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6), and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.924 ha.a/t of biodiesel and allocation of 86% x 72% x 87% = 53.87% to biodiesel.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.839 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 6), and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.664t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 6), and an indirect methane requirement of 4.043 x 10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 6), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct methane requirement of 3.70 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083 x 10^{-4} kg CH_4/MJ and a total methane requirement of 1.12 x 10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 6) and an indirect methane requirement of 4.043 x 10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total carbon requirement of 6.73 x 10^{-4} kg CH_4/kg of hexane (Ref. 6).

(p) Crude rapeseed oil requirement of 1.079 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 6) and an indirect methane requirement of 4.043 x 10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 6) and a direct methane requirement of 3.70 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083 x 10^{-4} kg CH_4/MJ and a total methane requirement of 1.12 x 10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 6) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 6) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total methane requirement of 1.23 x 10^{-3} kg CH_4 /kg for phosphoric acid (Ref. 6).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total methane requirement of 3.7 x 10^{-5} kg CH_4 /kg for smectite (Ref. 6).

(w) Refined rapeseed oil requirement of 1.052 t/t of biodiesel and allocation of 87% to biodiesel.

(x) Electricity consumption of 23 kWh/t of biodiesel (Ref. 6) and an indirect methane requirement of 4.043 x 10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(y) Natural gas consumption of 1,402 MJ/t of biodiesel (Ref. 6) and a direct methane requirement of 3.70 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083 x 10^{-4} kg CH_4/MJ and a total methane requirement of 1.12 x 10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 9).

(z) Heavy fuel oil consumption of 161 MJ/t of biodiesel (Ref. 6) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(aa) Light fuel oil consumption of 161 MJ/t of biodiesel (Ref. 6) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(bb) Caustic soda (50% concentration) consumption of 12 kg/t of biodiesel and a total methane requirement of 3.25 x 10^{-3} kg CH_4/kg of caustic soda (Ref. 6).

(cc) Methanol consumption of 109 kg/t of biodiesel and a total methane requirement of 1.3 x 10^{-3} kg CH_4/kg of methanol (Ref. 6).

(dd) Allocation of 87% to biodiesel.

(ee) Primary energy input of 131,004 ± 23,909 GJ for construction of a biodiesel plant (Ref. 11) with a capacity of a 40,000 t/a and a 25 year life, and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 12), assuming oil mill (assumed similar to solvent extraction plant) accounting for 72% of the primary energy input by weight and 72% contribution to biodiesel by price of co-products, and assuming refining and esterification plants accounting for 28% of the primary energy input by weight and 87% contribution to biodiesel by price of co-products.

(ff) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 11).

(gg) Average round trip distance of 450 km (Ref. 10) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 11).

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Table B4 Spreadsheet for Nitrous Oxide Outputs from Biodiesel Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Biodiesel at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to biodiesel, 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to biodiesel, and 0.100 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 2) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 2), giving a 87% allocation to biodiesel.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*0.706*	*±0.106*	*2.881*	*±0.432*	*3.587*	*±0.445*	(a)
- Other Fertiliser	*ha.a*	-	-	*0.003*	-	*0.003*	-	(b)
- Pesticides	*ha.a*	-	-	*0.004*	-	*0.004*	-	(c)
- Seeds	*ha.a*	-	-	*0.005*	-	*0.005*	-	(d)
- Diesel Fuel	*ha.a*	*0.001*	-	-	-	*0.001*	-	(e)
Reference System:								
- Diesel Fuel	*ha.a*	*-0.001*	-	-	-	*-0.001*	-	(f)
Sub-Totals	*ha.a*	*0.706*	*±0.106*	*2.893*	*±0.432*	*3.599*	*±0.445*	
	t bd	**0.351**	**±0.053**	**1.440**	**±0.215**	**1.791**	**±0.222**	(g)
Transport:								
- Diesel Fuel	*t ros*	-	-	-	-	-	-	(h)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(i)
Drying:								
- Fuel Oil	*t dos*	-	-	-	-	-	-	(j)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Storage:								
- Electricity	*t dos*	-	-	-	-	-	-	(l)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Solvent Extraction:								
- Natural Gas	*t cro*	-	-	-	-	-	-	(m)
- Electricity	*t cro*	-	-	*0.002*	-	*0.002*	-	(n)
- Hexane	*t cro*	-	-	-	-	-	-	(o)
Sub-Totals	*t cro*	-	-	*0.002*	-	*0.002*	-	
	t bd	**-**	**-**	**0.002**	**-**	**0.002**	**-**	(p)
Refining:								
- Electricity	*t rro*	-	-	-	-	-	-	(q)
- Natural Gas	*t rro*	-	-	-	-	-	-	(r)
- Heavy Fuel Oil	*t rro*	-	-	-	-	-	-	(s)
- Light Fuel Oil	*t rro*	-	-	-	-	-	-	(t)
- Phosph. Acid	*t rro*	-	-	-	-	-	-	(u)
- Smectite	*t rro*	-	-	-	-	-	-	(v)
Sub-Totals	*t rro*	-	-	-	-	-	-	
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Esterification:								
- Electricity	*t bd*	-	-	-	-	-	-	(x)
- Natural Gas	*t bd*	-	-	-	-	-	-	(y)
- Heavy Fuel Oil	*t bd*	-	-	-	-	-	-	(z)
- Light Fuel Oil	*t bd*	-	-	-	-	-	-	(aa)
- Caustic Soda	*t bd*	-	-	-	-	-	-	(bb)
- Methanol	*t bd*	-	-	*0.002*	-	*0.002*	-	(cc)
Sub-Totals	*t bd*	-	-	*0.002*	-	*0.002*	-	
	t bd	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(dd)
Plant Construction	**t bd**	**-**	**-**	**-**	**-**	**-**	**-**	(ee)
Plant Maintenance	**t bd**	**-**	**-**	**-**	**-**	**-**	**-**	(ff)
Distribution:								(gg)
- Diesel Fuel	**t bd**	**-**	**-**	**-**	**-**	**-**	**-**	
Totals	**t bd**	**0.351**	**±0.053**	**1.443**	**±0.215**	**1.794**	**±0.222**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil
t bd = tonne of biodiesel

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 4), an indirect nitrous oxide requirement of 0.0147 kg N_2O/kg N (Ref. 5) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 5).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 6), and for lime of 18.9 kg CaO (Ref. 4), with total nitrous oxide requirements for phosphate fertiliser of 4.2 x 10^{-5} kg N_2O/kg P_2O_5 , for potash fertiliser of 9.4 x 10^{-6} kg N_2O/ kg K_2O, and for lime of 1.6 x 10^{-5} kg N_2O/kg CaO (Ref. 4).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.51 x 10^{-3} kg N_2O/kg (Ref. 4).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total nitrous oxide requirement of 0.001 kg N_2O/kg of seed (Ref. 4).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 4), and a direct nitrous oxide requirement of 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 4), and a direct nitrous oxide requirement of 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.924 ha.a/t of biodiesel and allocation of 86% x 72% x 87% = 53.87% to biodiesel.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.839 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 4), and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.664t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 4), and an indirect nitrous oxide requirement of 5.577 x 10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 4), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 4) and an indirect nitrous oxide requirement of 5.577 x 10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total nitrous oxide requirement of 1.35 x 10^{-5} kg N_2O/kg of hexane (Ref. 4).

(p) Crude rapeseed oil requirement of 1.079 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 4) and an indirect nitrous oxide requirement of 5.577 x 10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 4) and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 4) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 4) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total nitrous oxide requirement of 2 x 10^{-5} kg N_2O /kg for phosphoric acid (Ref. 4).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total carbon requirement of 6.5 x 10^{-6} kg N_2O /kg for smectite (Ref. 4).

(w) Refined rapeseed oil requirement of 1.052 t/t of biodiesel and allocation of 87% to biodiesel.

(x) Electricity consumption of 23 kWh/t of biodiesel (Ref. 4) and an indirect nitrous oxide requirement of 5.577 x 10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(y) Natural gas consumption of 1,402 MJ/t of biodiesel (Ref. 4) and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 9).

(z) Heavy fuel oil consumption of 161 MJ/t of biodiesel (Ref. 4) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(aa) Light fuel oil consumption of 161 MJ/t of biodiesel (Ref. 4) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(bb) Caustic soda (50% concentration) consumption of 12 kg/t of biodiesel and a total nitrous oxide requirement of 0 kg N_2O/kg of caustic soda (Ref. 4).

(cc) Methanol consumption of 109 kg/t of biodiesel and a total methane requirement of 1.5 x 10^{-5} kg N_2O/kg of methanol (Ref. 4).

(dd) Allocation of 87% to biodiesel.

(ee) Primary energy input of 131,004 ± 23,909 GJ for construction of a biodiesel plant (Ref. 11) with a capacity of a 40,000 t/a and a 25 year life, and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 12), assuming oil mill (assumed similar to solvent extraction plant) accounting for 72% of the primary energy input by weight and 72% contribution to biodiesel by price of co-products, and assuming refining and esterification plants accounting for 28% of the primary energy input by weight and 87% contribution to biodiesel by price of co-products.

(ff) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 11).

(gg) Average round trip distance of 450 km (Ref. 10) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 11).

References

1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

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3. "Overall Nitrogen Fertiliser Application Rates for Some Major Crops, England and Wales" www.fma.org.uk/Stats, accessed 5 April 2002.

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11. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

12. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

Table B5 Spreadsheet for Greenhouse Gas Outputs from Biodiesel Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Biodiesel at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to biodiesel, 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to biodiesel, and 0.100 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 2) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 2), giving a 87% allocation to biodiesel.

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*226*	*±34*	*1,314*	*±148*	*1,538*	*±152*	(a)
- Other Fertiliser	*ha.a*	-	-	*61*	*±9*	*61*	*±9*	(a)
- Pesticides	*ha.a*	-	-	*15*	*±2*	*15*	*±2*	(a)
- Seeds	*ha.a*	-	-	*4*	-	*4*	-	(a)
- Diesel Fuel	*ha.a*	*164*	*±25*	*20*	*±3*	*184*	*±25*	(a)
Reference System:								
- Diesel Fuel	*ha.a*	*-64*	*±9*	*-7*	*±1*	*-71*	*±9*	(a)
Sub-Totals	*ha.a*	*326*	*±43*	*1,407*	*±148*	*1,731*	*±155*	
	t bd	**162**	**±21**	**700**	**±74**	**862**	**±77**	(b)
Transport:								
- Diesel Fuel	*t ros*	*15*	*±1*	*4*	-	*19*	*±1*	(a)
	t bd	**26**	**±1**	**7**	**±1**	**33**	**±1**	(c)
Drying:								
- Fuel Oil	*t dos*	*22*	*±3*	*2*	-	*24*	*±3*	(a)
	t bd	**37**	**±6**	**4**	**±1**	**41**	**±6**	(d)
Storage:								
- Electricity	*t dos*	-	-	*6*	*±1*	*6*	*±1*	(a)
	t bd	**-**	**-**	**18**	**±2**	**18**	**±2**	(d)
Solvent Extraction:								
- Natural Gas	*t cro*	*117*	*±18*	*10*	*±1*	*127*	*±18*	(a)
- Electricity	*t cro*	-	-	*49*	*±7*	*49*	*±7*	(a)
- Hexane	*t cro*	-	-	*1*	-	*1*	-	(a)
Sub-Totals	*t cro*	*117*	*±18*	*60*	*±7*	*177*	*±19*	
	t bd	**79**	**±12**	**41**	**±5**	**120**	**±13**	(e)
Refining:								
- Electricity	*t rro*	-	-	*2*	-	*2*	-	(a)
- Natural Gas	*t rro*	*9*	*±1*	*1*	-	*10*	*±1*	(a)
- Heavy Fuel Oil	*t rro*	*2*	-	-	-	*2*	-	(a)
- Light Fuel Oil	*t rro*	*11*	*±2*	*1*	-	*12*	*±2*	(a)
- Phosph. Acid	*t rro*	-	-	*1*	-	*1*	-	(a)
- Smectite	*t rro*	-	-	*1*	-	*1*	-	(a)
Sub-Totals	*t rro*	*22*	*±2*	*6*	-	*28*	*±2*	
	t bd	**20**	**±2**	**7**	**-**	**27**	**±2**	(f)
Esterification:								
- Electricity	*t bd*	-	-	*13*	*±2*	*13*	*±2*	(a)
- Natural Gas	*t bd*	*73*	*±11*	*6*	*±1*	*79*	*±11*	(a)
- Heavy Fuel Oil	*t bd*	*12*	*±2*	*1*	-	*13*	*±2*	(a)
- Light Fuel Oil	*t bd*	*12*	*±2*	*1*	-	*13*	*±2*	(a)
- Caustic Soda	*t bd*	-	-	*14*	*±2*	*14*	*±2*	(a)
- Methanol	*t bd*	-	-	*301*	*±45*	*301*	*±45*	(a)
Sub-Totals	*t bd*	*97*	*±11*	*336*	*±45*	*433*	*±46*	
	t bd	**84**	**±10**	**292**	**±39**	**376**	**±40**	(g)
Plant Construction	**t bd**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a)
Plant Maintenance	**t bd**	**-**	**-**	**2**	**-**	**2**	**-**	(a)
Distribution:								
- Diesel Fuel	**t bd**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(a)
Totals	**t bd**	**433**	**±27**	**1,083**	**±84**	**1,516**	**±88**	

Biofuel Specifications

Density of biodiesel	= 0.88 kg/l
Net calorific value of biodiesel	= 37.27 MJ/kg
Gross calorific value of biodiesel	= 37.84 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil
t bd = tonne of biodiesel

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 0.924 ha.a/t of biodiesel and allocation of 86% x 72% x 87% = 53.87% to biodiesel.

(c) Dried oilseed requirement of 2.664t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(d) Raw oilseed requirement of 2.839 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(e) Crude rapeseed oil requirement of 1.079 t/t of biodiesel and allocation of 72% x 87% = 62.64% to biodiesel.

(f) Refined rapeseed oil requirement of 1.052 t/t of biodiesel and allocation of 87% to biodiesel.

(g) Allocation of 87% to biodiesel.

References

1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

2. "The Cost of Production of Rape Methyl Ester (RME) Biodiesel" by P. Smith, Cargill plc, United Kingdom, January 2001.

APPENDIX C: Production of Biodiesel from Recycled Vegetable Oil

Figure C1 Flow Chart for the Production of Biodiesel from Recycled Vegetable Oil

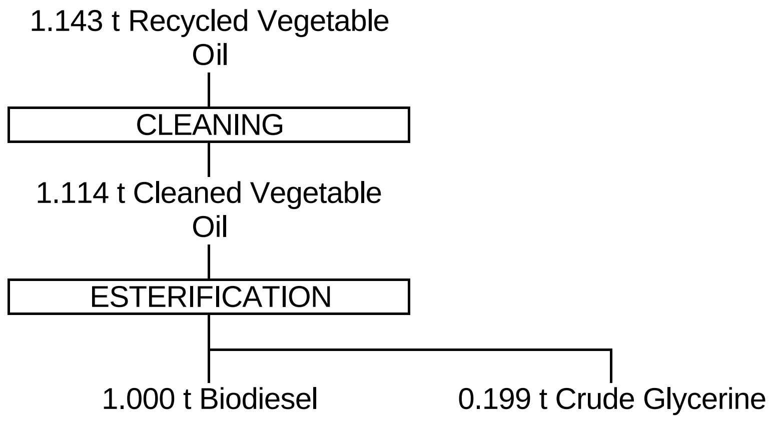

Table C1 Spreadsheet for Primary Energy Inputs to Biodiesel Production from Recycled Vegetable Oil

Functional Unit:	Biodiesel at point of distribution derived from recycled vegetable oil
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Based on average market prices, assuming 0.199 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 1) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 1), giving a 78% allocation to biodiesel.

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cleaning:										
- Natural Gas	*t rvo*	*3*	*±1*	*1*	*-*	*-*	*-*	*4*	*±1*	(a, b)
	t bd	**3**	**±1**	**1**	**-**	**-**	**-**	**4**	**±1**	(c)
Esterification:										
- Methanol	*t bd*	-	-	*7,947*	*±1,192*	-	-	*7,947*	*±1,192*	(b, d)
- Pot. Hydroxide	*t bd*	-	-	*339*	*±57*	-	-	*339*	*±57*	(e)
Sub-Totals	*t bd*	-	-	*8,286*	*±1,193*	-	-	*8,286*	*±1,193*	
	t bd			**6,463**	**±931**	**-**	**-**	**6,463**	**±931**	(f)
Plant Construction	*t bd*	*1*	*-*	*18*	*±3*	*-*	*-*	*19*	*±3*	(g)
	t bd	**1**	**-**	**14**	**±3**	**-**	**-**	**15**	**±3**	(f)
Plant Maintenance	*t bd*	*-*	*-*	*12*	*±2*	*-*	*-*	*12*	*±2*	(h)
	t bd	**-**	**-**	**9**	**±2**	**-**	**-**	**9**	**±2**	(f)
Distribution:										
- Diesel Fuel	**t bd**	**369**	**±14**	**129**	**±16**	**-**	**-**	**498**	**±21**	(i)
Totals	**t bd**	**373**	**±14**	**6,616**	**±931**			**6,989**	**±931**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

t rvo = tonne of recycled vegetable oil
t bd = tonne of biodiesel

Notes

(a) Natural gas consumption of 6.8 MJ/t of recycled vegetable oil for steam used to treat 50% of recycled vegetable oil input (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 3).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(c) Recycled vegetable oil requirement of 1.143 t/t of biodiesel and allocation of 78% to biodiesel.

(d) Methanol consumption of 208.7 kg/t biodiesel (Ref. 2) and a total energy requirement for methanol of 38.08 MJ/kg (Ref. 5).

(e) Potassium hydroxide consumption of 8.4 kg/t of biodiesel (Ref. 2) and a total energy requirement for potassium hydroxide of 40.3 ± 6.8 MJ/kg (Ref. 6).

(f) Allocation of 78% to biodiesel.

(g) Primary energy input of 18,919 ± 3,206 GJ for construction of a biodiesel plant (Ref. 7) with a capacity of a 40,000 t/a and a 25 year life, and 78% contribution to biodiesel by price of co-products.

(h) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 7).

(i) Average round trip distance of 450 km (Ref. 8) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 7).

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Table C2 Spreadsheet for Carbon Dioxide Outputs to Biodiesel Production from Recycled Vegetable Oil

Functional Unit:	Biodiesel at point of distribution derived from recycled vegetable oil
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Based on average market prices, assuming 0.199 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 1) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 1), giving a 78% allocation to biodiesel.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cleaning:								
- Natural Gas	*t rvo*	-	-	-	-	-	-	(a, b)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(c)
Esterification:								
- Methanol	*t bd*	-	-	*568*	*±85*	*568*	*±85*	(b, d)
- Pot. Hydroxide	*t bd*	-	-	*17*	-	*17*	-	(e)
Sub-Totals	*t bd*	-	-	*585*	*±85*	*585*	*±85*	
	t bd			**456**	**±66**	**456**	**±66**	(f)
Plant Construction								
	t bd	-	-	*1*	-	*1*	-	(g)
	t bd	**-**	**-**	**1**	**-**	**1**	**-**	(f)
Plant Maintenance								
	t bd	-	-	*1*	-	-	-	(h)
	t bd	**-**	**-**	**1**	**-**	**1**	**-**	(f)
Distribution:								
- Diesel Fuel	**t bd**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(i)
Totals	**t bd**	**25**	**±1**	**465**	**±66**	**490**	**±66**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

t rvo = tonne of recycled vegetable oil
t bd = tonne of biodiesel

Notes

(a) Natural gas consumption of 6.8 MJ/t of recycled vegetable oil for steam used to treat 50% of recycled vegetable oil input (Ref. 2) and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 3).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(c) Recycled vegetable oil requirement of 1.143 t/t of biodiesel and allocation of 78% to biodiesel.

(d) Methanol consumption of 208.7 kg/t biodiesel (Ref. 2) and a total carbon requirement of 2.722 kg CO_2/kg of methanol (Ref. 5).

(e) Potassium hydroxide consumption of 8.4 kg/t of biodiesel (Ref. 2) and a total carbon requirement for potassium hydroxide of 2 kg CO_2/kg (Ref. 6).

(f) Allocation of 78% to biodiesel.

(g) Carbon dioxide output of 884 ± 149 t CO_2 for construction of a biodiesel plant (Ref. 7) with a capacity of a 40,000 t/a and a 25 year life, and 78% contribution to biodiesel by price of co-products.

(h) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 7).

(i) Average round trip distance of 450 km (Ref. 8) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 7).

References

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Table C3 Spreadsheet for Methane Outputs to Biodiesel Production from Recycled Vegetable Oil

Functional Unit:	Biodiesel at point of distribution derived from recycled vegetable oil
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Based on average market prices, assuming 0.199 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 1) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 1), giving a 78% allocation to biodiesel.

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cleaning:								
- Natural Gas	*t rvo*	-	-	-	-	-	-	(a, b)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(c)
Esterification:								
- Methanol	*t bd*	-	-	*0.271*	*±0.041*	*0.271*	*±0.041*	(b, d)
- Pot. Hydroxide	*t bd*	-	-	*0.042*	-	*0.042*	-	(e)
Sub-Totals	*t bd*	-	-	*0.313*	*±0.041*	*0.313*	*±0.041*	
	t bd			**0.244**	**±0.032**	**0.244**	**±0.032**	(f)
Plant Construction								
	t bd	-	-	-	-	-	-	(g)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Plant Maintenance								
	t bd	-	-	-	-	-	-	(h)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Distribution:								
- Diesel Fuel	**t bd**	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(i)
Totals	**t bd**	**-**	**-**	**0.252**	**±0.032**	**0.252**	**±0.032**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

t rvo = tonne of recycled vegetable oil
t bd = tonne of biodiesel

Notes

(a) Natural gas consumption of 6.8 MJ/t of recycled vegetable oil for steam used to treat 50% of recycled vegetable oil input (Ref. 2) and a direct methane requirement of 3.70 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083 x 10^{-4} kg CH_4/MJ and a total methane requirement of 1.12 x 10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 3).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(c) Recycled vegetable oil requirement of 1.143 t/t of biodiesel and allocation of 78% to biodiesel.

(d) Methanol consumption of 208.7 kg/t biodiesel (Ref. 2) and a total methane requirement of 1.3 x 10^{-3} kg CH_4/kg of methanol (Ref. 5).

(e) Potassium hydroxide consumption of 8.4 kg/t of biodiesel (Ref. 2) and a total methane requirement for potassium hydroxide of 0.005 kg CH_4/kg (Ref. 6).

(f) Allocation of 78% to biodiesel.

(g) Primary energy input of 18,919 ± 3,206 GJ for construction of a biodiesel plant (Ref. 7) with a capacity of a 40,000 t/a and a 25 year life, assuming an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 9) and 78% contribution to biodiesel by price of co-products.

(h) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 7).

(i) Average round trip distance of 450 km (Ref. 8) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 7).

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Table C4 Spreadsheet for Nitrous Oxide Outputs to Biodiesel Production from Recycled Vegetable Oil

Functional Unit:	Biodiesel at point of distribution derived from recycled vegetable oil
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Based on average market prices, assuming 0.199 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 1) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 1), giving a 78% allocation to biodiesel.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cleaning:								
- Natural Gas	*t rvo*	-	-	-	-	-	-	(a, b)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(c)
Esterification:								
- Methanol	*t bd*	-	-	*0.003*	-	*0.003*	-	(b, d)
- Pot. Hydroxide	*t bd*	-	-	-	-	-	-	(e)
Sub-Totals	*t bd*	-	-	*0.003*	-	*0.003*	-	
	t bd			**0.002**	**-**	**0.002**	**-**	(f)
Plant Construction								
	t bd	-	-	-	-	-	-	(g)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Plant Maintenance								
	t bd	-	-	-	-	-	-	(h)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Distribution:								
- Diesel Fuel	**t bd**	**-**	**-**	**-**	**-**	**-**	**-**	(i)
Totals	**t bd**	**-**	**-**	**0.002**	**-**	**0.002**	**-**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

t rvo = tonne of recycled vegetable oil
t bd = tonne of biodiesel

Notes

(a) Natural gas consumption of 6.8 MJ/t of recycled vegetable oil for steam used to treat 50% of recycled vegetable oil input (Ref. 2) and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 3).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(c) Recycled vegetable oil requirement of 1.143 t/t of biodiesel and allocation of 78% to biodiesel.

(d) Methanol consumption of 208.7 kg/t biodiesel (Ref. 2) and a total nitrous oxide requirement of 1.5×10^{-5} kg N_2Okg of methanol (Ref. 5).

(e) Potassium hydroxide consumption of 8.4 kg/t of biodiesel (Ref. 2) and a total nitrous oxide requirement for potassium hydroxide of 5.4×10^{-5} kg N_2O/kg (Ref. 6).

(f) Allocation of 78% to biodiesel.

(g) Primary energy input of 18,919 ± 3,206 GJ for construction of a biodiesel plant (Ref. 7) with a capacity of a 40,000 t/a and a 25 year life, assuming an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 9) and 78% contribution to biodiesel by price of co-products.

(h) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 7).

(i) Average round trip distance of 450 km (Ref. 8) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 7).

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8. "Alternative Road Transport Fuels - A Preliminary Life-Cycle Study for the UK" by M. P. Gover, S. A. Collings, G. S. Hitchcock, D. P. Moon and G. T. Williams, Report ETSU-R-92, Volume 2, Energy Technology Support Unit, Harwell, United Kingdom, March 1996.

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Table C5 Spreadsheet for Greenhouse Gas Outputs to Biodiesel Production from Recycled Vegetable Oil

Functional Unit:	Biodiesel at point of distribution derived from recycled vegetable oil
Final Unit of Measurement:	1 tonne of biodiesel
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Based on average market prices, assuming 0.199 tonnes of glycerine at £388/t (UK 1997 - 2000 average; Ref. 1) and 1.000 tonnes of biodiesel at £268/t (UK 1997 - 2000 average; Ref. 1), giving a 78% allocation to biodiesel.

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cleaning:								
- Natural Gas	*t rvo*	-	-	-	-	-	-	(a)
	t bd	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Esterification:								
- Methanol	*t bd*	-	-	*576*	*±85*	*576*	*±85*	(a)
- Pot. Hydroxide	*t bd*	-	-	*18*	-	*18*	-	(a)
Sub-Totals	*t bd*	-	-	*594*	*±85*	*594*	*±85*	
	t bd			**463**	**±66**	**463**	**±66**	(c)
Plant Construction								
	t bd	-	-	*1*	-	*1*	-	(a)
	t bd	**-**	**-**	**1**	**-**	**1**	**-**	(c)
Plant Maintenance								
	t bd	-	-	*1*	-	-	-	(a)
	t bd	**-**	**-**	**1**	**-**	**1**	**-**	(c)
Distribution:								
- Diesel Fuel	**t bd**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(a)
Totals	**t bd**	**25**	**±1**	**472**	**±66**	**497**	**±66**	

Biofuel Specifications

Density of biodiesel = 0.88 kg/l
Net calorific value of biodiesel = 37.27 MJ/kg
Gross calorific value of biodiesel = 37.84 MJ/kg

Abbreviations

t rvo = tonne of recycled vegetable oil
t bd = tonne of biodiesel

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Recycled vegetable oil requirement of 1.143 t/t of biodiesel and allocation of 78% to biodiesel.

(c) Allocation of 78% to biodiesel.

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APPENDIX D: Large-Scale Production of Wood Chips from Forest Residues

Figure D1 Flow Chart for the Large Scale Production of Wood Chips from Forest Residues

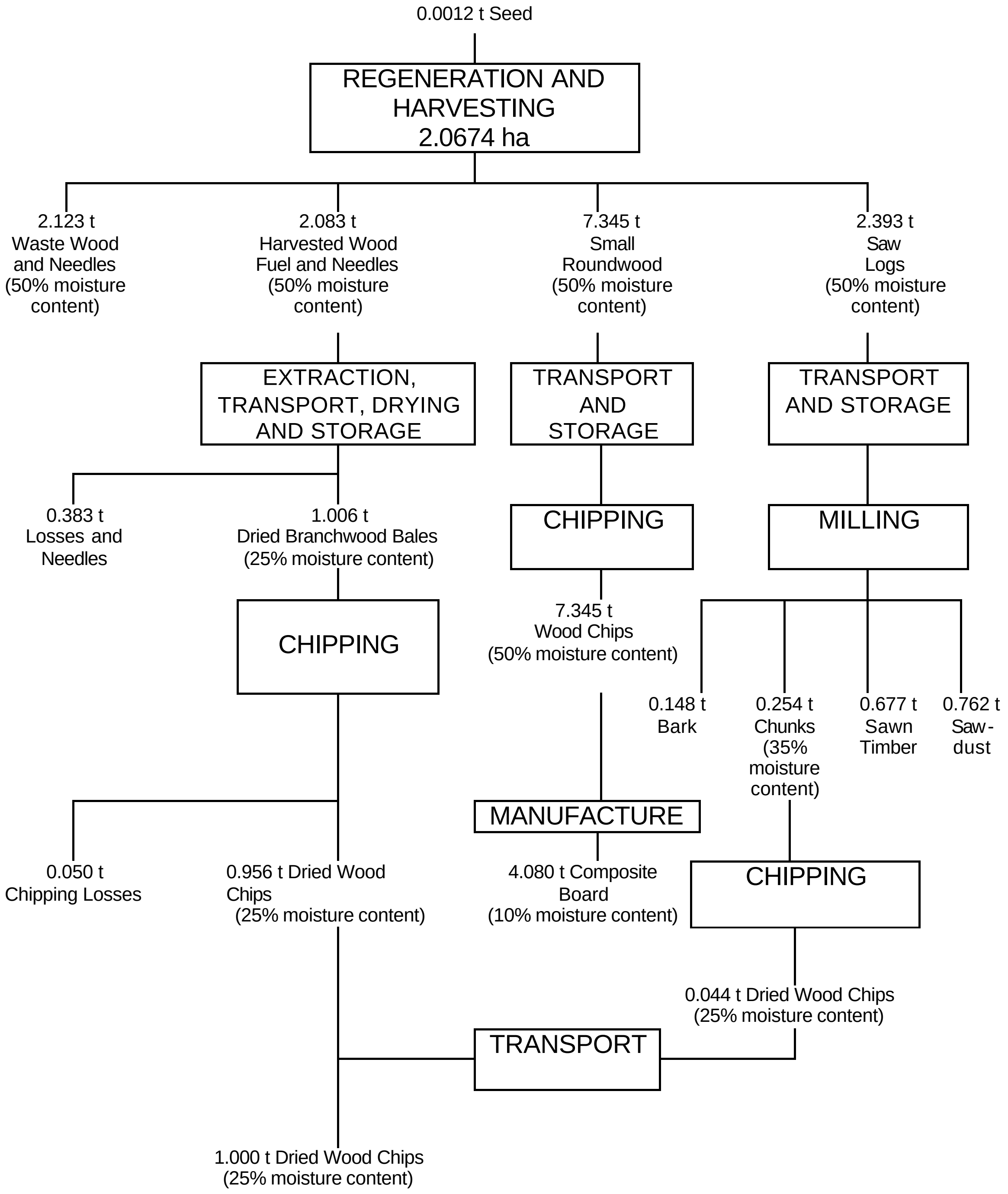

Table D1 Spreadsheet for Primary Energy Inputs to Large-Scale Production of Wood Chips from Forest Residues

Functional Unit:	Wood chips at point of consumption derived from large-scale forest management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Regeneration:										
- Diesel fuel	*ha.a*	*31*	*±10*	*3*	*±1*	-	-	*35*	*±11*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	*16*	*±5*	-	-	*16*	*±5*	(c)
- Machinery/Spares	*ha.a*	-	-	*4*	*±1*	-	-	*4*	*±1*	(d)
- Softwood	*ha.a*	-	-	*1*	-	-	-	*1*	-	(e)
- Steel	*ha.a*	-	-	*376*	*±113*	-	-	*376*	*±113*	(f)
- Preservative	*ha.a*	-	-	*62*	*±19*	-	-	*62*	*±19*	(g)
- Tree seedlings	*ha.a*	-	-	*39*	*±12*	-	-	*39*	*±12*	(h)
Reference System:										
- Diesel fuel	*ha.a*	-	-	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	*31*	*±10*	*501*	*±115*	-	-	*532*	*±116*	
	t dwc	**4**	**±1**	**64**	**±15**	**-**	**-**	**68**	**±15**	(j)
Harvesting:										
- Diesel fuel	*ha.a*	*308*	*±103*	*34*	*±12*	-	-	*342*	*±104*	(k)
- Lubricating oil	*ha.a*	*1*	-	-	-	-	-	*1*	-	(l)
- Machinery/Spares	*ha.a*	-	-	*60*	*±18*	-	-	*60*	*±18*	(m)
Sub-Totals	*ha.a*	*309*	*±103*	*94*	*±22*	-	-	*403*	*±106*	
	t dwc	**39**	**±13**	**12**	**±3**	**-**	**-**	**51**	**±13**	(j)
Extraction (residues):										
- Diesel fuel	*ha.a*	*24*	*±8*	*3*	*±1*	-	-	*26*	*±8*	(n)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(o)
- Machinery/Spares	*ha.a*	-	-	*25*	*±8*	-	-	*25*	*±8*	(p)
Sub-Totals	*ha.a*	*24*	*±8*	*28*	*±8*	-	-	*52*	*±11*	
	t dwc	**49**	**±16**	**58**	**±16**	**-**	**-**	**107**	**±23**	(q)
Transport (residues):										
- Diesel fuel	*t hwfn*	*74*	*±15*	*26*	*±6*	-	-	*99*	*±20*	(r)
	t dwc	**102**	**±21**	**36**	**±8**	**-**	**-**	**138**	**±28**	(s)
Storage and Drying (residues):										
- Storage/Drying	*t hwfn*	-	-	-	-	-	-	-	-	(t)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Chipping (residues):										
- Diesel fuel	*t dwf*	*35*	*±12*	*4*	*±1*	-	-	*39*	*±12*	(u)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	-	-	(v)
- Machinery/Spares	*t dwf*	-	-	*19*	*±6*	-	-	*19*	*±6*	(w)
Sub-Totals	*t dwf*	*35*	*±12*	*23*	*±6*	-	-	*59*	*±13*	
	t dwc	**35**	**±12**	**23**	**±6**	**-**	**-**	**59**	**±13**	(x)
Chipping (chunks):										
- Diesel fuel	*t dwch*	*35*	*±12*	*4*	*±1*	-	-	*39*	*±12*	(y)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	-	-	(z)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	-	-	(aa)
Sub-Totals	*t dwch*	*35*	*±12*	*4*	*±1*	-	-	*39*	*±12*	
	t dwc	**2**	**±1**	**-**	**-**	**-**	**-**	**2**	**±1**	(bb)
Transport (chips from chunks):										
- Diesel fuel	*t dwch*	*74*	*±15*	*26*	*±6*	-	-	*100*	*±20*	(cc)
	t dwc	**3**	**±1**	**1**	**-**	**-**	**-**	**4**	**±1**	(bb)
Totals	**t dwc**	**235**	**±32**	**194**	**±24**	**-**	**-**	**429**	**±43**	

Biofuel specifications

Density of wood chips (loose) = 132 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (25% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 31 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.0588 kg/ha.a (Ref. 1) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 4 MJ/ha.a (Ref. 1).

(e) Consumption of softwood in construction and maintenance of fences of 1.90 kg/ha.a (Ref. 1) with assumed stand area of 10 ha and a total energy requirement for softwood of 0.504 MJ/kg (Ref. 4).

(f) Consumption of steel wire in construction and maintenance of fences of 2.73 kg/ha.a (Ref. 1) with assumed stand area of 10 ha and a total energy requirement for steel wire of 137.2 MJ/kg (Ref. 4), and related consumption of mild steel of 0.050 kg/ha.a with a total energy requirement for mild steel of 31 MJ/kg (Ref. 5).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.62 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha and a total energy requirement for wood preservative of 100 MJ/kg (Ref. 5).

(h) Consumption of tree seedlings in stand establishment and regeneration of 29.4 seedlings/ha.a, based on standard planting densities recommended (Ref. 5) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total energy requirement of 1.319 MJ/seedling (Ref. 5).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area required is 2.067 ha.a/t of dried wood chips available at point of use and allocation of 6.15% to dried wood chips. Total production of utilisable stem wood at time of harvest is 177.2 t/ha based on utilisable stem volume (Ref. 7) for yield class 12 Sitka spruce planted at 2 m spacing with an nominal specific gravity of stem wood of 0.33 odt/m^3 (Ref. 8). This is converted to 49.2 t/ha potential sawlogs and 120.8 t/ha roundwood with the remainder (17.2 t/ha) becoming either waste or forming residual stem wood (Refs. 9 and 10). Stem defects are assumed to result in 20% of potential sawlog material being unsuitable, giving 39.4 t/ha actual sawlogs with the remainder (9.8 t/ha) forming part of the residual stem wood or going to waste. In addition, 52.1 t/ha of branchwood and needles (35.8 + 16.3 t/ha) are generated (Ref. 11). Harvested wood fuel is assumed to consist of one half of the residual stem wood and one half of the branchwood, giving 26.1 t/ha + 8.1 t/ha of attached needles. A relative value of sawlogs, roundwood and residues of 4:2:1 is assumed which, treating attached needles as waste, gives an allocation to residues of 26.1/(26.1 + 4 x 39.4 + 2 x 120.8) = 6.15%.

(k) Diesel fuel consumption of 308 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products (Ref. 1), including 2.27 litres diesel fuel consumed by tree processor per tonne utilisable stem biomass (Ref. 1) with estimates for conventional forest harvesting operations (Ref. 12) and utilisable stem biomass at time of harvest taken as 177.2 t/ha per hectare or 3.47 t/ha.a (Ref. 1), with a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 1 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 60 MJ/ha.a (Ref. 1 and 5).

(n) Diesel fuel consumption of 24 MJ/ha.a used by forestry machinery for collection, baling and extraction of harvested wood fuel (with needles attached), based on assumption of diesel consumption of 0.9 l/t of extracted material (Ref. 13) with harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips and a land area requirement of 2.067 ha/t dried wood chips, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 25 MJ/ha.a (Ref. 1 and 5).

(q) Land area required 2.067 ha.a/t of dried wood chips available at point of use.

(r) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 4).

(s) Harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips.

(t) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(u) Diesel fuel consumption of 35 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 13) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 5) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(w) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 19 MJ/t dwf (Refs. 1 and 4).

(x) Dried wood fuel requirement of 1.006 t/t dried wood chips.

(y) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 13) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 5) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(aa) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 19 MJ/t dwf (Refs. 1 and 4).

(bb) Dried wood chunk requirement of 0.044 t/t dried wood chips.

(cc) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 4).

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Table D2 Spreadsheet for Carbon Dioxide Outputs to Large-Scale Production of Wood Chips from Forest Residues

Functional Unit:	Wood chips at point of consumption derived from large-scale forest management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	*2*	*±1*	-	-	*2*	*±1*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Softwood	*ha.a*	-	-	-	-	-	-	(e)
- Steel	*ha.a*	-	-	*17*	*±6*	*17*	*±6*	(f)
- Preservative	*ha.a*	-	-	*1*	-	*1*	-	(g)
- Tree seedlings	*ha.a*	-	-	*2*	*±1*	*2*	*±1*	(h)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	*2*	*±1*	*21*	*±6*	*23*	*±6*	
	t dwc	**-**	**-**	**3**	**±1**	**3**	**±1**	(j)
Harvesting:								
- Diesel fuel	*ha.a*	*21*	*±7*	*2*	*±1*	*24*	*±7*	(k)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(l)
- Machinery/Spares	*ha.a*	-	-	*2*	*±1*	*2*	*±1*	(m)
Sub-Totals	*ha.a*	*21*	*±7*	*5*	*±1*	*26*	*±7*	
	t dwc	**3**	**±1**	**1**	**-**	**3**	**±1**	(j)
Extraction (residues):								
- Diesel fuel	*ha.a*	*2*	*±1*	-	-	*2*	*±1*	(n)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(o)
- Machinery/Spares	*ha.a*	-	-	*1*	-	*1*	-	(p)
Sub-Totals	*ha.a*	*2*	*±1*	*1*	-	*3*	*±1*	
	t dwc	**3**	**±1**	**2**	**±1**	**6**	**±1**	(q)
Transport (residues):								
- Diesel fuel	*t hwfn*	*5*	*±1*	*1*	-	*7*	*±1*	(r)
	t dwc	**7**	**±1**	**2**	**-**	**9**	**±2**	(s)
Storage and Drying (residues):								
- Storage/Drying	*t hwfn*	-	-	-	-	-	-	(t)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Chipping (residues):								
- Diesel fuel	*t dwf*	*2*	*±1*	-	-	*3*	*±1*	(u)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(v)
- Machinery/Spares	*t dwf*	-	-	*1*	-	*1*	-	(w)
Sub-Totals	*t dwf*	*2*	*±1*	*1*	-	*4*	*±1*	
	t dwc	**2**	**±1**	**1**	**-**	**4**	**±1**	(x)
Chipping (chunks):								
- Diesel fuel	*t dwch*	*2*	*±1*	-	-	*3*	*±1*	(y)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(z)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(aa)
Sub-Totals	*t dwch*	*2*	*±1*	-	-	*3*	*±1*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(bb)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	*5*	*±1*	*1*	-	*7*	*±1*	(cc)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(bb)
Totals	**t dwc**	**16**	**±2**	**9**	**±1**	**25**	**±3**	

Biofuel specifications

Density of wood chips (loose) = 132 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (25% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 31 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.0588 kg/ha.a (Ref. 1) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1, 2 and 4).

(e) Consumption of softwood in construction and maintenance of fences of 1.90 kg/ha.a (Ref. 1), with an assumed stand area of 10 ha and a total carbon requirement for softwood of 0.041 kg CO_2/kg (Ref. 5).

(f) Consumption of steel wire in construction and maintenance of fences of 2.73 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha and a total carbon requirement for steel wire of 6.31 kg CO_2/kg (Ref. 5), and related consumption of mild steel of 0.050 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha and a total carbon requirement for mild steel of 1.24 kg CO_2/kg (Ref. 4).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.62 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha and a total and a total carbon requirement for preservative of 1.41 kg CO_2/kg (Ref. 4).

(h) Consumption of tree seedlings in stand establishment and regeneration of 29.4 seedlings/ha.a, based on standard planting densities (Ref. 6) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total carbon requirement of 0.0567 kg CO_2/seedling (Ref. 4).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area required is 2.067 ha.a/t of dried wood chips available at point of use and allocation of 6.15% to dried wood chips. Total production of utilisable stem wood at time of harvest is 177.2 t/ha based on utilisable stem volume (Ref. 7) for yield class 12 Sitka spruce planted at 2 m spacing with an nominal specific gravity of stem wood of 0.33 odt/m^3 (Ref. 8). This is converted to 49.2 t/ha potential sawlogs and 120.8 t/ha roundwood with the remainder (17.2 t/ha) becoming either waste or forming residual stem wood (Ref. 9 and 10). Stem defects are assumed to result in 20% of potential sawlog material being unsuitable, giving 39.4 t/ha actual sawlogs with the remainder (9.8 t/ha) forming part of the residual stem wood or going to waste. In addition 52.1 t/ha of branchwood and needles (35.8 + 16.3 t/ha) are generated (Ref. 11). Harvested wood fuel is assumed to consist of one half of the residual stem wood and one half of the branchwood, giving 26.1 t/ha + 8.1 t/ha of attached needles. A relative value of sawlogs, roundwood and residues of 4:2:1 is assumed which, treating attached needles as waste, gives an allocation to residues of 26.1/(26.1 + 4 x 39.4 + 2 x 120.8) = 6.15%.

(k) Diesel fuel consumption of 308 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, including 2.27 litres diesel fuel consumed by tree processor per tonne utilisable stem biomass (Ref. 1) and utilisable stem biomass at time of harvest taken as 177.2 t/ha per hectare or 3.47 t/ha.a with estimates for conventional forest harvesting operations (Ref. 12), with a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 1 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2), based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 2 kg CO_2/ha.a (Ref. 1 and 4).

(n) Diesel fuel consumption of 24 MJ/ha.a used by forestry machinery for collection, baling and extraction of harvested wood fuel (with needles attached), based on assumption of diesel consumption of 0.9 l/t of extracted material (Ref. 13) with harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips and land area required 2.067 ha/t dried wood chips, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2), based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4).

(p) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 1 kg CO_2/ha.a (Ref. 1 and 4).

(q) Land area required 2.067 ha.a/t of dried wood chips available at point of use.

(r) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 5).

(s) Harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips.

(t) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(u) Diesel fuel consumption of 35 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 13) and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4) and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(w) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 1 kg CO_2/t dwf (Refs. 1 and 4).

(x) Dried wood fuel requirement of 1.006 t/t dried wood chips.

(y) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 13) and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4) and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(aa) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 1 kg CO_2/t dwf (Refs. 1 and 4).

(bb) Dried wood chunk requirement of 0.044 t/t dried wood chips.

(cc) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 5).

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13. Private communications with M. Wihersaari, VTT-Energy, Espoo, Finland, September 2002.

Table D3. Spreadsheet for Methane Outputs from Large-Scale Production of Wood Chips from Forest Residues

Functional Unit:	Wood chips at point of consumption derived from large-scale forest management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	-	-	*0.001*	-	*0.001*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Softwood	*ha.a*	-	-	-	-	-	-	(e)
- Steel	*ha.a*	-	-	-	-	-	-	(f)
- Preservative	*ha.a*	-	-	-	-	-	-	(g)
- Tree seedlings	*ha.a*	-	-	-	-	-	-	(h)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(j)
Harvesting:								
- Diesel fuel	*ha.a*	-	-	*0.006*	*±0.002*	*0.007*	*±0.002*	(k)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(l)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(m)
Sub-Totals	*ha.a*	-	-	*0.006*	*±0.002*	*0.006*	*±0.002*	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(j)
Extraction (residues):								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(n)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(o)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(p)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(q)
Transport (residues):								
- Diesel fuel	*t hwfn*	-	-	*0.002*	-	*0.002*	-	(r)
	t dwc	**-**	**-**	**0.002**	**-**	**0.002**	**-**	(s)
Storage and Drying (residues):								
- Storage/Drying	*t hwfn*	-	-	-	-	-	-	(t)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Chipping (residues):								
- Diesel fuel	*t dwf*	-	-	*0.001*	-	*0.001*	-	(u)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(v)
- Machinery/Spares	*t dwf*	-	-	-	-	-	-	(w)
Sub-Totals	*t dwf*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(x)
Chipping (chunks):								
- Diesel fuel	*t dwch*	-	-	*0.001*	-	*0.001*	-	(y)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(z)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(aa)
Sub-Totals	*t dwch*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(bb)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	-	-	*0.002*	-	*0.002*	-	(cc)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(bb)
Totals	**t dwc**	**-**	**-**	**0.005**	**±0.001**	**0.005**	**±0.001**	

Biofuel specifications

Density of wood chips (loose) = 132 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (25% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 31 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.0588 kg/ha.a (Ref. 1), and a total carbon requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Ref. 1, 2 and 4).

(e) Consumption of softwood in construction and maintenance of fences of 1.90 kg/ha.a (Ref. 1) with assumed stand area of 10 ha and a total energy requirement for softwood of 0.504 MJ/kg (Ref. 5), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 6).

(f) Consumption of steel wire in construction and maintenance of fences of 2.73 kg/ha.a (Ref. 1) with assumed stand area of 10 ha and a total energy requirement for steel wire of 137.2 MJ/kg (Ref. 4), and related consumption of mild steel of 0.050 kg/ha.a with a total energy requirement for mild steel of 31 MJ/kg (Ref. 5), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 6).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.62 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha and a total energy requirement for wood preservative of 100 MJ/kg (Ref. 5), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 6).

(h) Consumption of tree seedlings in stand establishment and regeneration of 29.4 seedlings/ha.a, based on standard planting densities (Ref. 7) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total methane requirement of 4.6 x 10^{-6} kg CH_4/seedling (Ref. 4).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area required is 2.067 ha.a/t of dried wood chips available at point of use and allocation of 6.15% to dried wood chips. Total production of utilisable stem wood at time of harvest is 177.2 t/ha based on utilisable stem volume (Ref. 8) for yield class 12 Sitka spruce planted at 2 m spacing with an nominal specific gravity of stem wood of 0.33 odt/m^3 (Ref. 9). This is converted to 49.2 t/ha potential sawlogs and 120.8 t/ha roundwood with the remainder (17.2 t/ha) becoming either waste or forming residual stem wood (Refs. 10 and 11). Stem defects are assumed to result in 20% of potential sawlog material being unsuitable, giving 39.4 t/ha actual sawlogs with the remainder (9.8 t/ha) forming part of the residual stem wood or going to waste. In addition, 52.1 t/ha of branchwood and needles (35.8 + 16.3 t/ha) are generated (Ref. 12). Harvested wood fuel is assumed to consist of one half of the residual stem wood and one half of the branchwood, giving 26.1 t/ha + 8.1 t/ha of attached needles. A relative value of sawlogs, roundwood and residues of 4:2:1 is assumed which, treating attached needles as waste, gives an allocation to residues of 26.1/(26.1 + 4 x 39.4 + 2 x 120.8) = 6.15%.

(k) Diesel fuel consumption of 308 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products (Ref. 1), including 2.27 litres diesel fuel consumed by tree processor per tonne utilisable stem biomass (Ref. 1) with estimates for conventional forest harvesting operations (Ref. 12) and utilisable stem biomass at time of harvest taken as 177.2 t/ha per hectare or 3.47 t/ha.a (Ref. 1), with a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 1 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Ref. 1 and 4).

(n) Diesel fuel consumption of 24 MJ/ha.a used by forestry machinery for collection, baling and extraction of harvested wood fuel (with needles attached), based on assumption of diesel consumption of 0.9 l/t of extracted material (Ref. 14) with harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips and a land area requirement of 2.067 ha/t dried wood chips, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 2), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Ref. 1 and 4).

(q) Land area required 2.067 ha.a/t of dried wood chips available at point of use.

(r) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 5).

(s) Harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips.

(t) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(u) Diesel fuel consumption of 35 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 14), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(w) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/t dwf (Refs. 1 and 4).

(x) Dried wood fuel requirement of 1.006 t/t dried wood chips.

(y) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 14), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(aa) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/t dwf (Refs. 1 and 4).

(bb) Dried wood chunk requirement of 0.044 t/t dried wood chips.

(cc) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 2).

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14. Private communications with M. Wihersaari, VTT-Energy, Espoo, Finland, September 2002.

Table D4 **Spreadsheet for Nitrous Oxide Outputs from Large-Scale Production of Wood Chips from Forest Residues**

Functional Unit:	Wood chips at point of consumption derived from large-scale forest management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonnes for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Softwood	*ha.a*	-	-	-	-	-	-	(e)
- Steel	*ha.a*	-	-	-	-	-	-	(f)
- Preservative	*ha.a*	-	-	-	-	-	-	(g)
- Tree seedlings	*ha.a*	-	-	-	-	-	-	(h)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(j)
Harvesting:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(k)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(l)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(m)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(j)
Extraction (residues):								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(n)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(o)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(p)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(q)
Transport (residues):								
- Diesel fuel	*t hwfn*	-	-	-	-	-	-	(r)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Storage and Drying (residues):								
- Storage/Drying	*t hwfn*	-	-	-	-	-	-	(t)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Chipping (residues):								
- Diesel fuel	*t dwf*	-	-	-	-	-	-	(u)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(v)
- Machinery/Spares	*t dwf*	-	-	-	-	-	-	(w)
Sub-Totals	*t dwf*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Chipping (chunks):								
- Diesel fuel	*t dwch*	-	-	-	-	-	-	(y)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(z)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(aa)
Sub-Totals	*t dwch*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(bb)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	-	-	-	-	-	-	(cc)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(bb)
Totals	**t dwc**	**-**	**-**	**-**	**-**	**-**	**-**	

Biofuel specifications

Density of wood chips (loose) = 132 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (25% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 31 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.0588 kg/ha.a (Ref. 1), and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.5 x 10^{-3} kg N_2O/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Ref. 1, 2 and 4).

(e) Consumption of softwood in construction and maintenance of fences of 1.90 kg/ha.a (Ref. 1) with assumed stand area of 10 ha and a total energy requirement for softwood of 0.504 MJ/kg (Ref. 5), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 6).

(f) Consumption of steel wire in construction and maintenance of fences of 2.73 kg/ha.a (Ref. 1) with assumed stand area of 10 ha and a total energy requirement for steel wire of 137.2 MJ/kg (Ref. 5), and related consumption of mild steel of 0.050 kg/ha.a with a total energy requirement for mild steel of 31 MJ/kg (Ref. 4), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 6).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.62 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha and a total energy requirement for wood preservative of 100 MJ/kg (Ref. 4), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 6).

(h) Consumption of tree seedlings in stand establishment and regeneration of 29.4 seedlings/ha.a, based on standard planting densities (Ref. 7) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total nitrous oxide requirement of 9.4 x 10^{-6} kg N_2O/seedling (Ref. 4).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area required is 2.067 ha.a/t of dried wood chips available at point of use and allocation of 6.15% to dried wood chips. Total production of utilisable stem wood at time of harvest is 177.2 t/ha based on utilisable stem volume (Ref. 8) for yield class 12 Sitka spruce planted at 2 m spacing with an nominal specific gravity of stem wood of 0.33 odt/m^3 (Ref. 9). This is converted to 49.2 t/ha potential sawlogs and 120.8 t/ha roundwood with the remainder (17.2 t/ha) becoming either waste or forming residual stem wood (Refs. 10 and 11). Stem defects are assumed to result in 20% of potential sawlog material being unsuitable, giving 39.4 t/ha actual sawlogs with the remainder (9.8 t/ha) forming part of the residual stem wood or going to waste. In addition, 52.1 t/ha of branchwood and needles (35.8 + 16.3 t/ha) are generated (Ref. 12). Harvested wood fuel is assumed to consist of one half of the residual stem wood and one half of the branchwood, giving 26.1 t/ha + 8.1 t/ha of attached needles. A relative value of sawbgs, roundwood and residues of 4:2:1 is assumed which, treating attached needles as waste, gives an allocation to residues of 26.1/(26.1 + 4 x 39.4 + 2 x 120.8) = 6.15%.

(k) Diesel fuel consumption of 308 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, including 2.27 litres diesel fuel consumed by tree processor per tonne utilisable stem biomass (Ref. 1) with estimates for conventional forest harvesting operations (Ref. 13) and utilisable stem biomass at time of harvest taken as 177.2 t/ha per hectare or 3.47 t/ha.a, with a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 1 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1 and 4).

(n) Diesel fuel consumption of 24 MJ/ha.a used by forestry machinery for collection, baling and extraction of harvested wood fuel (with needles attached), based on assumption of diesel consumption of 0.9 l/t of extracted material (Ref. 14) with harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips and land area required 2.067 ha/t dried wood chips, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 1), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1 and 4).

(q) Land area required 2.067 ha.a/t of dried wood chips available at point of use.

(r) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 5).

(s) Harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips.

(t) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(u) Diesel fuel consumption of 35 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 14) and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(w) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/t dwf (Refs. 1 and 4).

(x) Dried wood fuel requirement of 1.006 t/t dried wood chips.

(y) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 14), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(aa) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/t dwf (Refs. 1 and 4).

(bb) Dried wood chunk requirement of 0.044 t/t dried wood chips.

(cc) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 5).

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Table D5. Spreadsheet for Greenhouse Gas Outputs from Large-Scale Production of Wood Chips from Forest Residues

Functional Unit:	Wood chips at point of consumption derived from large-scale forest management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonnes for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	ha.a	2	±1	-	-	2	±1	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Agrochemicals	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(a)
- Softwood	ha.a	-	-	-	-	-	-	(a)
- Steel	ha.a	-	-	17	±6	17	±6	(a)
- Preservative	ha.a	-	-	1	±3	1	±3	(a)
- Tree seedlings	ha.a	-	-	2	±1	2	±1	(a)
Reference System:								
- Diesel fuel	ha.a	-	-	-	-	-	-	(a)
Sub-Totals	ha.a	2	±1	21	±7	23	±7	
	t dwc	**-**	**-**	**3**	**±1**	**3**	**±1**	(b)
Harvesting:								
- Diesel fuel	ha.a	21	±7	3	±1	24	±7	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	2	±1	2	±1	(a)
Sub-Totals	ha.a	21	±7	5	±1	26	±7	
	t dwc	**3**	**±1**	**1**	**-**	**3**	**±1**	(b)
Extraction (residues):								
- Diesel fuel	ha.a	2	±1	-	-	2	±1	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	1	-	1	-	(a)
Sub-Totals	ha.a	2	±1	1	-	3	±1	
	t dwc	**3**	**±1**	**3**	**±1**	**6**	**±1**	(c)
Transport (residues):								
- Diesel fuel	t hwfn	5	±1	1	-	7	±1	(a)
	t dwc	**7**	**±1**	**2**	**-**	**9**	**±2**	(d)
Storage and Drying (residues):								
- Storage/Drying	t hwfn	-	-	-	-	-	-	(a)
Sub-Totals	t hwfn	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(d)
Chipping (residues):								
- Diesel fuel	t dwf	2	±1	-	-	3	±1	(a)
- Lubricating oil	t dwf	-	-	-	-	-	-	(a)
- Machinery/Spares	t dwf	-	-	1	-	1	-	(a)
Sub-Totals	t dwf	2	±1	1	-	4	±1	
	t dwc	**2**	**±1**	**1**	**-**	**4**	**±1**	(e)
Chipping (chunks):								
- Diesel fuel	t dwch	2	±1	-	-	3	±1	(a)
- Lubricating oil	t dwch	-	-	-	-	-	-	(a)
- Machinery/Spares	t dwch	-	-	-	-	-	-	(a)
Sub-Totals	t dwch	2	±1	-	-	3	±1	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Transport (chips from chunks):								
- Diesel fuel	t dwch	5	±1	1	-	7	±1	(a)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Totals	**t dwc**	**16**	**±2**	**9**	**±1**	**25**	**±3**	

Biofuel specifications

Density of wood chips (loose) = 132 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (25% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg CO_2/kg N_2O.

(b) Land area required is 2.067 ha.a/t of dried wood chips available at point of use and allocation of 6.15% to dried wood chips. Total production of utilisable stem wood at time of harvest is 177.2 t/ha based on utilisable stem volume for yield class 12 Sitka spruce planted at 2 m spacing with an nominal specific gravity of stem wood of 0.33 odt/m^3. This is converted to 49.2 t/ha potential sawlogs and 120.8 t/ha roundwood with the remainder (17.2 t/ha) becoming either waste or forming residual stem wood. Stem defects are assumed to result in 20% of potential sawlog material being unsuitable, giving 39.4 t/ha actual sawlogs with the remainder (9.8 t/ha) forming part of the residual stem wood or going to waste. In addition, 52.1 t/ha of branchwood and needles (35.8 + 16.3 t/ha) are generated. Harvested wood fuel is assumed to consist of one half of the residual stem wood and one half of the branchwood, giving 26.1 t/ha + 8.1 t/ha of attached needles. A relative value of sawlogs, roundwood and residues of 4:2:1 is assumed which, treating attached needles as waste, gives an allocation to residues of 26.1/(26.1 + 4 x 39.4 + 2 x 120.8) = 6.15%.

(c) Land area required 2.067 ha.a/t of dried wood chips available at point of use.

(d) Harvested wood fuel (with needles) requirement of 1.389 t/t dried wood chips.

(e) Dried wood fuel requirement of 1.006 t/t dried wood chips.

(f) Dried wood chunk requirement of 0.044 t/t dried wood chips.

APPENDIX E: Small-Scale Production of Wood Chips from Woodland Management (Option A)

Figure E1 Flow Chart for the Small Scale Production of Wood Chips from Woodland Management (Option A)

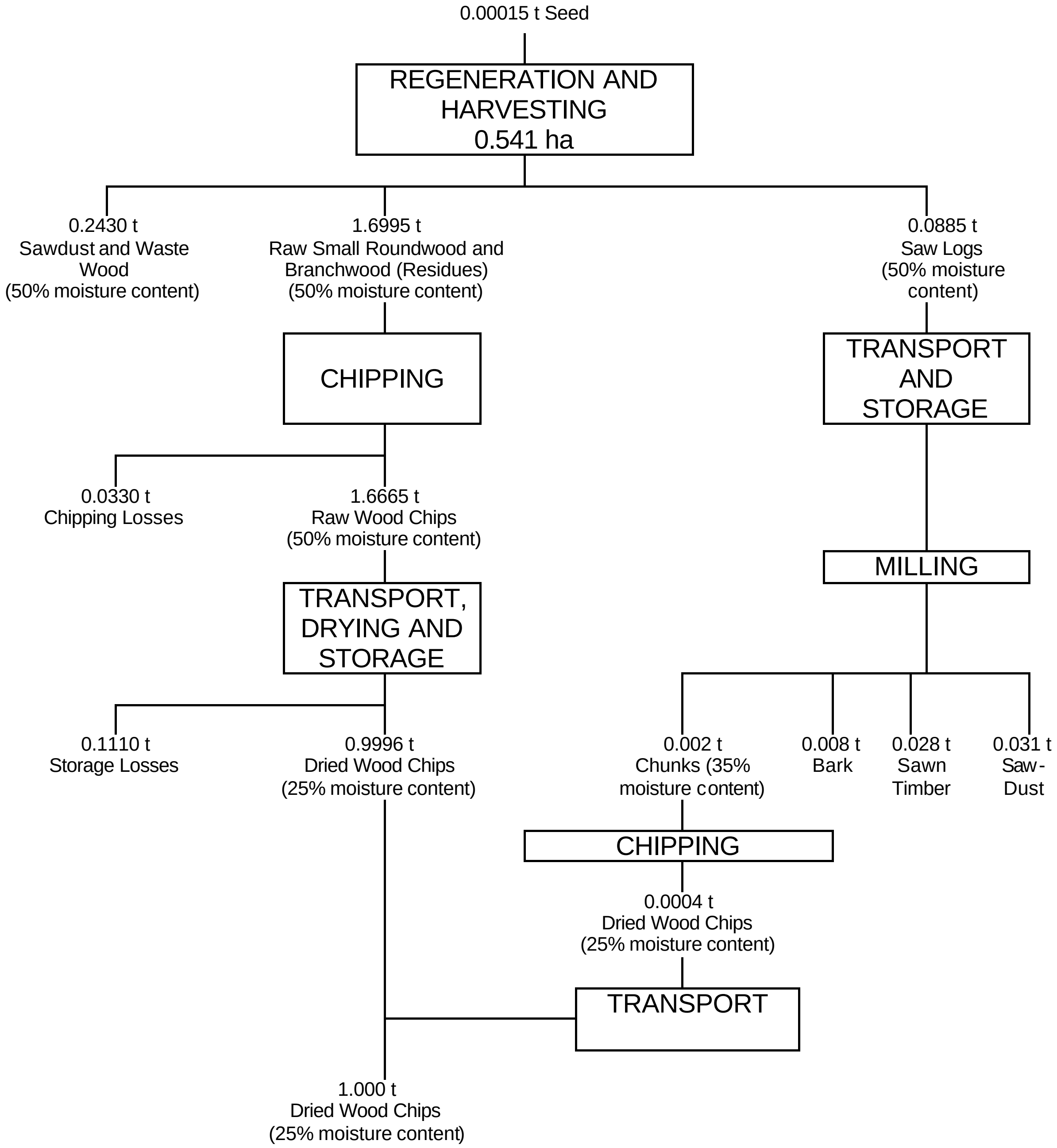

Table E1 Spreadsheet for Primary Energy Inputs to Small-Scale Production of Wood Chips from Woodland Management (Option A)

Functional Unit:	Wood chips at point of consumption derived from small-scale broadleaf woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to fuel wood and sawlogs by value, assuming a price ratio per oven dry tonnes for sawlogs and fuel wood of 10:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Regeneration:										
- Diesel fuel	*ha.a*	*20*	*±7*	*2*	*±1*	-	-	*22*	*±7*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	*10*	*±3*	-	-	*10*	*±3*	(c)
- Machinery/Spares	*ha.a*	-	-	*3*	*±1*	-	-	*3*	*±1*	(d)
- Tree shelters	*ha.a*	-	-	*49*	*±15*	-	-	*49*	*±15*	(e)
- Tree seedlings	*ha.a*	-	-	*24*	*±8*	-	-	*24*	*±8*	(f)
Reference System:										
- Diesel fuel	*ha.a*	-	-	-	-	-	-	-	-	(g)
Sub-Totals	*ha.a*	*20*	*±7*	*88*	*±17*	-	-	*108*	*±18*	
	t dwc	**7**	**±2**	**31**	**±6**	**-**	**-**	**38**	**±6**	(h)
Harvest for fuel:										
- Diesel fuel	*ha.a*	*33*	*±11*	*4*	*±1*	-	-	*37*	*±11*	(i)
- Motor spirit	*ha.a*	*98*	*±33*	*11*	*±4*	-	-	*108*	*±33*	(j)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(k)
- Machinery/Spares	*ha.a*	-	-	*1*	-	-	-	*1*	-	(l)
Sub-Totals	*ha.a*	*131*	*±35*	*15*	*±4*	-	-	*146*	*±35*	
	t dwc	**71**	**±19**	**8**	**±2**	**-**	**-**	**79**	**±19**	(m)
Harvest for logs:										
- Diesel fuel	*ha.a*	*7*	*±2*	*1*	-	-	-	*7*	*±2*	(n)
- Motor spirit	*ha.a*	*9*	*±3*	*1*	-	-	-	*10*	*±3*	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*15*	*±4*	*2*	-	-	-	*17*	*±4*	
	t dwc	**5**	**±1**	**1**	**-**	**-**	**-**	**5**	**±1**	(r)
Main harvest:										
- Diesel fuel	*ha.a*	*47*	*±16*	*5*	*±2*	-	-	*52*	*±16*	(s)
- Motor spirit	*ha.a*	*50*	*±17*	*5*	*±2*	-	-	*55*	*±17*	(t)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(u)
- Machinery/Spares	*ha.a*	-	-	*1*	-	-	-	*1*	-	(v)
Sub-Totals	*ha.a*	*97*	*±23*	*11*	*±3*	-	-	*108*	*±23*	
	t dwc	**27**	**±7**	**3**	**±1**	**-**	**-**	**31**	**±7**	(w)
Chipping (fuel wood):										
- Diesel fuel	*t hwf*	*43*	*±14*	*5*	*±2*	-	-	*48*	*±15*	(x)
- Lubricating oil	*t hwf*	-	-	-	-	-	-	-	-	(y)
- Machinery/Spares	*t hwf*	-	-	*19*	*±6*	-	-	*19*	*±6*	(z)
Sub-Totals	*t hwf*	*43*	*±14*	*24*	*±6*	-	-	*67*	*±16*	
	t dwc	**49**	**±16**	**27**	**±7**	**-**	**-**	**76**	**±18**	(aa)
Transport (fuel wood):										
- Diesel fuel	*t rwc*	*74*	*±15*	*26*	*±6*	-	-	*100*	*±20*	(bb)
	t dwc	**82**	**±17**	**29**	**±7**	**-**	**-**	**111**	**±23**	(cc)
Storage and Drying (fuel wood chips):										
- Diesel fuel	*t rwc*	*4*	*±1*	-	-	-	-	*4*	*±1*	(dd)
- Lubricating oil	*t rwc*	-	-	-	-	-	-	-	-	(ee)
- Machinery/Spares	*t rwc*	-	-	*1*	-	-	-	*1*	-	(ff)
Sub-Totals	*t rwc*	*4*	*±1*	*1*	-	-	-	*5*	*±1*	
	t dwc	**4**	**±1**	**1**	**-**	**-**	**-**	**6**	**±1**	(cc)
Chipping (chunks):										
- Diesel fuel	*t dwch*	*36*	*±12*	*4*	*±1*	-	-	*40*	*±12*	(gg)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	-	-	(hh)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	-	-	(ii)
Sub-Totals	*t dwch*	*36*	*±12*	*4*	*±1*	-	-	*40*	*±12*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(jj)
Transport (chips from chunks):										
- Diesel fuel	*t dwch*	*74*	*±15*	*26*	*±6*	-	-	*100*	*±20*	(kk)
	t dwc									(jj)
Totals	**t dwc**	**245**	**±31**	**101**	**±12**	**-**	**-**	**345**	**±36**	

Biofuel specifications

Density of wood chips (loose) = 196 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 20 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 3 MJ/ha.a (Ref. 1).

(e) Consumption of polyethylene as tree shelters of 0.556 kg/ha.a (Ref. 4) and a total energy requirement of 88.55 MJ/kg (Ref. 5).

(f) Consumption of tree seedlings in stand establishment and regeneration of 18.5 seedlings/ha.a, based on standard planting densities (Ref. 6) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total energy requirement of 1.319 MJ/seedling (Ref. 7).

(g) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(h) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 65.8% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 2.094 odt/ha.a harvested wood fuel and 0.109 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 2.094 / (10 x 0.109 + 2.94) = 65.8%.

(i) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from fuel harvest operations) to roadside, assuming 1 litre diesel fuel consumption per tonne of harvested wood fuel extracted (Ref. 12), with 0.842 odt/ha.a harvested wood fuel being produced from fuel harvest operations and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(j) Motor spirit consumption of 98 MJ/ha.a used by chainsaws in motor-manual felling of whole trees (as fuel harvest operations), assuming 8 periodic fuel harvests over life cycle of tree stand of 0.037, 0.186, 0..136, 0.120, 0.112, 0.105, 0.082 and 0.067 odt/ha.a (Refs. 8 to 11) with respective fuel consumption (dependent on mean tree size) of 8, 6, 4, 2, 1.8, 1.75, 1.7 and 1.6 l/odt (Ref. 14), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(k) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 7) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 1 MJ/ha.a (Ref. 1 and 7).

(m) Land area required 0.541 ha.a/t of dried wood chips available at point of use.

(n) Diesel fuel consumption of 7 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from log harvest operations), assuming1 litre diesel fuel consumption per tonne of harvested wood fuel extracted (Ref. 12) with 0.168 odt/ha.a harvested wood fuel being produced from log harvest operations to roadside, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Motor spirit consumption of 9 MJ/ha.a used by chainsaws in motor-manual felling of whole trees (as log harvest operations), assuming 4 periodic sawlog/fuel harvests over life cycle of tree stand of 0.052, 0.046, 0..039 and 0.031 odt/ha.a (Refs. 8 to 11) with respective fuel consumption (dependent on mean tree size) of 1.5, 1.45, 1.45 and 1.4 l/odt (Ref. 13), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 7), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Refs. 1 and 7).

(r) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 56.5% to harvested wood fuel. Production over 4 log harvests consists of 0.156 odt/ha.a harvested wood fuel and 0.012 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 0.156 / (10 x 0.012 + 0.156) = 56.5%.

(s) Diesel fuel consumption of 47 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from main harvest operations) to roadside, assuming 1 litre diesel fuel consumption per tonne of harvested wood fuel extracted (Ref. 12) with 1.195 odt/ha.a harvested wood fuel being produced from log harvest operations, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(t) Motor spirit consumption of 50 MJ/ha.a used by chainsaws in motor-manual felling of whole trees (as main harvest operation), assuming main harvest of 1.195 odt/ha.a (Refs. 8 to 11) with fuel consumption (dependent on mean tree size) of 1.2, l/odt (Ref. 13), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(u) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 7), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 1 MJ/ha.a (Ref. 1 and 7).

(w) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 54.7% to harvested wood fuel. Production from main harvest consists of 1.104 odt/ha.a harvested wood fuel and 0.091 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 1.104 / (10 x 0.091 + 1.104) = 54.7%.

(x) Diesel fuel consumption of 43 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 1.1 l/t for chipping operations with sub-optimal efficiency (Ref. 12), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(y) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 7), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 19 MJ/ha.a (Refs. 1 and 7).

(aa) Harvested wood fuel requirement of 1.133 t/t dried wood chips.

(bb) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 5).

(cc) Raw wood fuel requirement of 1.111 t/t dried wood chips.

(dd) Diesel fuel consumption of 4 MJ/t rwc during passive storage and drying of wood chips. Assumed minimal facilities for storage and passive drying of wood chips with 0.1 litre diesel oil per tonne dry wood chips consumed in machinery involved in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), a gross calorific value of 45.8 MJ/kg (Ref. 1) and gross energy requirement of 1.110 MJ/MJ (Ref. 7).

(ee) Lubricating oil consumption of 0 MJ/t dwf used by machinery in passive storage and drying of wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 7), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 1 MJ/ha.a (Ref. 7).

(gg) Diesel fuel consumption of 36 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 12), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(hh) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 7), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ii) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/t dwf (Refs. 1 and 7).

(jj) Dried wood chunk requirement of 0.0004 t/t dried wood chips.

(kk) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 5).

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Table E2 Spreadsheet for Carbon Dioxide Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option A)

Functional Unit:	Wood chips at point of consumption derived from small-scale broadleaf woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to fuel wood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs and fuel wood of 10:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*2*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Tree shelters	*ha.a*	-	-	*1*	-	*1*	-	(e)
- Tree seedlings	*ha.a*	-	-	*1*	-	*1*	-	(f)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(g)
Sub-Totals	*ha.a*	*1*	*±1*	*2*	-	*4*	*±1*	
	t dwc	**-**	**-**	**1**	**-**	**1**	**-**	(h)
Harvest for fuel:								
- Diesel fuel	*ha.a*	*2*	*±1*	-	-	*3*	*±1*	(i)
- Motor spirit	*ha.a*	*6*	*±2*	*1*	-	*7*	*±2*	(j)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(k)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(l)
Sub-Totals	*ha.a*	*9*	*±2*	*1*	-	*10*	*±2*	
	t dwc	**5**	**±1**	**1**	**-**	**5**	**±1**	(m)
Harvest for logs:								
- Diesel fuel	*ha.a*	-	-	-	-	*1*	-	(n)
- Motor spirit	*ha.a*	*1*	-	-	-	*1*	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Main harvest:								
- Diesel fuel	*ha.a*	*3*	*±1*	-	-	*4*	*±1*	(s)
- Motor spirit	*ha.a*	*3*	*±1*	-	-	*4*	*±1*	(t)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(u)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(v)
Sub-Totals	*ha.a*	*7*	*±1*	*1*	-	*7*	*±1*	
	t dwc	**2**	**-**	**-**	**-**	**2**	**-**	(w)
Chipping (fuel wood):								
- Diesel fuel	*t hwf*	*3*	*±1*	-	-	*3*	*±1*	(x)
- Lubricating oil	*t hwf*	-	-	-	-	-	-	(y)
- Machinery/Spares	*t hwf*	-	-	*1*	-	*1*	-	(z)
Sub-Totals	*t hwf*	*3*	*±1*	*1*	-	*4*	*±1*	
	t dwc	**3**	**±1**	**1**	**-**	**5**	**±1**	(aa)
Transport (fuel wood):								
- Diesel fuel	*t rwc*	*5*	*±1*	*1*	-	*7*	*±1*	(bb)
	t dwc	**6**	**±1**	**2**	**-**	**7**	**±1**	(cc)
Storage and Drying (fuel wood chips):								
- Diesel fuel	*t rwc*	-	-	-	-	-	-	(dd)
- Lubricating oil	*t rwc*	-	-	-	-	-	-	(ee)
- Machinery/Spares	*t rwc*	-	-	-	-	-	-	(ff)
Sub-Totals	*t rwc*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(cc)
Chipping (chunks):								
- Diesel fuel	*t dwch*	*2*	*±1*	-	-	*2*	*±1*	(gg)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(hh)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(ii)
Sub-Totals	*t dwch*	*2*	*±1*	-	-	*2*	*±1*	
	t dwc							(jj)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	*6*	*±1*	-	-	*6*	*±1*	(kk)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(jj)
Totals	**t dwc**	**17**	**±2**	**5**	**±1**	**21**	**±2**	

Biofuel specifications

Density of wood chips (loose) = 196 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 20 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1, 2 and 4).

(e) Consumption of polyethylene as tree shelters of 0.556 kg/ha.a (Ref. 5) and a total carbon requirement of 1.25 kg CO_2/kg (Ref. 6).

(f) Consumption of tree seedlings in stand establishment and regeneration of 18.5 seedlings/ha.a (based on standard planting densities (Ref. 7) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total carbon requirement of 0.0567 kg CO_2/seedling (Ref. 4).

(g) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(h) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 65.8% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 2.094 odt/ha.a harvested wood fuel and 0.109 odt/ha.a saw logs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 2.094 / (10 x 0.109 + 2.94) = 65.8%.

(i) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from fuel harvest operations) to roadside (Ref. 12), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(j) Motor spirit consumption of 98 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as fuel harvest operations (Ref. 12), and a direct carbon requirement 0.0661 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0742 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(m) Land area required 0.541 ha.a/t of dried wood chips available at point of use.

(n) Diesel fuel consumption of 7 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from log harvest operations) to roadside (Ref. 12), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Motor spirit consumption of 9 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as log harvest operations (Ref. 13), and a direct carbon requirement 0.0661 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0742 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Ref. 1 and 4).

(r) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 56.5% to harvested wood fuel calculated. Production over 4 log harvests consists of 0.156 odt/ha.a harvested wood fuel and 0.012 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 0.156 / (10 x 0.012 + 0.156) = 56.5%.

(s) Diesel fuel consumption of 47 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from main harvest operations) to roadside (Ref. 12), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(t) Motor spirit consumption of 50 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as main harvest operation (Ref. 13), and a direct carbon requirement 0.0661 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0742 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(u) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(v) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/t dwf (Ref. 1 and 4).

(w) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 54.7% to harvested wood fuel. Production from main harvest consists of 1.104 odt/ha.a harvested wood fuel and 0.091 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 1.104 / (10 x 0.091 + 1.104) = 54.7%.

(x) Diesel fuel consumption of 43 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 1.1 l/t for chipping operations with sub-optimal efficiency (Ref. 12), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(y) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(z) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 1 kg CO_2/t dwf (Ref. 1 and 4).

(aa) Harvested wood fuel requirement of 1.133 t/t dried wood chips.

(bb) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

(cc) Raw wood fuel requirement of 1.111 t/t dried wood chips.

(dd) Diesel fuel consumption of 4 MJ/t rwc during passive storage and drying of wood chips, assuming minimal facilities for storage and passive drying of wood chips with 0.1 litre diesel oil per tonne dry wood chips consumed in machinery involved in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), a gross calorific value of 45.8 MJ/kg (Ref. 1), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ee) Lubricating oil consumption of 0 MJ/t dwf used by machinery in passive storage and drying of wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a gross direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 1 kg CO_2/t dwf (Refs. 1 and 4).

(gg) Diesel fuel consumption of 36 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 12), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(hh) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(ii) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/t dwf (Refs. 1 and 4).

(jj) Dried wood chunk requirement of 0.0004 t/t dried wood chips.

(kk) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

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Table E3 Spreadsheet for Methane Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option A)

Functional Unit:	Wood chips at point of consumption derived from small-scale broadleaf woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to fuel wood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs and fuel wood of 10:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Tree shelters	*ha.a*	-	-	-	-	-	-	(e)
- Tree seedlings	*ha.a*	-	-	-	-	-	-	(f)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(g)
Sub-Totals	*ha.a*	-	-	-	-	*0.001*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(h)
Harvest for fuel:								
- Diesel fuel	*ha.a*	-	-	*0.001*	-	*0.001*	-	(i)
- Motor spirit	*ha.a*	-	-	*0.002*	*±0.001*	*0.002*	*±0.001*	(j)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(k)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(l)
Sub-Totals	*ha.a*	-	-	*0.003*	*±0.001*	*0.003*	*±0.001*	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(m)
Harvest for logs:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(n)
- Motor spirit	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Main harvest:								
- Diesel fuel	*ha.a*	-	-	*0.001*	-	*0.001*	-	(s)
- Motor spirit	*ha.a*	-	-	*0.001*	-	*0.001*	-	(t)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(u)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(v)
Sub-Totals	*ha.a*	-	-	*0.002*	-	*0.002*	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(w)
Chipping (fuel wood):								
- Diesel fuel	*t hwf*	-	-	*0.001*	-	*0.001*	-	(x)
- Lubricating oil	*t hwf*	-	-	-	-	-	-	(y)
- Machinery/Spares	*t hwf*	-	-	-	-	-	-	(z)
Sub-Totals	*t hwf*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(aa)
Transport (fuel wood):								
- Diesel fuel	*t rwc*	-	-	*0.002*	-	*0.002*	-	(bb)
	t dwc	**-**	**-**	**0.002**	**-**	**0.002**	**-**	(cc)
Storage and Drying (fuel wood chips):								
- Diesel fuel	*t rwc*	-	-	-	-	-	-	(dd)
- Lubricating oil	*t rwc*	-	-	-	-	-	-	(ee)
- Machinery/Spares	*t rwc*	-	-	-	-	-	-	(ff)
Sub-Totals	*t rwc*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(cc)
Chipping (chunks):								
- Diesel fuel	*t dwch*	-	-	*0.001*	-	*0.001*	-	(gg)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(hh)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(ii)
Sub-Totals	*t dwch*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(jj)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	-	-	*0.002*	-	*0.002*	-	(kk)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(jj)
Totals	**t dwc**	**-**	**-**	**0.005**	**±0.001**	**0.005**	**±0.001**	

Biofuel specifications

Density of wood chips (loose) = 196 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 20 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a gross direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(e) Consumption of polyethylene as tree shelters of 0.556 kg/ha.a (Ref. 5), a total energy requirement of 88.55 MJ/kg (Ref. 6), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(f) Consumption of tree seedlings in stand establishment and regeneration of 18.5 seedlings/ha.a, based on standard planting densities (Ref. 8) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total methane requirement of 4.6 x 10^{-6} kg CH_4/seedling (Ref. 4).

(g) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(h) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 65.8% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 2.094 odt/ha.a harvested wood fuel and 0.109 odt/ha.a sawlogs overbark (Refs. 9 to 12), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 2.094 / (10 x 0.109 + 2.94) = 65.8%.

(i) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from fuel harvest operations) to roadside (Ref. 13), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(j) Motor spirit consumption of 98 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as fuel harvest operations (Ref. 13), and a direct methane requirement 5.67 X 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 X 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 X 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(k) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Ref. 1 and 4).

(m) Land area required 0.541 ha.a/t of dried wood chips available at point of use.

(n) Diesel fuel consumption of 7 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from log harvest operations) to roadside (Ref. 13), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Motor spirit consumption of 9 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as log harvest operations(Ref. 14), and a direct methane requirement 5.67 X 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 X 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 X 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1 and 4).

(r) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 56.5% to harvested wood fuel. Production over 4 log harvests consists of 0.156 odt/ha.a harvested wood fuel and 0.012 odt/ha.a sawlogs overbark (Refs. 9 to 12), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 0.156 / (10 x 0.012 + 0.156) = 56.5%.

(s) Diesel fuel consumption of 47 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from main harvest operations) to roadside (Ref. 13), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(t) Motor spirit consumption of 50 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as main harvest operation (Ref. 14), and a direct methane requirement 5.67 X 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 X 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 X 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(u) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/t dwf (Refs. 1 and 4).

(w) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 54.7% to harvested wood fuel. Production from main harvest consists of 1.104 odt/ha.a harvested wood fuel and 0.091 odt/ha.a sawlogs overbark (Refs. 9 to 12), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 1.104 / (10 x 0.091 + 1.104) = 54.7%.

(x) Diesel fuel consumption of 43 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 1.1 l/t for chipping operations with sub-optimal efficiency (Ref. 13), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(y) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/t dwf (Refs. 1 and 4).

(aa) Harvested wood fuel requirement of 1.133 t/t dried wood chips.

(bb) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 6).

(cc) Raw wood fuel requirement of 1.111 t/t dried wood chips.

(dd) Diesel fuel consumption of 4 MJ/t rwc during passive storage and drying of wood chips, assumed minimal facilities for storage and passive drying of wood chips with 0.1 litre diesel oil per tonne dry wood chips consumed in machinery involved in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), gross calorific value of 45.8 MJ/kg (Ref. 1), and direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ee) Lubricating oil consumption of 0 MJ/t dwf used by machinery in passive storage and drying of wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/t dwf (Refs. 1 and 4).

(gg) Diesel fuel consumption of 36 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 13), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(hh) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ii) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/t dwf (Refs. 1 and 4).

(jj) Dried wood chunk requirement of 0.0004 t/t dried wood chips.

(kk) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 6).

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Table E4 Spreadsheet for Nitrous Oxide Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option A)

Functional Unit:	Wood chips at point of consumption derived from small-scale broadleaf woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to fuel wood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs and fuel wood of 10:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Tree shelters	*ha.a*	-	-	-	-	-	-	(e)
- Tree seedlings	*ha.a*	-	-	-	-	-	-	(f)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(g)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(h)
Harvest for fuel:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(i)
- Motor spirit	*ha.a*	-	-	-	-	-	-	(j)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(k)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(l)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(m)
Harvest for logs:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(n)
- Motor spirit	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Main harvest:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(s)
- Motor spirit	*ha.a*	-	-	-	-	-	-	(t)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(u)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(v)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Chipping (fuel wood):								
- Diesel fuel	*t hwf*	-	-	-	-	-	-	(x)
- Lubricating oil	*t hwf*	-	-	-	-	-	-	(y)
- Machinery/Spares	*t hwf*	-	-	-	-	-	-	(z)
Sub-Totals	*t hwf*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(aa)
Transport (fuel wood):								
- Diesel fuel	*t rwc*	-	-	-	-	-	-	(bb)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(cc)
Storage and Drying (fuel wood chips):								
- Diesel fuel	*t rwc*	-	-	-	-	-	-	(dd)
- Lubricating oil	*t rwc*	-	-	-	-	-	-	(ee)
- Machinery/Spares	*t rwc*	-	-	-	-	-	-	(ff)
Sub-Totals	*t rwc*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(cc)
Chipping (chunks):								
- Diesel fuel	*t dwch*	-	-	-	-	-	-	(gg)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(hh)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(ii)
Sub-Totals	*t dwch*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(jj)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	-	-	-	-	-	-	(kk)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(jj)
Totals	**t dwc**	**-**	**-**	**-**	**-**	**-**	**-**	

Biofuel specifications

Density of wood chips (loose) = 196 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 20 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a gross direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.5 x 10^{-3} kg N_2O/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Ref. 1, 2 and 4).

(e) Consumption of polyethylene as tree shelters of 0.556 kg/ha.a (Ref. 5), a total energy requirement of 88.55 MJ/kg (Ref. 6), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(f) Consumption of tree seedlings in stand establishment and regeneration of 18.5 seedlings/ha.a, based on standard planting densities (Ref. 8) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total nitrous oxide requirement of 9.4 x 10^{-6} kg N_2O/seedling (Ref. 4).

(g) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(h) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 65.8% to harvested wood. Total production of harvested wood over tree stand life cycle 2.094 odt/ha.a harvested wood fuel and 0.109 odt/ha.a sawlogs overbark (Refs. 9 to 12), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 2.094 / (10 x 0.109 + 2.94) = 65.8%.

(i) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from fuel harvest operations) to roadside (Ref. 13), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(j) Motor spirit consumption of 98 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as fuel harvest operations (Ref. 13), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(k) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Ref. 1 and 4).

(m) Land area required 0.541 ha.a/t of dried wood chips available at point of use.

(n) Diesel fuel consumption of 7 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from log harvest operations) to roadside (Ref. 13), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(o) Motor spirit consumption of 9 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as log harvest operations (Ref. 14), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Ref. 1 and 4).

(r) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 56.5% to harvested wood fuel. Production over 4 log harvests consists of 0.156 odt/ha.a harvested wood fuel and 0.012 odt/ha.a sawlogs overbark (Refs. 9 to 12), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 0.156 / (10 x 0.012 + 0.156) = 56.5%.

(s) Diesel fuel consumption of 47 MJ/ha.a used by forestry machinery for extraction of harvested wood fuel (from main harvest operations) to roadside (Ref. 13), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(t) Motor spirit consumption of 50 MJ/ha.a used by chainsaws in motor-manual felling of whole trees, as main harvest operation (Ref. 14), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(u) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(v) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/t dwf (Refs. 1 and 4).

(w) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 54.7% to harvested wood fuel. Production from main harvest consists of 1.104 odt/ha.a harvested wood fuel and 0.091 odt/ha.a sawlogs overbark (Refs. 9 to 12), assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 1.104 / (10 x 0.091 + 1.104) = 54.7%.

(x) Diesel fuel consumption of 43 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 1.1 l/t for chipping operations with sub-optimal efficiency (Ref. 13), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(y) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(z) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/t dwf (Refs. 1 and 4).

(aa) Harvested wood fuel requirement of 1.133 t/t dried wood chips.

(bb) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 6).

(cc) Raw wood fuel requirement of 1.111 t/t dried wood chips.

(dd) Diesel fuel consumption of 4 MJ/t rwc during passive storage and drying of wood chips, assuming minimal facilities for storage and passive drying of wood chips with 0.1 litre diesel oil per tonne dry wood chips consumed in machinery involved in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), a gross calorific value of 45.8 MJ/kg (Ref. 1), and direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ee) Lubricating oil consumption of 0 MJ/t dwf used by machinery in passive storage and drying of wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/t dwf (Refs. 1 and 4).

(gg) Diesel fuel consumption of 36 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 13), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(hh) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ii) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/t dwf (Refs. 1 and 4).

(jj) Dried wood chunk requirement of 0.0004 t/t dried wood chips.

(kk) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 6).

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Table E5 Spreadsheet for Greenhouse Gas Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option A)

Functional Unit:	Wood chips at point of consumption derived from small-scale broadleaf woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to fuel wood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs and fuel wood of 10:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	ha.a	1	-	-	-	2	-	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Agrochemicals	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(a)
- Tree shelters	ha.a	-	-	1	-	1	-	(a)
- Tree seedlings	ha.a	-	-	1	-	1	-	(a)
Reference System:								
- Diesel fuel	ha.a	-	-	-	-	-	-	(a)
Sub-Totals	ha.a	1	-	2	-	4	±1	
	t dwc	**-**	**-**	**1**	**-**	**1**	**-**	(b)
Harvest for fuel:								
- Diesel fuel	ha.a	2	±1	-	-	3	±1	(a)
- Motor spirit	ha.a	6	±2	1	-	7	±2	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(a)
Sub-Totals	ha.a	9	±2	1	-	10	±3	
	t dwc	**5**	**±1**	**1**	**-**	**5**	**±1**	(c)
Harvest for logs:								
- Diesel fuel	ha.a	-	-	-	-	1	-	(a)
- Motor spirit	ha.a	1	-	-	-	1	-	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(a)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(d)
Main harvest:								
- Diesel fuel	ha.a	3	±1	-	-	4	±1	(a)
- Motor spirit	ha.a	3	±1	1	-	4	±1	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(a)
Sub-Totals	ha.a	7	±1	1	-	7	±2	
	t dwc	**2**	**-**	**-**	**-**	**2**	**-**	(e)
Chipping (fuel wood):								
- Diesel fuel	t hwf	3	±1	-	-	3	±1	(a)
- Lubricating oil	t hwf	-	-	-	-	-	-	(a)
- Machinery/Spares	t hwf	-	-	1	-	1	-	(a)
Sub-Totals	t hwf	3	±2	1	-	4	±1	
	t dwc	**3**	**±1**	**1**	**-**	**5**	**±1**	(f)
Transport (fuel wood):								
- Diesel fuel	t rwc	5	±1	1	-	7	±1	(a)
	t dwc	**6**	**±1**	**2**	**-**	**7**	**±1**	(g)
Storage and Drying (fuel wood chips):								
- Diesel fuel	t rwc	-	-	-	-	-	-	(a)
- Lubricating oil	t rwc	-	-	-	-	-	-	(a)
- Machinery/Spares	t rwc	-	-	-	-	-	-	(a)
Sub-Totals	t rwc	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(g)
Chipping (chunks):								
- Diesel fuel	t dwch	2	±1	-	-	2	±1	(a)
- Lubricating oil	t dwch	-	-	-	-	-	-	(a)
- Machinery/Spares	t dwch	-	-	-	-	-	-	(a)
Sub-Totals	t dwch	2	±1	-	-	2	±1	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(h)
Transport (chips from chunks):								
- Diesel fuel	t dwch	6	±1	-	-	6	±1	(a)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(h)
Totals	**t dwc**	**17**	**±2**	**5**	**±1**	**21**	**±2**	

Biofuel specifications

Density of wood chips (loose) = 196 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg CO_2/kg N_2O.

(b) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 65.8% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 2.094 odt/ha.a harvested wood fuel and 0.109 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 2.094 / (10 x 0.109 + 2.94) = 65.8%.

(c) Land area required 0.541 ha.a/t of dried wood chips available at point of use.

(d) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 56.5% to harvested wood fuel. Production over 4 log harvests consists of 0.156 odt/ha.a harvested wood fuel and 0.012 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 0.156 / (10 x 0.012 + 0.156) = 56.5%.

(e) Land area requirement is 0.541 ha.a/t of dried wood chips available at point of use and allocation of 54.7% to harvested wood fuel. Production from main harvest consists of 1.104 odt/ha.a harvested wood fuel and 0.091 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 10:1 which gives an allocation to harvested wood fuel of 1.104 / (10 x 0.091 + 1.104) = 54.7%.

(f) Harvested wood fuel requirement of 1.133 t/t dried wood chips.

(g) Raw wood fuel requirement of 1.111 t/t dried wood chips.

(h) Dried wood chunk requirement of 0.0004 t/t dried wood chips.

APPENDIX F: Small-Scale Production of Wood Chips from Woodland Management (Option B)

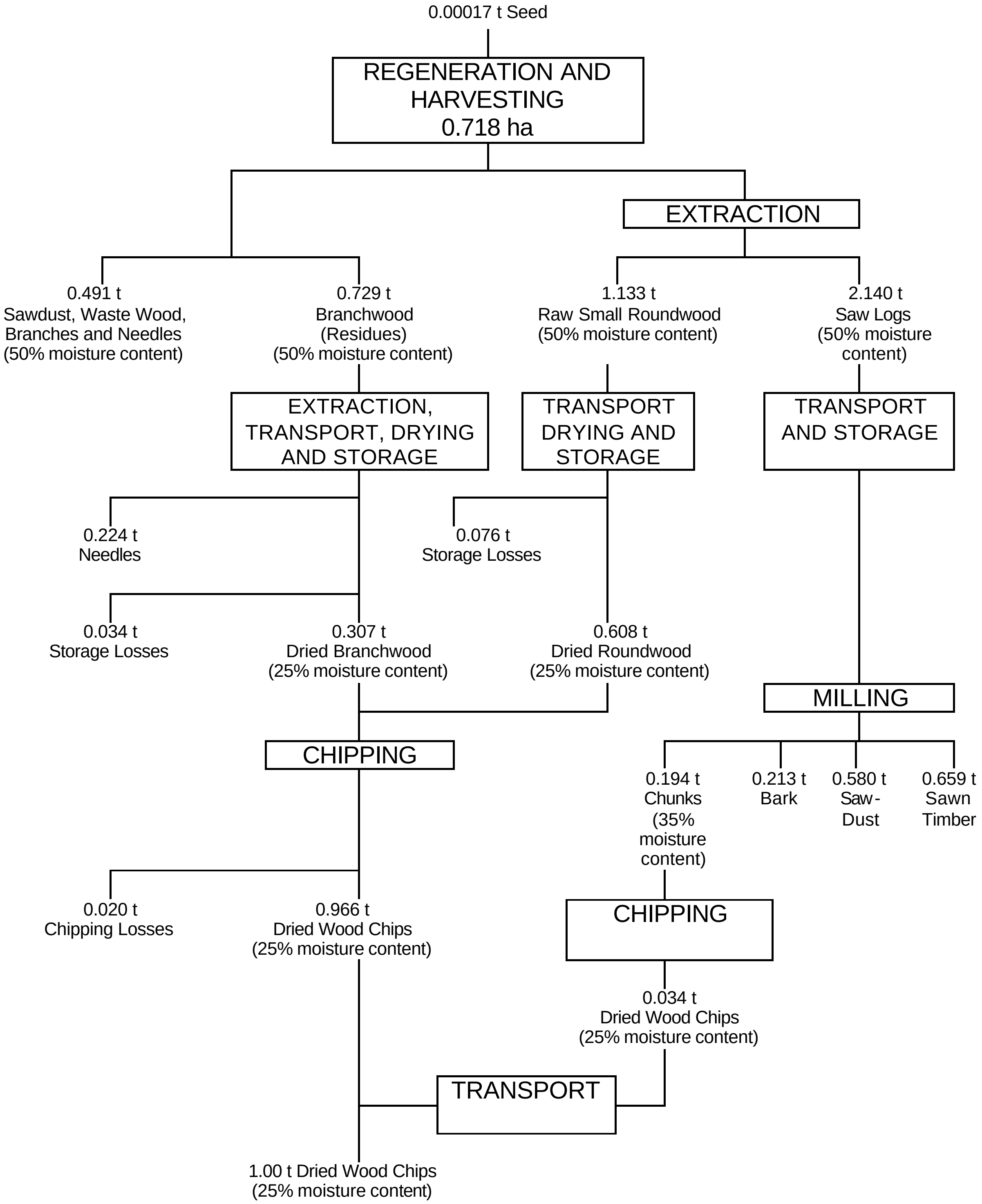

Table F1 **Spreadsheet for Primary Energy Inputs to Small-Scale Production of Wood Chips from Woodland Management** (Option B)

Functional Unit:	Wood chips at point of consumption derived from small-scale coniferous woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonnes for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Primary Energy Input (MJ)								Notes
		Direct		Indirect		Feedstock		Total		
		Value	Range	Value	Range	Value	Range	Value	Range	
Regeneration:										
- Diesel fuel	*ha.a*	*19*	*±7*	*2*	*±1*	-	-	*22*	*±7*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	*10*	*±3*	-	-	*10*	*±3*	(c)
- Machinery/Spares	*ha.a*	-	-	*2*	*±1*	-	-	*2*	*±1*	(d)
- Softwood	*ha.a*	-	-	*1*	-	-	-	*1*	-	(e)
- Steel	*ha.a*	-	-	*331*	*±99*	-	-	*331*	*±99*	(f)
- Preservative	*ha.a*	-	-	*55*	*±16*	-	-	*55*	*±16*	(g)
- Tree seedlings	*ha.a*	-	-	*24*	*±8*	-	-	*24*	*±8*	(h)
Reference System:										
- Diesel fuel	*ha.a*	-	-	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	*19*	*±7*	*425*	*±101*	-	-	*444*	*±101*	
	t dwc	**3**	**±1**	**75**	**±18**	**-**	**-**	**78**	**±18**	(j)
Harvest for fuel:										
- Diesel fuel	*ha.a*	*52*	*±18*	*6*	*±2*	-	-	*58*	*±18*	(k)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(l)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(m)
Sub-Totals	*ha.a*	*53*	*±18*	*6*	*±2*	-	-	*59*	*±18*	
	t dwc	**38**	**±13**	**4**	**±2**	**-**	**-**	**42**	**±13**	(n)
Harvest for logs 1:										
- Diesel fuel	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	
	t dwc	**4**	**±1**	**-**	**-**	**-**	**-**	**4**	**±1**	(r)
Harvest for logs 2:										
- Diesel fuel	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	
	t dwc	**3**	**±1**	**-**	**-**	**-**	**-**	**3**	**±1**	(s)
Harvest for logs 3:										
- Diesel fuel	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	
	t dwc	**2**	**±1**	**-**	**-**	**-**	**-**	**2**	**±1**	(t)
Harvest for logs 4:										
- Diesel fuel	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*12*	*±4*	*1*	-	-	-	*14*	*±4*	
	t dwc	**2**	**±1**	**-**	**-**	**-**	**-**	**2**	**±1**	(u)
Harvest for logs 5:										
- Diesel fuel	*ha.a*	*12*	*±4*	*1*	-	-	-	*13*	*±4*	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	*12*	*±4*	*1*	-	-	-	*13*	*±4*	
	t dwc	**1**	**-**	**-**	**-**	**-**	**-**	**2**	**-**	(v)
Harvest for logs 6:										
- Diesel fuel	*ha.a*	*10*	*±3*	*1*	-	-	-	*11*	*±3*	(w)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(x)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(y)
Sub-Totals	*ha.a*	*10*	*±3*	*1*	-	-	-	*11*	*±3*	
	t dwc	**1**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	(z)

Table F1 (continued) Spreadsheet for Primary Energy Inputs to Small-Scale Production of Wood Chips from Woodland Management (Option B)

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Main harvest:										
- Diesel fuel	*ha.a*	*120*	*±40*	*13*	*±5*	-	-	*133*	*±41*	(aa)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(bb)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(cc)
Sub-Totals	*ha.a*	*120*	*±40*	*14*	*±5*	-	-	*134*	*±41*	
	t dwc	**10**	**±3**	**1**	**-**	**-**	**-**	**11**	**±3**	(dd)
Main extraction (logs and roundwood):										
- Diesel fuel	*ha.a*	*34*	*±11*	*4*	*±1*	-	-	*37*	*±11*	(ee)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(ff)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(gg)
Sub-Totals	*ha.a*	*34*	*±11*	*4*	*±1*	-	-	*37*	*±11*	
	t dwc	**2**	**±1**	**-**	**-**	**-**	**-**	**2**	**±1**	(hh)
Main extraction (residues):										
- Diesel fuel	*ha.a*	*15*	*±5*	*2*	*±1*	-	-	*17*	*±5*	(ii)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	-	-	(jj)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	-	-	(kk)
Sub-Totals	*ha.a*	*16*	*±5*	*2*	*±1*	-	-	*17*	*±5*	
	t dwc	**11**	**±4**	**1**	**-**	**-**	**-**	**12**	**±4**	(n)
Transport (residues and roundwood):										
- Diesel fuel	*t hwfn*	*76*	*±16*	*27*	*±6*	-	-	*103*	*±21*	(ll)
	t dwc	**95**	**±19**	**33**	**±8**	**-**	**-**	**128**	**±26**	(mm)
Storage and Drying (residues and roundwood):										
- Storage and drying	*t hwfn*	-	-	-	-	-	-	-	-	(nn)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(mm)
Chipping (residues and roundwood):										
- Diesel fuel	*t dwf*	*41*	*±14*	*5*	*±2*	-	-	*46*	*±14*	(oo)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	-	-	(pp)
- Machinery/Spares	*t dwf*	-	-	*23*	*±7*	-	-	*23*	*±7*	(qq)
Sub-Totals	*t dwf*	*41*	*±14*	*27*	*±7*	-	-	*69*	*±16*	
	t dwc	**41**	**±14**	**27**	**±7**	**-**	**-**	**68**	**±15**	(rr)
Chipping (chunks):										
- Diesel fuel	*t dwch*	*35*	*±12*	*4*	*±1*	-	-	*39*	*±12*	(ss)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	-	-	(tt)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	-	-	(uu)
Sub-Totals	*t dwch*	*35*	*±12*	*4*	*±1*	-	-	*39*	*±12*	
	t dwc	**1**	**-**	**1**	**-**	**-**	**-**	**1**	**-**	(vv)
Transport (chips from chunks):										
- Diesel fuel	*t dwch*	*74*	*±15*	*26*	*±6*	-	-	*100*	*±20*	(ww)
	t dwc	**2**	**±1**	**1**	**-**	**-**	**-**	**3**	**±1**	(vv)
Totals	**t dwc**	**216**	**±27**	**144**	**±21**	**-**	**-**	**360**	**±38**	

Biofuel specifications

Density of wood chips (loose) = 168 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 19 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 2 MJ/ha.a (Ref. 1).

(e) Consumption of softwood in construction and maintenance of fences of 1.67 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total energy requirement for softwood of 0.504 MJ/kg (Ref. 4).

(f) Consumption of steel wire in construction and maintenance of fences of 2.40 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total energy requirement for steel wire of 137.2 MJ/kg (Ref. 4), and related consumption of mild steel of 0.044 kg/ha.a with a total energy requirement for mild steel of 31 MJ/kg (Ref. 5) and an assumed stand area of 5 ha.

(g) Consumption of wood preservative in construction and maintenance of fences of 0.55 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total energy requirement for wood preservative of 100 MJ/kg (Ref. 5).

(h) Consumption of tree seedlings in stand establishment and regeneration of 18.3 seedlings/ha.a, based on standard planting densities (Ref. 6) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total energy requirement of 1.319 MJ/seedling (Ref. 5).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 24.5% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 0.34 odt/ha.a woody residues (for wood fuel), 0.755 odt/ha.a roundwood (for wood fuel) and 1.427 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 which gives an allocation to harvested wood fuel of (0.34 + 2 x 0.755) / (0.34 + 2 x 0.755 + 4 x 1.427) = 24.5%.

(k) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for felling and extraction of whole trees as harvested wood fuel (from fuel harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested wood fuel (with attached needles) extracted (Ref. 11) with 0.761 odt/ha.a harvested wood fuel being produced from fuel harvest operations of which 0.517 odt/ha.a is stem wood, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Refs. 1 and 5).

(n) Land area required 0.718 ha.a/t of dried wood chips available at point of use.

(o) Diesel fuel consumption of 12 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 11) with 0.137 (+2/-4) odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Refs. 1 and 5).

(r) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 41.5% to harvested roundwood (for wood fuel). Production at first log harvest consists of 0.0799 odt/ha.a harvested roundwood and 0.0563 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0799 / (2 x 0.0563 + 0.0799) = 41.5%.

(s) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 31.7% to harvested roundwood (for wood fuel). Production at second log harvest consists of 0.0661 odt/ha.a harvested roundwood and 0.0712 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0661 / (2 x 0.0712 + 0.0661) = 31.7%.

(t) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 21.6% to harvested roundwood (for wood fuel). Production at third log harvest consists of 0.0492 odt/ha.a harvested roundwood and 0.0891 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0492 / (2 x 0.0891 + 0.0492) = 21.6%.

(u) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 17.6% to harvested roundwood (for wood fuel). Production at fourth log harvest consists of 0.0415 odt/ha.a harvested roundwood and 0.0973 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0415 / (2 x 0.0973 + 0.0415) = 17.6%.

(v) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 13.2% to harvested roundwood (for wood fuel). Production at fifth log harvest consists of 0.0312 odt/ha.a harvested roundwood and 0.1024 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0312 / (2 x 0.1024 + 0.0312) = 13.2%.

(w) Diesel fuel consumption of 10 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 11) with 0.114 odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(x) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(y) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a Ref. 1 and 5).

(z) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 11.2% to harvested roundwood (for wood fuel). Production at sixth log harvest consists of 0.0230 odt/ha.a harvested roundwood and 0.0918 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0230 / (2 x 0.0918 + 0.0230) = 11.2%.

(aa) Diesel fuel consumption of 120 MJ/ha.a used by forestry machinery for felling and conversion of trees to sawlogs, roundwood (for wood fuel) and residues (also for wood fuel), assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted (Ref. 11) with 1.723 odt/ha.a harvested stem wood fuel being produced from the main harvest operation, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(bb) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(cc) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Ref. 1 and 5).

(dd) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 12.0% to harvested roundwood (for wood fuel) and residues (for wood fuel). Production at main harvest consists of 0.3694 odt/ha.a retrieved residues (not including mass of attached needles), 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 this gives an allocation to harvested wood fuel of (2 x 0.2438 + 0.3694) / (4 x 1.4792 + 2 x 0.2438 + 0.3694) = 12.0%.

(ee) Diesel fuel consumption of 34 MJ/ha.a used by forestry machinery for extraction of sawlogs and roundwood (for wood fuel) to roadside, assuming 0.5 litre diesel fuel consumption per tonne of wood extracted (Ref. 11) with 1.723 odt/ha.a of sawlogs and roundwood fuel being produced from the main harvest operation, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(gg) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Refs. 1 and 5).

(hh) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 7.6% to harvested roundwood (for wood fuel). Production at main harvest consists of 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.2438 / (2 x 1.4792 + 0.2438) = 7.6%.

(ii) Diesel fuel consumption of 15 MJ/ha.a used by forestry machinery for extraction of residues (for wood fuel) to roadside, assuming 0.8 litre diesel fuel consumption per tonne of wood extracted (Ref. 11) with 0.4956 odt/ha.a of residues fuel being produced from the main harvest operation, and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(jj) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed per litre diesel fuel/motor spirit consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(kk) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Ref. 1 and 5).

(ll) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 4).

(mm) Harvested wood fuel (with needles) requirement of 1.241 t/t dried wood chips.

(nn) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(oo) Diesel fuel consumption of 41 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for chipping operations with high efficiency (Ref. 11), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(pp) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(qq) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 23 MJ/ha.a (Refs. 1 and 5).

(rr) Dried wood fuel requirement of 0.966 t/t dried wood chips.

(ss) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 11), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(tt) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood chunks to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 5), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(uu) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 MJ/ha.a (Refs. 1 and 5).

(vv) Dried wood chunk requirement of 0.034 t/t dried wood chips.

(ww) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 4).

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Table F2 Spreadsheet for Carbon Dioxide Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option B)

Functional Unit:	Wood chips at point of consumption derived from small-scale coniferous woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(b)
- Agrochemicals	ha.a	-	-	-	-	-	-	(c)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(d)
- Softwood	ha.a	-	-	-	-	-	-	(e)
- Steel	ha.a	-	-	15	±5	15	±5	(f)
- Preservative	ha.a	-	-	1	-	1	-	(g)
- Tree seedlings	ha.a	-	-	1	-	1	-	(h)
Reference System:								
- Diesel fuel	ha.a	-	-	-	-	-	-	(i)
Sub-Totals	ha.a	1	-	18	±5	19	±5	
	t dwc	**-**	**-**	**3**	**±1**	**3**	**±1**	(j)
Harvest for fuel:								
- Diesel fuel	ha.a	4	±1	-	-	4	±1	(k)
- Lubricating oil	ha.a	-	-	-	-	-	-	(l)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(m)
Sub-Totals	ha.a	4	±1	-	-	4	±1	
	t dwc	**3**	**±1**	**-**	**-**	**3**	**±1**	(n)
Harvest for logs 1:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(o)
- Lubricating oil	ha.a	-	-	-	-	-	-	(p)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(q)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Harvest for logs 2:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(o)
- Lubricating oil	ha.a	-	-	-	-	-	-	(p)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(q)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Harvest for logs 3:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(o)
- Lubricating oil	ha.a	-	-	-	-	-	-	(p)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(q)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(t)
Harvest for logs 4:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(o)
- Lubricating oil	ha.a	-	-	-	-	-	-	(p)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(q)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Harvest for logs 5:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(o)
- Lubricating oil	ha.a	-	-	-	-	-	-	(p)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(q)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Harvest for logs 6:								
- Diesel fuel	ha.a	1	-	-	-	1	-	(w)
- Lubricating oil	ha.a	-	-	-	-	-	-	(x)
- Machinery/Spares	ha.a	-	-	-	-	-	-	(y)
Sub-Totals	ha.a	1	-	-	-	1	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(z)

Table F2 (continued) Spreadsheet for Carbon Dioxide Outputs from Small-Scale Production Wood Chips from Woodland Management (Option B)

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Main harvest:								
- Diesel fuel	*ha.a*	*8*	*±3*	*1*	-	*9*	*±3*	(aa)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(bb)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(cc)
Sub-Totals	*ha.a*	*8*	*±3*	*1*	-	*9*	*±3*	
	t dwc	**1**	**-**	**-**	**-**	**1**	**-**	(dd)
Main extraction (logs and roundwood):								
- Diesel fuel	*ha.a*	*2*	*±1*	-	-	*3*	*±1*	(ee)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(ff)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(gg)
Sub-Totals	*ha.a*	*2*	*±1*	-	-	*3*	*±1*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(hh)
Main extraction (residues):								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(ii)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(jj)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(kk)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**1**	**-**	**-**	**-**	**1**	**-**	(n)
Transport (residues and roundwood):								
- Diesel fuel	*t hwfn*	*5*	*±1*	*2*	-	*7*	*±1*	(ll)
	t dwc	**7**	**±1**	**2**	**-**	**8**	**±2**	(mm)
Storage and Drying (residues and roundwood):								
- Storage and drying	*t hwfn*	-	-	-	-	-	-	(nn)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(mm)
Chipping (residues and roundwood):								
- Diesel fuel	*t dwf*	*3*	*±1*	-	-	*3*	*±1*	(oo)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(pp)
- Machinery/Spares	*t dwf*	-	-	*1*	-	*1*	-	(qq)
Sub-Totals	*t dwf*	*3*	*±1*	*1*	-	*4*	*±1*	
	t dwc	**3**	**±1**	**1**	**-**	**4**	**±1**	(rr)
Chipping (chunks):								
- Diesel fuel	*t dwch*	*2*	*±1*	-	-	*3*	*±1*	(ss)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(tt)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(uu)
Sub-Totals	*t dwch*	*2*	*±1*	-	-	*3*	*±1*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(vv)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	*5*	*±1*	*1*	-	*7*	*±1*	(ww)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(vv)
Totals	**t dwc**	**15**	**±2**	**7**	**±1**	**22**	**±2**	

Biofuel specifications

Density of wood chips (loose) = 168 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 19 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (refs. 1, 2 and 4).

(e) Consumption of softwood in construction and maintenance of fences of 1.67 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total carbon requirement 0.041 kg CO_2/kg (Ref. 5).

(f) Consumption of steel wire in construction and maintenance of fences of 2.40 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total carbon requirement for steel wire of 6.31 kg CO_2/kg (Ref. 5), and related consumption of mild steel of 0.050 kg/ha.a (Ref. 1) with an assumed stand area of 10 ha, and a total carbon requirement for mild steel of 1.24 kg CO_2/kg (Ref. 4).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.55 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total carbon requirement for wood preservative of 1.41 kg CO_2/kg (Ref. 4).

(h) Consumption of tree seedlings in stand establishment and regeneration of 18.3 seedlings/ha.a, based on standard planting densities (Ref. 6) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total carbon requirement of 0.0567 kg CO_2/seedling (Ref. 4).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 24.5% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 0.34 odt/ha.a woody residues (for wood fuel), 0.755 odt/ha.a roundwood (for wood fuel) and 1.427 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 which gives an allocation to harvested wood fuel of (0.34 + 2 x 0.755) / (0.34 + 2 x 0.755 + 4 x 1.427) = 24.5%.

(k) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for felling and extraction of whole trees as harvested wood fuel (from fuel harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested wood fuel (with attached needles) extracted (Ref. 11) with 0.761 odt/ha.a harvested wood fuel being produced from fuel harvest operations of which 0.517 odt/ha.a is stem wood, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(n) Land area required 0.718 ha.a/t of dried wood chips available at point of use.

(o) Diesel fuel consumption of 12 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 11) with 0.137 (+2/-4) odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(r) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 41.5% to harvested roundwood (for wood fuel). Production at first log harvest consists of 0.0799 odt/ha.a harvested roundwood and 0.0563 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0799 / (2 x 0.0563 + 0.0799) = 41.5%.

(s) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 31.7% to harvested roundwood (for wood fuel). Production at second log harvest consists of 0.0661 odt/ha.a harvested roundwood and 0.0712 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0661 / (2 x 0.0712 + 0.0661) = 31.7%.

(t) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 21.6% to harvested roundwood (for wood fuel). Production at third log harvest consists of 0.0492 odt/ha.a harvested roundwood and 0.0891 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0492 / (2 x 0.0891 + 0.0492) = 21.6%.

(u) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 17.6% to harvested roundwood (for wood fuel). Production at fourth log harvest consists of 0.0415 odt/ha.a harvested roundwood and 0.0973 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0415 / (2 x 0.0973 + 0.0415) = 17.6%.

(v) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 13.2% to harvested roundwood (for wood fuel). Production at fifth log harvest consists of 0.0312 odt/ha.a harvested roundwood and 0.1024 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0312 / (2 x 0.1024 + 0.0312) = 13.2%.

(w) Diesel fuel consumption of 10 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 11) with 0.114 odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(x) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(y) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(z) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 11.2% to harvested roundwood (for wood fuel). Production at sixth log harvest consists of 0.0230 odt/ha.a harvested roundwood and 0.0918 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0230 / (2 x 0.0918 + 0.0230) = 11.2%.

(aa) Diesel fuel consumption of 120 MJ/ha.a used by forestry machinery for felling and conversion of trees to sawlogs, roundwood (for wood fuel) and residues (also for wood fuel), assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted (Ref. 11) with 1.723 odt/ha.a harvested stem wood fuel being produced from the main harvest operation, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(bb) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(cc) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Ref. 1 and 4).

(dd) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 12.0% to harvested roundwood (for wood fuel) and residues (for wood fuel). Production at main harvest consists of 0.3694 odt/ha.a retrieved residues (not including mass of attached needles), 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 this gives an allocation to harvested wood fuel of (2 x 0.2438 + 0.3694) / (4 x 1.4792 + 2 x 0.2438 + 0.3694) = 12.0%.

(ee) Diesel fuel consumption of 34 MJ/ha.a used by forestry machinery for extraction of sawlogs and roundwood (for wood fuel) to roadside, assuming 0.5 litre diesel fuel consumption per tonne of wood extracted (Ref. 11) with 1.723 odt/ha.a of sawlogs and roundwood fuel being produced from the main harvest operation, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(gg) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(hh) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 7.6% to harvested roundwood (for wood fuel). Production at main harvest consists of 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 7 to 10), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.2438 / (2 x 1.4792 + 0.2438) = 7.6%.

(ii) Diesel fuel consumption of 15 MJ/ha.a used by forestry machinery for extraction of residues (for wood fuel) to roadside, assuming 0.8 litre diesel fuel consumption per tonne of wood extracted (Ref. 11) with 0.4956 odt/ha.a of residues fuel being produced from the main harvest operation, and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(jj) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(kk) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(ll) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 5).

(mm) Harvested wood fuel (with needles) requirement of 1.241 t/t dried wood chips.

(nn) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(oo) Diesel fuel consumption of 41 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for chipping operations with high efficiency (Ref. 11), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(pp) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(qq) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 1 kg CO_2/ha.a (Refs. 1 and 4).

(rr) Dried wood fuel requirement of 0.966 t/t dried wood chips.

(ss) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 11) and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(tt) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood chunks to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(uu) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/ha.a (Refs. 1 and 4).

(vv) Dried wood chunk requirement of 0.034 t/t dried wood chips.

(ww) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 5).

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Table F3 Spreadsheet for Methane Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option B)

Functional Unit:	Wood chips at point of consumption derived from small-scale coniferous woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Softwood	*ha.a*	-	-	-	-	-	-	(e)
- Steel	*ha.a*	-	-	-	-	-	-	(f)
- Preservative	*ha.a*	-	-	-	-	-	-	(g)
- Tree seedlings	*ha.a*	-	-	-	-	-	-	(h)
Reference System:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(j)
Harvest for fuel:								
- Diesel fuel	*ha.a*	-	-	*0.001*	-	*0.001*	-	(k)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(l)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(m)
Sub-Totals	*ha.a*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(n)
Harvest for logs 1:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Harvest for logs 2:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Harvest for logs 3:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(t)
Harvest for logs 4:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Harvest for logs 5:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Harvest for logs 6:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(w)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(x)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(y)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(z)

Table F3 (continued) Spreadsheet for Methane Outputs from Wood Chip Production from Small-Scale Coniferous Woodland Management (Option B)

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Main harvest:								
- Diesel fuel	*ha.a*	-	-	*0.002*	*±0.001*	*0.003*	*±0.001*	(aa)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(bb)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(cc)
Sub-Totals	*ha.a*	-	-	*0.002*	*±0.001*	*0.003*	*±0.001*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(dd)
Main extraction (logs and roundwood):								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(ee)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(ff)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(gg)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(hh)
Main extraction (residues):								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(ii)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(jj)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(kk)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Transport (residues and roundwood):								
- Diesel fuel	*t hwfn*	-	-	*0.002*	-	*0.002*	-	(ll)
	t dwc	**-**	**-**	**0.002**	**-**	**0.002**	**-**	(mm)
Storage and Drying (residues and roundwood):								
- Storage and drying	*t hwfn*	-	-	-	-	-	-	(nn)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(mm)
Chipping (residues and roundwood):								
- Diesel fuel	*t dwf*	-	-	*0.001*	-	*0.001*	-	(oo)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(pp)
- Machinery/Spares	*t dwf*	-	-	-	-	-	-	(qq)
Sub-Totals	*t dwf*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(rr)
Chipping (chunks):								
- Diesel fuel	*t dwch*	-	-	*0.001*	-	*0.001*	-	(ss)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(tt)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(uu)
Sub-Totals	*t dwch*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(vv)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	-	-	*0.002*	-	*0.002*	-	(ww)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(vv)
Totals	**t dwc**	**-**	**-**	**0.004**	**±0.001**	**0.005**	**±0.001**	

Biofuel specifications

Density of wood chips (loose) = 168 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 19 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x

10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(e) Consumption of softwood in construction and maintenance of fences of 1.67 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, a total energy requirement for softwood of 0.504 MJ/kg (Ref. 5) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 6).

(f) Consumption of steel wire in construction and maintenance of fences of 2.40 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, a total energy requirement for steel wire of 137.2 MJ/kg (Ref. 5), and related consumption of mild steel of 0.044 kg/ha.a with a total energy requirement for mild steel of 31 MJ/kg (Ref. 4) and an assumed stand area of 5 ha, and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 6).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.55 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, a total energy requirement for wood preservative of 100 MJ/kg (Ref. 4), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 6).

(h) Consumption of tree seedlings in stand establishment and regeneration of 18.3 seedlings/ha.a, based on standard planting densities (Ref.7) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total methane requirement of 4.6 x 10^{-6} kg CH_4/seedling (Ref. 4).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 24.5% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 0.34 odt/ha.a woody residues (for wood fuel), 0.755 odt/ha.a roundwood (for wood fuel) and 1.427 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 which gives an allocation to harvested wood fuel of (0.34 + 2 x 0.755) / (0.34 + 2 x 0.755 + 4 x 1.427) = 24.5%.

(k) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for felling and extraction of whole trees as harvested wood fuel (from fuel harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested wood fuel (with attached needles) extracted (Ref. 12) with 0.761 odt/ha.a harvested wood fuel being produced from fuel harvest operations of which 0.517 odt/ha.a is stem wood, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a Refs. 1, 2 and 4).

(n) Land area required 0.718 ha.a/t of dried wood chips available at point of use.

(o) Diesel fuel consumption of 12 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 12) with 0.137 (+2/-4) odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(r) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 41.5% to harvested roundwood (for wood fuel). Production at first log harvest consists of 0.0799 odt/ha.a harvested roundwood and 0.0563 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0799 / (2 x 0.0563 + 0.0799) = 41.5%.

(s) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 31.7% to harvested roundwood (for wood fuel). Production at second log harvest consists of 0.0661 odt/ha.a harvested roundwood and 0.0712 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0661 / (2 x 0.0712 + 0.0661) = 31.7%.

(t) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 21.6% to harvested roundwood (for wood fuel). Production at third log harvest consists of 0.0492 odt/ha.a harvested roundwood and 0.0891 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0492 / (2 x 0.0891 + 0.0492) = 21.6%.

(u) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 17.6% to harvested roundwood (for wood fuel). Production at fourth log harvest consists of 0.0415 odt/ha.a harvested roundwood and 0.0973 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0415 / (2 x 0.0973 + 0.0415) = 17.6%.

(v) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 13.2% to harvested roundwood (for wood fuel). Production at fifth log harvest consists of 0.0312 odt/ha.a harvested roundwood and 0.1024 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0312 / (2 x 0.1024 + 0.0312) = 13.2%.

(w) Diesel fuel consumption of 10 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 12) with 0.114 odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(x) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(y) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a Refs. 1, 2 and 4).

(z) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 11.2% to harvested roundwood (for wood fuel). Production at sixth log harvest consists of 0.0230 odt/ha.a harvested roundwood and 0.0918 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0230 / (2 x 0.0918 + 0.0230) = 11.2%.

(aa) Diesel fuel consumption of 120 MJ/ha.a used by forestry machinery for felling and conversion of trees to sawlogs, roundwood (for wood fuel) and residues (also for wood fuel), assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted (Ref. 12) with 1.723 odt/ha.a harvested stem wood fuel being produced from the main harvest operation, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(bb) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(cc) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(dd) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 12.0% to harvested roundwood (for wood fuel) and residues (for wood fuel). Production at main harvest consists of 0.3694 odt/ha.a retrieved residues (not including mass of attached needles), 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 this gives an allocation to harvested wood fuel of (2 x 0.2438 + 0.3694) / (4 x 1.4792 + 2 x 0.2438 + 0.3694) = 12.0%.

(ee) Diesel fuel consumption of 34 MJ/ha.a used by forestry machinery for extraction of sawlogs and roundwood (for wood fuel) to roadside, assuming 0.5 litre diesel fuel consumption per tonne of wood extracted (Ref. 12) with 1.723 odt/ha.a of sawlogs and roundwood fuel being produced from the main harvest operation, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2)..

(ff) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(gg) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(hh) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 7.6% to harvested roundwood (for wood fuel). Production at main harvest consists of 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.2438 / (2 x 1.4792 + 0.2438) = 7.6%.

(ii) Diesel fuel consumption of 15 MJ/ha.a used by forestry machinery for extraction of residues (for wood fuel) to roadside, assuming 0.8 litre diesel fuel consumption per tonne of wood extracted (Ref. 12) with 0.4956 odt/ha.a of residues fuel being produced from the main harvest operation, and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(jj) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(kk) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(ll) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 5).

(mm) Harvested wood fuel (with needles) requirement of 1.241 t/t dried wood chips.

(nn) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(oo) Diesel fuel consumption of 41 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for chipping operations with high efficiency (Ref. 12), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(pp) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(qq) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(rr) Dried wood fuel requirement of 0.966 t/t dried wood chips.

(ss) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 12), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(tt) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood chunks to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(uu) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1, 2 and 4).

(vv) Dried wood chunk requirement of 0.034 t/t dried wood chips.

(ww) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 5).

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Table F4 Spreadsheet for Nitrous Oxide Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option B)

Functional Unit:	Wood chips at point of consumption derived from small-scale coniferous woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonne for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(b)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(c)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(d)
- Softwood	*ha.a*	-	-	-	-	-	-	(e)
- Steel	*ha.a*	-	-	-	-	-	-	(f)
- Preservative	*ha.a*	-	-	-	-	-	-	(g)
- Tree seedlings	*ha.a*	-	-	-	-	-	-	(h)
Reference System:		-	-	-	-	-	-	
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(i)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(j)
Harvest for fuel:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(k)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(l)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(m)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Harvest for logs 1:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Harvest for logs 2:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Harvest for logs 3:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(t)
Harvest for logs 4:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Harvest for logs 5:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(o)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(p)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(q)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Harvest for logs 6:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(w)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(x)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(y)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(z)

Table F4 (continued) Spreadsheet for Nitrous Oxide Outputs from Small-Scale Production Wood Chips from Woodland Management (Option B)

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Main harvest:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(aa)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(bb)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(cc)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(dd)
Main extraction (logs and roundwood):								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(ee)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(ff)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(gg)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(hh)
Main extraction (residues):								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(ii)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(jj)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(kk)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Transport (residues and roundwood):								
- Diesel fuel	*t hwfn*	-	-	-	-	-	-	(ll)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(mm)
Storage and Drying (residues and roundwood):								
- Storage and drying	*t hwfn*	-	-	-	-	-	-	(nn)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(mm)
Chipping (residues and roundwood):								
- Diesel fuel	*t dwf*	-	-	-	-	-	-	(oo)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(pp)
- Machinery/Spares	*t dwf*	-	-	-	-	-	-	(qq)
Sub-Totals	*t dwf*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(rr)
Chipping (chunks):								
- Diesel fuel	*t dwch*	-	-	-	-	-	-	(ss)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(tt)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(uu)
Sub-Totals	*t dwch*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(vv)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	-	-	-	-	-	-	(ww)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(vv)
Totals	**t dwc**	**-**	**-**	**-**	**-**	**-**	**-**	

Biofuel specifications

Density of wood chips (loose) = 168 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 19 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(b) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for mounding and spreading herbicides (Ref. 1), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (based on Ref. 2).

(c) Application rate for a mixture of herbicides of 0.037 kg/ha.a (Ref. 1), and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.5 x 10^{-3} kg N_2O/kg (Ref. 3).

(d) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(e) Consumption of softwood in construction and maintenance of fences of 1.67 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total energy requirement for softwood of 0.504 MJ/kg (Ref. 5), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 6).

(f) Consumption of steel wire in construction and maintenance of fences of 2.40 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total energy requirement for steel wire of 137.2 MJ/kg (Ref. 5), and related consumption of mild steel of 0.044 kg/ha.a with a total energy requirement for mild steel of 31 MJ/kg (Ref. 4), and an assumed stand area of 5 ha, and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 6).

(g) Consumption of wood preservative in construction and maintenance of fences of 0.55 kg/ha.a (Ref. 1) with an assumed stand area of 5 ha, and a total energy requirement for wood preservative of 100 MJ/kg (Ref. 4), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 6).

(h) Consumption of tree seedlings in stand establishment and regeneration of 18.3 seedlings/ha.a, based on standard planting densities (Ref. 7) and assuming that half of trees originate from natural regeneration with remainder originating from enrichment planting, and a total nitrous oxide requirement of 9.4 x 10^{-6} kg N_2O/seedling (Ref. 4).

(i) Reference system consisting of allowing land to revert to wilderness with no energy inputs.

(j) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 24.5% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 0.34 odt/ha.a woody residues (for wood fuel), 0.755 odt/ha.a roundwood (for wood fuel) and 1.427 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 which gives an allocation to harvested wood fuel of (0.34 + 2 x 0.755) / (0.34 + 2 x 0.755 + 4 x 1.427) = 24.5%.

(k) Diesel fuel consumption of 33 MJ/ha.a used by forestry machinery for felling and extraction of whole trees as harvested wood fuel (from fuel harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested wood fuel (with attached needles) extracted (Ref. 12) with 0.761 odt/ha.a harvested wood fuel being produced from fuel harvest operations of which 0.517 odt/ha.a is stem wood, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(l) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(m) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(n) Land area required 0.718 ha.a/t of dried wood chips available at point of use.

(o) Diesel fuel consumption of 12 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 12) with 0.137 (+2/-4) odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(p) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(q) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(r) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 41.5% to harvested roundwood (for wood fuel). Production at first log harvest consists of 0.0799 odt/ha.a harvested roundwood and 0.0563 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0799 / (2 x 0.0563 + 0.0799) = 41.5%.

(s) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 31.7% to harvested roundwood (for wood fuel). Production at second log harvest consists of 0.0661 odt/ha.a harvested roundwood and 0.0712 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0661 / (2 x 0.0712 + 0.0661) = 31.7%.

(t) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 21.6% to harvested roundwood (for wood fuel). Production at third log harvest consists of 0.0492 odt/ha.a harvested roundwood and 0.0891 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0492 / (2 x 0.0891 + 0.0492) = 21.6%.

(u) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 17.6% to harvested roundwood (for wood fuel). Production at fourth log harvest consists of 0.0415 odt/ha.a harvested roundwood and 0.0973 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0415 / (2 x 0.0973 + 0.0415) = 17.6%.

(v) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 13.2% to harvested roundwood (for wood fuel). Production at fifth log harvest consists of 0.0312 odt/ha.a harvested roundwood and 0.1024 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0312 / (2 x 0.1024 + 0.0312) = 13.2%.

(w) Diesel fuel consumption of 10 MJ/ha.a used by forestry machinery for felling, conversion and extraction of roundwood (for harvested wood fuel) and sawlogs (for harvested wood fuel) (from log harvest operations) to roadside, assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted and 0.5 litre diesel fuel consumption per tonne of harvested stem wood extracted (Ref. 12) with 0.114 odt/ha.a harvested stem wood fuel being produced from a log harvest operation, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(x) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products and a direct nitrous oxide requirement 4.01 x 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 x 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (based on Ref. 2). Based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4).

(y) location of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(z) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 11.2% to harvested roundwood (for wood fuel). Production at sixth log harvest consists of 0.0230 odt/ha.a harvested roundwood and 0.0918 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0230 / (2 x 0.0918 + 0.0230) = 11.2%.

(aa) Diesel fuel consumption of 120 MJ/ha.a used by forestry machinery for felling and conversion of trees to sawlogs, roundwood (for wood fuel) and residues (also for wood fuel), assuming 1.786 litre diesel fuel consumption per tonne of stem wood of trees felled and converted (Ref. 12) with 1.723 odt/ha.a harvested stem wood fuel being produced from the main harvest operation, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(bb) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(cc) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(dd) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 12.0% to harvested roundwood (for wood fuel) and residues (for wood fuel). Production at main harvest consists of 0.3694 odt/ha.a retrieved residues (not including mass of attached needles), 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs, roundwood and residues of 4:2:1 this gives an allocation to harvested wood fuel of (2 x 0.2438 + 0.3694) / (4 x 1.4792 + 2 x 0.2438 + 0.3694) = 12.0%.

(ee) Diesel fuel consumption of 34 MJ/ha.a used by forestry machinery for extraction of sawlogs and roundwood (for wood fuel) to roadside, assuming 0.5 litre diesel fuel consumption per tonne of wood extracted (Ref. 12) with 1.723 odt/ha.a of sawlogs and roundwood fuel being produced from the main harvest operation, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(ff) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(gg) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(hh) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 7.6% to harvested roundwood (for wood fuel). Production at main harvest consists of 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark (Refs. 8 to 11), assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.2438 / (2 x 1.4792 + 0.2438) = 7.6%.

(ii) Diesel fuel consumption of 15 MJ/ha.a used by forestry machinery for extraction of residues (for wood fuel) to roadside, assuming 0.8 litre diesel fuel consumption per tonne of wood extracted (Ref. 12) with 0.4956 odt/ha.a of residues fuel being produced from the main harvest operation, and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(jj) Lubricating oil consumption of 0 MJ/ha.a used by forestry machinery for combined tree felling and conversion to products, based on 0.002 litres lubricating oil consumed by tree processor per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(kk) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(ll) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 5).

(mm) Harvested wood fuel (with needles) requirement of 1.241 t/t dried wood chips.

(nn) Assumed minimal facilities for storage and passive drying of wood chips with negligible energy inputs.

(oo) Diesel fuel consumption of 41 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for chipping operations with high efficiency (Ref. 12), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(pp) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood fuel to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 x 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 x 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(qq) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1, 2 and 4).

(rr) Dried wood fuel requirement of 0.966 t/t dried wood chips.

(ss) Diesel fuel consumption of 35 MJ/t dwch used by machinery in conversion of dried wood chunks to dried wood chips, based on assumed diesel fuel consumption of 0.9 l/t for efficient chipping operations (Ref. 12), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(tt) Lubricating oil consumption of 0 MJ/t dwf used by machinery in conversion of dried wood chunks to dried wood chips, based on 0.002 litres lubricating oil consumed by forestry machinery per litre diesel fuel consumed (Ref. 4), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 2).

(uu) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Ref. 1, 2 and 4).

(vv) Dried wood chunk requirement of 0.034 t/t dried wood chips.

(ww) Assumed average round trip distance of 90 ± 18 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 5).

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Table F5 Spreadsheet for Greenhouse Gas Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option B)

Functional Unit:	Wood chips at point of consumption derived from small-scale coniferous woodland management
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	Energy inputs during regeneration and harvesting allocated to residues, roundwood and sawlogs by value, assuming a price ratio per oven dry tonnes for sawlogs, roundwood and residues of 4:2:1. All energy inputs to transport and milling of sawlogs allocated to sawn timber, with chunks regarded effectively as waste product and production of chips from chunks regarded as a means of waste disposal. Energy inputs to chipping of chunks fully attributed to the chips derived.

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Regeneration:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*2*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
- Softwood	*ha.a*	-	-	-	-	-	-	(a)
- Steel	*ha.a*	-	-	*15*	*±5*	*15*	*±5*	(a)
- Preservative	*ha.a*	-	-	*1*	*±3*	*1*	*±3*	(a)
- Tree seedlings	*ha.a*	-	-	*1*	-	*1*	-	(a)
Reference System:		-	-	-	-	-	-	(a)
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	*18*	*±6*	*19*	*±6*	
	t dwc	**-**	**-**	**3**	**±1**	**3**	**±1**	(b)
Harvest for fuel:								
- Diesel fuel	*ha.a*	*4*	*±1*	-	-	*4*	*±1*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*4*	*±1*	-	-	*4*	*±1*	
	t dwc	**3**	**±1**	**-**	**-**	**3**	**±1**	(c)
Harvest for logs 1:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(d)
Harvest for logs 2:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(e)
Harvest for logs 3:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Harvest for logs 4:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(g)
Harvest for logs 5:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(h)
Harvest for logs 6:								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(i)

Table F5 (continued) Spreadsheet for Greenhouse Gas Outputs from Small-Scale Production of Wood Chips from Woodland Management (Option B)

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Main harvest:								
- Diesel fuel	*ha.a*	*8*	*±3*	*1*	-	*9*	*±3*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*8*	*±3*	*1*	-	*9*	*±3*	
	t dwc	**1**	**-**	**-**	**-**	**1**	**-**	(j)
Main extraction (logs and roundwood):								
- Diesel fuel	*ha.a*	*2*	*±1*	-	-	*3*	*±1*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*2*	*±1*	-	-	*3*	*±1*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Main extraction (residues):								
- Diesel fuel	*ha.a*	*1*	-	-	-	*1*	-	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(a)
Sub-Totals	*ha.a*	*1*	-	-	-	*1*	-	
	t dwc	**1**	**-**	**-**	**-**	**1**	**-**	(c)
Transport (residues and roundwood):								
- Diesel fuel	*t hwfn*	*5*	*±1*	*2*	-	*7*	*±1*	(a)
	t dwc	**7**	**±1**	**2**	**-**	**8**	**±2**	(l)
Storage and Drying (residues and roundwood):								
- Storage and drying	*t hwfn*	-	-	-	-	-	-	(a)
Sub-Totals	*t hwfn*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(l)
Chipping (residues and roundwood):								
- Diesel fuel	*t dwf*	*3*	*±1*	-	-	*3*	*±1*	(a)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(a)
- Machinery/Spares	*t dwf*	-	-	*1*	-	*1*	-	(a)
Sub-Totals	*t dwf*	*3*	*±1*	*1*	-	*4*	*±1*	
	t dwc	**3**	**±1**	**1**	**-**	**4**	**±1**	(m)
Chipping (chunks):								
- Diesel fuel	*t dwch*	*2*	*±1*	-	-	*3*	*±1*	(a)
- Lubricating oil	*t dwch*	-	-	-	-	-	-	(a)
- Machinery/Spares	*t dwch*	-	-	-	-	-	-	(a)
Sub-Totals	*t dwch*	*2*	*±1*	-	-	*3*	*±1*	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Transport (chips from chunks):								
- Diesel fuel	*t dwch*	*5*	*±1*	*1*	-	*7*	*±1*	(a)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Totals	**t dwc**	**15**	**±2**	**7**	**±1**	**22**	**±2**	

Biofuel specifications

Density of wood chips (loose) = 168 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwfn = tonne of harvested wood fuel with needles attached (50% moisture content, wet basis)
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwch = tonne of dried wood chunks (25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg CO_2/kg N_2O.

(b) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 24.5% to harvested wood fuel. Total production of harvested wood over tree stand life cycle 0.34 odt/ha.a woody residues (for wood fuel), 0.755 odt/ha.a roundwood (for wood fuel) and 1.427 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs, roundwood and residues of 4:2:1 which gives an allocation to harvested wood fuel of (0.34 + 2 x 0.755) / (0.34 + 2 x 0.755 + 4 * 1.427) = 24.5%.

(c) Land area required 0.718 ha.a/t of dried wood chips available at point of use.

(d) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 41.5% to harvested roundwood (for wood fuel). Production at first log harvest consists of 0.0799 odt/ha.a harvested roundwood and 0.0563 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0799 / (2 x 0.0563 + 0.0799) = 41.5%.

(e) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 31.7% to harvested roundwood (for wood fuel). Production at second log harvest consists of 0.0661 odt/ha.a harvested roundwood and 0.0712 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0661 / (2 x 0.0712 + 0.0661) = 31.7%.

(f) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 21.6% to harvested roundwood (for wood fuel). Production at third log harvest consists of 0.0492 odt/ha.a harvested roundwood and 0.0891 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0492 / (2 x 0.0891 + 0.0492) = 21.6%.

(g) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 17.6% to harvested roundwood (for wood fuel). Production at fourth log harvest consists of 0.0415 odt/ha.a harvested roundwood and 0.0973 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0415 / (2 x 0.0973 + 0.0415) = 17.6%.

(h) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 13.2% to harvested roundwood (for wood fuel). Production at fifth log harvest consists of 0.0312 odt/ha.a harvested roundwood and 0.1024 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0312 / (2 x 0.1024 + 0.0312) = 13.2%.

(i) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 11.2% to harvested roundwood (for wood fuel). Production at sixth log harvest consists of 0.0230 odt/ha.a harvested roundwood and 0.0918 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.0230 / (2 x 0.0918 + 0.0230) = 11.2%.

(j) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 12.0% to harvested roundwood (for wood fuel) and residues (for wood fuel). Production at main harvest consists of 0.3694 odt/ha.a retrieved residues (not including mass of attached needles), 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs, roundwood and residues of 4:2:1 which gives an allocation to harvested wood fuel of (2 x 0.2438 + 0.3694) / (4 x 1.4792 + 2 x 0.2438 + 0.3694) = 12.0%.

(k) Land area requirement is 0.718 ha.a/t of dried wood chips available at point of use and allocation of 7.6% to harvested roundwood (for wood fuel). Production at main harvest consists of 0.2438 odt/ha.a harvested roundwood and 1.4792 odt/ha.a sawlogs overbark, assuming a relative value of sawlogs and harvested wood fuel of 2:1 which gives an allocation to harvested wood fuel of 0.2438 / (2 x 1.4792 + 0.2438) = 7.6%.

(l) Harvested wood fuel (with needles) requirement of 1.241 t/t dried wood chips.

(m) Dried wood fuel requirement of 0.966 t/t dried wood chips.

(n) Dried wood chunk requirement of 0.034 t/t dried wood chips.

APPENDIX G: Production of Wood Chips from Short Rotation Coppice (Option A)

Figure G1 Flow Chart for the Production of Wood Chips from Short Rotation Coppice (Option A)

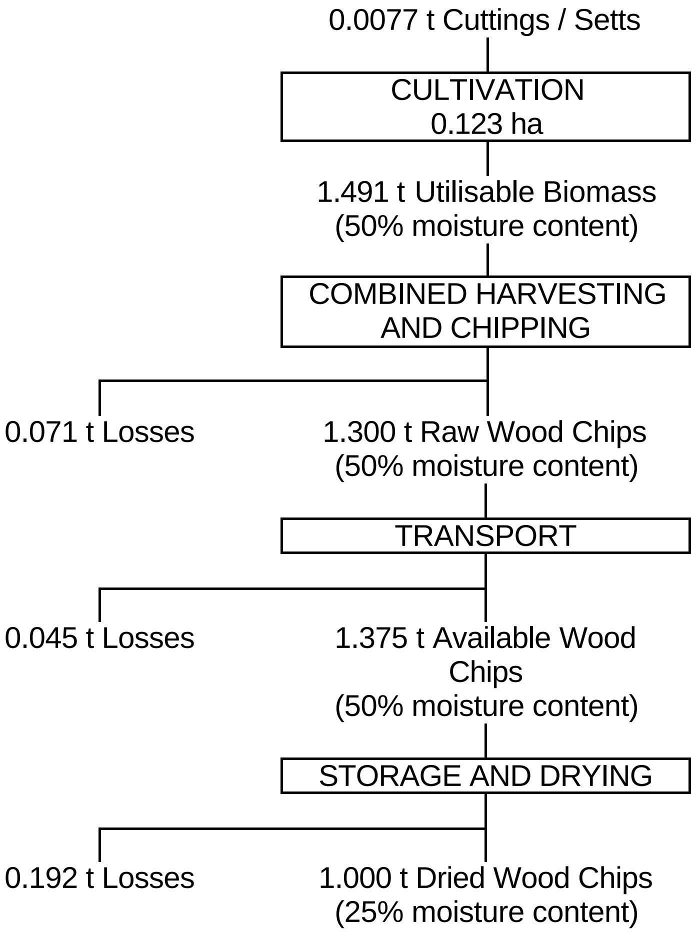

Table G1 Spreadsheet for Primary Energy Inputs to Production of Wood Chips from Short Rotation Coppice (Option A)

Functional Unit:		Wood chips at point of consumption derived from short rotation coppice through combined harvesting and chipping								
Final Unit of Measurement:		1 oven-dry tonne of wood chips								
Relevant Location:		United Kingdom								
Relevant Period:		2002								
Allocation Procedures:		None required								
Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation:										
- Diesel fuel	ha.a	440	±148	48	±18	-	-	488	±149	(a)
- Motor spirit	ha.a	588	±197	65	±24	-	-	653	±199	(b)
- Lubricating oil	ha.a	1	-	-	-	-	-	1	-	(c)
- Agrochemicals	ha.a	-	-	617	±185	-	-	617	±185	(d)
- Machinery/Spares	ha.a	-	-	55	±17	-	-	55	±17	(e)
- Softwood	ha.a	-	-	4	±2	-	-	4	±2	(f)
- Steel	ha.a	-	-	1694	±508	-	-	1694	±508	(g)
- Preservative	ha.a	-	-	280	±84	-	-	280	±84	(h)
- Cutting/Setts	ha.a	-	-	758	±1148	-	-	758	±1148	(i)
Reference System:										
- Diesel fuel	ha.a	-922	±145	-101	±49	-	-	-1023	±153	(j)
Sub-Totals	ha.a	107	±286	3422	±1273	-	-	3529	±1305	
	t dwc	**13**	**±35**	**421**	**±157**	**-**	**-**	**434**	**±161**	(k)
Harvesting and Chipping:										
- Diesel fuel	ha.a	780	±261	86	±32	-	-	865	±263	(l)
- Lubricating oil	ha.a	14	±5	2	±1	-	-	16	±5	(m)
- Machinery/Spares	ha.a	-	-	137	±41	-	-	137	±41	(n)
Sub-Totals	ha.a	794	±262	225	±52	-	-	1018	±267	
	t dwc	**105**	**±32**	**28**	**±6**	**-**	**-**	**133**	**±33**	(k)
Transport:										
- Diesel fuel	t rwc	53	±11	18	±4	-	-	71	±15	(o)
	t dwc	**65**	**±13**	**23**	**±5**	**-**	**-**	**88**	**±18**	(p)
Storage and Drying:										
- Diesel fuel	t dwc	3	±1	-	-	-	-	3	±1	(q)
- Lubricating oil	t dwc	-	-	-	-	-	-	-	-	(r)
- Machinery/Spares	t dwc	-	-	1	-	-	-	1	-	(s)
Sub-Totals	t dwc	3	±1	1	-	-	-	4	±1	
	t dwc	**3**	**±1**	**1**	**-**	**-**	**-**	**4**	**±1**	
Totals	**t dwc**	**179**	**±49**	**472**	**±157**	**-**	**-**	**651**	**±165**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 55 MJ/ha.a (Ref. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) and a total energy requirement 0.5 MJ/kg (Ref. 6).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total energy requirement 137.2 MJ/kg (Ref. 6), and related consumption of mild steel of 0.22 kg/ha.a with a total energy requirement of 31 MJ/kg (Ref. 1).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3) and a total energy requirement of 100 MJ/kg (Refs. 1 to 3).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 3, and 6) and total energy requirements of 0.101 MJ/cutting and 0.404 MJ/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.123 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 780 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Refs. 1 to 3), including 1.8 litres diesel oil consumed by forage harvester per tonne utilisable biomass (Ref. 7) and utilisable biomass of 10.5 odt/ha.a (Ref. 8), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4)

(m) Lubricating oil consumption of 14 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Ref. 1 to 3), including 0.036 litres lubricating oil consumed by forage harvester per tonne utilisable biomass (Ref. 7) and utilisable biomass of 10.5 odt/ha.a (Ref. 8), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 137 MJ/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 6).

(p) Raw wood chip requirement of 1.231 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood chips (Ref. 3) with 0.1 litre diesel oil per tonne dry wood chips consumed in machinery involved in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l, a gross calorific value of 45.8 MJ/kg and a gross energy requirement of 1.110 MJ/MJ (Refs. 1 and 4).

(r) Lubrication oil consumption of 0 MJ/t dwc used by machinery involved in maintenance of wood chip piles (Ref. 1).

(s) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 1 MJ/t dwc (Refs. 1 and 2)

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Table G2 Spreadsheet for Carbon Dioxide Outputs from Production of Wood Chips from Short Rotation Coppice (Option A)

Functional Unit:		Wood chips at point of consumption derived from short rotation coppice through combined harvesting and chipping						
Final Unit of Measurement:		1 oven-dry tonne of wood chips						
Relevant Location:		United Kingdom						
Relevant Period:		2002						
Allocation Procedures:		None required						
Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	*30*	*±10*	*4*	*±1*	*34*	*±10*	(a)
- Motor spirit	*ha.a*	*39*	*±13*	*5*	*±2*	*44*	*±13*	(b)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(c)
- Agrochemicals	*ha.a*	-	-	*11*	*±4*	*11*	*±4*	(d)
- Machinery/Spares	*ha.a*	-	-	*2*	*±1*	*2*	*±1*	(e)
- Softwood	*ha.a*	-	-	-	-	-	-	(f)
- Steel	*ha.a*	-	-	*78*	*±26*	*78*	*±26*	(g)
- Preservative	*ha.a*	-	-	*4*	*±1*	*4*	*±1*	(h)
- Cutting/Setts	*ha.a*	-	-	*32*	*±49*	*32*	*±49*	(i)
Reference System:								
- Diesel fuel	*ha.a*	*-63*	*±9*	*-7*	*±1*	*-71*	*±9*	(j)
Sub-Totals	*ha.a*	*6*	*±19*	*129*	*±56*	*135*	*±59*	
	t dwc	**1**	**±2**	**16**	**±7**	**17**	**±7**	(k)
Harvesting and Chipping:								
- Diesel fuel	*ha.a*	*53*	*±18*	*6*	*±2*	*60*	*±18*	(l)
- Lubricating oil	*ha.a*	*1*	-	-	-	*1*	-	(m)
- Machinery/Spares	*ha.a*	-	-	*6*	*±2*	*6*	*±2*	(n)
Sub-Totals	*ha.a*	*55*	*±18*	*12*	*±3*	*66*	*±18*	
	t dwc	**7**	**±2**	**1**	**-**	**8**	**±2**	(k)
Transport:								
- Diesel fuel	*t rwc*	*4*	*±1*	*1*	-	*5*	*±1*	(o)
	t dwc	**4**	**±1**	**1**	**-**	**6**	**±1**	(p)
Storage and Drying:								
- Diesel fuel	*t dwc*	-	-	-	-	-	-	(q)
- Lubricating oil	*t dwc*	-	-	-	-	-	-	(r)
- Machinery/Spares	*t dwc*	-	-	-	-	-	-	(s)
Sub-Totals	*t dwc*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	
Totals	**t dwc**	**12**	**±3**	**19**	**±7**	**31**	**±8**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct carbon requirement 0.0661 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0742 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of

0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (based on Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 2 kg CO_2/ha.a (Ref. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) and a total carbon requirement 0.041 kg CO_2/kg (Ref. 6).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total carbon requirement 6.31 kg CO_2/kg (Ref. 6) and related consumption of mild steel of 0.22 kg/ha.a with a total carbon requirement of 1.24 kg CO_2/kg (Ref. 1).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1-3) and a total carbon requirement of 1.41 kg CO_2/kg (Refs. 1-3).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1-3, modified on basis of Ref. 6) and total carbon requirements of 0.00430 kg CO_2/cutting and 0.0172 CO_2/sett (revised estimates based on methodology in Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6) and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.123 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 780 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Refs. 1 to 3), including 1.8 litres diesel oil consumed by forage harvester per tonne utilisable biomass (Ref. 7) and utilisable biomass of 10.5 odt/ha.a (Ref. 8), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 14 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection(Refs. 1 to 3), including 0.036 litres lubricating oil consumed by forage harvester per tonne utilisable biomass (Ref. 7) and utilisable biomass of 10.5 odt/ha.a (Ref. 8), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 6 kg CO_2/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 4).

(p) Raw wood chip requirement of 1.231 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood chips (Ref. 3) with 0.1 litre diesel oil per tonne dry wood chips consumed in machinery involved in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(r) Lubrication oil consumption equivalent to output of 0 kg CO_2/t dwc used by machinery involved in maintenance of wood chip piles (Ref. 1).

(s) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/t dwc (Refs. 1 and 2).

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Table G3 Spreadsheet for Methane Outputs from Production of Wood Chips from Short Rotation Coppice (Option A)

Functional Unit:	Wood chips at point of consumption derived from short rotation coppice through combined harvesting and chipping
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	None required

Contribution	Per Unit	Methane Output (kg CH_4)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	-	-	*0.009*	*±0.003*	*0.009*	*±0.003*	(a)
- Motor spirit	*ha.a*	-	-	*0.002*	*±0.001*	*0.002*	*±0.001*	(b)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(c)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(d)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(e)
- Softwood	*ha.a*	-	-	-	-	-	-	(f)
- Steel	*ha.a*	-	-	-	-	-	-	(g)
- Preservative	*ha.a*	-	-	-	-	-	-	(h)
- Cutting/Setts	*ha.a*	-	-	*0.006*	*±0.010*	*0.006*	*±0.010*	(i)
Reference System:								
- Diesel fuel	*ha.a*	*-0.001*	-	*-0.019*	*±0.003*	*-0.019*	*±0.003*	(j)
Sub-Totals	*ha.a*	-	-	*0.009*	*±0.012*	*0.009*	*±0.012*	
	t dwc	**-**	**-**	**0.001**	**±0.001**	**0.001**	**±0.001**	(k)
Harvesting and Chipping:								
- Diesel fuel	*ha.a*	-	-	*0.016*	*±0.006*	*0.016*	*±0.006*	(l)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(m)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(n)
Sub-Totals	*ha.a*	*0.001*	-	*0.016*	*±0.006*	*0.017*	*±0.006*	
	t dwc	**-**	**-**	**0.002**	**±0.001**	**0.002**	**±0.001**	(k)
Transport:								
- Diesel fuel	*t rwc*	-	-	*0.001*	-	*0.001*	-	(o)
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(p)
Storage and Drying:								
- Diesel fuel	*t dwc*	-	-	-	-	-	-	(q)
- Lubricating oil	*t dwc*	-	-	-	-	-	-	(r)
- Machinery/Spares	*t dwc*	-	-	-	-	-	-	(s)
Sub-Totals	*t dwc*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	
Totals	**t dwc**	**-**	**-**	**0.004**	**±0.002**	**0.005**	**±0.002**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct methane requirement 5.67 X 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 X 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 X 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3), a total energy requirement 0.5 MJ/kg (Ref. 6), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total energy requirement 137.2 MJ/kg (Ref. 6), related consumption of mild steel of 0.22 kg/ha.a with a total energy requirement of 31 MJ/kg (Ref. 1), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3), a total energy requirement of 100 MJ/kg (Refs. 1 to 3), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 4) and total energy requirements of 8.51 x 10^{-7} kg CH_4/cutting and 3.41 x 10^{-6} CH_4/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5) and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.123 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 780 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Refs. 1 to 3), including 1.8 litres diesel oil consumed by forage harvester per tonne utilisable biomass (Ref. 8) and utilisable biomass of 10.5 odt/ha.a (Ref. 9), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 14 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Refs. 1 to 3), including 0.036 litres lubricating oil consumed by forage harvester per tonne utilisable biomass (Ref. 8) and utilisable biomass of 10.5 odt/ha.a (Ref. 9), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 kg CH_4/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 4).

(p) Raw wood chip requirement of 1.231 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood chips (Ref. 3) with 0.1 litre diesel oil per tonne dry wood chips consumed in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement 2.04 x 10^{-5} kg CH_{24}/MJ and a total methane requirement 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(r) Lubrication oil consumption equivalent to output of 0 kg CH_4/t dwc used by machinery involved in maintenance of wood chip piles (Ref. 1).

(s) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 CH_4/t dwc (Refs. 1 and 2).

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Table G4 Spreadsheet for Nitrous Oxide Outputs from Production of Wood Chips from Short Rotation Coppice (Option A)

Functional Unit:	Wood chips at point of consumption derived from short rotation coppice through combined harvesting and chipping
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Motor spirit	*ha.a*	-	-	-	-	-	-	(b)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(c)
- Agrochemicals	*ha.a*	-	-	*0.003*	*±0.001*	*0.003*	*±0.001*	(d)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(e)
- Softwood	*ha.a*	-	-	-	-	-	-	(f)
- Steel	*ha.a*	-	-	-	-	-	-	(g)
- Preservative	*ha.a*	-	-	-	-	-	-	(h)
- Cutting/Setts	*ha.a*	-	-	*0.026*	*±0.004*	*0.026*	*±0.004*	(i)
Reference System:								
- Diesel fuel	*ha.a*	*-0.001*	-	-	-	*-0.001*	-	(j)
Sub-Totals	*ha.a*	-	-	*0.029*	*±0.004*	*0.029*	*±0.004*	
	t dwc	**-**	**-**	**0.004**	**-**	**0.004**	**-**	(k)
Harvesting and Chipping:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(l)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(m)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(n)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Transport:								
- Diesel fuel	*t rwc*	-	-	-	-	-	-	(o)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(p)
Storage and Drying:								
- Diesel fuel	*t dwc*	-	-	-	-	-	-	(q)
- Lubricating oil	*t dwc*	-	-	-	-	-	-	(r)
- Machinery/Spares	*t dwc*	-	-	-	-	-	-	(s)
Sub-Totals	*t dwc*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	
Totals	**t dwc**	**-**	**-**	**0.004**	**-**	**0.004**	**-**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct nitrous oxide requirement 5.95 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6.21 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (based on Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.5 x 10^{-3} kg N_2O/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Ref. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) with a total energy requirement 0.5 MJ/kg (Ref. 6) and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total energy requirement 137.2 MJ/kg (Ref. 6), and related consumption of mild steel of 0.22 kg/ha.a with a total energy requirement of 31 MJ/kg (Ref. 1), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3) and a total energy requirement of 100 MJ/kg (Refs. 1 to 3), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 4) and total energy requirements of 3.40 x 10^{-6} kg N_2O/cutting and 1.36 x 10^{-5} N_2O/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.123 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 780 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Refs. 1 to 3), including 1.8 litres diesel oil consumed by forage harvester per tonne utilisable biomass (Ref. 8) and utilisable biomass of 10.5 odt/ha.a (Ref. 9) and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 14 MJ/ha.a used by agricultural machinery for combined harvesting and chipping, and collection (Ref. 1 to 3), including 0.036 litres lubricating oil consumed by forage harvester per tonne utilisable biomass (Ref. 8) and utilisable biomass of 10.5 odt/ha.a (Ref. 9), and a direct nitrous oxide requirement 5.95 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6.21 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 kg CH_4/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total methane requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 4).

(p) Raw wood chip requirement of 1.231 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood chips (Ref. 3) with 0.1 litre diesel oil per tonne dry wood chips consumed in maintenance of wood chip piles, diesel oil density of 0.8532 kg/l (Ref. 1), a direct nitrous oxide requirement of 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(r) Lubrication oil consumption equivalent to output of 0 kg N_2O/t dwc used by machinery involved in maintenance of wood chip piles (Ref. 1).

(s) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 N_2O/t dwc (Refs. 1 and 2).

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Table G5 Spreadsheet for Greenhouse Gas Outputs from Production of Wood Chips from Short Rotation Coppice (Option A)

Functional Unit:	Wood chips at point of consumption derived from short rotation coppice through combined harvesting and chipping
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	None required

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	ha.a	30	±10	4	1	34	10	(a)
- Motor spirit	ha.a	39	±13	5	±2	44	±13	(a)
- Lubricating oil	ha.a	-	-	-	-	-	-	(a)
- Agrochemicals	ha.a	-	-	12	±4	12	±4	(a)
- Machinery/Spares	ha.a	-	-	2	±1	2	±1	(a)
- Softwood	ha.a	-	-	-	-	-	-	(a)
- Steel	ha.a	-	-	78	±26	78	±26	(a)
- Preservative	ha.a	-	-	4	±13	4	±13	(a)
- Cutting/Setts	ha.a	-	-	41	±62	41	±62	(a)
Reference System:								
- Diesel fuel	ha.a	-63	9	-8	±1	-71	±9	(a)
Sub-Totals	ha.a	6	±19	138	±69	144	±71	(a)
	t dwc	**1**	**±2**	**17**	**±8**	**18**	**±9**	(b)
Harvesting and Chipping:								
- Diesel fuel	ha.a	54	±18	7	±2	60	±18	(a)
- Lubricating oil	ha.a	1	-	-	-	-	-	(a)
- Machinery/Spares	ha.a	-	-	6	±2	6	±2	(a)
Sub-Totals	ha.a	55	±18	12	±3	67	±18	(a)
	t dwc	**7**	**±2**	**2**	**-**	**8**	**±2**	(b)
Transport:								
- Diesel fuel	t rwc	4	±1	1	-	5	±1	(a)
	t dwc	**4**	**±1**	**1**	**-**	**6**	**±1**	(c)
Storage and Drying:								
- Diesel fuel	t dwc	-	-	-	-	-	-	(a)
- Lubricating oil	t dwc	-	-	-	-	-	-	(a)
- Machinery/Spares	t dwc	-	-	-	-	-	-	(a)
Sub-Totals	t dwc	-	-	-	-	-	-	(a)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Totals	**t dwc**	**12**	**±3**	**20**	**±8**	**32**	**±9**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg CO_2/kg N_2O.

(b) Land requirement 0.123 ha.a/t of dried wood chips available at point of use.

(c) Raw wood chip requirement of 1.231 t/t of dried wood chips available at point of use.

APPENDIX H: Production of Wood Chips from Short Rotation Coppice (Option B)

Figure H1 Flow Chart for the Production of Wood Chips from Short Rotation Coppice (Option B)

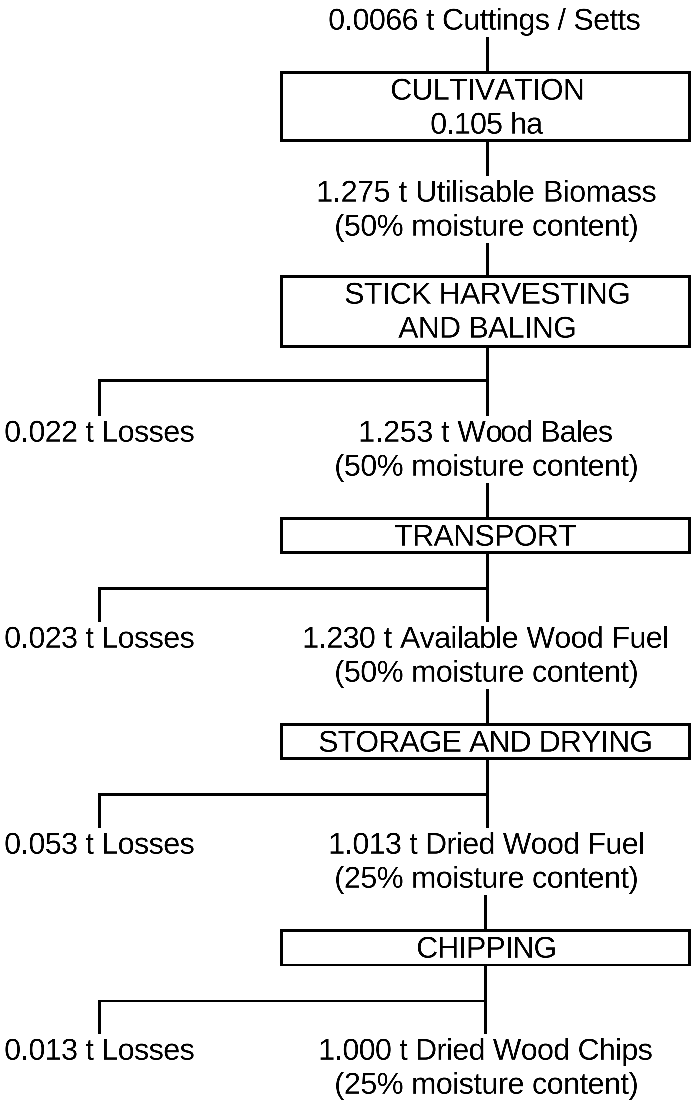

Table H1 Spreadsheet for Primary Energy Inputs to Production Wood Chips from Short Rotation Coppice (Option B)

Functional Unit:	Wood chips at point of consumption derived from short rotation coppice through combined harvesting and baling
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	None required

Contribution	Per Unit	Primary Energy Input (MJ)								Notes
		Direct		Indirect		Feedstock		Total		
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation:										
- Diesel fuel	*ha.a*	*440*	*±148*	*48*	*±18*	-	-	*488*	*±149*	(a)
- Motor spirit	*ha.a*	*588*	*±197*	*65*	*±24*	-	-	*653*	*±199*	(b)
- Lubricating oil	*ha.a*	*1*	-	-	-	-	-	*1*	-	(c)
- Agrochemicals	*ha.a*	-	-	*617*	*±185*	-	-	*617*	*±185*	(d)
- Machinery/Spares	*ha.a*	-	-	*55*	*±17*	-	-	*55*	*±17*	(e)
- Softwood	*ha.a*	-	-	*4*	*±2*	-	-	*4*	*±2*	(f)
- Steel	*ha.a*	-	-	*1694*	*±508*	-	-	*1694*	*±508*	(g)
- Preservative	*ha.a*	-	-	*280*	*±84*	-	-	*280*	*±84*	(h)
- Cutting/Setts	*ha.a*	-	-	*152*	*±230*	-	-	*152*	*±230*	(i)
Reference System:										
- Diesel fuel	*ha.a*	*-922*	*±145*	*-101*	*±49*	-	-	*-1023*	*±153*	(j)
Sub-Totals	*ha.a*	*107*	*±286*	*3422*	*±1273*	-	-	*3529*	*±1305*	
	t dwc	**11**	**±30**	**360**	**±134**	**-**	**-**	**371**	**±137**	(k)
Harvesting and Baling:										
- Diesel fuel	*ha.a*	*278*	*±93*	*31*	*±11*	-	-	*308*	*±94*	(l)
- Lubricating oil	*ha.a*	*3*	*±1*	-	-	-	-	*4*	*±1*	(m)
- Machinery/Spares	*ha.a*	-	-	*102*	*±31*	-	-	*102*	*±31*	(n)
Sub-Totals	*ha.a*	*281*	*±93*	*133*	*±33*	-	-	*414*	*±99*	
	t dwc	**30**	**±10**	**14**	**±3**	**-**	**-**	**44**	**±10**	(k)
Transport:										
- Diesel fuel	*t hwf*	*53*	*±11*	*18*	*±4*	-	-	*71*	*±15*	(o)
	t dwc	**57**	**±12**	**20**	**±5**	**-**	**-**	**77**	**±16**	(p)
Storage and Drying:										
- Storage/Drying	*t hwf*	-	-	-	-	-	-	-	-	(q)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(p)
Chipping:										
- Diesel fuel	*t dwf*	*35*	*±12*	*4*	*±1*	-	-	*39*	*±12*	(r)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	-	-	(s)
- Machinery/Spares	*t dwf*	-	-	*29*	*±9*	-	-	*29*	*±9*	(t)
Sub-Totals	*t dwf*	*35*	*±12*	*33*	*±9*	-	-	*68*	*±15*	
	t dwc	**36**	**±12**	**33**	**±9**	**-**	**-**	**69**	**±15**	(u)
Totals	**t dwc**	**134**	**±36**	**427**	**±134**	**-**	**-**	**561**	**±139**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (bales at 50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (bales at 25% moisture content, wet basis)
t dwc = tonne of dried wood chips (at 25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3) and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3) and a gross energy requirement of 1.110 MJ/MJ for motor spirit in the UK for 1996 (Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 55 MJ/ha.a (Refs. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) and a total energy requirement 0.5 MJ/kg (Ref. 6).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total energy requirement 137.2 MJ/kg (Ref. 6), and related consumption of mild steel of 0.22 kg/ha.a with a total energy requirement of 31 MJ/kg (Ref. 1).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3) and a total energy requirement of 100 MJ/kg (Refs. 1 to 3).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 3, and 7) and total energy requirements of 0.101 MJ/cutting and 0.404 MJ/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.105 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 278 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Ref. 1 to 3), including 22.75 litres diesel fuel consumed by harvester/baler per hectare (Ref. 8), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 3 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Ref. 1 to 3), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 102 MJ/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0352 MJ/t-km (Ref. 6).

(p) Harvested wood fuel requirement of 1.093 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood bales (Ref. 3) with negligible associated energy consumption.

(r) Diesel fuel consumption of 36 MJ/t dry wood bales for chipping, based on assumed 0.9 litre diesel fuel consumption per tonne of wood bale chipped (Ref. 9) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(s) Lubricating oil consumption of 0 MJ/t dry wood bales for chipping, based on assumed 0.0018 litre lubricating oil per tonne of wood bale chipped (Refs. 1 and 9).

(t) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 1 MJ/t dwc (Refs. 1 and 2).

(u) Dried wood fuel requirement of 1.013 t/t of dried wood chips available at point of use.

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Table H2 Spreadsheet for Carbon Dioxide Outputs from Production of Wood Chips from Short Rotation Coppice (Option B)

Functional Unit:	Wood chips at point of consumption derived from short rotation coppice through combined harvesting and baling
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	None required

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	*30*	*±10*	*4*	*±1*	*34*	*±10*	(a)
- Motor spirit	*ha.a*	*39*	*±13*	*5*	*±2*	*44*	*±13*	(b)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(c)
- Agrochemicals	*ha.a*	-	-	*11*	*±4*	*11*	*±4*	(d)
- Machinery/Spares	*ha.a*	-	-	*2*	*±1*	*2*	*±1*	(e)
- Softwood	*ha.a*	-	-	-	-	-	-	(f)
- Steel	*ha.a*	-	-	*78*	*±26*	*78*	*±26*	(g)
- Preservative	*ha.a*	-	-	*4*	*±1*	*4*	*±1*	(h)
- Cutting/Setts	*ha.a*	-	-	*32*	*±49*	*32*	*±49*	(i)
Reference System:								
- Diesel fuel	*ha.a*	*-63*	*±9*	*-7*	*1*	*-71*	*±9*	(j)
Sub-Totals	*ha.a*	*6*	*±19*	*129*	*±56*	*135*	*±59*	
	t dwc	**1**	**±2**	**14**	**±6**	**14**	**±6**	(k)
Harvesting and Baling:								
- Diesel fuel	*ha.a*	*19*	*±6*	*2*	*±1*	*21*	*±6*	(l)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(m)
- Machinery/Spares	*ha.a*	-	-	*4*	*±1*	*4*	*±1*	(n)
Sub-Totals	*ha.a*	*19*	*±6*	*6*	*±2*	*26*	*±7*	
	t dwc	**2**	**±1**	**1**	**-**	**3**	**±1**	(k)
Transport:								
- Diesel fuel	*t hwf*	*4*	*±1*	*1*	-	*5*	*±1*	(o)
	t dwc	**4**	**±1**	**1**	**-**	**5**	**±1**	(p)
Storage and Drying:								
- Storage/Dying	*t hwf*	-	-	-	-	-	-	(q)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(p)
Chipping:								
- Diesel fuel	*t dwf*	*2*	*±1*	-	-	*3*	*±1*	(r)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(s)
- Machinery/Spares	*t dwf*	-	-	*1*	-	*1*	-	(t)
Sub-Totals	*t dwf*	*2*	*±1*	*1*	-	*4*	*±1*	
	t dwc	**2**	**±1**	**1**	**-**	**4**	**±1**	(u)
Totals	**t dwc**	**9**	**±2**	**17**	**±6**	**26**	**±6**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (bales at 50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (bales at 25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct carbon requirement 0.0661 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0742 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 2 kg CO_2/ha.a (Refs. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) and a total carbon requirement 0.041 kg CO_2/kg (Ref. 6).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total carbon requirement 6.31 kg CO_2/kg (Ref. 6), and related consumption of mild steel of 0.22 kg/ha.a with a total carbon requirement of 1.24 kg CO_2/kg (Ref. 1).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3) and a total carbon requirement of 1.41 kg CO_2/kg (Refs. 1 to 3).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 3, and 7) and total carbon requirements of 0.00430 kg CO_2/cutting and 0.0172 CO_2/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5) and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.105 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 278 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Refs. 1 to 3), including 22.75 litres diesel fuel consumed by harvester/baler per hectare (Ref. 8), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 3 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Refs. 1 to 3), and a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 6 kg CO_2/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

(p) Harvested wood fuel requirement of 1.093 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood bales (Ref. 3) with negligible associated energy consumption.

(r) Diesel fuel consumption of 36 MJ/t dry wood bales for chipping, based on assumed 0.9 litre diesel fuel consumption per tonne of wood bale chipped (Ref. 9), and a direct carbon requirement 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(s) Lubrication oil consumption equivalent to output of 0 kg CO_2/t dwc used by machinery involved in maintenance of wood chip piles, based on assumed 0.0018 litre lubricating oil per tonne of wood bale chipped (Refs. 1 and 9), a direct carbon requirement 0.0743 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0824 kg CO_2/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(t) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CO_2/t dwc (Refs. 1 and 2).

(u) Dried wood fuel requirement of 1.013 t/t of dried wood chips available at point of use.

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Table H3 Spreadsheet for Methane Outputs from Production of Wood Chips from Short Rotation Coppice (Option B)

Functional Unit:		Wood chips at point of consumption derived from short rotation coppice through combined harvesting and baling						
Final Unit of Measurement:		1 oven-dry tonne of wood chips						
Relevant Location:		United Kingdom						
Relevant Period:		2002						
Allocation Procedures:		None required						
Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	-	-	*0.009*	*±0.003*	*0.009*	*±0.003*	(a)
- Motor spirit	*ha.a*	-	-	*0.012*	*±0.004*	*0.002*	*±0.004*	(b)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(c)
- Agrochemicals	*ha.a*	-	-	-	-	-	-	(d)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(e)
- Softwood	*ha.a*	-	-	-	-	-	-	(f)
- Steel	*ha.a*	-	-	-	-	-	-	(g)
- Preservative	*ha.a*	-	-	-	-	-	-	(h)
- Cutting/Setts	*ha.a*	-	-	*0.006*	*±0.010*	*0.006*	*±0.010*	(i)
Reference System:								
- Diesel fuel	*ha.a*	*-0.001*	-	*-0.019*	*±0.003*	*-0.019*	*±0.003*	(j)
Sub-Totals	*ha.a*	-	-	*0.009*	*±0.012*	*0.009*	*±0.012*	
	t dwc	**-**	**-**	**0.001**	**±0.001**	**0.001**	**±0.001**	(k)
Harvesting and Baling:								
- Diesel fuel	*ha.a*	-	-	*0.006*	*±0.002*	*0.006*	*±0.002*	(l)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(m)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(n)
Sub-Totals	*ha.a*	-	-	*0.006*	*±0.002*	*0.006*	*±0.002*	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(k)
Transport:								
- Diesel fuel	*t hwf*	-	-	*0.001*	-	*0.001*	-	(o)
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(p)
Storage and Drying:								
- Storage/Drying	*t hwf*	-	-	-	-	-	-	(q)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(p)
Chipping:								
- Diesel fuel	*t dwf*	-	-	*0.001*	-	*0.001*	-	(r)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(s)
- Machinery/Spares	*t dwf*	-	-	-	-	-	-	(t)
Sub-Totals	*t dwf*	-	-	*0.001*	-	*0.001*	-	
	t dwc	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(u)
Totals	**t dwc**	**-**	**-**	**0.003**	**±0.001**	**0.004**	**±0.001**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (bales at 50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (bales at 25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct methane requirement 5.67 X 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 X 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 X 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg CH_4/ha.a (Refs. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) with a total energy requirement 0.5 MJ/kg (Ref. 6) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total energy requirement 137.2 MJ/kg (Ref. 6), and related consumption of mild steel of 0.22 kg/ha.a with a total energy requirement of 31 MJ/kg (Ref. 1), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3) with a total energy requirement of 100 MJ/kg (Refs. 1 to 3), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to production (Ref. 7).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 3, and 8) and total energy requirements of 8.51 x 10^{-7} kg CH_4/cutting and 3.41 x 10^{-6} CH_4/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_{24}/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.105 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 278 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Refs. 1 to 3), including 22.75 litres diesel fuel consumed by harvester/baler per hectare (Ref. 9), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_{24}/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 3 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection, and a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 kg CH_4/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 6).

(p) Harvested wood fuel requirement of 1.093 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood bales (Ref. 3) with negligible associated energy consumption.

(s) Diesel fuel consumption of 36 MJ/t dry wood bales for chipping, based on assumed 0.9 litre diesel fuel consumption per tonne of wood bale chipped (Ref. 10), and a direct methane requirement 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(r) Lubrication oil consumption equivalent to output of 0 kg CH_4/t dwc used by machinery involved in maintenance of wood chip piles (Ref. 1), based on assumed 0.0018 litre lubricating oil per tonne of wood bale chipped (Refs. 1 and 10), a direct methane requirement 2.64 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK for 1996 (based on Ref. 4).

(s) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 CH_4/t dwc (Refs. 1 and 2).

(u) Dried wood fuel requirement of 1.013 t/t of dried wood chips available at point of use.

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Table H4 Spreadsheet for Nitrous Oxide Outputs from Production of Wood Chips from Short Rotation Coppice (Option B)

Functional Unit:	Wood chips at point of consumption derived from short rotation coppice through combined harvesting and baling
Final Unit of Measurement:	1 oven-dry tonne of wood chips
Relevant Location:	United Kingdom
Relevant Period:	2002
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(a)
- Motor spirit	*ha.a*	-	-	-	-	-	-	(b)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(c)
- Agrochemicals	*ha.a*	-	-	*0.003*	*±0.001*	*0.003*	*±0.001*	(d)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(e)
- Softwood	*ha.a*	-	-	-	-	-	-	(f)
- Steel	*ha.a*	-	-	-	-	-	-	(g)
- Preservative	*ha.a*	-	-	-	-	-	-	(h)
- Cutting/Setts	*ha.a*	-	-	*0.026*	*±0.004*	*0.026*	*±0.004*	(i)
Reference System:								
- Diesel fuel	*ha.a*	*-0.001*	-	-	-	*-0.001*	-	(j)
Sub-Totals	*ha.a*	-	-	*0.029*	*±0.004*	*0.029*	*±0.004*	
	t dwc	**-**	**-**	**0.003**	**-**	**0.003**	**-**	(k)
Harvesting and Baling:								
- Diesel fuel	*ha.a*	-	-	-	-	-	-	(l)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(m)
- Machinery/Spares	*ha.a*	-	-	-	-	-	-	(n)
Sub-Totals	*ha.a*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Transport:								
- Diesel fuel	*t hwf*	-	-	-	-	-	-	(o)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(p)
Storage and Drying:								
- Storage/Drying	*t hwf*	-	-	-	-	-	-	(q)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(p)
Chipping:								
- Diesel fuel	*t dwf*	-	-	-	-	-	-	(r)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(s)
- Machinery/Spares	*t dwf*	-	-	-	-	-	-	(t)
Sub-Totals	*t dwf*	-	-	-	-	-	-	
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Totals	**t dwc**	**-**	**-**	**0.003**	**-**	**0.003**	**-**	

Biofuel specifications

Density of wood chips = 124 kg/m^3
Net calorific value of wood chips = 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t hwf = tonne of harvested wood fuel (bales at 50% moisture content, wet basis)
t dwf = tonne of dried wood fuel (bales at 25% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Diesel fuel consumption of 440 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides (Refs. 1 to 3), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(b) Motor spirit consumption of 588 MJ/ha.a used by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct nitrous oxide requirement 4.01 X 10^{-9} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 X 10^{-10} kg N_2O/MJ and a total nitrous oxide requirement of 2.1 X 10^{-5} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(c) Lubricating oil consumption of 1 MJ/ha.a used by agricultural machinery for sub-soiling, ploughing, harrowing, rotavating and spreading herbicides and by brushcutters in cutting back to establish coppice stools (Refs. 1 to 3), and a direct nitrous oxide requirement 5.95 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6.21 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(d) Application rate for a mixture of herbicides of 2.25 kg/ha.a (Refs. 1 to 3) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.5 x 10^{-3} kg N_2O/kg (Ref. 5).

(e) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares equivalent to 0 kg N_2O/ha.a (Refs. 1 to 3).

(f) Consumption of softwood in construction and maintenance of fences of 8.55 kg/ha.a (Refs. 1 to 3) with a total energy requirement 0.5 MJ/kg (Ref. 6), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(g) Consumption of steel wire in construction and maintenance of fences of 12.30 kg/ha.a (Refs. 1 to 3) with a total energy requirement 137.2 MJ/kg (Ref. 6), and related consumption of mild steel of 0.22 kg/ha.a with a total energy requirement of 31 MJ/kg (Ref. 1), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(h) Consumption of wood preservative in construction and maintenance of fences of 2.80 kg/ha.a (Refs. 1 to 3) with a total energy requirement of 100 MJ/kg (Refs. 1 to 3), and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to production (Ref. 7).

(i) Consumption of poplar/willow cuttings and setts in crop establishment of 6250 cuttings/ha.a and 312.5 setts (Refs. 1 to 3, and 8) and total energy requirements of 3.40 x 10^{-6} kg N_2O/cutting and 1.36 x 10^{-5} N_2O/sett (Ref. 1).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(k) Land requirement 0.105 ha.a/t of dried wood chips available at point of use.

(l) Diesel fuel consumption of 278 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Refs. 1 to 3), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(m) Lubricating oil consumption of 3 MJ/ha.a used by agricultural machinery for combined harvesting and baling, and collection (Refs. 1 to 3), including 22.75 litres diesel fuel consumed by harvester/baler per hectare (Ref. 9) and a direct nitrous oxide requirement 5.95 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6.21 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(n) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 kg CH_4/ha.a (Refs. 1 to 3).

(o) Assumed average round trip distance of 64.37 ± 12.87 km (Ref. 3) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total methane requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 6).

(p) Harvested wood fuel requirement of 1.093 t/t dry wood chips.

(q) Assumed minimal facilities for storage and passive drying of wood bales (Ref. 3) with negligible associated energy consumption.

(r) Diesel fuel consumption of 36 MJ/t dry wood bales for chipping, based on assumed 0.9 litre diesel fuel consumption per tonne of wood bale chipped (Ref. 10), and a direct nitrous oxide requirement 5.64 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.90 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(s) Lubrication oil consumption equivalent to output of 0 kg N_2O/t dwc used by machinery involved in maintenance of wood chip piles (Ref. 1), based on assumed 0.0018 litre lubricating oil per tonne of wood bale chipped (Refs. 1 and 10), a direct nitrous oxide requirement 5.95 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6.21 x 10^{-7} kg N_2O/MJ for diesel fuel in the UK for 1996 (Ref. 4).

(t) Allocation of part of energy inputs to manufacture of machinery and allowance for consumption of spares of 0 N_2O/t dwc (Refs. 1 and 2).

(u) Dried wood fuel requirement of 1.013 t/t of dried wood chips available at point of use.

References

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9. Private communication with D. Culshaw, Border Biofuels, Tweed Horizons Centre, Melrose, UK, February 2002.

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Table H5 Spreadsheet for Greenhouse Gas Outputs from Production of Wood Chips from Short Rotation Coppice (Option B)

Functional Unit:		Wood chips at point of consumption derived from short rotation coppice through combined harvesting and baling						
Final Unit of Measurement:		1 oven-dry tonne of wood chips						
Relevant Location:		United Kingdom						
Relevant Period:		2002						
Allocation Procedures:		None required						
Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- Diesel fuel	*ha.a*	*30*	*±10*	*4*	*±1*	*34*	*±10*	(a)
- Motor spirit	*ha.a*	*39*	*±13*	*5*	*±2*	*44*	*±13*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Agrochemicals	*ha.a*	-	-	*12*	*±4*	*12*	*±4*	(a)
- Machinery/Spares	*ha.a*	-	-	*2*	*±1*	*2*	*±1*	(a)
- Softwood	*ha.a*	-	-	-	-	-	-	(a)
- Steel	*ha.a*	-	-	*78*	*±26*	*78*	*±26*	(a)
- Preservative	*ha.a*	-	-	*4*	*±13*	*4*	*±13*	(a)
- Cutting/Setts	*ha.a*	-	-	*41*	*±62*	*41*	*±62*	(a)
Reference System:								
- Diesel fuel	*ha.a*	*-63*	*±9*	*-8*	*±1*	*-71*	*±9*	(a)
Sub-Totals	*ha.a*	*6*	*±19*	*138*	*±69*	*144*	*±71*	
	t dwc	**1**	**±2**	**15**	**±7**	**15**	**±7**	(b)
Harvesting and Baling:								
- Diesel fuel	*ha.a*	*19*	*±6*	*2*	*±1*	*22*	*±6*	(a)
- Lubricating oil	*ha.a*	-	-	-	-	-	-	(a)
- Machinery/Spares	*ha.a*	-	-	*4*	*±1*	*4*	*±1*	(a)
Sub-Totals	*ha.a*	*19*	*±6*	*7*	*±2*	*26*	*±7*	
	t dwc	**2**	**±1**	**1**	**-**	**3**	**±1**	(b)
Transport:								
- Diesel fuel	*t hwf*	*4*	*±1*	*1*	-	*5*	*±1*	(a)
	t dwc	**4**	**±1**	**1**	**-**	**5**	**±1**	(c)
Storage and Drying:								
- Storage/Drying	*t hwf*	-	-	-	-	-	-	(a)
	t dwc	**-**	**-**	**-**	**-**	**-**	**-**	(c)
Chipping:								
- Diesel fuel	*t dwf*	*2*	*±1*	-	-	*3*	*±1*	(a)
- Lubricating oil	*t dwf*	-	-	-	-	-	-	(a)
- Machinery/Spares	*t dwf*	-	-	*1*	-	*1*	-	(a)
Sub-Totals	*t dwf*	*2*	*±1*	*1*	-	*4*	*±1*	
	t dwc	**2**	**±1**	**1**	**-**	**4**	**±1**	(d)
Totals	**t dwc**	**9**	**±2**	**18**	**±7**	**27**	**±8**	

Biofuel specifications

Density of wood chips	= 124 kg/m^3
Net calorific value of wood chips	= 17.8 MJ/kg

Abbreviations

ha.a = hectare year
t rwc = tonne of raw wood chips (50% moisture content, wet basis)
t dwc = tonne of dried wood chips (25% moisture content, wet basis)

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg CO_2/kg N_2O.

(b) Land requirement 0.105 ha.a/t of dried wood chips available at point of use.

(c) Harvested wood fuel requirement of 1.093 t/t of dried wood chips available at point of use.

(d) Dried wood fuel requirement of 1.013 t/t of dried wood chips available at point of use.

APPENDIX I: Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Figure I1 Flow Chart for Large Scale Combined Heat and Power Generation with an Industrial Load by Combustion of Wood Chips

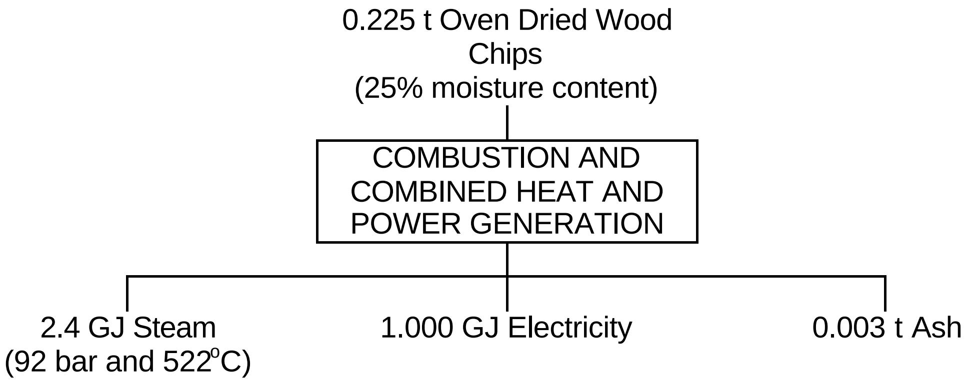

Table I1 Spreadsheet for Primary Energy Inputs to Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Functional Unit:	Electricity and steam at point of generation from combustion of wood chips
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of steam at 522°C and 92 bar
Relevant Location:	United Kingdom
Relevant Period:	1995
Allocation Procedures:	None required

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**									(a)
Plant Construction:	**GJ**	**-**	**-**	**66**	**±10**	**-**	**-**	**66**	**±10**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**42**	**±6**	**-**	**-**	**42**	**±6**	(b, d, e)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b, f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**3**	**±1**	**-**	**-**	**3**	**±1**	(b, h)
Totals	**GJ**	**-**	**-**	**111**	**±12**	**-**	**-**	**111**	**±12**	

Abbreviation

GJ = GJ of electricity or steam.

Notes

(a) Not specified.

(b) Simulated wood-fired combined heat and power plant consuming 32,086 oven dried tonnes (25% moisture content) of wood chip per year, based on the Masnedø co-fired (straw and wood) combined heat and power plant with a net electrical output rating of 8.2 MW and a steam output rating of 20.8 MW, and a load factor of 55% (Ref. 1).

(c) Primary energy input to plant construction based on a capital cost of 28 million DKK (1995), an overall load factor of 55%, a plant life of 25 years and a 1995 energy intensity for industrial plant and steelwork of 31.4 MJ/£ (Ref. 2).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(e) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 4).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 5) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 4).

(g) Ash output of 1.5% of oven dried wood chip input, or 0.882 kg/GJ of electricity or steam (Ref. 5).

(h) Primary energy input to plant decommissioning assumed to be 4% ±1% of the primary energy input to plant construction (Ref. 4).

References

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Table I2 Spreadsheet for Carbon Dioxide Outputs from Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Functional Unit:	Electricity and steam at point of generation from combustion of wood chips
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of steam at 522°C and 92 bar
Relevant Location:	United Kingdom
Relevant Period:	1995
Allocation Procedures:	None required

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**							(a)
Plant Construction:	**GJ**	**-**	**-**	**3**	**±1**	**3**	**±1**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**2**	**-**	**2**	**-**	(b, d, e)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b, f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**-**	**-**	**5**	**±1**	**5**	**±1**	

Abbreviation

GJ = GJ of electricity or steam.

Notes

(a) Not specified.

(b) Simulated wood-fired combined heat and power plant consuming 32,086 oven dried tonnes (25% moisture content) of wood chip per year, based on the Masnedø co-fired (straw and wood) combined heat and power plant with a net electrical output rating of 8.2 MW and a steam output rating of 20.8 MW, a load factor of 55% and an overall thermal efficiency of 85% (Ref. 1).

(c) Carbon dioxide output from plant construction based on a capital cost of 28 million DKK (1995), an overall load factor of 55%, a plant life of 25 years and a 1995 carbon intensity for industrial plant and steelwork of 1.580 kg CO_2/£ (Ref. 2).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(e) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output of plant construction (Ref. 4).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 5) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 4).

(g) Ash output of 1.5% of oven dried wood chip input, or 0.882 kg/GJ of electricity or steam (Ref. 5).

(h) Carbon dioxide output from plant decommissioning assumed to be 4% ±1% of the carbon dioxide output from plant construction (Ref. 4).

References

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Table I3 Spreadsheet for Methane Outputs from Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Functional Unit:	Electricity and steam at point of generation from combustion of wood chips							
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of steam at 522°C and 92 bar							
Relevant Location:	United Kingdom							
Relevant Period:	1995							
Allocation Procedures:	None required							
Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**							(a)
Direct Emissions	**GJ**	**0.002**	**-**	**-**	**-**	**0.002**	**-**	(b, c)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, d, e)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, e, f)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(c, g) (h)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, i)
Totals	**GJ**	**0.002**	**-**	**-**	**-**	**0.002**	**-**	

Abbreviation GJ = GJ of electricity or steam.

Notes

(a) Not specified.

(b) Direct emissions of 0.002 kg CH_4/MJ of wood chips (Ref. 1).

(c) Simulated wood-fired combined heat and power plant consuming 32,086 oven dried tonnes (25% moisture content) of wood chip per year, based on the Masnedø co-fired (straw and wood) combined heat and power plant with a net electrical output rating of 8.2 MW and a steam output rating of 20.8 MW, a load factor of 55% and an overall thermal efficiency of 85% (Ref. 2).

(d) Methane output from plant construction based on a capital cost of 28 million DKK (1995), an overall load factor of 55%, a plant life of 25 years, a 1995 energy intensity for industrial plant and steelwork of 31.4 MJ/£ (Ref. 3), and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 4).

(e) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(f) Methane output of annual plant maintenance assumed to be 2.5% of methane output of plant construction (Ref. 6).

(g) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 7) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 6).

(h) Ash output of 1.5% of oven dried wood chip input, or 0.882 kg/GJ of electricity or steam (Ref. 7).

(i) Methane output from plant decommissioning assumed to be 4% ±1% of the methane output from plant construction (Ref. 6).

References

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Table I4 Spreadsheet for Nitrous Oxide Outputs from Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Functional Unit:	Electricity and steam at point of generation from combustion of wood chips							
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of steam at 522°C and 92 bar							
Relevant Location:	United Kingdom							
Relevant Period:	1995							
Allocation Procedures:	None required							
Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**							(a)
Direct Emissions	**GJ**	**0.005**	**-**	**-**	**-**	**0.005**	**-**	(b)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, d, e)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, e, f)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(c, g) (h)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, i)
Totals	**GJ**	**0.005**	**-**	**-**	**-**	**0.005**	**-**	

Abbreviation

GJ = GJ of electricity or steam.

Notes

(a) Not specified.

(b) Direct emissions of 0.004 kg N_2O/MJ of wood chips (Ref. 1).

(c) Simulated wood-fired combined heat and power plant consuming 32,086 oven dried tonnes (25% moisture content) of wood chip per year, based on the Masnedø co-fired (straw and wood) combined heat and power plant with a net electrical output rating of 8.2 MW and a steam output rating of 20.8 MW, a load factor of 55% and an overall thermal efficiemcy of 85% (Ref. 2).

(d) Nitrous oxide output from plant construction based on a capital cost of 28 million DKK (1995), an overall load factor of 55%, a plant life of 25 years, a 1995 energy intensity for industrial plant and steelwork of 31.4 MJ/£ (Ref. 3), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ of primary energy input to construction (Ref. 4).

(e) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(f) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output of plant construction (Ref. 6).

(g) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 7) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 6).

(h) Ash output of 1.5% of oven dried wood chip input, or 0.882 kg/GJ of electricity or steam (Ref. 7).

(i) Nitrous oxide output from plant decommissioning assumed to be 4% ±1% of the nitrous oxide output from plant construction (Ref. 6).

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4. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

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7. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table I5 Spreadsheet for Greenhouse Gas Outputs from Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Functional Unit:	Electricity and steam at point of generation from combustion of wood chips							
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of steam at 522°C and 92 bar							
Relevant Location:	United Kingdom							
Relevant Period:	1995							
Allocation Procedures:	None required							
Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**							(a)
Direct Emissions	**GJ**	**2**	**-**	**-**	**-**	**2**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**3**	**±1**	**3**	**±1**	(b)
Plant Maintenance:	**GJ**	**-**	**-**	**2**	**-**	**2**	**-**	(b)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b) (c)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Totals	**GJ**	**2**	**-**	**5**	**±1**	**7**	**±1**	

Abbreviation

GJ = GJ of electricity or steam.

Notes

(a) Not specified.

(b) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(c) Ash output of 1.5% of oven dried wood chip input, or 0.882 kg/GJ of electricity or steam.

APPENDIX J: Small-Scale Combined Heat and Power Generation by Gasification of Wood Chips

Figure J1 Flow Chart for Small Scale Combined Heat and Power Generation by Gasification of Wood Chips

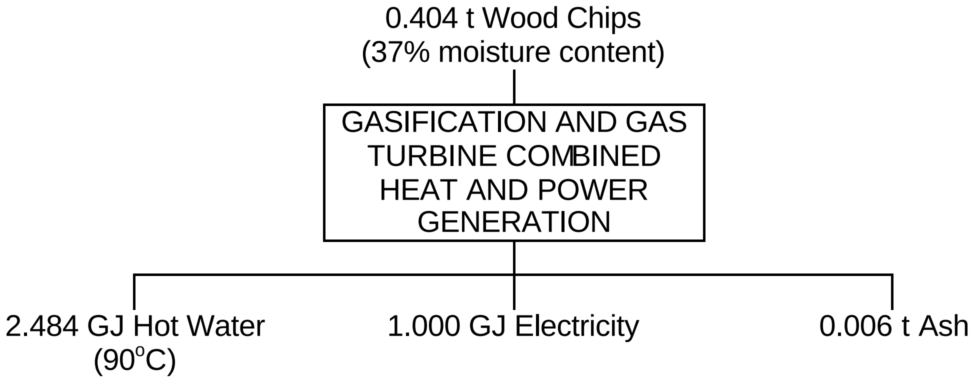

Table J1 Spreadsheet for Primary Energy Inputs to Small-Scale Combined Heat and Power Generation by Gasification of Wood Chips

Functional Unit:	Electricity and hot water at point of generation from gasification of wood chips									
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of hot water at 90^{o}C									
Relevant Location:	United Kingdom									
Relevant Period:	2000									
Allocation Procedures:	None required									
Contribution	Per Unit	Primary Energy Input (MJ)								Notes
		Direct		Indirect		Feedstock		Total		
		Value	Range	Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**1**	**-**	**15**	**±2**	**-**	**-**	**16**	**±2**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**10**	**±1**	**-**	**-**	**10**	**±1**	(b, d, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b, f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**1**	**-**	**-**	**-**	**1**	**-**	(b, h)
Totals	**GJ**	**1**	**-**	**26**	**±2**	**-**	**-**	**27**	**±2**	

Abbreviation

GJ = GJ of electricity or hot water.

Notes

(a) Assuming natural gas consumption of 32,364 MJ/start (Ref. 1), a regime of 2 starts per year over the 25 year life of the plant, and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Modular wood gasification combined heat and power plant with a net electrical output rating of 2.50 MW and a hot water output rating of 6.21 MW and a load factor of 55%, consuming 17,518 tonnes (37% moisture content) of wood chips (Ref. 1).

(c) Primary energy input to plant construction of 58,424 ± 6,886 GJ (Ref. 3).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(e) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 3).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 5) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 3).

(g) Ash output of 1.5% of oven dried wood chip input, or 1.722 kg/GJ of electricity or hot water (Ref. 1).

(h) Primary energy input to plant decommissioning assumed to be 4% ±1% of the primary energy input to plant construction (Ref. 3).

References

1. "Design of a 2.5 MW(e) Biomass Gasification Power Generation Module" by R. McLellan, Wellman Process Engineering Ltd., ETSU B/T1/00569, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

3. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

4. "Comparison of Transport Fuels: Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles" by. T. Beer, T. Grant, G. Morgan, J. Lapszewicz, P. Anyon, J. Edwards, P. Nelson, H. Watson and D. Williams, CSIRO, Aspendale, Australia, 2002.

5. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table J2 Spreadsheet for Carbon Dioxide Outputs from Small-Scale Combined Heat and Power Generation by Gasification of Wood Chips

<table>
<tr><td colspan="2">Functional Unit:</td><td colspan="7">Electricity and hot water at point of generation from gasification of wood chips</td></tr>
<tr><td colspan="2">Final Unit of Measurement:</td><td colspan="7">1 GJ of electricity or 1 GJ of hot water at 90°C</td></tr>
<tr><td colspan="2">Relevant Location:</td><td colspan="7">United Kingdom</td></tr>
<tr><td colspan="2">Relevant Period:</td><td colspan="7">2000</td></tr>
<tr><td colspan="2">Allocation Procedures:</td><td colspan="7">None required</td></tr>
<tr><td rowspan="3">Contribution</td><td rowspan="3">Per Unit</td><td colspan="7">Carbon Dioxide Output (kg CO_2)</td></tr>
<tr><td colspan="2">Direct</td><td colspan="2">Indirect</td><td colspan="2">Total</td><td rowspan="2">Notes</td></tr>
<tr><td>Value</td><td>Range</td><td>Value</td><td>Range</td><td>Value</td><td>Range</td></tr>
<tr><td>Start-Up Fuel:</td><td>GJ</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>(a)</td></tr>
<tr><td>Plant Construction:</td><td>GJ</td><td>-</td><td>-</td><td>1</td><td>-</td><td>1</td><td>-</td><td>(b, c, d)</td></tr>
<tr><td>Plant Maintenance:</td><td>GJ</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>(b, d, e)</td></tr>
<tr><td>Ash Disposal:</td><td>GJ</td><td>-
-</td><td>-
-</td><td>-
-</td><td>-
-</td><td>-
-</td><td>-
-</td><td>(b, f)
(g)</td></tr>
<tr><td>Plant Decommission:</td><td>GJ</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>(b, h)</td></tr>
<tr><td>Totals</td><td>GJ</td><td>-</td><td>-</td><td>1</td><td>-</td><td>1</td><td>-</td><td></td></tr>
</table>

Abbreviation

GJ = GJ of electricity or hot water.

Notes

(a) Assuming natural gas consumption of 32,364 MJ/start (Ref. 1), a regime of 2 starts per year over the 25 year life of the plant, and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Modular wood gasification combined heat and power plant with a net electrical output rating of 2.50 MW and a hot water output rating of 6.21 MW and a load factor of 55%, consuming 17,518 tonnes (37% moisture content) of wood chips (Ref. 1).

(c) Carbon dioxide output from plant construction of 2,802 ± 187 tonnes of CO_2 (Ref. 3).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(e) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output of plant construction (Ref. 3).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 5) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 3).

(g) Ash output of 1.5% of oven dried wood chip input, or 1.772 kg/GJ of electricity or hot water (Ref. 1).

(h) Carbon dioxide output from plant decommissioning assumed to be 4% ±1% of the carbon dioxide output from plant construction (Ref. 3).

References

1. "Design of a 2.5 MW(e) Biomass Gasification Power Generation Module" by R. McLellan, Wellman Process Engineering Ltd., ETSU B/T1/00569, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

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Table J3 Spreadsheet for Methane Outputs from Small-Scale Combined Heat and Power Generation by Gasification of Wood Chips

Functional Unit:	Electricity and hot water at point of generation from gasification of wood chips
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of hot water at 90°C
Relevant Location:	United Kingdom
Relevant Period:	2000
Allocation Procedures:	None required

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, d, e)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b, f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	

Abbreviation

GJ = GJ of electricity or hot water.

Notes

(a) Assuming natural gas consumption of 32,364 MJ/start (Ref. 1), a regime of 2 starts per year over the 25 year life of the plant, and a direct methane requirement of 3.70 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083 x 10^{-4} kg CH_4/MJ and a total methane requirement of 1.12 x 10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Modular wood gasification combined heat and power plant with a net electrical output rating of 2.50 MW and a hot water output rating of 6.21 MW and a load factor of 55%, consuming 17,518 tonnes (37% moisture content) of wood chips (Ref. 1).

(c) Primary energy input to plant construction of 58,424 ± 6,886 GJ (Ref. 3) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 4).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(e) Methane output of annual plant maintenance assumed to be 2.5% of methane output of plant construction (Ref. 3).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 6) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref.3).

(g) Ash output of 1.5% of oven dried wood chip input, or 1.772 kg/GJ of electricity or hot water (Ref. 1).

(h) Methane output from plant decommissioning assumed to be 4% ±1% of the methane output from plant construction (Ref. 3).

References

1. "Design of a 2.5 MW(e) Biomass Gasification Power Generation Module" by R. McLellan, Wellman Process Engineering Ltd., ETSU B/T1/00569, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

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4. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

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6. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table J4 Spreadsheet for Nitrous Oxide Outputs from Small-Scale Combined Heat and Power Generation by Gasification of Wood Chips

Functional Unit:	Electricity and hot water at point of generation from gasification of wood chips
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of hot water at 90°C
Relevant Location:	United Kingdom
Relevant Period:	2000
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	-	-	-	-	-	-	(a)
Plant Construction:	**GJ**	-	-	-	-	-	-	(b, c, d)
Plant Maintenance:	**GJ**	-	-	-	-	-	-	(b, d, e)
Ash Disposal:	**GJ**	- -	- -	- -	- -	- -	- -	(b, f) (g)
Plant Decommission:	**GJ**	-	-	-	-	-	-	(b, h)
Totals	**GJ**	-	-	-	-	-	-	

Abbreviation

GJ = GJ of electricity or steam.

Notes

(a) Assuming natural gas consumption of 32,364 MJ/start (Ref. 1), a regime of 2 starts per year over the 25 year life of the plant, and a direct nitrous requirement of 8.9 x 10^{8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Modular wood gasification combined heat and power plant with a net electrical output rating of 2.50 MW and a hot water output rating of 6.21 MW and a load factor of 55%, consuming 17,518 tonnes (37% moisture content) of wood chips (Ref. 1).

(c) Primary energy input to plant construction of 58,424 ± 6,886 GJ (Ref. 3) and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ of primary energy input to construction (Ref. 4).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(e) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output of plant construction (Ref. 3).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 6) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{8} kg N_2O/t-km (Ref. 3).

(g) Ash output of 1.5% of oven dried wood chip input, or 1.772 kg/GJ of electricity or hot water (Ref. 1).

(h) Nitrous oxide output from plant decommissioning assumed to be 4% ±1% of the nitrous oxide output from plant construction (Ref. 3).

References

1. "Design of a 2.5 MW(e) Biomass Gasification Power Generation Module" by R. McLellan, Wellman Process Engineering Ltd., ETSU B/T1/00569, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

3. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

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6. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table J5 Spreadsheet for Greenhouse Gas Outputs from Large-Scale Combined Heat and Power Generation with Industrial Load by Combustion of Wood Chips

Functional Unit:	Electricity and hot water at point of generation from gasification of wood chips
Final Unit of Measurement:	1 GJ of electricity or 1 GJ of hot water at 90^{o}C
Relevant Location:	United Kingdom
Relevant Period:	2000
Allocation Procedures:	None required

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Ash Disposal:		-	-	-	-	-	-	(b)
	GJ	**-**	**-**	**-**	**-**	**-**	**-**	(c)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Totals	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	

Abbreviation

GJ = GJ of electricity or hot water.

Notes

(a) Not specified.

(b) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(c) Ash output of 1.5% of oven dried wood chip input, or 1.772 kg/GJ of electricity or hot water.

APPENDIX K: Generation of Electricity by Combustion of Wood Chips

Figure K1 Flow Chart for the Generation of Electricity by Combustion of Wood Chips

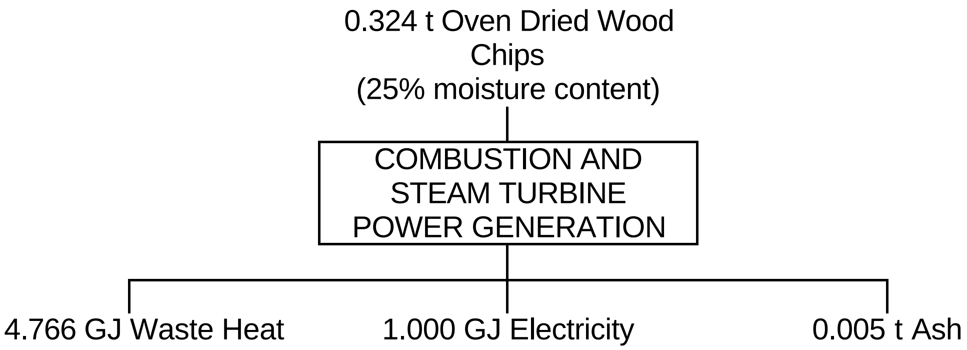

Table K1 Spreadsheet for Primary Energy Inputs to Electricity Generation by Combustion of Wood Chips

Functional Unit:	Electricity at point of generation from combustion of wood chips									
Final Unit of Measurement:	1 GJ of electricity									
Relevant Location:	United Kingdom									
Relevant Period:	1995									
Allocation Procedures:	None required									
Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**102**	**±15**	**-**	**-**	**102**	**±15**	(b, c)
Plant Maintenance:	**GJ**	**-**	**-**	**64**	**±10**	**-**	**-**	**64**	**±10**	(c, d)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(e) (f)
Plant Decommission:	**GJ**	**4**	**±1**	**-**	**-**	**-**	**-**	**4**	**±1**	(b, g)
Totals	**GJ**	**4**	**±1**	**166**	**±18**	**-**	**-**	**170**	**±18**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Not specified.

(b) Primary energy input of 1,050,300 GJ for construction of a wood-fired power only plant consuming 132,808 oven dried tonnes (25% moisture content) of wood chip per year, with a net output rating of 20 MW, an average load factor of 65% and a 25 year life, based on similarities with a straw -fired power only plant (Ref. 1).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 2).

(d) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 3).

(e) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 3).

(f) Ash output of 1.5% of oven dried wood chip input, or 4.859 kg/GJ of electricity (Ref. 4).

(g) Primary energy input to plant decommissioning assumed to be 4% ±1% of the primary energy input to plant construction (Ref. 3).

References

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Table K2 Spreadsheet for Carbon Dioxide Outputs from Electricity Generation by Combustion of Wood Chips

Functional Unit:	Electricity at point of generation by combustion of wood chips
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1995
Allocation Procedures:	None required

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**5**	**±1**	**5**	**±1**	(b, c)
Plant Maintenance:	**GJ**	**-**	**-**	**3**	**±1**	**3**	**±1**	(c, d)
Ash Disposal:		-	-	-	-	-	-	(e)
	GJ	**-**	**-**	**-**	**-**	**-**	**-**	(f)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, g)
Totals	**GJ**	**-**	**-**	**8**	**±1**	**8**	**±1**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Not specified.

(b) Carbon dioxide output of 56,200 tonnes of CO_2 for construction of a wood-fired power only plant consuming 132,808 oven dried tonnes (25% moisture content) of wood chip per year with a net output rating of 20 MW, an average load factor of 65% and a 25 year life, based on similarities with a straw-fired power only plant (Ref. 1).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 2).

(d) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 3).

(e) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 3).

(f) Ash output of 1.5% of oven dried wood chip input, or 4.859 kg/GJ of electricity (Ref. 4).

(g) Carbon dioxide output from plant decommissioning assumed to be 4% ±1% of the carbon dioxide output from plant construction (Ref. 3).

References

1. "Energy and Carbon Analysis of Using Straw as a Fuel" by J. F. Grant, R. Hetherington, R. E. Horne and N. D. Mortimer, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom, 1995.

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Table K3 Spreadsheet for Methane Outputs from Electricity Generation by Combustion of Wood Chips

Functional Unit:	Electricity at point of generation from combustion of wood chips							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	1995							
Allocation Procedures:	None required							
Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Direct Emissions	**GJ**	**0.002**	**-**	**-**	**-**	**0.002**	**-**	(b)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(d, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, h)
Totals	**GJ**	**0.002**	**-**	**-**	**-**	**0.002**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Not specified.

(b) Direct emissions of 0.005 kg CH_4/MJ of wood chips (Ref. 1).

(c) Primary energy input of 1,050,300 GJ for construction of a wood-fired power only plant consuming 132,808 oven dried tonnes (25% moisture content) of wood chip per year with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 21% and a 25 year life, based on similarities with a straw-fired power only plant (Ref. 2), and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 3).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(e) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 5).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 6) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 5).

(g) Ash output of 1.5% of oven dried wood chip input, or 4.859 kg/GJ of electricity (Ref. 6).

(h) Methane output from plant decommissioning assumed to be 4% ±1% of the methane output from plant construction (Ref. 5).

References

1. Private communication with G. Jungmeier, Joanneum Research, Austria, 15 January 2003.

2. "Energy and Carbon Analysis of Using Straw as a Fuel" by J. F. Grant, R. Hetherington, R. E. Horne and N. D. Mortimer, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom, 1995.

3. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

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6. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table K4 Spreadsheet for Nitrous Oxide Outputs from Electricity Generation by Combustion of Wood Chips

Functional Unit:	Electricity at point of generation from combustion of wood chips
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1995
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Direct Emissions	**GH**	**0.019**	**-**	**-**	**-**	**0.019**	**-**	(b)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(d, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, h)
Totals	**GJ**	**0.019**	**-**	**-**	**-**	**0.019**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Not specified.

(b) Direct emissions of 0.004 kg N_2O/MJ of wood chips (Ref. 1).

(c) Primary energy input of 1,050,300 GJ for construction of a wood-fired power only plant consuming 132,808 oven dried tonnes (25% moisture content) of wood chip per year with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 21% and a 25 year life, based on similarities with a straw-fired power only plant (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 3).

(d) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(e) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output from plant construction (Ref. 5).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 6) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{8}$ kg N_2O/t-km (Ref. 5).

(g) Ash output of 1.5% of oven dried wood chip input, or 4.859 kg/GJ of electricity (Ref. 6).

(h) Nitrous oxide output from plant decommissioning assumed to be 4% ±1% of the nitrous oxide output from plant construction (Ref. 5).

References

1. Private communication with G. Jungmeier, Joanneum Research, Austria, 15 January 2003.

2. "Energy and Carbon Analysis of Using Straw as a Fuel" by J. F. Grant, R. Hetherington, R. E. Horne and N. D. Mortimer, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom, 1995.

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6. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table K5 Spreadsheet for Greenhouse Gas Outputs from Electricity Generation by Combustion of Wood Chips

Functional Unit:	Electricity at point of generation from combustion of wood chips							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	1995							
Allocation Procedures:	None required							
Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Direct Emissions	**GJ**	**6**	**-**	**-**	**-**	**6**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**5**	**±1**	**5**	**±1**	(b)
Plant Maintenance:	**GJ**	**-**	**-**	**3**	**±1**	**3**	**±1**	(b)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b) (c)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Totals	**GJ**	**6**	**-**	**8**	**±1**	**14**	**±1**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Not specified.

(b) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(c) Ash output of 1.5% of oven dried wood chip input, or 4.859 kg/GJ of electricity.

APPENDIX L: Generation of Electricity by Gasification of Wood Chips

Figure L1 Flow Chart for the Production of Electricity from Gasification of Wood Chips

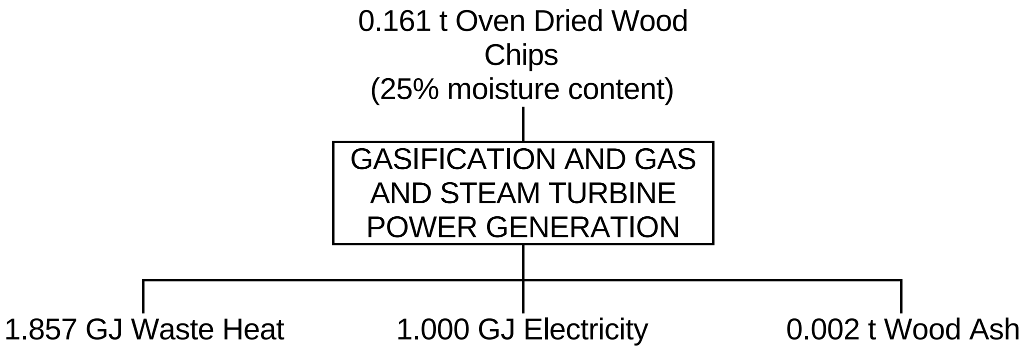

Table L1 Spreadsheet for Primary Energy Inputs to Electricity Generation by Gasification of Wood Chips

Functional Unit:	Electricity at point of generation from gasification of wood chips
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	2001
Allocation Procedures:	None required

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**22**	**±3**	**2**	**±1**	**-**	**-**	**24**	**±4**	(a, b, c)
Plant Construction:	**GJ**	**1**	**-**	**23**	**±3**	**-**	**-**	**24**	**±3**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**15**	**±2**	**-**	**-**	**15**	**±2**	(b, c, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**1**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	(b, h)
Totals	**GJ**	**24**	**±3**	**40**	**±4**	**-**	**-**	**64**	**±5**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Assuming a natural gas start-up fuel consumption of 5,400 GJ/start and a start-up regime of a 1 week cold warm-through during commissioning, 26 cold-starts in the first 6 months, 6 cold-starts in the next 6 months and 2 cold-starts each year for the remaining 24 years of the plant life (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood gasification power only plant with a net electrical output rating of 30.0 MW, a load factor of 85% and a plant life of 25 years, consuming 129,080 oven dried tonnes (25% moisture content) of wood chips per year (Ref. 4).

(d) Primary energy input to plant construction of 483,620 ± 56,775 GJ (Ref. 5).

(e) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 5).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 5).

(g) Ash output of 1.5% of oven dried wood chip input, or 2.408 kg/GJ of electricity (Ref. 4).

(h) Primary energy input to plant decommissioning assumed to be 4% ±1% of the primary energy input to plant construction (Ref. 5).

References

1. Personal communication with Mr. H. Moss, First Renewables Ltd., 18 April 2002.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

3. "Comparison of Transport Fuels: Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles" by. T. Beer, T. Grant, G. Morgan, J. Lapszewicz, P. Anyon, J. Edwards, P. Nelson, H. Watson and D. Williams, CSIRO, Aspendale, Australia, 2002.

4. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

5. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

Table L2 Spreadsheet for Carbon Dioxide Outputs from Electricity Generation by Gasification of Wood Chips

Functional Unit:	Electricity at point of generation by gasification of wood chips							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**1**	**-**	**-**	**-**	**1**	**-**	(a, b, c)
Plant Construction:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b, c, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**1**	**-**	**2**	**-**	**3**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Assuming a natural gas start-up fuel consumption of 5,400 GJ/start and a start-up regime of a 1 week cold warm-through during commissioning, 26 cold-starts in the first 6 months, 6 cold-starts in the next 6 months and 2 cold-starts each year for the remaining 24 years of the plant life (Ref. 1), and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood gasification power only plant with a net electrical output rating of 30.0 MW, a load factor of 85% and a plant life of 25 years, consuming 129,080 oven dried tonnes (25% moisture content) of wood chips per year (Ref. 4).

(d) Carbon dioxide output from plant construction of 21,817 ± 2,522 tonnes of CO_2 (Ref. 5).

(e) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 5).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 5).

(g) Ash output of 1.5% of oven dried wood chip input, or 2.408 kg/GJ of electricity (Ref. 4).

(h) Carbon dioxide output from plant decommissioning assumed to be 4% ±1% of the carbon dioxide output from plant construction (Ref. 5).

References

1. Personal communication with Mr. H. Moss, First Renewables Ltd., 18 April 2002.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

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4. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

5. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

Table L3 Spreadsheet for Methane Outputs from Electricity Generation by Gasification of Wood Chips

Functional Unit:	Electricity at point of generation from gasification of wood chips
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	2001
Allocation Procedures:	None required

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**0.002**	**-**	**0.002**	**-**	(a, b, c)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**-**	**-**	**0.002**	**-**	**0.002**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Assuming a natural gas start-up fuel consumption of 5,400 GJ/start and a start-up regime of a 1 week cold warm-through during commissioning, 26 cold-starts in the first 6 months, 6 cold-starts in the next 6 months and 2 cold-starts each year for the remaining 24 years of the plant life (Ref. 1), and a direct methane requirement of 3.70×10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083×10^{-4} kg CH_4/MJ and a total methane requirement of 1.12×10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood gasification power only plant with a net electrical output rating of 30.0 MW, a load factor of 85% and a plant life of 25 years, consuming 129,080 oven dried tonnes (25% moisture content) of wood chips per year (Ref. 4).

(d) Primary energy input to plant construction of 483,620 ± 56,775 GJ (Ref. 5) and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 6).

(e) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 5).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 5).

(g) Ash output of 1.5% of oven dried wood chip input, or 2.408 kg/GJ of electricity (Ref. 4).

(h) Methane output from plant decommissioning assumed to be 4% ±1% of the methane output from plant construction (Ref. 5).

References

1. Personal communication with Mr. H. Moss, First Renewables Ltd., 18 April 2002.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

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4. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

5. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

6. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

Table L4 Spreadsheet for Nitrous Oxide Outputs from Electricity Generation by Gasification of Wood Chips

Functional Unit:	Electricity at point of generation from gasification of wood chips
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	2001
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a, b, c)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, e)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Assuming a natural gas start-up fuel consumption of 5,400 GJ/start and a start-up regime of a 1 week cold warm-through during commissioning, 26 cold-starts in the first 6 months, 6 cold-starts in the next 6 months and 2 cold-starts each year for the remaining 24 years of the plant life (Ref. 1), and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 2).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood gasification power only plant with a net electrical output rating of 30.0 MW, a load factor of 85% and a plant life of 25 years, consuming 129,080 oven dried tonnes (25% moisture content) of wood chips per year (Ref. 4).

(d) Primary energy input to plant construction of 483,620 ± 56,775 GJ (Ref. 5) and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ of primary energy input to construction (Ref. 6).

(e) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output from plant construction (Ref. 5).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{8} kg N_2O/t-km (Ref. 5).

(g) Ash output of 1.5% of oven dried wood chip input, or 2.408 kg/GJ of electricity (Ref. 4).

(h) Nitrous oxide output from plant decommissioning assumed to be 4% ±1% of the nitrous oxide output from plant construction (Ref. 5).

References

1. Personal communication with Mr. H. Moss, First Renewables Ltd., 18 April 2002.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

3. "Comparison of Transport Fuels: Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles" by. T. Beer, T. Grant, G. Morgan, J. Lapszewicz, P. Anyon, J. Edwards, P. Nelson, H. Watson and D. Williams, CSIRO, Aspendale, Australia, 2002.

4. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

5. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

6. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

Table L5 Spreadsheet for Greenhouse Gas Outputs from Electricity Generation by Gasification of Wood Chips

Functional Unit:	Electricity at point of generation from gasification of wood chips							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**1**	**-**	**-**	**-**	**1**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b)
Plant Maintenance:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b) (c)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Totals	**GJ**	**1**	**-**	**2**	**-**	**3**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Not specified.

(b) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(c) Ash output of 1.5% of oven dried wood chip input, or 2.408 kg/GJ of electricity.

APPENDIX M: Generation of Electricity from Pyrolysis of Wood Chips

Figure M1 Flow Chart for the Production of Electricity from Pyrolysis of Wood Chip

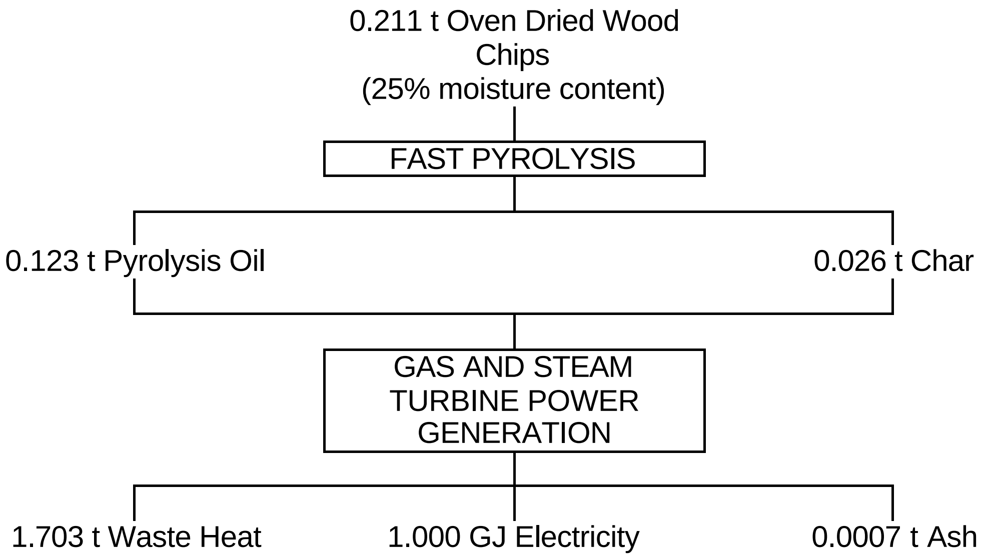

Table M1 Spreadsheet for Primary Energy Inputs to Electricity Generation by Pyrolysis of Wood Chips

Functional Unit:	Electricity at point of generation from pyrolysis of wood chips									
Final Unit of Measurement:	1 GJ of electricity									
Relevant Location:	United Kingdom									
Relevant Period:	2001									
Allocation Procedures:	None required									
Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Process Fuel:	**GJ**	**123**	**±19**	**14**	**±7**	**-**	**-**	**137**	**±20**	(a, b, c)
Plant Construction:	**GJ**	**1**	**-**	**36**	**±3**	**-**	**-**	**37**	**±3**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**19**	**±2**	**-**	**-**	**19**	**±2**	(b, c, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**1**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	(b, h)
Totals	**GJ**	**125**	**±19**	**69**	**±8**	**-**	**-**	**194**	**±20**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Natural gas consumption of 1 MJ/kg of pyrolysis oil or 123 MJ/GJ of electricity generated (Ref. 1), and a gross energy requirement of 1.110 MJ/MJ (Ref. 2).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood pyrolysis power only plant with a net electrical output rating of 20.0 MW, a load factor of 90% and a plant life of 20 years, consuming 119,774 oven dried tonnes (25% moisture content) of wood chip per year (Ref. 1).

(d) Primary energy input to plant construction of 421,499 ± 39,163 GJ (Ref. 4).

(e) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 4).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 5) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 4).

(g) Ash output of 0.42 % of oven dried wood chip input, or 0.700 kg/GJ of electricity (Ref. 1).

(h) Primary energy input to plant decommissioning assumed to be 4% ±1% of the primary energy input to plant construction (Ref. 4).

References

1. "Fast Pyrolysis of Biomass for Green Power Generation" by R. Thamburaij, Orenda Aerospace Corporation, and Dynamotive Energy Systems Corporation, First World Conference and Exhibition on Biomass for Energy and Industry, Seville, Spain, 2000.

2. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

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Table M2 Spreadsheet for Carbon Dioxide Outputs from Electricity Generation by Pyrolysis of Wood Chips

Functional Unit:	Electricity at point of generation by pyrolysis of wood chips							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Process Fuel:	**GJ**	**6**	**±1**	**-**	**-**	**6**	**±1**	(a, b, c)
Plant Construction:	**GJ**	**-**	**-**	**2**	**-**	**2**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b, c, e)
Ash Disposal:		-	-	-	-	-	-	(f)
	GJ	**-**	**-**	**-**	**-**	**-**	**-**	(g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**6**	**±1**	**3**	**-**	**9**	**±1**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Natural gas consumption of 1 MJ/kg of pyrolysis oil or 123 MJ/GJ of electricity generated (Ref. 1), and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 2)

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood pyrolysis power only plant with a net electrical output rating of 20.0 MW, a load factor of 90% and a plant life of 20 years, consuming 119,774 oven dried tonnes (25% moisture content) of wood chip per year (Ref. 1).

(d) Carbon dioxide output from plant construction of 19,840 ± 1,882 tonnes of CO_2 (Ref. 4).

(e) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 4).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 5) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 4).

(g) Ash output of 0.42 % of oven dried wood chip input, or 0.700 kg/GJ of electricity (Ref. 1).

(h) Carbon dioxide output from plant decommissioning assumed to be 4% ±1% of the carbon dioxide output from plant construction (Ref. 4).

References

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Table M3 Spreadsheet for Methane Outputs from Electricity Generation by Pyrolysis of Wood Chips

Functional Unit:	Electricity at point of generation from pyrolysis of wood chips							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Process Fuel:	**GJ**	**-**	**-**	**0.013**	**±0.002**	**0.013**	**±0.002**	(a, b, c)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, e)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**-**	**-**	**0.013**	**±0.002**	**0.013**	**±0.002**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Natural gas consumption of 1 MJ/kg of pyrolysis oil or 123 MJ/GJ of electricity generated (Ref. 1), and a direct methane requirement of 3.70×10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083×10^{-4} kg CH_4/MJ and a total methane requirement of 1.12×10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 2)

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood pyrolysis power only plant with a net electrical output rating of 20.0 MW, a load factor of 90% and a plant life of 20 years, consuming 119,774 oven dried tonnes (25% moisture content) of wood chip per year (Ref. 1).

(d) Primary energy input to plant construction of 421,499 ± 39,163 GJ (Ref. 4) and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 5).

(e) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 4).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 6) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 4).

(g) Ash output of 0.42 % of oven dried wood chip input, or 0.700 kg/GJ of electricity (Ref. 1).

(h) Methane output from plant decommissioning assumed to be 4% ±1% of the methane output from plant construction (Ref. 4).

References

1. "Fast Pyrolysis of Biomass for Green Power Generation" by R. Thamburaij, Orenda Aerospace Corporation, and Dynamotive Energy Systems Corporation, First World Conference and Exhibition on Biomass for Energy and Industry, Seville, Spain, 2000.

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5. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

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Table M4 Spreadsheet for Nitrous Oxide Outputs from Electricity Generation by Pyrolysis of Wood Chips

Functional Unit:	Electricity at point of generation from pyrolysis of wood chips
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	2001
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Process Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a, b, c)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, d)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, c, e)
Ash Disposal:	**GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(f) (g)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, h)
Totals	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Natural gas consumption of 1 MJ/kg of pyrolysis oil or 123 MJ/GJ of electricity generated (Ref. 1), and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 2)

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 3).

(c) Large-scale wood pyrolysis power only plant with a net electrical output rating of 20.0 MW, a load factor of 90% and a plant life of 20 years, consuming 119,774 oven dried tonnes (25% moisture content) of wood chip per year (Ref. 1).

(d) Primary energy input to plant construction of 421,499 ± 39,163 GJ (Ref. 4) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ of primary energy input to construction (Ref. 5).

(e) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output from plant construction (Ref. 4).

(f) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 6) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 4).

(g) Ash output of 0.42 % of oven dried wood chip input, or 0.700 kg/GJ of electricity (Ref. 1).

(h) Nitrous oxide output from plant decommissioning assumed to be 4% ±1% of the nitrous oxide output from plant construction (Ref. 4).

References

1. "Fast Pyrolysis of Biomass for Green Power Generation" by R. Thamburaij, Orenda Aerospace Corporation, and Dynamotive Energy Systems Corporation, First World Conference and Exhibition on Biomass for Energy and Industry, Seville, Spain, 2000.

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Table M5 Spreadsheet for Greenhouse Gas Outputs from Electricity Generation by Pyrolysis of Wood Chips

Functional Unit: Electricity at point of generation from pyrolysis of wood chips
Final Unit of Measurement: 1 GJ of electricity
Relevant Location: United Kingdom
Relevant Period: 2001
Allocation Procedures: None required

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Process Fuel:	GJ	6	±1	-	-	6	±1	(a)
Plant Construction:	GJ	-	-	2	-	2	-	(a)
Plant Maintenance:	GJ	-	-	1	-	1	-	(a)
Ash Disposal:		-	-	-	-	-	-	(b)
	GJ	-	-	-	-	-	-	(b)
Plant Decommission:	GJ	-	-	-	-	-	-	(a)
Totals	GJ	6	±1	3	-	9	±1	

Abbreviation

GJ = GJ of electricity.

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Ash output of 0.42 % of oven dried wood chip input, or 0.700 kg/GJ of electricity.

APPENDIX N: Generation of Electricity by Combustion of Miscanthus

Figure N1 Flow Chart for the Production of Electricity from Combustion of Miscanthus

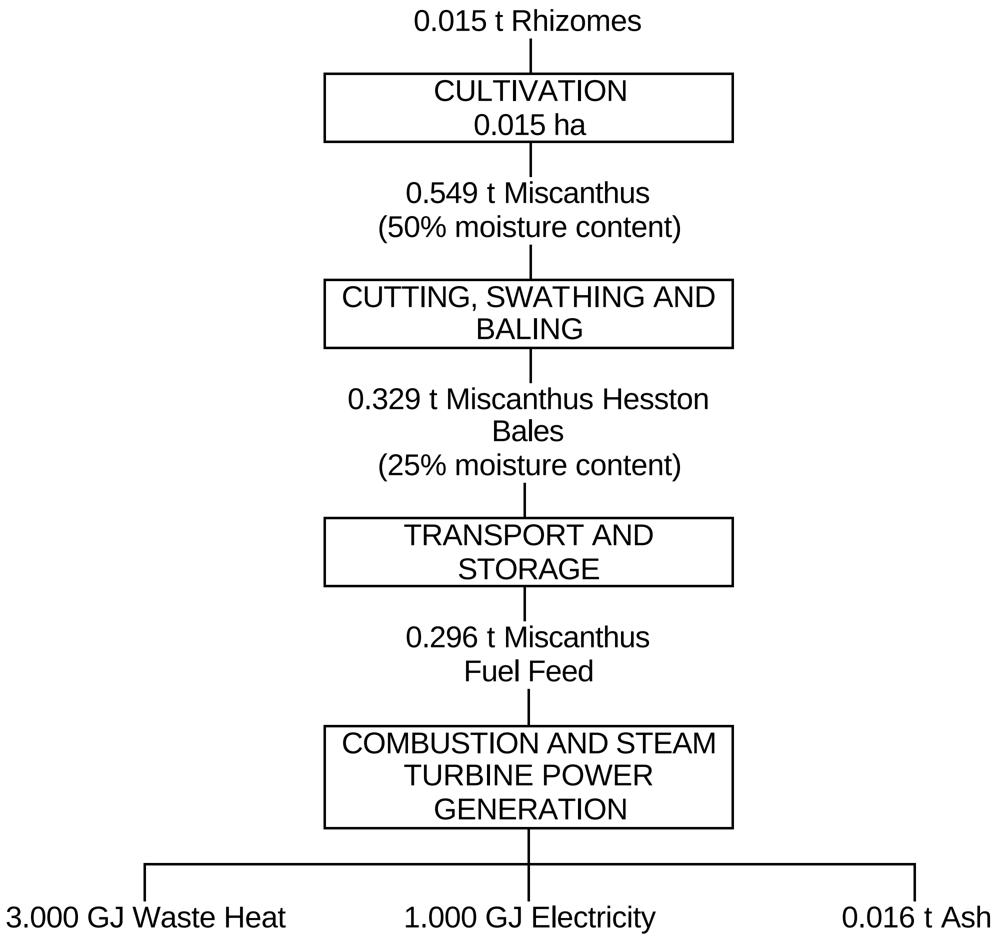

Table N1 Spreadsheet for Primary Energy Inputs to Electricity Generation by Combustion of Miscanthus

Functional Unit:	Electricity at the point of generation from the combustion of miscanthus									
Final Unit of Measurement:	1 GJ of electricity									
Relevant Location:	United Kingdom									
Relevant Period:	1996									
Allocation Procedures:	None required									
Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation:										
- N Fertiliser	*ha.a*	-	-	*74*	*±29*	*140*	*±6*	*214*	*±30*	(a)
- P Fertiliser	*ha.a*	-	-	*76*	*±11*	-	-	*76*	*±11*	(b, c)
- K Fertiliser	*ha.a*	-	-	*47*	*±7*	-	-	*47*	*±7*	(c, d)
- Lime	*ha.a*	-	-	*332*	*±50*	-	-	*332*	*±50*	(c, e)
- Manganese	*ha.a*	-	-	*40*	*±3*	-	-	*40*	*±3*	(c, f)
- Herbicide	*ha.a*	-	-	*1,894*	*±284*	-	-	*1,894*	*±284*	(c, g)
- Rhizomes	*ha.a*	-	-	*421*	*±63*	-	-	*421*	*±63*	(c, h)
- Diesel Fuel	*ha.a*	*477*	*±75*	*52*	*±25*	-	-	*529*	*±79*	(c, i)
Sub-Totals	*ha.a*	*477*	*±75*	*2,936*	*±298*	*140*	*±6*	*3,553*	*±307*	
	GJe	**7**	**±1**	**44**	**±4**	**2**	**-**	**53**	**±5**	(j)
Harvesting:										
- Diesel Fuel	*t mhb*	*53*	*±9*	*6*	*±2*	-	-	*59*	*±9*	(c, k)
	GJe	**17**	**±3**	**2**	**±1**	**-**	**-**	**19**	**±3**	(l)
Storage:										
- Diesel Fuel	*t mff*	*43*	*±7*	*5*	*±2*	-	-	*48*	*±7*	(c, m)
- Barn	*t mff*	-	-	*18*	*±3*	-	-	*18*	*±3*	(c, n)
Sub-Totals	*t mff*	*43*	*±7*	*23*	*±4*	-	-	*66*	*±8*	
	GJe	**13**	**±2**	**7**	**±1**	**-**	**-**	**20**	**±2**	(o)
Transport:										
- Diesel Fuel	*t mff*	*33*	*±1*	*11*	*±1*	-	-	*44*	*±1*	(c, p)
	GJe	**10**	**-**	**3**	**-**	**-**	**-**	**13**	**-**	(o)
Plant Construction:	**GJe**	**-**	**-**	**102**	**±15**	**-**	**-**	**102**	**±15**	(q)
Plant Maintenance	**GJe**	**-**	**-**	**64**	**±10**	**-**	**-**	**64**	**±10**	(r)
Ash Disposal:										
- Diesel Fuel	*t ash*	*33*	*±1*	*11*	-	-	-	*33*	*±1*	(s)
	GJe	**1**	**-**	**-**	**-**			**1**	**-**	(t)
Totals	**GJe**	**48**	**±4**	**222**	**±19**	**2**	**-**	**272**	**±19**	

Abbreviations

ha.a = hectare year
t mhb = tonne of miscanthus Hesston bales
t mff = tonne of miscanthus fuel feed
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 100 kg N /ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.26 kg N/ha.a over the 19 year production period, and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for ammonium nitrate (Ref. 2).

(b) Phosphate fertiliser application rate of 40 kg P/ha, or 92 kg P_2O_5/ ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 4.82 kg P_2O_5/ha.a over the 19 year production period, and a total energy requirement for phosphate fertiliser of 15.8 MJ/kg P_2O_5 (Ref. 3).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 80 kg K/ha, or 96 kg K_2O/ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.07 kg K_2O/ha.a over the 19 year production period, and a total energy requirement for potash fertiliser of 9.3 MJ/ kg K_2O (Ref. 3).

(e) Lime application rate of 3,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 157.89 kg/ha.a over the 19 year production period, and a total energy requirement for lime of 2.1 MJ/kg (Ref. 3).

(f) Manganese application rate of 4 litres of $MnSo_4$/ha.a and a total energy requirement of 10 MJ/litre (Ref. 1).

(g) Advance (bromoxylnil/ioxynil/fluroxynil) herbicide application rate of 2.0 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.105 kg/ha.a over the 19 year production period, Trifolex-Tra (MCPA + MCPB) herbicide application rate of 7.7 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.405 kg/ha.a over the 19 year production period, and glyphosate herbicide application rate of 4.0 litres/ha.a (Ref. 1), with an assumed density of 1 kg/litre, and total energy requirements of 238 MJ/kg for Advance herbicide, 130 MJ/kg for Trifolex-Tra herbicide, and 454 MJ/kg for glyphosate herbicide (Ref. 1).

(h) Rhizome planting rate of 1,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual rate of 52.63 kg/ha.a over the 19 year production period, and a total energy requirement of 8 MJ/kg (Ref. 1).

(i) Effective diesel fuel consumption for land preparation of 118 MJ/ha.a, for planting of 109 MJ/ha.a, for fertiliser application of 125 MJ/ha.a, and for herbicide application of 125 MJ/ha.a (Ref. 1), and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(j) Land requirement of 0.015 ha/GJ of electricity, based on an effective annual yield of 36 tonnes of miscanthus (50% moisture content)/ha.a, 10% losses during harvesting, 10% losses during storage, a calorific value for miscanthus of 18 MJ/ dry miscanthus (25% moisture content) and a thermal efficiency of 18.77% for a combustion power only plant.

(k) Diesel fuel consumption for cutting, swathing, baling, loading, carting and transferring of miscanthus of 52.8 MJ/t of miscanthus Hesston bales (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(l) Requirement for miscanthus in Hesston bales of 0.329 tonnes/GJ of electricity.

(m) Effective diesel fuel consumption of handling of 42.9 MJ/t of miscanthus fuel feed (Ref. 1) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(n) Effective total energy requirement of open-sided storage barn of 17.9 MJ/t of miscanthus Hesston bales (Ref. 1), or 19.9 MJ/t of miscanthus fuel feed.

(o) Miscanthus fuel feed requirement of 0.296 t/GJ of electricity.

(p) Average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 6).

(q) Primary energy input of 1,050,300 GJ for construction of miscanthus-fired power only plant consuming 121,350 tonnes of miscanthus fuel feed per year, based on a straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% and a 25 year life (Ref. 7).

(r) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 6).

(s) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 6).

(t) Ash output of 5.5% of miscanthus fuel feed, or 16 kg/GJ of electricity, based on ash output of straw-fired power only plant (Ref. 2).

References

1. "Estimating the Energy Requirements and CO_2 Emissions from Production of the Perennial Grasses Miscanthus, Switchgrass and Reed Canary Grass" by M. Bullard and P. Metcalfe, Report ETSU B/U1/00645, Energy Technology Support Unit, Harwell, United Kingdom, 2001.

2. "Evaluation of the Comparative Energy, Global Warming and Social Costs and Benefits of Biodiesel" by N. D. Mortimer, P. Cormack, M. A. Elsayed and R. E. Horne, Resources Research Unit, Sheffield Hallam University, United Kingdom, January 2003.

3. "Nachwachsende Energieträger – Grundlagen, Verfaben, Ökologische Bilanzierung" (Renewable Energy Sources, Basis, Processes and Ecological Balance) by M. Kaltschmitt and G. A. Reinhardt (eds), Vieweg, Braunschweig/Weisbaden, Germany, 1997.

4. "Comparison of Transport Fuels: Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles" by. T. Beer, T. Grant, G. Morgan, J. Lapszewicz, P. Anyon, J. Edwards, P. Nelson, H. Watson and D. Williams, CSIRO, Aspendale, Australia, 2002.

5. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

6. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

7. "Energy and Carbon Analysis of Using Straw as a Fuel" by J. F. Grant, R. Hetherington, R. E. Horne and N. D. Mortimer, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom, 1995.

Table N2 Spreadsheet for Carbon Dioxide Outputs Electricity Generation by Combustion of Miscanthus

Functional Unit:	Electricity at the point of generation from the combustion of miscanthus
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- N Fertiliser	*ha.a*	-	-	*10*	*±1*	*10*	*±1*	(a)
- P Fertiliser	*ha.a*	-	-	*3*	*±1*	*3*	*±1*	(b, c)
- K Fertiliser	*ha.a*	-	-	*2*	-	*2*	-	(c, d)
- Lime	*ha.a*	-	-	*28*	*±4*	*28*	*±4*	(c, e)
- Manganese	*ha.a*	-	-	*3*	-	*3*	-	(c, f)
- Herbicide	*ha.a*	-	-	*111*	*±17*	*111*	*±17*	(c, g)
- Rhizomes	*ha.a*	-	-	*280*	*±42*	*280*	*±42*	(c, h)
- Diesel Fuel	*ha.a*	*33*	*±5*	*4*	*±2*	*37*	*±6*	(c, i)
Sub-Totals	*ha.a*	*33*	*±5*	*441*	*±46*	*474*	*±46*	
	GJe	**-**	**-**	**7**	**±1**	**7**	**±1**	(j)
Harvesting:								
- Diesel Fuel	*t mhb*	*4*	*±1*	-	-	*4*	*±1*	(c, k)
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(l)
Storage:								
- Diesel Fuel	*t mff*	*3*	-	-	-	*3*	-	(c, m)
- Barn	*t mff*	-	-	-	-	-	-	(c, n)
Sub-Totals	*t mff*	*3*	-	-	-	*3*	-	
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(o)
Transport:								
- Diesel Fuel	*t mff*	*2*	-	*1*	-	*3*	-	(c, p)
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(o)
Plant Construction:	**GJe**	**-**	**-**	**5**	**±1**	**5**	**±1**	(q)
Plant Maintenance	**GJe**	**-**	**-**	**3**	**-**	**3**	**-**	(r)
Ash Disposal:								
- Diesel Fuel	*t ash*	*2*	-	*1*	-	*3*	-	(s)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(t)
Totals	**GJe**	**3**	**-**	**15**	**±1**	**18**	**±1**	

Abbreviations

ha.a = hectare year
t mhb = tonne of miscanthus Hesston bales
t mff = tonne of miscanthus fuel feed
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 100 kg N /ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.26 kg N/ha.a over the 19 year production period, and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 2).

(b) Phosphate fertiliser application rate of 40 kg P/ha, or 92 kg P_2O_5/ ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 4.82 kg P_2O_5/ha.a over the 19 year production period, and a total carbon requirement for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 (Ref. 3).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 80 kg K/ha, or 96 kg K_2O/ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.07 kg K_2O/ha.a over the 19 year production period, and a total carbon requirement for potash fertiliser of 0.453 kg CO_2/ kg K_2O (Ref. 3).

(e) Lime application rate of 3,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 157.89 kg/ha.a over the 19 year production period, and a total carbon requirement for lime of 0.179 kg CO_2/kg CaO (Ref. 3).

(f) Manganese application rate of 4 litres of $MnSo_4$/ha.a and a total carbon requirement of 0.750 kg CO_2/litre (Ref. 1).

(g) Advance (bromoxylnil/ioxynil/fluroxynil) herbicide application rate of 2.0 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.105 kg/ha.a over the 19 year production period, Trifolex-Tra (MCPA + MCPB) herbicide application rate of 7.7 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.405 kg/ha.a over the 19 year production period, and glyphosate herbicide application rate of 4.0 litres/ha.a (Ref. 1), with an assumed density of 1 kg/litre, and total carbon requirements of 14 kg CO_2/kg for Advance herbicide, 14 kg CO_2/kg for Trifolex-Tra herbicide, and 26 kg CO_2/kg for glyphosate herbicide (Ref. 1).

(h) Rhizome planting rate of 1,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual rate of 52.63 kg/ha.a over the 19 year production period, and a total carbon requirement of 0.28 kg CO_2/kg (Ref. 1).

(i) Effective diesel fuel consumption for land preparation of 118 MJ/ha.a, for planting of 109 MJ/ha.a, for fertiliser application of 125 MJ/ha.a, and for herbicide application of 125 MJ/ha.a (Ref. 1), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(j) Land requirement of 0.015 ha/GJ of electricity, based on an effective annual yield of 36 tonnes of miscanthus (50% moisture content)/ha.a, 10% losses during harvesting, 10% losses during storage, a calorific value for miscanthus of 18 MJ/ dry miscanthus (25% moisture content) and a thermal efficiency of 18.77% for a combustion power only plant.

(k) Diesel fuel consumption for cutting, swathing, baling, loading, carting and transferring of miscanthus of 52.8 MJ/t of miscanthus Hesston bales (Ref. 1) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(l) Requirement for miscanthus in Hesston bales of 0.329 tonnes/GJ of electricity.

(m) Effective diesel fuel consumption of handling of 42.9 MJ/t of miscanthus fuel feed (Ref. 1) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(n) Effective total energy requirement of open-sided storage barn of 0.410 kg CO_2/t of miscanthus Hesston bales (Ref. 1), or 0.456 kg CO_2/t of miscanthus fuel feed.

(o) Miscanthus fuel feed requirement of 0.296 t/GJ of electricity.

(p) Average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

(q) Carbon dioxide output of 56,200 tonnes of CO_2 for construction of miscanthus-fired power only plant consuming 121,350 tonnes of miscanthus fuel feed per year, based on a straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% and a 25 year life (Ref. 7).

(r) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 6).

(s) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

(t) Ash output of 5.5% of miscanthus fuel feed, or 16 kg/GJ of electricity, based on ash output of straw-fired power only plant (Ref. 2).

References

1. "Estimating the Energy Requirements and CO_2 Emissions from Production of the Perennial Grasses Miscanthus, Switchgrass and Reed Canary Grass" by M. Bullard and P. Metcalfe, Report ETSU B/U1/00645, Energy Technology Support Unit, Harwell, United Kingdom, 2001.

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7. "Energy and Carbon Analysis of Using Straw as a Fuel" by J. F. Grant, R. Hetherington, R. E. Horne and N. D. Mortimer, Report ETSU B/M4/00487/01, Energy Technology Support Unit, Harwell, United Kingdom, 1995.

Table N3 Spreadsheet for Methane Outputs Electricity Generation by Combustion of Miscanthus

Functional Unit:	Electricity at the point of generation from the combustion of miscanthus
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Methane Output (kg CH_4)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- N Fertiliser	*ha.a*	-	-	*0.019*	*±0.003*	*0.019*	*±0.003*	(a)
- P Fertiliser	*ha.a*	-	-	-	-	-	-	(b, c)
- K Fertiliser	*ha.a*	-	-	-	-	-	-	(c, d)
- Lime	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c, e)
- Manganese	*ha.a*	-	-	-	-	-	-	(c, f)
- Herbicide	*ha.a*	-	-	-	-	-	-	(c, g)
- Rhizomes	*ha.a*	-	-	-	-	-	-	(c, h)
- Diesel Fuel	*ha.a*	-	-	*0.010*	*±0.001*	*0.010*	*±0.001*	(c, i)
Sub-Totals	*ha.a*	-	-	*0.030*	*±0.003*	*0.030*	*±0.003*	
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(j)
Harvesting:								
- Diesel Fuel	*t mhb*	-	-	-	-	-	-	(c, k)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(l)
Storage:								
- Diesel Fuel	*t mff*	-	-	*0.001*	-	*0.001*	-	(c, m)
- Barn	*t mff*	-	-	-	-	-	-	(c, n)
Sub-Totals	*t mff*	-	-	*0.001*	-	*0.001*	-	
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Transport:								
- Diesel Fuel	*t mff*	-	-	*0.001*	-	*0.001*	-	(c, p)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Direct Emissions	**GJe**	**0.008**	**-**	**-**	**-**	**0.008**	**-**	(q, r)
Plant Construction:								
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Plant Maintenance								
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Ash Disposal:								
- Diesel Fuel	*t ash*	-	-	*0.001*	-	*0.001*	-	(t)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Totals	**GJe**	**0.008**	**-**	**-**	**-**	**0.008**	**-**	

Abbreviations

ha.a	= hectare year
t mhb	= tonne of miscanthus Hesston bales
t mff	= tonne of miscanthus fuel feed
t ash	= tonne of ash
GJe	= GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 100 kg N /ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.26 kg N/ha.a over the 19 year production period, and a total methane requirement for ammonium nitrate of $3.6 \times 10^{-3} \pm 0.6 \times 10^{-3}$ kg CH_4/kg N (Ref. 2).

(b) Phosphate fertiliser application rate of 40 kg P/ha, or 92 kg P_2O_5/ ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 4.82 kg P_2O_5/ha.a over the 19 year production period, and total methane requirement for phosphate fertiliser of 2.3×10^{-5} kg CH_4/kg P_2O_5 (Ref. 3).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 80 kg K/ha, or 96 kg K_2O/ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.07 kg K_2O/ha.a over the 19 year production period, and a total methane requirement for potash fertiliser of 2.1×10^{-5} kg CH_4/ kg K_2O (Ref. 3).

(e) Lime application rate of 3,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 157.89 kg/ha.a over the 19 year production period, and total methane requirement for lime of 3.9×10^{-6} kg CH_4/kg CaO (Ref. 3).

(f) Manganese application rate of 4 litres of $MnSo_4$/ha.a and a total energy requirement of 10 MJ/litre (Ref. 1), with an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 5).

(g) Advance (bromoxylnil/ioxynil/fluroxynil) herbicide application rate of 2.0 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.105 kg/ha.a over the 19 year production period, Trifolex-Tra (MCPA + MCPB) herbicide application rate of 7.7 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.405 kg/ha.a over the 19 year production period, and glyphosate herbicide application rate of 4.0 litres/ha.a (Ref. 1), with an assumed density of 1 kg/litre, and total energy requirements of 238 MJ/kg for Advance herbicide, 130 MJ/kg for Trifolex-Tra herbicide, and 454 MJ/kg for glyphosate herbicide (Ref. 1), with an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 5).

(h) Rhizome planting rate of 1,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual rate of 52.63 kg/ha.a over the 19 year production period, and a total energy requirement of 8 MJ/kg (Ref. 1), with an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input (Ref. 5).

(i) Effective diesel fuel consumption for land preparation of 118 MJ/ha.a, for planting of 109 MJ/ha.a, for fertiliser application of 125 MJ/ha.a, and for herbicide application of 125 MJ/ha.a (Ref. 1), and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(j) Land requirement of 0.015 ha/GJ of electricity, based on an effective annual yield of 36 tonnes of miscanthus (50% moisture content)/ha.a, 10% losses during harvesting, 10% losses during storage, a calorific value for miscanthus of 18 MJ/ dry miscanthus (25% moisture content) and a thermal efficiency of 18.77% for a combustion power only plant.

(k) Diesel fuel consumption for cutting, swathing, baling, loading, carting and transferring of miscanthus of 52.8 MJ/t of miscanthus Hesston bales (Ref. 1) and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(l) Requirement for miscanthus in Hesston bales of 0.329 tonnes/GJ of electricity.

(m) Effective diesel fuel consumption of handling of 42.9 MJ/t of miscanthus fuel feed (Ref. 1) and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(n) Effective total energy requirement of open-sided storage barn of 17.9 MJ/t of miscanthus Hesston bales (Ref. 1), or 19.9 MJ/t of miscanthus fuel feed, with an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 5).

(o) Miscanthus fuel feed requirement of 0.296 t/GJ of electricity.

(p) Average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 7).

(q) Direct emissions of 0.002 g CH_4/MJ of miscanthus fuel feed (Ref. 8).

(r) Primary energy input of 1,050,300 GJ for construction of miscanthus-fired power only plant consuming 121,350 tonnes of miscanthus fuel feed per year, based on a straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% and a 25 year life (Ref. 9), with an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 5).

(s) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 7).

(t) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 7).

(u) Ash output of 5.5% of miscanthus fuel feed, or 16 kg/GJ of electricity, based on ash output of straw-fired power only plant (Ref. 2).

References

1. "Estimating the Energy Requirements and CO_2 Emissions from Production of the Perennial Grasses Miscanthus, Switchgrass and Reed Canary Grass" by M. Bullard and P. Metcalfe, Report ETSU B/U1/00645, Energy Technology Support Unit, Harwell, United Kingdom, 2001.

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Table N4 Spreadsheet for Nitrous Oxide Outputs Electricity Generation by Combustion of Miscanthus

Functional Unit:	Electricity at the point of generation from the combustion of miscanthus							
Final Unit of Measurement:	1 GJ of electricity							
Relevant Location:	United Kingdom							
Relevant Period:	1996							
Allocation Procedures:	None required							
Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- N Fertiliser	*ha.a*	*0.019*	*±0.003*	*0.077*	*±0.012*	*0.096*	*±0.012*	(a)
- P Fertiliser	*ha.a*	-	-	-	-	-	-	(b, c)
- K Fertiliser	*ha.a*	-	-	-	-	-	-	(c, d)
- Lime	*ha.a*	-	-	*0.003*	-	*0.003*	-	(c, e)
- Manganese	*ha.a*	-	-	-	-	-	-	(c, f)
- Herbicide	*ha.a*	-	-	-	-	-	-	(c, g)
- Rhizomes	*ha.a*	-	-	-	-	-	-	(c, h)
- Diesel Fuel	*ha.a*	-	-	-	-	-	-	(c, i)
Sub-Totals	*ha.a*	*0.019*	*±0.003*	*0.080*	*±0.012*	*0.099*	*±0.012*	
	GJe	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(j)
Harvesting:								
- Diesel Fuel	*t mhb*	-	-	-	-	-	-	(c, k)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(l)
Storage:								
- Diesel Fuel	*t mff*	-	-	-	-	-	-	(c, m)
- Barn	*t mff*	-	-	-	-	-	-	(c, n)
Sub-Totals	*t mff*	-	-	-	-	-	-	
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Transport:								
- Diesel Fuel	*t mff*	-	-	-	-	-	-	(c, p)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Direct Emissions	**GJe**	**0.020**	**-**	**-**	**-**	**0.020**	**-**	(q, r)
Plant Construction:	**GJe**	**-**	**-**	**-**	**-**	**-**	**-**	(r)
Plant Maintenance	**GJe**	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Ash Disposal:								
- Diesel Fuel	*t ash*	-	-	-	-	-	-	(t)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Totals	**GJe**	**0.020**	**-**	**0.001**	**-**	**0.021**	**-**	

Abbreviations

ha.a	= hectare year
t mhb	= tonne of miscanthus Hesston bales
t mff	= tonne of miscanthus fuel feed
t ash	= tonne of ash
GJe	= GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 100 kg N /ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.26 kg N/ha.a over the 19 year production period, and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 2), an indirect nitrous oxide requirement of 0.0147 kg N_2O/kg N (Ref. 3) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 3).

(b) Phosphate fertiliser application rate of 40 kg P/ha, or 92 kg P_2O_5/ ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 4.82 kg P_2O_5/ha.a over the 19 year production period, and with a total nitrous oxide requirement for phosphate fertiliser of 4.2×10^{-5} kg N_2O/kg P_2O_5 (Ref. 2).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 80 kg K/ha, or 96 kg K_2O/ha, during establishment in the first year (Ref. 1), giving an effective annual application rate of 5.07 kg K_2O/ha.a over the 19 year production period, and a total nitrous oxide requirement for potash fertiliser of 9.4×10^{-6} kg N_2O/ kg K_2O (Ref. 2).

(e) Lime application rate of 3,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual application rate of 157.89 kg/ha.a over the 19 year production period, and a total nitrous oxide requirement for lime of 1.6 x 10^{-5} kg N_2O/kg CaO (Ref. 2).

(f) Manganese application rate of 4 litres of $MnSo_4$/ha.a and a total energy requirement of 10 MJ/litre (Ref. 1), with an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 5).

(g) Advance (bromoxylnil/ioxynil/fluroxynil) herbicide application rate of 2.0 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.105 kg/ha.a over the 19 year production period, Trifolex-Tra (MCPA + MCPB) herbicide application rate of 7.7 litres/ha, with an assumed density of 1 kg/litre, during establishment in the first year (Ref. 1), giving an effective annual application rate of 0.405 kg/ha.a over the 19 year production period, and glyphosate herbicide application rate of 4.0 litres/ha.a (Ref. 1), with an assumed density of 1 kg/litre, and total energy requirements of 238 MJ/kg for Advance herbicide, 130 MJ/kg for Trifolex-Tra herbicide, and 454 MJ/kg for glyphosate herbicide (Ref. 1), with an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 5).

(h) Rhizome planting rate of 1,000 kg/ha during establishment in the first year (Ref. 1), giving an effective annual rate of 52.63 kg/ha.a over the 19 year production period, and a total energy requirement of 8 MJ/kg (Ref. 1), with an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input (Ref. 5).

(i) Effective diesel fuel consumption for land preparation of 118 MJ/ha.a, for planting of 109 MJ/ha.a, for fertiliser application of 125 MJ/ha.a, and for herbicide application of 125 MJ/ha.a (Ref. 1), and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 6).

(j) Land requirement of 0.015 ha/GJ of electricity, based on an effective annual yield of 36 tonnes of miscanthus (50% moisture content)/ha.a, 10% losses during harvesting, 10% losses during storage, a calorific value for miscanthus of 18 MJ/ dry miscanthus (25% moisture content) and a thermal efficiency of 18.77% for a combustion power only plant.

(k) Diesel fuel consumption for cutting, swathing, baling, loading, carting and transferring of miscanthus of 52.8 MJ/t of miscanthus Hesston bales (Ref. 1) and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 6).

(l) Requirement for miscanthus in Hesston bales of 0.329 tonnes/GJ of electricity.

(m) Effective diesel fuel consumption of handling of 42.9 MJ/t of miscanthus fuel feed (Ref. 1) and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 6).

(n) Effective total energy requirement of open-sided storage barn of 17.9 MJ/t of miscanthus Hesston bales (Ref. 1), or 19.9 MJ/t of miscanthus fuel feed, with an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 5).

(o) Miscanthus fuel feed requirement of 0.296 t/GJ of electricity.

(p) Average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 7).

(q) Direct emissions of 0.005 g N_2O/MJ of miscanthus fuel feed (Ref. 8).

(r) Primary energy input of 1,050,300 GJ for construction of miscanthus-fired power only plant consuming 121,350 tonnes of miscanthus fuel feed per year, based on a straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% and a 25 year life (Ref. 9), with an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 5).

(s) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output from plant construction (Ref. 7).

(t) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 40 km (Ref. 1) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{8} kg N_2O/t-km (Ref. 7).

(u) Ash output of 5.5% of miscanthus fuel feed, or 16 kg/GJ of electricity, based on ash output of straw-fired power only plant (Ref. 2).

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Table N5 Spreadsheet for Greenhouse Gas Outputs Electricity Generation by Combustion of Miscanthus

Functional Unit:	Electricity at the point of generation from the combustion of miscanthus
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation:								
- N Fertiliser	*ha.a*	*6*	*±1*	*35*	*±4*	*41*	*±4*	(a)
- P Fertiliser	*ha.a*	-	-	*3*	*±1*	*3*	*±1*	(a)
- K Fertiliser	*ha.a*	-	-	*2*	-	*2*	-	(a)
- Lime	*ha.a*	-	-	*29*	*±4*	*29*	*±4*	(a)
- Manganese	*ha.a*	-	-	*3*	-	*3*	-	(a)
- Herbicide	*ha.a*	-	-	*111*	*±17*	*111*	*±17*	(a)
- Rhizomes	*ha.a*	-	-	*280*	*±42*	*280*	*±42*	(a)
- Diesel Fuel	*ha.a*	*33*	*±5*	*4*	*±2*	*37*	*±6*	(a)
Sub-Totals	*ha.a*	*39*	*±5*	*467*	*±46*	*506*	*±46*	
	GJe	**1**	**-**	**7**	**±1**	**8**	**±1**	(b)
Harvesting:								
- Diesel Fuel	*t mhb*	*4*	*±1*	-	-	*4*	*±1*	(a)
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(c)
Storage:								
- Diesel Fuel	*t mff*	*3*	-	-	-	*3*	-	(a)
- Barn	*t mff*	-	-	-	-	-	-	(a)
Sub-Totals	*t mff*	*3*	-	-	-	*3*	-	
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(d)
Transport:								
- Diesel Fuel	*t mff*	*2*	-	*1*	-	*3*	-	(a)
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(d)
Direct Emissions	**GJe**	**7**	**-**	**-**	**-**	**7**	**-**	(a)
Plant Construction:	**GJe**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a)
Plant Maintenance	**GJe**	**-**	**-**	**3**	**-**	**3**	**-**	(a)
Ash Disposal:								
- Diesel Fuel	*t ash*	*2*	-	*1*	-	*3*	-	(a)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(e)
Totals		**11**	**-**	**15**	**±1**	**26**	**±1**	

Abbreviations

ha.a = hectare year
t mhb = tonne of miscanthus Hesston bales
t mff = tonne of miscanthus fuel feed
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 0.015 ha/GJ of electricity, based on an effective annual yield of 36 tonnes of miscanthus (50% moisture content)/ha.a, 10% losses during harvesting, 10% losses during storage, a calorific value for miscanthus of 18 MJ/ dry miscanthus (25% moisture content) and a thermal efficiency of 18.77% for a combustion power only plant.

(c) Requirement for miscanthus in Hesston bales of 0.329 tonnes/GJ of electricity.

(d) Miscanthus fuel feed requirement of 0.296 t/GJ of electricity.

(e) Ash output of 5.5% of miscanthus fuel feed, or 16 kg/GJ of electricity, based on ash output of straw -fired power only plant.

APPENDIX O:Generation of Electricity by Combustion of Straw

Figure O1 Flow Chart for the Production of Electricity by Combustion of Straw

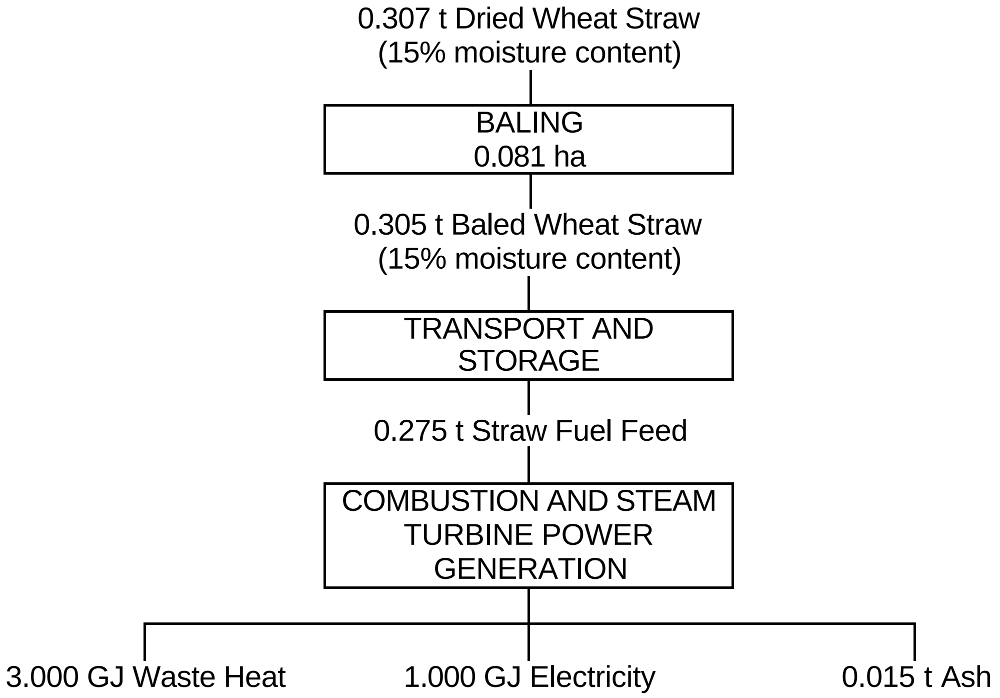

Table O1 Spreadsheet for Primary Energy Inputs to Electricity Generation by Combustion of Wheat Straw

Functional Unit:	Electricity at point of generation obtained by combustion of wheat straw
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Primary Energy Input (MJ)								Notes
		Direct		Indirect		Feedstock		Total		
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:										
- N Fertiliser	*ha.a*	-	-	*862*	*±342*	*1,636*	*±65*	*2,498*	*±348*	(a)
- P Fertiliser	*ha.a*	-	-	*411*	*±62*	-	-	*411*	*±62*	(b, c)
- K Fertiliser	*ha.a*	-	-	*1,218*	*±183*	-	-	*1,218*	*±183*	(c, d)
- Diesel Fuel	*ha.a*	*370*	*±59*	*41*	*±20*	-	-	*411*	*±62*	(c, e)
- Machinery	*ha.a*	-	-	*437*	*±66*	-	-	*437*	*±66*	(c, f)
- Twine	*ha.a*	-	-	-	-	*102*	*±15*	*102*	*±15*	(c, g)
- Maintenance	*ha.a*	-	-	*188*	*±28*	-	-	*188*	*±28*	(c, h)
Reference System:										
- Diesel Fuel	*ha.a*	*- 787*	*±124*	*- 86*	*±41*	-	-	*- 873*	*±131*	(c, i)
- Machinery	*ha.a*	-	-	*- 199*	*±30*	-	-	*- 199*	*±30*	(c, j)
- Maintenance	*ha.a*	-	-	*- 107*	*±16*	-	-	*- 107*	*±16*	(c, k)
- Crop Loss	*ha.a*	*- 59*	*±9*	-		-	-	*- 59*	*±9*	(c, l)
Sub-Totals	*ha.a*	*- 476*	*±138*	*2,765*	*±403*	*1,738*	*±67*	*4,027*	*±431*	
	GJe	**- 39**	**±11**	**224**	**±33**	**141**	**±5**	**326**	**±35**	(m)
Transport:										
- Diesel Fuel	*t bws*	*66*	*±2*	*23*	*±3*	-	-	*89*	*±4*	(n)
	GJe	**20**	**±1**	**7**	**±1**	**-**	**-**	**27**	**±1**	(o)
Storage:										
- Diesel Fuel	*t bws*	*66*	*±10*	*7*	*±3*	-	-	*73*	*±11*	(c, p)
- Sheeting	*t bws*	-	-	*94*	*±14*	*92*	*±14*	*186*	*±20*	(c, q)
- Machinery	*t bws*	-	-	*21*	*±3*	-	-	*21*	*±3*	(c, r)
- Maintenance	*t bws*	-	-	*7*	*±1*	-	-	*7*	*±1*	(c, s)
Sub-Totals	*t bws*	*66*	*±10*	*129*	*±15*	*92*	*±14*	*287*	*±23*	
	GJe	**20**	**±3**	**39**	**±5**	**28**	**±4**	**87**	**±7**	(o)
Plant Construction	**GJe**	**-**	**-**	**102**	**±15**	**-**	**-**	**102**	**±15**	(c, t)
Plant Maintenance	**GJe**	**-**	**-**	**64**	**±10**	**-**	**-**	**64**	**±10**	(u)
Ash Disposal:										
- Diesel Fuel	*t ash*	*66*	*±2*	*23*	*±3*	-	-	*89*	*±4*	(v)
	GJe	**1**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	(w)
Totals	**GJe**	**2**	**±11**	**436**	**±38**	**168**	**±6**	**607**	**±40**	

Abbreviations

ha.a	= hectare year
t bws	= tonne of baled wheat straw
t ash	= tonne of ash
GJe	= GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for ammonium nitrate (Ref. 3).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total energy requirement for phosphate fertiliser of 15.8 MJ/kg P_2O_5 (Ref. 4).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total energy requirement for potash fertiliser of 9.3 MJ/ kg K_2O (Ref. 4).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(f) Primary energy input to manufacture of tractor for baling of 55.9 MJ/ha.a, Hesston baler of 336.9 MJ/ha.a and telescopic handler for loading in field of 44.1 MJ/ha.a (Ref. 2).

(g) Primary energy input to manufacture of baling twine of 101.8 MJ/ha.a (Ref. 2).

(h) Primary energy input to maintenance and repair of tractor for baling of 14.3 MJ/ha.a, of Hesston baler of 158.9 MJ/ha.a and of telescopic handler for loading in the field of 15.2 MJ/ha.a (Ref. 2).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 2).

(j) Primary energy input to manufacture of straw chopper of 71.9 MJ/ha.a, of tractor of 93.3 MJ/ha.a and straw incorporating cultivator of 33.5 MJ/ha.a (Ref. 2).

(k) Primary energy input to maintenance of straw chopper of 36.8 MJ/ha.a, of tractor of 24.3 MJ/ha.a and straw incorporating cultivator of 46.1 MJ/ha.a (Ref. 2).

(l) Primary energy input of 58.8 MJ/ha.a for extra cultivation due to loss in yield of following crop (Ref. 2).

(m) Land requirement of 0.081 ha.a/GJ of electricity based on an average dried wheat straw yield of 3.78 t/ha.a, 0.65% straw losses in baling, 10.00% straw losses in storage and a straw fuel feed requirement of 0.275 t/GJ of electricity.

(n) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 7).

(o) Baled wheat straw requirement of 0.305 t/GJ of electricity.

(p) Diesel fuel consumption for baled straw handling in storage of 65.8 MJ/t of baled wheat straw (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(q) Based on 2 tonnes of polyethylene sheeting used to protect each storage stack of 1,000 tonnes of baled wheat straw, with a life of 1 year and a direct energy requirement of 47 MJ/kg and a feedstock energy requirement of 46 MJ/kg for low density polyethylene (Ref. 2).

(r) Primary energy input for manufacture of telescopic handler of 21.0 MJ/t of baled wheat straw (Ref. 2).

(s) Primary energy input to maintenance and repair of telescopic handler of 7.2 MJ/t of baled wheat straw (Ref. 2).

(t) Primary energy input of 1,050,300 GJ for construction of straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% and a 25 year life (Ref. 2).

(u) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 7).

(v) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 7).

(w) Ash output of 5.5% of straw fuel feed, or 15 kg/GJ of electricity (Ref. 2).

<u>References</u>

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Table O2 Spreadsheet for Carbon Dioxide Outputs from Electricity Generation by Combustion of Wheat Straw

Functional Unit:	Electricity at point of generation obtained by combustion of wheat straw
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*117*	*±17*	*117*	*±17*	(a)
- P Fertiliser	*ha.a*	-	-	*18*	*±3*	*18*	*±3*	(b, c)
- K Fertiliser	*ha.a*	-	-	*59*	*±9*	*59*	*±9*	(c, d)
- Diesel Fuel	*ha.a*	*25*	*±4*	*3*	-	*28*	*±4*	(c, e)
- Machinery	*ha.a*	-	-	*20*	*±3*	*20*	*±3*	(c, f)
- Twine	*ha.a*	-	-	*8*	*±1*	*8*	*±1*	(c, g)
- Maintenance	*ha.a*	-	-	*9*	*±1*	*9*	*±1*	(c, h)
Reference System:								
- Diesel Fuel	*ha.a*	*- 54*	*±7*	*- 6*	*±3*	*- 60*	*±8*	(c, i)
- Machinery	*ha.a*	-	-	*- 9*	*±3*	*- 9*	*±3*	(c, j)
- Maintenance	*ha.a*	-	-	*- 5*	*±1*	*- 5*	*±1*	(c, k)
- Crop Loss	*ha.a*	*- 3*	-	-	-	*- 3*	-	(c, l)
Sub-Totals	*ha.a*	*- 32*	*±8*	*214*	*±20*	*182*	*±22*	
	GJe	**- 3**	**±1**	**17**	**±2**	**14**	**±2**	(m)
Transport:								
- Diesel Fuel	*t bws*	*4*	-	*1*	-	*5*	-	(n)
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(o)
Storage:								
- Diesel Fuel	*t bws*	*5*	*±1*	*1*	-	*6*	*±1*	(c, p)
- Sheeting	*t bws*	-	-	*12*	*±2*	*12*	*±2*	(c, q)
- Machinery	*t bws*	-	-	*1*	-	*1*	-	(c, r)
- Maintenance	*t bws*	-	-	-	-	-	-	(c, s)
Sub-Totals	*t bws*	*5*	*±1*	*14*	*±2*	*19*	*±2*	
	GJe	**2**	**-**	**4**	**±1**	**6**	**±1**	(o)
Plant Construction	**GJe**	**-**	**-**	**5**	**±1**	**5**	**±1**	(t)
Plant Maintenance	**GJe**	**-**	**-**	**3**	**-**	**3**	**-**	(u)
Ash Disposal:								
- Diesel Fuel	*t ash*	*4*	-	-	-	*4*	-	(v)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Totals	**GJe**	**0**	**±1**	**29**	**±2**	**29**	**±2**	

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 3).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total carbon requirement for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 (Ref. 4).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total carbon requirement for potash fertiliser of 0.453 kg CO_2/ kg K_2O (Ref. 4).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 2) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(f) Carbon dioxide output from manufacture of tractor for baling of 2.6 kg CO_2/ha.a, Hesston baler of 15.5 kg CO_2/ha.a and telescopic handler for loading in field of 2.0 kg CO_2/ha.a (Ref. 2).

(g) Carbon dioxide output from manufacture of baling twine of 7.6 kg CO_2/ha.a (Ref. 2).

(h) Carbon dioxide output from maintenance and repair of tractor for baling of 0.7 kg CO_2/ha.a, of Hesston baler of 7.3 kg CO_2/ha.a and of telescopic handler for loading in the field of 0.7 kg CO_2/ha.a (Ref. 2).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 2) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(k) Carbon dioxide output from manufacture of straw chopper of 3.3 kg CO_2/ha.a, tractor of 4.3 kg CO_2/ha.a and straw incorporating cultivator of 1.5 kg CO_2/ha.a (Ref. 2).

(l) Carbon dioxide from extra cultivation for loss of yield in following crop of 2.7 kg CO_2/ha.a.

(m) Land requirement of 0.081 ha.a/GJ of electricity based on an average dried wheat straw yield of 3.78 t/ha.a, 0.65% straw losses in baling, 10.00% straw losses in storage and a straw fuel feed requirement of 0.275 t/GJ of electricity.

(n) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 7).

(o) Baled wheat straw requirement of 0.305 t/GJ of electricity.

(p) Diesel fuel consumption for baled straw handling in storage of 65.8 MJ/t of baled wheat straw (Ref. 2) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(q) Based on 2 tonnes of polyethylene sheeting used to protect each storage stack of 1,000 tonnes of baled wheat straw, with a life of 1 year and a direct carbon requirement of 6.216 kg CO_2/kg for low density polyethylene (Ref. 2).

(r) Carbon dioxide output from manufacture of telescopic handler of 0.970 kg CO_2/t of baled wheat straw (Ref. 2).

(s) Carbon dioxide output from maintenance and repair of telescopic handler of 0.334 kg CO_2/t of baled wheat straw (Ref. 2).

(t) Carbon dioxide output of 56,200 tonnes of CO_2 for construction of straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% and a 25 year life (Ref. 2).

(u) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 7).

(v) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 7).

(w) Ash output of 5.5% of straw fuel feed, or 15 kg/GJ of electricity (Ref. 2).

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Table O3 Spreadsheet for Methane Outputs from Electricity Generation by Combustion of Wheat Straw

Functional Unit:	Electricity at point of generation obtained by combustion of wheat straw
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*0.221*	*±0.037*	*0.221*	*±0.037*	(a)
- P Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.003*	-	*0.003*	-	(c, d)
- Diesel Fuel	*ha.a*	-	-	*0.008*	*±0.001*	*0.008*	*±0.001*	(c, e)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, f)
- Twine	*ha.a*	-	-	-	-	-	-	(c, g)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, h)
Reference System:								
- Diesel Fuel	*ha.a*	-	-	*- 0.016*	-	*- 0.016*	-	(c, i)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, j)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, k)
- Crop Loss	*ha.a*	-	-	*- 0.001*	-	*- 0.001*	-	(c, l)
Sub-Totals	*ha.a*	-		*0.216*	*±0.037*	*0.216*	*±0.037*	
	GJe	**-**	**-**	**0.017**	**±0.003**	**0.017**	**±0.003**	(m)
Transport:								
- Diesel Fuel	*t bws*	-	-	*0.001*	-	*0.001*	-	(n)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Storage:								
- Diesel Fuel	*t bws*	-	-	*0.001*	-	*0.001*	-	(c, p)
- Sheeting	*t bws*	-	-	-	-	-	-	(c, q)
- Machinery	*t bws*	-	-	-	-	-	-	(c, r)
- Maintenance	*t bws*	-	-	-	-	-	-	(c, s)
Sub-Totals	*t bws*			*0.001*	-	*0.001*	-	
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Direct Emissions	**GJe**	**0.008**	**-**	**-**	**-**	**0.008**	**-**	(t)
Plant Construction	**GJe**	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Plant Maintenance	**GJe**	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Ash Disposal:								
- Diesel Fuel	*t ash*	-	-	*0.001*	-	*0.001*	-	(w)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Totals	**GJe**	**0.008**	**-**	**0.017**	**±0.003**	**0.025**	**±0.003**	

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total methane requirement for ammonium nitrate of $3.6 \times 10^{-3} \pm 0.6 \times 10^{-3}$ kg CH_4/kg N (Ref. 3).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and total methane requirement for phosphate fertiliser of 2.3×10^{-5} kg CH_4/kg P_2O_5 (Ref. 4).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total methane requirement for potash fertiliser of 2.1×10^{-5} kg CH_4/ kg K_2O (Ref. 4).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 2) and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(f) Primary energy input to manufacture of tractor for baling of 55.9 MJ/ha.a, Hesston baler of 336.9 MJ/ha.a and telescopic handler for loading in field of 44.1 MJ/ha.a (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Refs. 2 and 7).

(g) Primary energy input to manufacture of baling twine of 101.8 MJ/ha.a (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Refs. 2 and 7).

(h) Primary energy input to maintenance and repair of tractor for baling of 14.3 MJ/ha.a, of Hesston baler of 158.9 MJ/ha.a and of telescopic handler for loading in the field of 15.2 MJ/ha.a (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input (Refs. 2 and 7).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 2), and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(j) Primary energy input to manufacture of straw chopper of 71.9 MJ/ha.a, of tractor of 93.3 MJ/ha.a and straw incorporating cultivator of 33.5 MJ/ha.a (Ref. 2), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Refs. 2 and 7).

(k) Primary energy input to maintenance of straw chopper of 36.8 MJ/ha.a, of tractor of 24.3 MJ/ha.a and straw incorporating cultivator of 46.1 MJ/ha.a (Ref. 2), and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Refs. 2 and 7).

(l) Primary energy input of 58.8 MJ/ha.a for extra cultivation due to loss in yield of following crop (Ref. 2), and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(m) Land requirement of 0.081 ha.a/GJ of electricity based on an average dried wheat straw yield of 3.78 t/ha.a, 0.65% straw losses in baling, 10.00% straw losses in storage and a straw fuel feed requirement of 0.275 t/GJ of electricity.

(n) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 8).

(o) Baled wheat straw requirement of 0.305 t/GJ of electricity.

(p) Diesel fuel consumption for baled straw handling in storage of 65.8 MJ/t of baled wheat straw (Ref. 2) and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(q) Based on 2 tonnes of polyethylene sheeting used to protect each storage stack of 1,000 tonnes of baled wheat straw, with a life of 1 year and a direct energy requirement of 47 MJ/kg for low density polyethylene (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 7).

(r) Primary energy input for manufacture of telescopic handler of 21.0 MJ/t of baled wheat straw (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 7).

(s) Primary energy input to maintenance and repair of telescopic handler of 7.2 MJ/t of baled wheat straw (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to maintenance and repair (Ref. 7).

(t) Direct emissions of 0.002 g CH_4/ MJ of straw fuel feed (Ref. 8) and straw fuel feed requirement of 0.275 t/GJ of electricity.

(u) Primary energy input of 1,050,300 GJ for construction of straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a thermal efficiency of 25% a 25 year life (Ref. 2) and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 7).

(v) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 9).

(w) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 9).

(x) Ash output of 5.5% of straw fuel feed, or 15 kg/GJ of electricity (Ref. 2).

References

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Table O4 Spreadsheet for Nitrous Oxide Outputs from Electricity Generation by Combustion of Wheat Straw

Functional Unit:	Electricity at point of generation obtained by combustion of wheat straw
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*0.221*	*±0.033*	*0.904*	*±0.136*	*1.125*	*±0.140*	(a)
- P Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c, d)
- Diesel Fuel	*ha.a*	-	-	-	-	-	-	(c, e)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, f)
- Twine	*ha.a*	-	-	-	-	-	-	(c, g)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, h)
Reference System:								
- Diesel Fuel	*ha.a*	-	-	-	-	-	-	(c, i)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, j)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, k)
- Crop Loss	*ha.a*	-	-	-	-	-	-	(c, l)
Sub-Totals	*ha.a*	*0.221*	*±0.033*	*0.906*	*±0.136*	*1.127*	*±0.140*	
	GJe	**0.018**	**±0.003**	**0.073**	**±0.011**	**0.091**	**±0.011**	(m)
Transport:								
- Diesel Fuel	*t bws*	-	-	-	-	-	-	(n)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Storage:								
- Diesel Fuel	*t bws*	-	-	-	-	-	-	(c, p)
- Sheeting	*t bws*	-	-					(c, q)
- Machinery	*t bws*	-	-					(c, r)
- Maintenance	*t bws*	-	-					(c, s)
Sub-Totals	*t bws*	-	-					
	GJe	**-**	**-**		**-**	**-**	**-**	(o)
Direct Emissions	**GJe**	**0.020**	**-**	**-**	**-**	**0.020**	**-**	(t)
Plant Construction	**GJe**	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Plant Maintenance	**GJe**	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Ash Disposal:								
- Diesel Fuel	*t ash*	-	-	-	-	-	-	(w)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Totals	**GJe**	**0.038**	**0.003**	**0.073**	**±0.011**	**0.111**	**±0.011**	

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 3), an indirect nitrous oxide requirement of 0.0147 kg N_2O/kg N (Ref. 4) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 4).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and with total nitrous oxide requirement for phosphate fertiliser of 4.2×10^{-5} kg N_2O/kg P_2O_5 (Ref. 3).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 5).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 1) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 2) and a total nitrous oxide requirement for potash fertiliser of 9.4×10^{-6} kg N_2O/ kg K_2O (Ref. 3).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 2), and a direct nitrous requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.9×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(f) Primary energy input to manufacture of tractor for baling of 55.9 MJ/ha.a, Hesston baler of 336.9 MJ/ha.a and telescopic handler for loading in field of 44.1 MJ/ha.a (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Refs. 2 and 7).

(g) Primary energy input to manufacture of baling twine of 101.8 MJ/ha.a (Ref. 2) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 2 and 7).

(h) Primary energy input to maintenance and repair of tractor for baling of 14.3 MJ/ha.a, of Hesston baler of 158.9 MJ/ha.a and of telescopic handler for loading in the field of 15.2 MJ/ha.a (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input (Refs. 2 and 7).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 2), and a direct nitrous requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.9×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 6).

(j) Primary energy input to manufacture of straw chopper of 71.9 MJ/ha.a, of tractor of 93.3 MJ/ha.a and straw incorporating cultivator of 33.5 MJ/ha.a (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Refs. 2 and 7).

(k) Primary energy input to maintenance of straw chopper of 36.8 MJ/ha.a, of tractor of 24.3 MJ/ha.a and straw incorporating cultivator of 46.1 MJ/ha.a (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Refs. 2 and 7).

(l) Primary energy input of 58.8 MJ/ha.a for extra cultivation due to loss in yield of following crop (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Refs. 2 and 7).

(m) Land requirement of 0.081 ha.a/GJ of electricity based on an average dried wheat straw yield of 3.78 t/ha.a, 0.65% straw losses in baling, 10.00% straw losses in storage and a straw fuel feed requirement of 0.275 t/GJ of electricity.

(n) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 8).

(o) Baled wheat straw requirement of 0.305 t/GJ of electricity.

(p) Diesel fuel consumption for baled straw handling in storage of 65.8 MJ/t of baled wheat straw (Ref. 2) and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 6).

(q) Based on 2 tonnes of polyethylene sheeting used to protect each storage stack of 1,000 tonnes of baled wheat straw, with a life of 1 year and a direct energy requirement of 47 MJ/kg for low density polyethylene (Ref. 2) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(r) Primary energy input for manufacture of telescopic handler of 21.0 MJ/t of baled wheat straw (Ref. 2) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(s) Primary energy input to maintenance and repair of telescopic handler of 7.2 MJ/t of baled wheat straw (Ref. 2) and an estimated total nitrous oxide requirement of 1.866×10^{9} kg N_2O/MJ primary energy input to maintenance and repair (Ref. 7).

(t) Direct emissions of 0.002 g CH_4/ MJ of straw fuel feed (Ref. 8) and straw fuel feed requirement of 0.275 t/GJ of electricity.

(u) Primary energy input of 1,050,300 GJ for construction of straw-fired power only plant with a net output rating of 20 MW, an average load factor of 65%, a 25 year life (Ref. 2) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 7).

(v) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output from plant construction (Ref. 9).

(w) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 9).

(x) Ash output of 5.5% of straw fuel feed, or 15 kg/GJ of electricity (Ref. 2).

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1. "Assessment of Net Emissions of Greenhouse Gases from Ethanol-Blended Gasolines in Canada: Lignocellulosic Feedstocks" R-2000-2, Levelton Engineering Ltd., Richmond, Canada, December 1998.

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Table O5 Spreadsheet for Greenhouse Gas Outputs from Electricity Generation by Combustion of Wheat Straw

Functional Unit:	Electricity at point of generation obtained by combustion of wheat straw
Final Unit of Measurement:	1 GJ of electricity
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	None required

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	ha.a	71	±11	412	±47	483	±48	(a)
- P Fertiliser	ha.a	-	-	18	±3	18	±3	(a)
- K Fertiliser	ha.a	-	-	59	±9	59	±9	(a)
- Diesel Fuel	ha.a	25	±4	3	-	28	±4	(a)
- Machinery	ha.a	-	-	20	±3	20	±3	(a)
- Twine	ha.a	-	-	8	±1	8	±1	(a)
- Maintenance	ha.a	-	-	9	±1	9	±1	(a)
Reference System:								
- Diesel Fuel	ha.a	- 54	±7	- 6	±3	- 60	±8	(a)
- Machinery	ha.a	-	-	- 9	±3	- 9	±3	(a)
- Maintenance	ha.a	-	-	- 5	±1	- 5	±1	(a)
- Crop Loss	ha.a	- 3	-	-	-	- 3	-	(a)
Sub-Totals	ha.a	39	±14	509	±48	548	±49	
	GJe	**3**	**±1**	**41**	**±4**	**44**	**±4**	(b)
Transport:								
- Diesel Fuel	t bws	4	-	1	-	5	-	(a)
	GJe	**1**	**-**	**-**	**-**	**1**	**-**	(c)
Storage:								
- Diesel Fuel	t bws	5	±1	1	-	6	±1	(a)
- Sheeting	t bws	-	-	12	±2	12	±2	(a)
- Machinery	t bws	-	-	1	-	1	-	(a)
- Maintenance	t bws	-	-	-	-	-	-	(a)
Sub-Totals	t bws	5	±1	14	±2	19	±2	
	GJe	**2**	**-**	**4**	**±1**	**6**	**±1**	(c)
Direct Emissions	**GJe**	**7**	**-**	**-**	**-**	**7**	**-**	(a)
Plant Construction	**GJe**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a)
Plant Maintenance	**GJe**	**-**	**-**	**3**	**-**	**3**	**-**	(a)
Ash Disposal:								
- Diesel Fuel	t ash	4	-	-	-	4	-	(a)
	GJe	**-**	**-**	**-**	**-**	**-**	**-**	(d)
Totals	**GJe**	**13**	**±1**	**53**	**±4**	**66**	**±4**	

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t ash = tonne of ash
GJe = GJ of electricity

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 0.081 ha.a/GJ of electricity based on an average dried wheat straw yield of 3.78 t/ha.a, 0.65% straw losses in baling, 10.00% straw losses in storage and a straw fuel feed requirement of 0.275 t/GJ of electricity.

(c) Baled wheat straw requirement of 0.305 t/GJ of electricity.

(d) Ash output of 5.5% of straw fuel feed, or 15 kg/GJ of electricity.

APPENDIX P: Production of Ethanol from Lignocellulosics (Wheat Straw)

Figure P1 Flow Chart for the Production of Ethanol from Lignocellulosics (Wheat Straw)

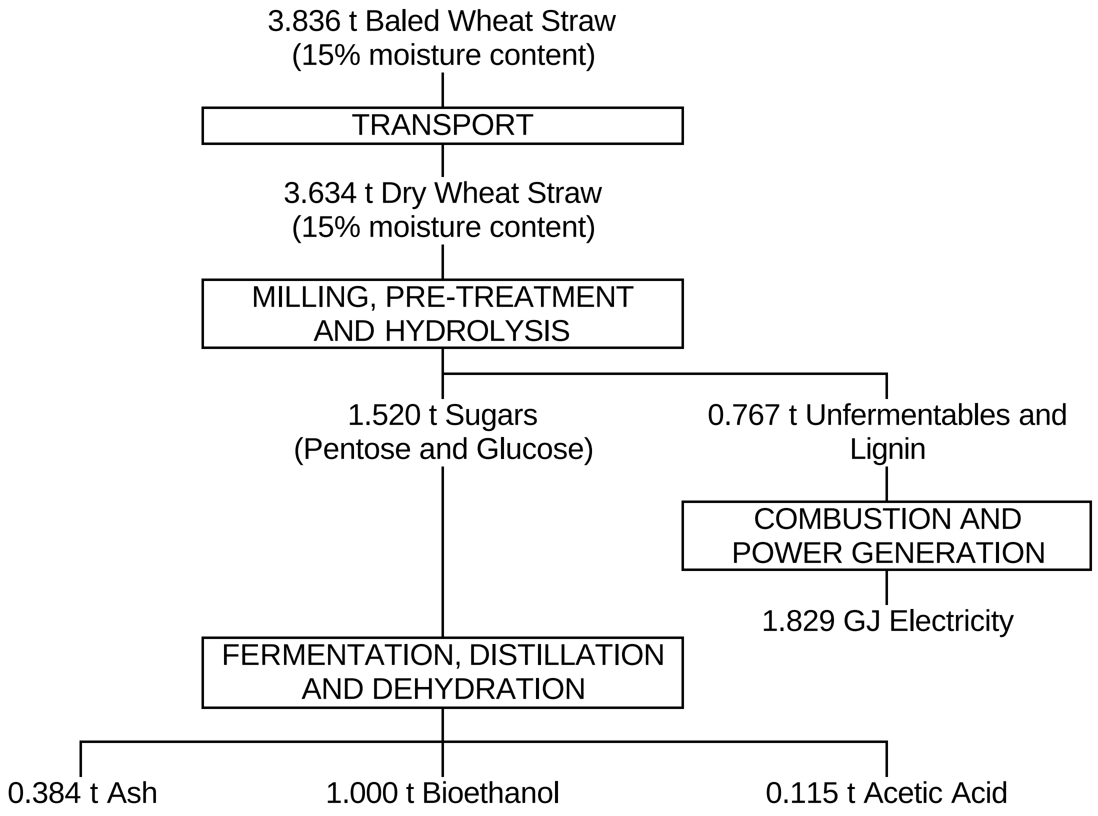

Table P1 Spreadsheet for Primary Energy Inputs to Bioethanol Production from Lignocellulosics (Wheat Straw)

Functional Unit:	Bioethanol at point of distribution derived from wheat straw
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on substitution of average grid electricity in the United Kingdom in 1996 (Ref. 1) by 508 kWh of surplus electricity and substitution of acetic acid from main source of production (Ref. 2) by 115 kg of co-product acetic acid.

Contribution	Per Unit	Primary Energy Input (MJ)								Notes
		Direct		Indirect		Feedstock		Total		
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:										
- N Fertiliser	*ha.a*	-	-	*862*	*±342*	*1,636*	*±65*	*2,498*	*±348*	(a)
- P Fertiliser	*ha.a*	-	-	*411*	*±62*	-	-	*411*	*±62*	(b, c)
- K Fertiliser	*ha.a*	-	-	*1,218*	*±183*	-	-	*1,218*	*±183*	(c, d)
- Diesel Fuel	*ha.a*	*370*	*±59*	*41*	*±20*	-	-	*411*	*±62*	(c, e)
- Machinery	*ha.a*	-	-	*437*	*±66*	-	-	*437*	*±66*	(c, f)
- Twine	*ha.a*	-	-	-	-	*102*	*±15*	*102*	*±15*	(c, g)
- Maintenance	*ha.a*	-	-	*188*	*±28*	-	-	*188*	*±28*	(c, h)
Reference System:										
- Diesel Fuel	*ha.a*	*- 787*	*±124*	*- 86*	*±41*	-	-	*- 873*	*±131*	(c, i)
- Machinery	*ha.a*	-	-	*- 199*	*±30*	-	-	*- 199*	*±30*	(c, j)
- Maintenance	*ha.a*	-	-	*- 107*	*±16*	-	-	*- 107*	*±16*	(c, k)
- Crop Loss	*ha.a*	*- 59*	*±9*	-		-	-	*- 59*	*±9*	(c, l)
Sub-Totals	*ha.a*	*- 476*	*±138*	*2,765*	*±403*	*1,738*	*±67*	*4,027*	*±431*	
	t be	**- 483**	**±140**	**2,806**	**±409**	**1,764**	**±68**	**4,087**	**±437**	(m)
Transport:										
- Diesel Fuel	*t bws*	*246*	*±9*	*86*	*±11*	-	-	*332*	*±14*	(n)
	t be	**943**	**±36**	**329**	**±41**	**-**	**-**	**1,272**	**±55**	(o)
Handling:										
- Diesel Fuel	*t dws*	*104*	*±17*	*12*	*±5*	-	-	*116*	*±17*	(b, p)
	t be	**379**	**±60**	**42**	**±20**	**-**	**-**	**421**	**±63**	(q)
Processing:										
- Sulphuric Acid	*t dws*	-	-	*26*	*±29*	-	-	*26*	*±29*	(r)
- Lime	*t dws*	-	-	*21*	*±3*	-	-	*21*	*±3*	(b, s)
- Electricity (credit)	*t dws*	-	-	*- 1,554*	*±233*	-	-	*- 1,554*	*±233*	(b, t)
- Acetic Acid (credit)	*t dws*	-	-	*- 483*	*±72*	-	-	*- 483*	*±72*	(b, u)
Sub Totals	*t dws*	-	-	*- 1,990*	*±246*	-	-	*- 1,990*	*±246*	
	t be	**-**	**-**	**- 7,232**	**±893**	**-**	**-**	**- 7,232**	**±893**	(q)
Plant Construction	**t be**	**3**	**-**	**97**	**±18**	**-**	**-**	**100**	**±18**	(v)
Plant Maintenance	**t be**	**-**	**-**	**82**	**±15**	**-**	**-**	**82**	**±15**	(w)
Ash Disposal:										
- Diesel Fuel	*t ash*	*26*	*±1*	*9*	*±1*	-	-	*35*	*±1*	(x)
	t be	**10**	**-**	**4**	**-**	**-**	**-**	**14**	-	(y)
Distribution:										
- Diesel Fuel	**t be**	**369**	**±14**	**129**	**±16**	**-**	**-**	**498**	**±21**	(z)
Totals	**t be**	**1,221**	**±157**	**- 3,743**	**±984**	**1,764**	**±68**	**- 758**	**±998**	

Biofuel Specifications

Density of bioethanol	= 0.79 kg/l
Net calorific value of bioethanol	= 26.72 MJ/kg
Gross calorific value of bioethanol	= 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t dws = tonne of dried wheat straw
t ash = tonne of ash
t be = tonne of bioethanol

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for ammonium nitrate (Ref. 4).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total energy requirement for phosphate fertiliser of 15.8 MJ/kg P_2O_5 (Ref. 5).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 6).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total energy requirement for potash fertiliser of 9.3 MJ/ kg K_2O (Ref. 5).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 3) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(f) Primary energy input to manufacture of tractor for baling of 55.9 MJ/ha.a, Hesston baler of 336.9 MJ/ha.a and telescopic handler for loading in field of 44.1 MJ/ha.a (Ref. 3).

(g) Primary energy input to manufacture of baling twine of 101.8 MJ/ha.a (Ref. 3).

(h) Primary energy input to maintenance and repair of tractor for baling of 14.3 MJ/ha.a, of Hesston baler of 158.9 MJ/ha.a and of telescopic handler for loading in the field of 15.2 MJ/ha.a (Ref. 3).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 3).

(j) Primary energy input to manufacture of straw chopper of 71.9 MJ/ha.a, of tractor of 93.3 MJ/ha.a and straw incorporating cultivator of 33.5 MJ/ha.a (Ref. 3).

(k) Primary energy input to maintenance of straw chopper of 36.8 MJ/ha.a, of tractor of 24.3 MJ/ha.a and straw incorporating cultivator of 46.1 MJ/ha.a (Ref. 3).

(l) Primary energy input of 58.8 MJ/ha.a for extra cultivation due to loss in yield of following crop (Ref. 3).

(m) Land requirement of 1.015 ha.a/t of bioethanol based on an average baled wheat straw yield of 3.78 t/ha.a and a baled wheat straw requirement of 3.836 t/t of bioethanol.

(n) Average round trip distance of 300 km (Ref. 2) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 7).

(o) Baled wheat straw requirement of 3.836 t/t of bioethanol.

(p) Diesel fuel consumption for baled straw handling of 104.3 MJ/t of baled wheat straw (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(q) Dry wheat straw requirement of 3.634 t/t of bioethanol.

(r) Sulphuric acid consumption of 10 kg H_2SO_4/t of dry wheat straw (Ref. 2) and a total energy requirement of 2.6 ± 2.9 MJ/ kg H_2SO_4 (Ref. 8).

(s) Lime consumption of 10 kg CaO/t of dry wheat straw (Ref. 2) and a total energy requirement of lime of 2.1 MJ/kg CaO (Ref. 5).

(t) Assuming the processing plant is self-sufficient in steam and electricity generated from lignin and unfermentables, and provides a surplus of 140 kWh/t of dry wheat straw (Ref. 2) which displaces average electricity in the UK in 1996 with a gross energy efficiency of 0.3244 MJ/MJ (Ref. 1).

(u) Acetic acid output of 30 kg/t of dry wheat straw which (Ref. 2) displaces main production with a total energy requirement of 16.1 MJ/kg (Ref. 2).

(v) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 7) with a capacity of a 40,000 t/a and a 25 year life.

(w) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 7).

(x) Ash sent for landfill disposal with an average round trip distance of 32 km (Ref. 2) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 7).

(y) Ash output of 10% of dry wheat straw, or 363 kg/t bioethanol (Ref. 2).

(z) Average round trip distance of 450 km (Ref. 9) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 7).

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Table P2 Spreadsheet for Carbon Dioxide Outputs from Bioethanol Production from Lignocellulosics (Wheat Straw)

Functional Unit:	Bioethanol at point of distribution derived from wheat straw
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on substitution of average grid electricity in the United Kingdom in 1996 (Ref. 1) by 508 kWh of surplus electricity and substitution of acetic acid from main source of production (Ref. 2) by 115 kg of co-product acetic acid.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*117*	*±17*	*117*	*±17*	(a)
- P Fertiliser	*ha.a*	-	-	*18*	*±3*	*18*	*±3*	(b, c)
- K Fertiliser	*ha.a*	-	-	*59*	*±9*	*59*	*±9*	(c, d)
- Diesel Fuel	*ha.a*	*25*	*±4*	*3*	-	*28*	*±4*	(c, e)
- Machinery	*ha.a*	-	-	*20*	*±3*	*20*	*±3*	(c, f)
- Twine	*ha.a*	-	-	*8*	*±1*	*8*	*±1*	(c, g)
- Maintenance	*ha.a*	-	-	*9*	*±1*	*9*	*±1*	(c, h)
Reference System:								
- Diesel Fuel	*ha.a*	*- 54*	*±7*	*- 6*	*±3*	*- 60*	*±8*	(c, i)
- Machinery	*ha.a*	-	-	*- 9*	*±3*	*- 9*	*±3*	(c, j)
- Maintenance	*ha.a*	-	-	*- 5*	*±1*	*- 5*	*±1*	(c, k)
- Crop Loss	*ha.a*	*- 3*	-	-	-	*- 3*	-	(c, l)
Sub-Totals	*ha.a*	*- 32*	*±8*	*214*	*±20*	*182*	*±22*	
	t be	**- 32**	**±8**	**217**	**±20**	**185**	**±22**	(m)
Transport:								
- Diesel Fuel	*t bws*	*17*	*±1*	*5*	-	*22*	*±1*	(n)
	t be	**65**	**±2**	**19**	**±2**	**84**	**±3**	(o)
Handling:								
- Diesel Fuel	*t dws*	*7*	*±1*	*1*	-	*8*	*±1*	(b, p)
	t be	**26**	**±4**	**3**	**-**	**29**	**±4**	(q)
Processing:								
- Sulphuric Acid	*t dws*	-	-	*1*	*±1*	*1*	-	(r)
- Lime	*t dws*	-	-	*2*	-	*2*	-	(b, s)
- Electricity (credit)	*t dws*	-	-	*- 76*	*±11*	*- 76*	*±11*	(b, t)
- Acetic Acid (credit)	*t dws*	-	-	*- 21*	*±3*	*- 21*	*±3*	(b, u)
Sub Totals	*t dws*	-	-	*- 94*	*±11*	*- 94*	*±11*	
	t be	**-**	**-**	**- 342**	**±41**	**- 342**	**±41**	(q)
Plant Construction	**t be**	**-**	**-**	**5**	**±1**	**5**	**±1**	(v)
Plant Maintenance	**t be**	**-**	**-**	**3**	**±1**	**3**	**±1**	(w)
Ash Disposal:								
- Diesel Fuel	*t ash*	*2*	-	-	-	*2*	-	(x)
	t be	**1**	**-**	**-**	**-**	**1**	**-**	(y)
Distribution:								
- Diesel Fuel	**t be**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(z)
Totals	**t be**	**85**	**±9**	**- 88**	**±46**	**- 3**	**±47**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t dws = tonne of dried wheat straw
t ash = tonne of ash
t be = tonne of bioethanol

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 4).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total carbon requirement for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 (Ref. 5).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 6).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total carbon requirement for potash fertiliser of 0.453 kg CO_2/ kg K_2O (Ref. 5).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 3) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(f) Carbon dioxide output from manufacture of tractor for baling of 2.6 kg CO_2/ha.a, Hesston baler of 15.5 kg CO_2/ha.a and telescopic handler for loading in field of 2.0 kg CO_2/ha.a (Ref. 3).

(g) Carbon dioxide output from manufacture of baling twine of 7.6 kg CO_2/ha.a (Ref. 3).

(h) Carbon dioxide output from maintenance and repair of tractor for baling of 0.7 kg CO_2/ha.a, of Hesston baler of 7.3 kg CO_2/ha.a and of telescopic handler for loading in the field of 0.7 kg CO_2/ha.a (Ref. 3).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 3) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(k) Carbon dioxide output from manufacture of straw chopper of 3.3 kg CO_2/ha.a, tractor of 4.3 kg CO_2/ha.a and straw incorporating cultivator of 1.5 kg CO_2/ha.a (Ref. 3).

(l) Carbon dioxide from extra cultivation for loss of yield in following crop of 2.7 kg CO_2/ha.a (Ref. 3).

(m) Land requirement of 1.015 ha.a/t of bioethanol based on an average baled wheat straw yield of 3.78 t/ha.a and a baled wheat straw requirement of 3.836 t/t of bioethanol.

(n) Average round trip distance of 300 km (Ref. 2) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 7).

(o) Baled wheat straw requirement of 3.836 t/t of bioethanol.

(p) Diesel fuel consumption for baled straw handling of 104.3 MJ/t of baled wheat straw (Ref. 2) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(q) Dry wheat straw requirement of 3.634 t/t of bioethanol.

(r) Sulphuric acid consumption of 10 kg H_2SO_4/t of dry wheat straw (Ref. 2) and a total carbon requirement of 0.126 ± 0.141 kg CO_2/ kg H_2SO_4 (Ref. 8).

(s) Lime consumption of 10 kg CaO/t of dry wheat straw (Ref. 2) and a total carbon requirement of lime of 0.179 kg CO_2/kg CaO (Ref. 5).

(t) Assuming the processing plant is self-sufficient in steam and electricity generated from lignin and unfermentables, and provides a surplus of 140 kWh/t of dry wheat straw (Ref. 2) which displaces average electricity in the UK in 1996 with an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 1).

(u) Acetic acid output of 30 kg/t of dry wheat straw which (Ref. 2) displaces main production with a total carbon requirement of 0.704 kg CO_2/kg (Ref. 2).

(v) Carbon dioxide output of 6,287 ± 1,116 tonnes CO_2 from construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 7) with a capacity of a 40,000 t/a and a 25 year life.

(w) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 7).

(x) Ash sent for landfill disposal with an average round trip distance of 32 km (Ref. 2) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 7).

(y) Ash output of 10% of dry wheat straw, or 363 kg/t bioethanol (Ref. 2).

(z) Average round trip distance of 450 km (Ref. 9) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 7).

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Table P3 Spreadsheet for Methane Outputs from Bioethanol Production from Lignocellulosics (Wheat Straw)

Functional Unit: Bioethanol at point of distribution derived from wheat straw
Final Unit of Measurement: 1 tonne of bioethanol
Relevant Location: United Kingdom
Relevant Period: 1996
Allocation Procedures: Based on substitution of average grid electricity in the United Kingdom in 1996 (Ref. 1) by 508 kWh of surplus electricity and substitution of acetic acid from main source of production (Ref. 2) by 115 kg of co-product acetic acid.

Contribution	Per Unit	Methane Output (kg CH$_4$)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*0.221*	*±0.037*	*0.221*	*±0.037*	(a)
- P Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.003*	-	*0.003*	-	(c, d)
- Diesel Fuel	*ha.a*	-	-	*0.008*	*±0.001*	*0.008*	*±0.001*	(c, e)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, f)
- Twine	*ha.a*	-	-	-	-	-	-	(c, g)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, h)
Reference System:								
- Diesel Fuel	*ha.a*	-	-	*- 0.016*	-	*- 0.016*	-	(c, i)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, j)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, k)
- Crop Loss	*ha.a*	-	-	*- 0.001*	-	*- 0.001*	-	(c, l)
Sub-Totals	*ha.a*	-		*0.216*	*±0.037*	*0.216*	*±0.037*	
	t be	**-**	**-**	**0.219**	**±0.038**	**0.219**	**±0.038**	(m)
Transport:								
- Diesel Fuel	*t bws*	-	-	*0.005*	-	*0.005*	-	(n)
	t be	**0.001**	**-**	**0.019**	**±0.001**	**0.020**	**±0.001**	(o)
Handling:								
- Diesel Fuel	*t dws*	-	-	*0.002*	-	*0.002*	-	(b, p)
	t be	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(q)
Processing:								
- Sulphuric Acid	*t dws*	-	-	*0.003*	*±0.003*	*0.003*	*±0.003*	(r)
- Lime	*t dws*	-	-	-	-	-	-	(b, s)
- Electricity (credit)	*t dws*	-	-	*- 0.204*	*±0.031*	*- 0.204*	*±0.031*	(b, t)
- Acetic Acid (credit)	*t dws*	-	-	*- 0.044*	*±0.007*	*- 0.044*	*±0.007*	(b, u)
Sub Totals	*t dws*	-	-	*- 0.245*	*±0.032*	*- 0.245*	*±0.032*	
	t be	**-**	**-**	**- 0.890**	**±0.116**	**- 0.890**	**±0.116**	(q)
Plant Construction	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Plant Maintenance	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Ash Disposal:								
- Diesel Fuel	*t ash*	-	-	*0.001*	-	*0.001*	-	(x)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(y)
Distribution:								
- Diesel Fuel	**t be**	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(z)
Totals	**t be**	**0.001**	**-**	**- 0.636**	**±0.122**	**- 0.636**	**±0.122**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t dws = tonne of dried wheat straw
t ash = tonne of ash
t be = tonne of bioethanol

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total methane requirement for ammonium nitrate of $3.6 \times 10^{-3} \pm 0.6 \times 10^{-3}$ kg CH_4/kg N (Ref. 4).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and total methane requirement for phosphate fertiliser of 2.3×10^{-5} kg CH_4/kg P_2O_5 (Ref. 5).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 6).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total methane requirement for potash fertiliser of 2.1×10^{-5} kg CH_4/ kg K_2O (Ref. 5).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 3) and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(f) Primary energy input to manufacture of tractor for baling of 55.9 MJ/ha.a, Hesston baler of 336.9 MJ/ha.a and telescopic handler for loading in field of 44.1 MJ/ha.a (Ref. 3) and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 7).

(g) Primary energy input to manufacture of baling twine of 101.8 MJ/ha.a (Ref. 3) and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 7).

(h) Primary energy input to maintenance and repair of tractor for baling of 14.3 MJ/ha.a, of Hesston baler of 158.9 MJ/ha.a and of telescopic handler for loading in the field of 15.2 MJ/ha.a (Ref. 3) and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input (Ref. 7).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 3), and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(j) Primary energy input to manufacture of straw chopper of 71.9 MJ/ha.a, of tractor of 93.3 MJ/ha.a and straw incorporating cultivator of 33.5 MJ/ha.a (Ref. 3), and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to manufacturing (Refs. 2 and 7).

(k) Primary energy input to maintenance of straw chopper of 36.8 MJ/ha.a, of tractor of 24.3 MJ/ha.a and straw incorporating cultivator of 46.1 MJ/ha.a (Ref. 2), and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to manufacturing (Ref. 7).

(l) Primary energy input of 58.8 MJ/ha.a for extra cultivation due to loss in yield of following crop (Ref. 3), and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 7).

(m) Land requirement of 1.015 ha.a/t of bioethanol based on an average baled wheat straw yield of 3.78 t/ha.a and a baled wheat straw requirement of 3.836 t/t of bioethanol.

(n) Average round trip distance of 300 km (Ref. 2) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 8).

(o) Baled wheat straw requirement of 3.836 t/t of bioethanol.

(p) Diesel fuel consumption for baled straw handling of 104.3 MJ/t of baled wheat straw (Ref. 2) and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(q) Dry wheat straw requirement of 3.634 t/t of bioethanol.

(r) Sulphuric acid consumption of 10 kg H_2SO_4/t of dry wheat straw (Ref. 2) and a total methane requirement of $2.6 \times 10^{-4} \pm 3.2 \times 10^{-4}$ kg CH_4/ kg H_2SO_4 (Ref. 9).

(s) Lime consumption of 10 kg CaO/t of dry wheat straw (Ref. 2) and a total methane requirement of lime of 3.9×10^{-6} kg CH_4/kg CaO (Ref. 5).

(t) Assuming the processing plant is self-sufficient in steam and electricity generated from lignin and unfermentables, and provides a surplus of 140 kWh/t of dry wheat straw (Ref. 2) which displaces average electricity in the UK in 1996 with an indirect methane requirement of 4.043×10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 1).

(u) Acetic acid output of 30 kg/t of dry wheat straw which (Ref. 2) displaces main production with a total methane requirement of 1.46 x 10^{-3} kg CH_4/kg (Ref. 2).

(v) Primary energy input of 131,004 ± 23,909 GJ for construction of a biodiesel plant (Ref. 8) with a capacity of a 40,000 t/a and a 25 year life, and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 7).

(w) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 8).

(x) Ash sent for landfill disposal with an average round trip distance of 32 km (Ref. 2) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 8).

(y) Ash output of 10% of dry wheat straw, or 363 kg/t bioethanol (Ref. 2).

(z) Average round trip distance of 450 km (Ref. 10) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 8).

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Table P4 Spreadsheet for Nitrous Oxide Outputs from Bioethanol Production from Lignocellulosics (Wheat Straw)

Functional Unit:	Bioethanol at point of distribution derived from wheat straw
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on substitution of average grid electricity in the United Kingdom in 1996 (Ref. 1) by 508 kWh of surplus electricity and substitution of acetic acid from main source of production (Ref. 2) by 115 kg of co-product acetic acid.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*0.221*	*±0.033*	*0.904*	*±0.136*	*1.125*	*±0.140*	(a)
- P Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c, d)
- Diesel Fuel	*ha.a*	-	-	-	-	-	-	(c, e)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, f)
- Twine	*ha.a*	-	-	-	-	-	-	(c, g)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, h)
Reference System:								
- Diesel Fuel	*ha.a*	-	-	-	-	-	-	(c, i)
- Machinery	*ha.a*	-	-	-	-	-	-	(c, j)
- Maintenance	*ha.a*	-	-	-	-	-	-	(c, k)
- Crop Loss	*ha.a*	-	-	-	-	-	-	(c, l)
Sub-Totals	*ha.a*	*0.221*	*±0.033*	*0.906*	*±0.136*	*1.127*	*±0.140*	
	t be	**0.224**	**±0.033**	**0.920**	**±0.138**	**1.144**	**±0.142**	(m)
Transport:								
- Diesel Fuel	*t bws*	-	-	-	-	-	-	(n)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Handling:								
- Diesel Fuel	*t dws*	-	-	-	-	-	-	(b, p)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(q)
Processing:								
- Sulphuric Acid	*t dws*	-	-	-	-	-	-	(r)
- Lime	*t dws*	-	-	-	-	-	-	(b, s)
- Electricity (credit)	*t dws*	-	-	*- 0.003*	-	*- 0.003*	-	(b, t)
- Acetic Acid (credit)	*t dws*	-	-	-	-	-	-	(b, u)
Sub Totals	*t dws*	-	-	*- 0.003*	-	*- 0.003*	-	
	t be	**-**	**-**	**- 0.011**	**-**	**- 0.011**	**-**	(q)
Plant Construction	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Plant Maintenance	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Ash Disposal:								
- Diesel Fuel	*t ash*	-	-	-	-	-	-	(x)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(y)
Distribution:								
- Diesel Fuel	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(z)
Totals	**t be**	**0.224**	**0.033**	**0.909**	**±0.138**	**1.144**	**±0.142**	

Biofuel Specifications

Density of bioethanol	= 0.79 kg/l
Net calorific value of bioethanol	= 26.72 MJ/kg
Gross calorific value of bioethanol	= 29.74 MJ/kg

Abbreviations

ha.a	= hectare year
t bws	= tonne of baled wheat straw
t dws	= tonne of dried wheat straw
t ash	= tonne of ash
t be	= tonne of bioethanol

Notes

(a) Ammonium nitrate fertiliser application rate of 61.5 kg N /ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 4), an indirect nitrous oxide requirement of 0.0147 kg N_2O/kg N (Ref. 5) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 5).

(b) Phosphate fertiliser application rate of 26.0 kg P_2O_5/ ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and with total nitrous oxide requirement for phosphate fertiliser of 4.2×10^{-5} kg N_2O/kg P_2O_5 (Ref. 4).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 6).

(d) Potash fertiliser application rate of 131.0 kg K_2O/ha.a to replace straw removal based on Canadian data (Ref. 2) adjusted pro rata to an average wheat straw yield of 3.78 t/ha.a for East Anglia in the UK (Ref. 3) and a total nitrous oxide requirement for potash fertiliser of 9.4×10^{-6} kg N_2O/ kg K_2O (Ref. 4).

(e) Diesel fuel consumption for baling of 232.0 MJ/ha.a and loading in the field of 138.1 MJ/ha.a (Ref. 3) and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 1).

(f) Primary energy input to manufacture of tractor for baling of 55.9 MJ/ha.a, Hesston baler of 336.9 MJ/ha.a and telescopic handler for loading in field of 44.1 MJ/ha.a (Ref. 3) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(g) Primary energy input to manufacture of baling twine of 101.8 MJ/ha.a (Ref. 3) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(h) Primary energy input to maintenance and repair of tractor for baling of 14.3 MJ/ha.a, of Hesston baler of 158.9 MJ/ha.a and of telescopic handler for loading in the field of 15.2 MJ/ha.a (Ref. 3) and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input (Ref. 7).

(i) Diesel fuel consumption for straw chopping of 399.8 MJ/ha.a and for extra ploughing of 387.0 MJ/ha.a (Ref. 3), and a direct nitrous requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 5.9×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 1).

(j) Primary energy input to manufacture of straw chopper of 71.9 MJ/ha.a, of tractor of 93.3 MJ/ha.a and straw incorporating cultivator of 33.5 MJ/ha.a (Ref. 3), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(k) Primary energy input to maintenance of straw chopper of 36.8 MJ/ha.a, of tractor of 24.3 MJ/ha.a and straw incorporating cultivator of 46.1 MJ/ha.a (Ref. 3), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(l) Primary energy input of 58.8 MJ/ha.a for extra cultivation due to loss in yield of following crop (Ref. 3), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to manufacturing (Ref. 7).

(m) Land requirement of 1.015 ha.a/t of bioethanol based on an average baled wheat straw yield of 3.78 t/ha.a and a baled wheat straw requirement of 3.836 t/t of bioethanol.

(n) Average round trip distance of 300 km (Ref. 2) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 8).

(o) Baled wheat straw requirement of 3.836 t/t of bioethanol.

(p) Diesel fuel consumption for baled straw handling of 104.3 MJ/t of baled wheat straw (Ref. 2) and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 9) (Ref. 1).

(q) Dry wheat straw requirement of 3.634 t/t of bioethanol.

(r) Sulphuric acid consumption of 10 kg H_2SO_4/t of dry wheat straw (Ref. 2) and a total nitrous oxide requirement of $2.6 \times 10^{-7} \pm 2.9 \times 10^{-7}$ kg N_2O/ kg H_2SO_4 (Ref. 9).

(s) Lime consumption of 10 kg CaO/t of dry wheat straw (Ref. 2) and a total nitrous oxide requirement of lime of 1.6×10^{-5} kg CH_4/kg CaO (Ref. 4).

(t) Assuming the processing plant is self-sufficient in steam and electricity generated from lignin and unfermentables, and provides a surplus of 140 kWh/t of dry wheat straw (Ref. 2) which displaces average electricity in the UK in 1996 with an indirect nitrous oxide requirement of 5.577 x 10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 1).

(u) Acetic acid output of 30 kg/t of dry wheat straw which (Ref. 2) displaces main production with a total methane requirement of 1.3 x 10^{-6} kg N_2O/kg (Ref. 2).

(v) Primary energy input of 131,004 ± 23,909 GJ for construction of a biodiesel plant (Ref. 8) with a capacity of a 40,000 t/a and a 25 year life, and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 7).

(w) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 8).

(x) Ash sent for landfill disposal with an average round trip distance of 32 km (Ref. 2) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 8).

(y) Ash output of 10% of dry wheat straw, or 363 kg/t bioethanol (Ref. 2).

(z) Average round trip distance of 450 km (Ref. 10) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 8).

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Table P5 Spreadsheet for Greenhouse Gas Outputs from Bioethanol Production from Lignocellulosics (Wheat Straw)

Functional Unit:	Bioethanol at point of distribution derived from wheat straw
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on substitution of average grid electricity in the United Kingdom in 1996 (Ref. 1) by 508 kWh of surplus electricity and substitution of acetic acid from main source of production (Ref. 2) by 115 kg of co-product acetic acid.

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*71*	*±11*	*412*	*±47*	*483*	*±48*	(a)
- P Fertiliser	*ha.a*	-	-	*18*	*±3*	*18*	*±3*	(a)
- K Fertiliser	*ha.a*	-	-	*59*	*±9*	*59*	*±9*	(a)
- Diesel Fuel	*ha.a*	*25*	*±4*	*3*	-	*28*	*±4*	(a)
- Machinery	*ha.a*	-	-	*20*	*±3*	*20*	*±3*	(a)
- Twine	*ha.a*	-	-	*8*	*±1*	*8*	*±1*	(a)
- Maintenance	*ha.a*	-	-	*9*	*±1*	*9*	*±1*	(a)
Reference System:								
- Diesel Fuel	*ha.a*	*- 54*	*±7*	*- 6*	*±3*	*- 60*	*±8*	(a)
- Machinery	*ha.a*	-	-	*- 9*	*±3*	*- 9*	*±3*	(a)
- Maintenance	*ha.a*	-	-	*- 5*	*±1*	*- 5*	*±1*	(a)
- Crop Loss	*ha.a*	*- 3*	-	-	-	*- 3*	-	(a)
Sub-Totals	*ha.a*	*39*	*±14*	*509*	*±48*	*548*	*±49*	
	t be	**40**	**±14**	**517**	**±49**	**557**	**±51**	(b)
Transport:								
- Diesel Fuel	*t bws*	*17*	*±1*	*5*	-	*22*	*±1*	(a)
	t be	**65**	**±2**	**19**	**±2**	**84**	**±3**	(c)
Handling:								
- Diesel Fuel	*t dws*	*7*	*±1*	*1*	-	*8*	*±1*	(a)
	t be	**26**	**±4**	**3**	**-**	**29**	**±4**	(d)
Processing:								
- Sulphuric Acid	*t dws*	-	-	*1*	*±1*	*1*	-	(a)
- Lime	*t dws*	-	-	*2*	-	*2*	-	(a)
- Electricity (credit)	*t dws*	-	-	*- 82*	*±11*	*- 82*	*±11*	(a)
- Acetic Acid (credit)	*t dws*	-	-	*- 22*	*±3*	*- 22*	*±3*	(a)
Sub Totals	*t dws*	-	-	*- 101*	*±11*	*- 101*	*±11*	
	t be	**-**	**-**	**- 367**	**±41**	**- 367**	**±41**	(d)
Plant Construction	**t be**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a)
Plant Maintenance	**t be**	**-**	**-**	**3**	**±1**	**3**	**±1**	(a)
Ash Disposal:								
- Diesel Fuel	*t ash*	*2*	-	-	-	*2*	-	(a)
	t be	**1**	**-**	**-**	**-**	**1**	**-**	(e)
Distribution:								
- Diesel Fuel	**t be**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(a)
Totals	**t be**	**157**	**±15**	**187**	**±64**	**344**	**±66**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t bws = tonne of baled wheat straw
t dws = tonne of dried wheat straw
t ash = tonne of ash
t be = tonne of bioethanol

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 1.015 ha.a/t of bioethanol based on an average baled wheat straw yield of 3.78 t/ha.a and a baled wheat straw requirement of 3.836 t/t of bioethanol.

(c) Baled wheat straw requirement of 3.836 t/t of bioethanol.

(d) Dry wheat straw requirement of 3.634 t/t of bioethanol.

(e) Ash output of 10% of dry wheat straw, or 363 kg/t bioethanol.

APPENDIX Q:Production of Ethanol from Sugar Beet

Figure Q1 Flow Chart for the Production of Ethanol from Sugar Beet

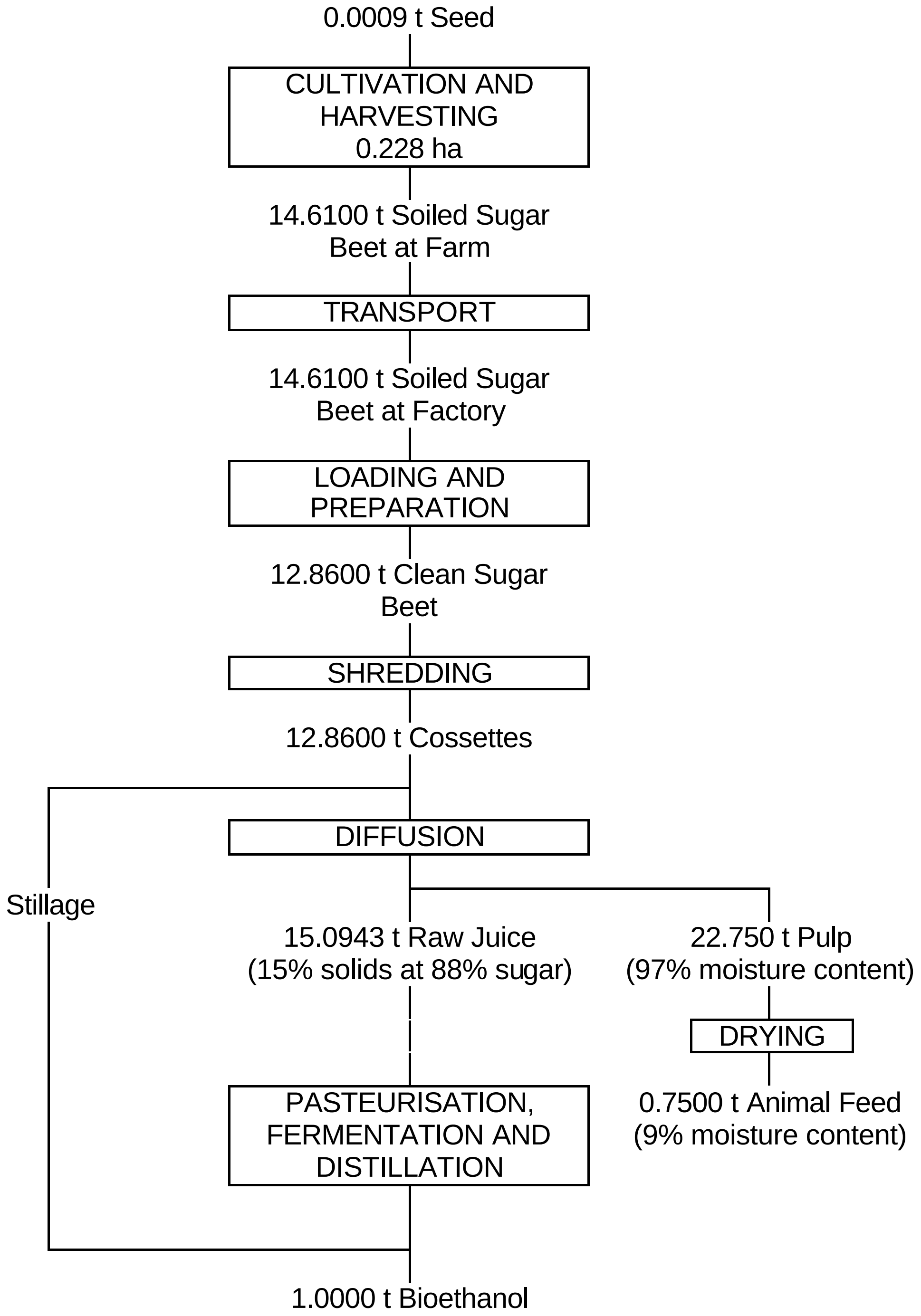

Table Q1 Spreadsheet for Primary Energy Inputs to Ethanol Production from Sugar Beet

Functional Unit:	Bioethanol at point of distribution derived from sugar beet
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average effective prices, assuming 22.750 tonnes of pulp with a moisture content of 97% and an effective price of £3.3/t derived from animal feed with a moisture content of 9% and an average market price for sugar beet pulp nuts of £122.5/t (Ref. 1), and 15.0943 tonnes of raw juice with 15% solids content and 88% sugar and an effective price of £16.1/t derived from thick juice with a 67% solids content and 92.5% sugar and an effective price of £75.5/t (Ref. 2).

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:										
- N Fertiliser	*ha.a*	-	-	*2,066*	*±825*	*3,920*	*±156*	*5,986*	*±840*	(a)
- P Fertiliser	*ha.a*	-	-	*885*	*±133*	-	-	*885*	*±133*	(b, c)
- K Fertiliser	*ha.a*	-	-	*1,311*	*±197*	-	-	*1,311*	*±197*	(c, d)
- Pesticides	*ha.a*	-	-	*315*	*±47*	-	-	*315*	*±47*	(c, e)
- Seed	*ha.a*	-	-	*142*	*±21*	-	-	*142*	*±21*	(c, f)
- Diesel Fuel	*ha.a*	*3,000*	*±475*	*330*	*±157*	-	-	*3,330*	*±500*	(c, g)
Reference System:										
- Diesel Fuel	*ha.a*	*- 922*	*±146*	*- 101*	*±48*	-	-	*- 1,023*	*±154*	(c, h)
Sub-Totals	*ha.a*	*2,078*	*±497*	*4,948*	*±876*	*3,920*	*±156*	*10,946*	*±1,019*	
	t be	**362**	**±87**	**862**	**±153**	**683**	**±27**	**1,907**	**±178**	(i)
Transport:										
- Diesel Fuel	*t ssb*	*66*	*±2*	*23*	*±3*	-	-	*89*	*±4*	(j)
	t be	**737**	**±22**	**257**	**±33**	**-**		**994**	**±40**	(k)
Loading and Preparation:										
- Electricity	*t ssb*	*16*	*±3*	*1*	-	-	-	*17*	*±3*	(c, l)
	t be	**179**	**±33**	**11**	**-**	**-**	**-**	**190**	**±33**	(k)
Storage:										
- Electricity	*t csb*	*1*	-	*1*	-	-	-	*4*	-	(c, m)
	t be	**15**	**±2**	**1**	**-**	**-**	**-**	**16**	**±2**	(n)
Shredding:										
- Electricity	*t csb*	*2*	-	*1*	-	-	-	*3*	-	(c, o)
	t be	**25**	**±4**	**3**	**±1**	**-**	**-**	**28**	**±4**	(n)
Diffusion:										
- Electricity	*t csb*	*7*	*±1*	*1*	-	-	-	*8*	*±1*	(c, p)
- Steam	*t csb*	*75*	*±12*	*9*	*±4*	-	-	*84*	*±13*	(c, q)
Sub-Totals	*t csb*	*82*	*±12*	*10*	*±4*	-	-	*92*	*±13*	
	t be	**806**	**±118**	**98**	**±39**	**-**	**-**	**904**	**±124**	(n)
Pasteurisation:										
- Steam	*t csb*	*52*	*±9*	*5*	-	-	-	*57*	*±9*	(c, r)
	t be	**509**	**±81**	**56**	**±27**	**-**	**-**	**565**	**±85**	(s)
Fermentation:										
- Steam	**t be**	**108**	**±17**	**12**	**±6**	**-**	**-**	**120**	**±18**	(c, t)
Distillation:										
- Electricity	*t be*	*122*	*±19*	*14*	*±6*	-	-	*136*	*±20*	(c, u)
- Steam	*t be*	*6,941*	*±1,097*	*764*	*±364*	-	-	*7,705*	*±1,156*	(c, v)
Sub-Totals	**t be**	**7,063**	**±1,097**	**778**	**±364**	**-**	**-**	**7,841**	**±1,156**	
Plant Construction	**t be**	**3**	**-**	**97**	**±18**	**-**	**-**	**100**	**±18**	(w)
Plant Maintenance	**t be**	**-**	**-**	**82**	**±15**	**-**	**-**	**82**	**±15**	(x)
Distribution	**t be**	**369**	**±14**	**129**	**±16**	**-**	**-**	**498**	**±15**	(y)
Totals	**t be**	**10,176**	**±1,111**	**2,386**	**±400**	**683**	**±27**	**13,245**	**±1,181**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t csb = tonne of clean sugar beet
t ssb = tonne of soiled sugar beet
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 147.4 kg N/ha.a (Ref. 2) and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for nitrogen fertiliser (Ref. 3).

(b) Phosphate fertiliser application rates of 56 kg P_2O_5/ ha.a and a total energy requirement for phosphate fertiliser of 15.8 MJ/kg P_2O_5 (Ref. 2).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 141 kg K_2O/ha.a and a total energy requirement for potash fertiliser of 9.3 MJ/ kg K_2O (Ref. 2).

(e) Herbicide and insecticide application rate of 1.15 kg/ha.a and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 2).

(f) Sowing rate of 4 kg/ha.a and a total energy requirement of 35.5 MJ/kg of seed (Ref. 2).

(g) Diesel fuel consumption of 3,000 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, herbicides and insecticides, and harvesting (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(h) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(i) Land requirement of 0.228 ha.a/t of bioethanol and allocation of 76.4% to bioethanol.

(j) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 6).

(k) Soiled sugar beet requirement of 14.6100 t/t of bioethanol and allocation of 76.4% to bioethanol.

(l) Loading, preparation, earth handling and water effluent treatment electricity consumption of 3.7 kWh/t of soiled sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(m) Storage electricity consumption of 0.35 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(n) Clean sugar beet requirement of 12.8600 t/t of bioethanol and allocation of 76.4% to bioethanol.

(o) Shredding electricity consumption of 0.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(p) Diffusion electricity consumption of 1.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(q) Diffusion steam consumption of 64 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(r) Pasteurisation steam consumption of 44 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(s) Clean sugar beet requirement of 12.8600 t/t of bioethanol.

(t) Fermentation electricity consumption of 25.5 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(u) Molesieve distillation electricity consumption of 40 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(v) Molesieve distillation steam consumption of 5,900 MJ/t of pure bioethanol with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(w) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 6) with a capacity of a 40,000 t/a and a 25 year life, assuming 76.4% contribution to bioethanol by price of co-products.

(x) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 6).

(y) Average round trip distance of 450 km (Ref. 7) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 6).

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1. "Farm Management Pocket Handbook" by J. Nix, 27th Edition, Wye College, University of London, United Kingdom, September 1996.

2. "Nachwachsende Energieträger – Grundlagen, Verfaben, Ökologische Bilanzierung" (Renewable Energy Sources, Basis, Processes and Ecological Balance) by M. Kaltschmitt and G. A. Reinhardt (eds), Vieweg, Braunschweig/Weisbaden, Germany, 1997.

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Table Q2 Spreadsheet for Carbon Dioxide Outputs from Ethanol Production from Sugar Beet

Functional Unit:	Bioethanol at point of distribution derived from sugar beet
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average effective prices, assuming 22.750 tonnes of pulp with a moisture content of 97% and an effective price of £3.3/t derived from animal feed with a moisture content of 9% and an average market price for sugar beet pulp nuts of £122.5/t (Ref. 1), and 15.0943 tonnes of raw juice with 15% solids content and 88% sugar and an effective price of £16.1/t derived from thick juice with a 67% solids content and 92.5% sugar and an effective price of £75.5/t (Ref. 2).

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*281*	*±41*	*281*	*±41*	(a)
- P Fertiliser	*ha.a*	-	-	*39*	*±6*	*39*	*±6*	(b, c)
- K Fertiliser	*ha.a*	-	-	*64*	*±10*	*64*	*±10*	(c, d)
- Pesticides	*ha.a*	-	-	*6*	*±1*	*6*	*±1*	(c, e)
- Seed	*ha.a*	-	-	*7*	*±1*	*7*	*±1*	(c, f)
- Diesel Fuel	*ha.a*	*206*	*±33*	*24*	*±11*	*230*	*±34*	(c, g)
Reference System:								
- Diesel Fuel	*ha.a*	*- 63*	*±10*	*- 7*	*±3*	*- 70*	*±11*	(c, h)
Sub-Totals	*ha.a*	*143*	*±34*	*414*	*±44*	*557*	*±56*	
	t be	**25**	**±6**	**72**	**±8**	**97**	**±10**	(i)
Transport:								
- Diesel Fuel	*t ssb*	*4*	-	*1*	-	*5*	-	(j)
	t be	**50**	**±2**	**14**	**±2**	**64**	**±3**	(k)
Loading and Preparation:								
- Electricity	*t ssb*	*1*	-	-	-	*1*	-	(c, l)
	t be	**13**	**±2**	**1**	**-**	**14**	**±2**	(k)
Storage:								
- Electricity	*t csb*	-	-	-	-	-	-	(c, m)
	t be	**1**	**-**	**-**	**-**	**1**	**-**	(n)
Shredding:								
- Electricity	*t csb*	-	-	-	-	-	-	(c, o)
	t be	**2**	**-**	**-**	**-**	**2**	**-**	(n)
Diffusion:								
- Electricity	*t csb*	-	-	-	-	-	-	(c, p)
- Steam	*t csb*	*5*	*±1*	*1*	-	*6*	*±1*	(c, q)
Sub-Totals	*t csb*	*5*	*±1*	*1*	-	*6*	*±1*	
	t be	**49**	**±10**	**10**	**-**	**59**	**±10**	(n)
Pasteurisation:								
- Steam	*t csb*	*4*	*±1*	-	-	*4*	*±1*	(c, r)
	t be	**49**	**±7**	**5**	**±2**	**54**	**±8**	(n)
Fermentation:								
- Steam	**t be**	**8**	**±1**	**1**	**-**	**9**	**±1**	(s)
Distillation:								
- Electricity	*t be*	*12*	*±2*	*1*	-	*13*	*±2*	(t)
- Steam	*t be*	*507*	*±80*	*56*	*±26*	*563*	*±84*	(u)
Sub-Totals	**t be**	**519**	**±80**	**57**	**±26**	**576**	**±84**	(v)
Plant Construction	**t be**	**-**	**-**	**5**	**±1**	**5**	**±1**	(w)
Plant Maintenance	**t be**	**-**	**-**	**3**	**±1**	**3**	**±1**	(x)
Distribution	**t be**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(y)
Totals	**t be**	**741**	**±81**	**175**	**±27**	**916**	**±86**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t csb = tonne of clean sugar beet
t ssb = tonne of soiled sugar beet
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 147.4 kg N/ha.a (Ref. 2) and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 3).

(b) Phosphate fertiliser application rates of 56 kg P_2O_5/ ha.a and a total carbon requirement for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 (Ref. 2).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 141 kg K_2O/ha.a and a total carbon requirement for potash fertiliser of 0.453 kg CO_2/ kg K_2O (Ref. 2).

(e) Herbicide and insecticide application rate of 1.15 kg/ha.a and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 2).

(f) Sowing rate of 4 kg/ha.a and a total carbon requirement of 1.775 kg CO_2 /kg of seed (Ref. 2).

(g) Diesel fuel consumption of 3,000 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, herbicides and insecticides, and harvesting (Ref. 2), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(h) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 2) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(i) Land requirement of 0.228 ha.a/t of bioethanol and allocation of 76.4% to bioethanol.

(j) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

(k) Soiled sugar beet requirement of 14.6100 t/t of bioethanol and allocation of 76.4% to bioethanol.

(l) Loading, preparation, earth handling and water effluent treatment electricity consumption of 3.7 kWh/t of soiled sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(m) Storage electricity consumption of 0.35 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(n) Clean sugar beet requirement of 12.8600 t/t of bioethanol and allocation of 76.4% to bioethanol.

(o) Shredding electricity consumption of 0.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(p) Diffusion electricity consumption of 1.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(q) Diffusion steam consumption of 64 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(r) Pasteurisation steam consumption of 44 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(s) Clean sugar beet requirement of 12.8600 t/t of bioethanol.

(t) Fermentation electricity consumption of 25.5 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(u) Molesieve distillation electricity consumption of 40 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(v) Molesieve distillation steam consumption of 5,900 MJ/t of pure bioethanol with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(w) Carbon dioxide output of 6,287 ± 1,116 tonnes CO_2 from construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 6) with a capacity of a 40,000 t/a and a 25 year life, assuming 76.4% contribution to bioethanol by price of co-products.

(x) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 6).

(y) Average round trip distance of 450 km (Ref. 7) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 6).

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Table Q3 Spreadsheet for Methane Outputs from Ethanol Production from Sugar Beet

Functional Unit:	Bioethanol at point of distribution derived from sugar beet
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average effective prices, assuming 22.750 tonnes of pulp with a moisture content of 97% and an effective price of £3.3/t derived from animal feed with a moisture content of 9% and an average market price for sugar beet pulp nuts of £122.5/t (Ref. 1), and 15.0943 tonnes of raw juice with 15% solids content and 88% sugar and an effective price of £16.1/t derived from thick juice with a 67% solids content and 92.5% sugar and an effective price of £75.5/t (Ref. 2).

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*0.531*	*±0.088*	*0.531*	*±0.088*	(a)
- P Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.003*	-	*0.003*	-	(c, d)
- Pesticides	*ha.a*	-	-	-	-	-	-	(c, e)
- Seed	*ha.a*	-	-	*0.008*	*±0.001*	*0.008*	*±0.001*	(c, f)
- Diesel Fuel	*ha.a*	*0.002*	-	*0.061*	*±0.009*	*0.063*	*±0.009*	(c, g)
Reference System:								
- Diesel Fuel	*ha.a*	*-0.001*	-	*-0.019*	*±0.003*	*-0.020*	*±0.003*	(c, h)
Sub-Totals	*ha.a*	*0.001*	-	*0.585*	*±0.089*	*0.586*	*±0.089*	
	t be	**-**	**-**	**0.102**	**±0.016**	**0.102**	**±0.016**	(i)
Transport:								
- Diesel Fuel	*t ssb*	-	-	*0.001*	-	*0.001*	-	(j)
	t be	**-**	**-**	**0.015**	**±0.001**	**0.015**	**±0.001**	(k)
Loading and Preparation:								
- Electricity	*t ssb*	-	-	-	-	-	-	(c, l)
	t be	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(k)
Storage:								
- Electricity	*t csb*	-	-	-	-	-	-	(c, m)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Shredding:								
- Electricity	*t csb*	-	-	-	-	-	-	(c, o)
	t be	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(n)
Diffusion:								
- Electricity	*t csb*	-	-	-	-	-	-	(c, p)
- Steam	*t csb*	-	-	*0.002*	-	*0.002*	-	(c, q)
Sub-Totals	*t csb*	-	-	*0.002*	-	*0.002*	-	
	t be	**0.001**	**-**	**0.025**	**±0.004**	**0.026**	**±0.004**	(n)
Pasteurisation:								
- Steam	*t csb*	-	-	*0.001*	-	*0.001*	-	(c, r)
	t be	**0.002**	**-**	**0.014**	**±0.002**	**0.016**	**±0.002**	(n)
Fermentation:								
- Steam	**t be**	**-**	**-**	**0.002**	**-**	**0.002**	**-**	(s)
Distillation:								
- Electricity	*t be*	-	-	*0.003*	*±0.001*	*0.003*	*±0.001*	(t)
- Steam	*t be*	*0.018*	*±0.003*	*0.142*	*±0.021*	*0.160*	*±0.021*	(u)
Sub-Totals	**t be**	**0.018**	**±0.003**	**0.145**	**±0.021**	**0.163**	**±0.021**	(v)
Plant Construction	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Plant Maintenance	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Distribution	**t be**	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(y)
Totals	**t be**	**0.021**	**±0.003**	**0.313**	**±0.027**	**0.334**	**±0.027**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t csb = tonne of clean sugar beet
t ssb = tonne of soiled sugar beet
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 147.4 kg N/ha.a (Ref. 2) and a total methane requirement for ammonium nitrate of 3.6 x 10^{-3} ± 0.6 x 10^{-3} kg CH_4/kg N (Ref. 3).

(b) Phosphate fertiliser application rates of 56 kg P_2O_5/ ha.a and a total methane requirement for phosphate fertiliser of 2.3 x 10^{-5} kg CH_4/kg P_2O_5 (Ref. 2).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(d) Potash fertiliser application rate of 141 kg K_2O/ha.a and a total methane requirement for potash fertiliser of 2.1 x 10^{-5} kg CH_4/ kg K_2O (Ref. 2).

(e) Herbicide and insecticide application rate of 1.15 kg/ha.a and a total methane requirement for general pesticides, herbicides and fungicides of 1.8 x 10^{-4} kg CH_4/kg (Ref. 2).

(f) Sowing rate of 4 kg/ha.a and a total methane requirement of 0.002 kg CH_4 /kg of seed (Ref. 2).

(g) Diesel fuel consumption of 3,000 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, herbicides and insecticides, and harvesting (Ref. 2), and a direct methane requirement of 6.0 x 10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.1 x 10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(h) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 2) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(i) Land requirement of 0.228 ha.a/t of bioethanol and allocation of 76.4% to bioethanol.

(j) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 6).

(k) Soiled sugar beet requirement of 14.6100 t/t of bioethanol and allocation of 76.4% to bioethanol.

(l) Loading, preparation, earth handling and water effluent treatment electricity consumption of 3.7 kWh/t of soiled sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(m) Storage electricity consumption of 0.35 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(n) Clean sugar beet requirement of 12.8600 t/t of bioethanol and allocation of 76.4% to bioethanol.

(o) Shredding electricity consumption of 0.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(p) Diffusion electricity consumption of 1.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(q) Diffusion steam consumption of 64 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(r) Pasteurisation steam consumption of 44 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6×10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.3×10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(s) Clean sugar beet requirement of 12.8600 t/t of bioethanol.

(t) Fermentation electricity consumption of 25.5 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6×10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.3×10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(u) Molesieve distillation electricity consumption of 40 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6×10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.3×10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(v) Molesieve distillation steam consumption of 5,900 MJ/t of pure bioethanol with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct methane requirement of 2.6×10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.3×10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(w) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant, assumed to be similar to a biodiesel plant (Ref. 6), with a capacity of a 40,000 t/a and a 25 year life, and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 8), assuming 76.4% contribution to bioethanol by price of co-products.

(x) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 6).

(y) Average round trip distance of 450 km (Ref. 7) by bulk road carrier transport a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 6).

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Table Q4 Spreadsheet for Nitrous Oxide Outputs from Ethanol Production from Sugar Beet

Functional Unit:	Bioethanol at point of distribution derived from sugar beet
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average effective prices, assuming 22.750 tonnes of pulp with a moisture content of 97% and an effective price of £3.3/t derived from animal feed with a moisture content of 9% and an average market price for sugar beet pulp nuts of £122.5/t (Ref. 1), and 15.0943 tonnes of raw juice with 15% solids content and 88% sugar and an effective price of £16.1/t derived from thick juice with a 67% solids content and 92.5% sugar and an effective price of £75.5/t (Ref. 2).

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*0.531*	*±0.080*	*2.167*	*±0.325*	*2.698*	*±0.335*	(a, b)
- P Fertiliser	*ha.a*	-	-	*0.002*	-	*0.002*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, d)
- Pesticides	*ha.a*	-	-	*0.002*	-	*0.002*	-	(b, e)
- Seed	*ha.a*	-	-	*0.004*	*±0.001*	*0.004*	*±0.001*	(b, f)
- Diesel Fuel	*ha.a*	*0.002*	-	-	-	*0.002*	-	(b, g)
Reference System:								
- Diesel Fuel	*ha.a*	*-0.001*	-	-	-	*-0.001*	-	(b, h)
Sub-Totals	*ha.a*	*0.532*	*±0.080*	*2.176*	*±0.325*	*2.708*	*±0.335*	
	t be	**0.093**	**±0.014**	**0.379**	**±0.057**	**0.472**	**±0.058**	(i)
Transport:								
- Diesel Fuel	*t ssb*	-	-	-	-	-	-	(j)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Loading and Preparation:								
- Electricity	*t ssb*	-	-	-	-	-	-	(b, l)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Storage:								
- Electricity	*t csb*	-	-	-	-	-	-	(b, m)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Shredding:								
- Electricity	*t csb*	-	-	-	-	-	-	(b, o)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Diffusion:								
- Electricity	*t csb*	-	-	-	-	-	-	(b, p)
- Steam	*t csb*	-	-	-	-	-	-	(b, q)
Sub-Totals	*t csb*	-	-	-	-	-	-	
	t be	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(n)
Pasteurisation:								
- Steam	*t csb*	-	-	-	-	-	-	(b, r)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(n)
Fermentation:								
- Steam	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Distillation:								
- Electricity	*t be*	-	-	-	-	-	-	(t)
- Steam	*t be*	*0.004*	*±0.001*	-	-	*0.004*	*±0.001*	(u)
Sub-Totals	**t be**	**0.004**	**±0.001**	**-**	**-**	**0.004**	**±0.001**	(v)
Plant Construction	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Plant Maintenance	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Distribution	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(y)
Totals	**t be**	**0.097**	**±0.014**	**0.380**	**±0.057**	**0.477**	**±0.058**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t csb = tonne of clean sugar beet
t ssb = tonne of soiled sugar beet
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 147.4 kg N/ha.a (Ref. 2) and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 5), an indirect nitrous oxide requirement of 0.0147 kg N_2O/kg N (Ref. 2) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 3).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 4).

(c) Phosphate fertiliser application rates of 56 kg P_2O_5/ ha.a and a total nitrous oxide requirement for phosphate fertiliser of 4.2×10^{-5} kg N_2O/kg P_2O_5 (Ref. 2).

(d) Potash fertiliser application rate of 141 kg K_2O/ha.a and a total nitrous oxide requirement for potash fertiliser of 9.4×10^{-6} kg N_2O/ kg K_2O (Ref. 2).

(e) Herbicide and insecticide application rate of 1.15 kg/ha.a and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.51×10^{3} kg N_2O/kg (Ref. 2).

(f) Sowing rate of 4 kg/ha.a and a total nitrous oxide requirement of 0.001 kg N_2O /kg of seed (Ref. 2).

(g) Diesel fuel consumption of 3,000 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, herbicides and insecticides, and harvesting (Ref. 2), and a direct nitrous oxide requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60×10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(h) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 2) and a direct nitrous oxide requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60×10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 5).

(i) Land requirement of 0.228 ha.a/t of bioethanol and allocation of 76.4% to bioethanol.

(j) Average round trip distance of 80 km (Ref. 2) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 6).

(k) Soiled sugar beet requirement of 14.6100 t/t of bioethanol and allocation of 76.4% to bioethanol.

(l) Loading, preparation, earth handling and water effluent treatment electricity consumption of 3.7 kWh/t of soiled sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(m) Storage electricity consumption of 0.35 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(n) Clean sugar beet requirement of 12.8600 t/t of bioethanol and allocation of 76.4% to bioethanol.

(o) Shredding electricity consumption of 0.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(p) Diffusion electricity consumption of 1.6 kWh/t of clean sugar beet with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(q) Diffusion steam consumption of 64 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(r) Pasteurisation steam consumption of 44 MJ/t of clean sugar beet with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(s) Clean sugar beet requirement of 12.8600 t/t of bioethanol.

(t) Fermentation electricity consumption of 25.5 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(u) Molesieve distillation electricity consumption of 40 kWh/t of pure bioethanol with electricity provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for electricity or steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(v) Molesieve distillation steam consumption of 5,900 MJ/t of pure bioethanol with steam provided by a heavy fuel oil-fired combined heat and power plant with an overall thermal efficiency for steam of 85% (Ref. 2) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 5).

(w) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 6) with a capacity of a 40,000 t/a and a 25 year life, assuming an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ of primary energy input to construction (Ref. 8) and a 76.4% contribution to bioethanol by price of co-products

(x) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 6).

(y) Average round trip distance of 450 km (Ref. 7) by bulk road carrier transport a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 6).

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Table Q5 Spreadsheet for Total Greenhouse Gas Outputs from Ethanol Production from Sugar Beet

Functional Unit:	Bioethanol at point of distribution derived from sugar beet
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average effective prices, assuming 22.750 tonnes of pulp with a moisture content of 97% and an effective price of £3.3/t derived from animal feed with a moisture content of 9% and an average market price for sugar beet pulp nuts of £122.5/t (Ref. 1), and 15.0943 tonnes of raw juice with 15% solids content and 88% sugar and an effective price of £16.1/t derived from thick juice with a 67% solids content and 92.5% sugar and an effective price of £75.5/t (Ref. 2).

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	ha.a	170	-	987	±112	1,157	±112	(a)
- P Fertiliser	ha.a	-	-	40	±6	40	±6	(a)
- K Fertiliser	ha.a	-	-	64	±10	64	±10	(a)
- Pesticides	ha.a	-	-	7	±1	7	±1	(a)
- Seed	ha.a	-	-	8	±1	8	±1	(a)
- Diesel Fuel	ha.a	207	±33	25	±11	232	±34	(a)
Reference System:								
- Diesel Fuel	ha.a	- 63	±10	- 7	±3	- 70	±11	(a)
Sub-Totals	ha.a	314	±34	1,124	±113	1,438	±118	
	t be	**55**	**±6**	**196**	**±20**	**251**	**±21**	(b)
Transport:								
- Diesel Fuel	t ssb	4	-	1	-	5	-	(a)
	t be	**50**	**±2**	**14**	**±2**	**64**	**±3**	(c)
Loading and Preparation:								
- Electricity	t ssb	1	-	-	-	1	-	(a)
	t be	**13**	**±2**	**1**	**-**	**14**	**±2**	(c)
Storage:								
- Electricity	t csb	-	-	-	-	-	-	(a)
	t be	**1**	**-**	**-**	**-**	**1**	**-**	(d)
Shredding:								
- Electricity	t csb	-	-	-	-	-	-	(a)
	t be	**2**	**-**	**-**	**-**	**2**	**-**	(d)
Diffusion:								
- Electricity	t csb	-	-	-	-	-	-	(a)
- Steam	t csb	5	±1	1	-	6	±1	(a)
								(a)
Sub-Totals	t csb	5	±1	1	-	6	±1	
	t be	**49**	**±10**	**11**	**-**	**60**	**±10**	(d)
Pasteurisation:								
- Steam	t csb	4	±1	-	-	4	±1	(a)
	t be	**49**	**±7**	**5**	**±2**	**54**	**±8**	(e)
Fermentation:								
- Steam	**t be**	**8**	**±1**	**1**	**-**	**9**	**±1**	(a)
Distillation:								
- Electricity	t be	12	±2	1	-	13	±2	(a)
- Steam	t be	509	±80	59	±26	568	±84	(a)
Sub-Totals	**t be**	**521**	**±80**	**60**	**±26**	**581**	**±84**	
Plant Construction	**t be**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a)
Plant Maintenance	**t be**	**-**	**-**	**3**	**±1**	**3**	**±1**	(a)
Distribution	**t be**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(a)
Totals	**t be**	**773**	**±81**	**303**	**±33**	**1,076**	**±87**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t csb = tonne of clean sugar beet
t ssb = tonne of soiled sugar beet
t be = tonne of bioethanol

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 0.228 ha.a/t of bioethanol and allocation of 76.4% to bioethanol.

(c) Soiled sugar beet requirement of 14.6100 t/t of bioethanol and allocation of 76.4% to bioethanol.

(d) Clean sugar beet requirement of 12.8600 t/t of bioethanol and allocation of 76.4% to bioethanol.

(e) Clean sugar beet requirement of 12.8600 t/t of bioethanol.

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APPENDIX R: Production of Ethanol from Wheat

Figure R1 Flow Chart for the Production of Ethanol from Wheat

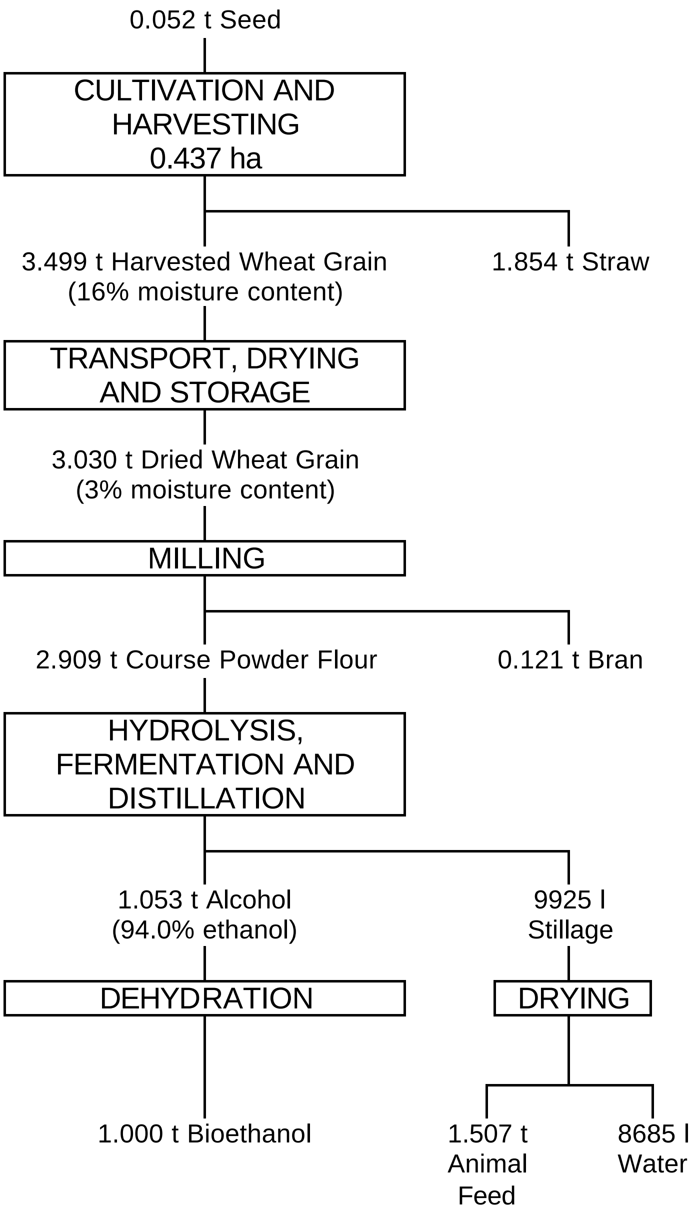

Table R1 Spreadsheet for Primary Energy Inputs to Ethanol Production from Wheat

Functional Unit:	Bioethanol at point of distribution derived from wheat
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 1.854 tonnes of wheat straw at £25/t (Ref. 1) and 3.499 tonnes of harvested wheat grain at £99/t (Ref. 2), giving a 88.2% allocation to bioethanol, 0.121 tonnes of bran at £10/t (Ref. 3) and 2.909 tonnes of course powder flour at £303/t (Ref. 4), giving a 99.9% allocation to bioethanol, and 1.507 tonnes of animal feed at £80/t (Ref. 3) and 1.000 tonnes of bioethanol at £388/t (Ref. 3), giving a 76.3% allocation to bioethanol.

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:										
- N Fertiliser	*ha.a*	-	-	*736*	*±294*	*1,396*	*±56*	*2,132*	*±299*	(a)
- P Fertiliser	*ha.a*	-	-	*948*	*±142*	-	-	*948*	*±142*	(b, c)
- K Fertiliser	*ha.a*	-	-	*558*	*±84*	-	-	*558*	*±84*	(c, d)
- Insecticide	*ha.a*	-	-	*38*	*±6*	-	-	*38*	*±6*	(c, e)
- Herbicides	*ha.a*	-	-	*1,472*	*±221*	-	-	*1,472*	*±221*	(c, f)
- Fungicide	*ha.a*	-	-	*795*	*±119*	-	-	*795*	*±119*	(c, g)
- Seed	*ha.a*	-	-	*1,620*	*±243*	-	-	*1,620*	*±243*	(c, h)
- Diesel Fuel	*ha.a*	*3,801*	*±601*	*418*	*±199*	-	-	*4,219*	*±633*	(c, i)
Reference System:										
- Diesel Fuel	*ha.a*	*- 922*	*±146*	*- 101*	*±48*	-	-	*-1,023*	*±154*	(c, j)
Sub-Totals	*ha.a*	*2,879*	*±618*	*6,484*	*±527*	*1,396*	*±56*	*10,759*	*±814*	
	t be	**846**	**±182**	**1,905**	**±155**	**410**	**±16**	**3,161**	**±239**	(k)
Transport:										
- Diesel Fuel	*t hwg*	*213*	*±8*	*74*	*±9*	-	-	*287*	*±12*	(l)
	t be	**568**	**±21**	**197**	**±24**	**-**	**-**	**765**	**±32**	(m)
Drying:										
- Fuel Oil	*t dwg*	*661*	*±105*	*73*	*±35*	-	-	*734*	*±111*	(c, n)
	t be	**1,527**	**±243**	**169**	**±80**	**-**	**-**	**1,696**	**±256**	(o)
Storage:										
- Electricity	*t dwg*	*42*	*±6*	*87*	*±9*	-	-	*129*	*±11*	(c, p)
	t be	**97**	**±14**	**201**	**±21**	**-**	**-**	**298**	**±25**	(o)
Milling:										
- Electricity	*t dwg*	*44*	*±11*	*93*	*±16*	-	-	*137*	*±20*	(c, q)
	t be	**102**	**±25**	**215**	**±37**	**-**	**-**	**317**	**±45**	(o)
Hydrolysis, Fermentation and Distillation:										
- Natural Gas	*t dwg*	*2,117*	*±317*	*233*	*±105*	-	-	*2,350*	*±334*	(c, r)
	t be	**4,894**	**±733**	**539**	**±243**	**-**	**-**	**5,433**	**±772**	(s)
Dehydration:										
- Natural Gas	*t dwg*	*12*	*±2*	*1*	-	-	-	*13*	*±2*	(c, t)
	t be	**36**	**±5**	**3**	**-**	**-**	**-**	**39**	**±5**	(u)
Plant Construction	**t be**	**3**	**-**	**97**	**±18**	**-**	**-**	**100**	**±18**	(v)
Plant Maintenance	**t be**	**-**	**-**	**82**	**±15**	**-**	**-**	**82**	**±15**	(w)
Distribution:										
- Diesel Fuel	**t be**	**369**	**±14**	**129**	**±16**	**-**	**-**	**498**	**±21**	(x)
Totals	**t be**	**8,442**	**±794**	**3,537**	**±304**	**410**	**±15**	**12,389**	**±850**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t hwg = tonne of harvested wheat grain
t dwg = tonne of dried wheat grain
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 150 kg NH_4NO_3/ha.a, or 52.5 kg N/ha.a assuming 0.35 kg N/kg NH_4NO_3 (Ref. 3) and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for nitrogen fertiliser (Ref. 5).

(b) Phosphate fertiliser application rates of 60 kg P_2O_5/ ha.a (Ref. 3) and a total energy requirement for phosphate fertiliser of 15.8 MJ/kg P_2O_5 (Ref. 6).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 7).

(d) Potash fertiliser application rate of 60 kg K_2O/ha.a (Ref. 3) and a total energy requirement for potash fertiliser of 9.3 MJ/ kg K_2O (Ref. 6).

(e) Insecticide application rate of 0.14 kg/ha.a (Ref. 3) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 6).

(f) Herbicide and plant inhibitor application rate of 5.37 kg/ha.a (Ref. 3) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 6).

(g) Fungicide application rate of 2.9 kg/ha.a (Ref. 3) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 6).

(h) Sowing rate of 120 kg/ha.a and a total energy requirement of 13.5 MJ/kg of seed (Ref. 3).

(i) Diesel fuel consumption of 3,801 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 3) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(k) Land requirement of 0.437 ha.a/t of bioethanol and allocation of 88.2% x 99.9% x 76.3% = 67.2% to bioethanol.

(l) Average round trip distance of 260 km (Ref. 3) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 9).

(m) Harvested wheat grain requirement of 3.499 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(n) Based on pro-rata fuel oil consumption of 305 MJ/t for drying of oilseed rape from 15% to 9% moisture content (Ref. 6), giving fuel oil consumption of 661 MJ/t for drying wheat grain from 16% to 3% moisture content, and a gross energy requirement of 1.110 MJ/MJ for fuel oil in the UK in 1996 (Ref. 8).

(o) Dried wheat grain requirement of 3.030 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(p) Electricity consumption of 11.6 kWh/t of dried wheat grain for cooling, assumed similar to dried rapeseed cooling in storage (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 8).

(q) Assuming milling accounts for all electricity consumption of 12.3 kWh/t of dried wheat grain (Ref. 3) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 8).

(r) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with distillation accounting for 54.8% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 8).

(s) Dried wheat grain requirement 3.030 t/t of bioethanol and allocation of 76.3% to bioethanol.

(t) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with dehydration accounting for 0.3% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 8).

(u) Dried wheat grain requirement of 3.030 t/t of bioethanol.

(v) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 9) with a capacity of a 40,000 t/a and a 25 year life, assuming 76.3% contribution to bioethanol by price of co-products.

(w) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 9).

(x) Average round trip distance of 450 km (Ref. 3) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 9).

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Table R2 Spreadsheet for Carbon Dioxide Outputs from Ethanol Production from Wheat

Functional Unit: :	Bioethanol at point of distribution derived from wheat
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 1.854 tonnes of wheat straw at £25/t (Ref. 1) and 3.499 tonnes of harvested wheat grain at £99/t (Ref. 2), giving a 88.2% allocation to bioethanol, 0.121 tonnes of bran at £10/t (Ref. 3) and 2.909 tonnes of course powder flour at £303/t (Ref. 4), giving a 99.9% allocation to bioethanol, and 1.507 tonnes of animal feed at £80/t (Ref. 3) and 1.000 tonnes of bioethanol at £388/t (Ref. 3), giving a 76.3% allocation to bioethanol.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*100*	*±14*	*100*	*±14*	(a)
- P Fertiliser	*ha.a*	-	-	*42*	*±6*	*42*	*±6*	(b, c)
- K Fertiliser	*ha.a*	-	-	*27*	*±4*	*27*	*±4*	(c, d)
- Insecticide	*ha.a*	-	-	*1*	-	*1*	-	(c, e)
- Herbicides	*ha.a*	-	-	*26*	*±4*	*26*	*±4*	(c, f)
- Fungicide	*ha.a*	-	-	*14*	*±2*	*14*	*±2*	(c, g)
- Seed	*ha.a*	-	-	*66*	*±10*	*66*	*±10*	(c, h)
- Diesel Fuel	*ha.a*	*261*	*±42*	*31*	*±14*	*292*	*±44*	(c, i)
Reference System:								
- Diesel Fuel	*ha.a*	*- 63*	*±10*	*- 7*	*±3*	*- 70*	*±11*	(j)
Sub-Totals	*ha.a*	*198*	*±43*	*300*	*±24*	*498*	*±49*	
	t be	**58**	**±13**	**88**	**±7**	**146**	**±14**	(k)
Transport:								
- Diesel Fuel	*t hwg*	*15*	*±1*	*4*	-	*19*	*±1*	(l)
	t be	**40**	**±3**	**11**	**-**	**51**	**±3**	(m)
Drying:								
- Fuel Oil	*t dwg*	*48*	*±8*	*5*	*±2*	*53*	*±8*	(c, n)
	t be	**111**	**±18**	**11**	**±5**	**122**	**±19**	(o)
Storage:								
- Electricity	*t dwg*	-	-	*6*	*±1*	*6*	*±1*	(c, p)
	t be	**-**	**-**	**14**	**±2**	**14**	**±2**	(o)
Milling:								
- Electricity	*t dwg*	-	-	*7*	*±1*	*7*	*±1*	(c, q)
	t be	**-**	**-**	**16**	**±2**	**16**	**±2**	(o)
Hydrolysis, Fermentation and Distillation:								
- Natural Gas	*t dwg*	*110*	*±17*	*4*	*±1*	*114*	*±17*	(c, r)
	t be	**254**	**±39**	**9**	**±2**	**263**	**±39**	(s)
Dehydration:								
- Natural Gas	*t dwg*	*1*	-	-	-	*1*	-	(c, t)
	t be	**2**	**-**	**-**	**-**	**2**	**-**	(u)
Plant Construction	**t be**	**-**	**-**	**5**	**±1**	**5**	**±1**	(v)
Plant Maintenance	**t be**	**-**	**-**	**3**	**±1**	**3**	**±1**	(w)
Distribution:								
- Diesel Fuel	**t be**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(x)
Totals	**t be**	**490**	**±45**	**164**	**±9**	**654**	**±46**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t hwg = tonne of harvested wheat grain
t dwg = tonne of dried wheat grain
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 150 kg NH_4NO_3/ha.a, or 52.5 kg N/ha.a assuming 0.35 kg N/kg NH_4NO_3 (Ref. 3) and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 5).

(b) Phosphate fertiliser application rates of 60 kg P_2O_5/ ha.a (Ref. 3) and a total carbon requirement for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 (Ref. 6).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 7).

(d) Potash fertiliser application rate of 60 kg K_2O/ha.a (Ref. 3) and a total carbon requirement for potash fertiliser of 0.453 kg CO_2/ kg K_2O (Ref. 6).

(e) Insecticide application rate of 0.14 kg/ha.a (Ref. 3) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 6).

(f) Herbicide and plant inhibitor application rate of 5.37 kg/ha.a (Ref. 3) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 6).

(g) Fungicide application rate of 2.9 kg/ha.a (Ref. 3) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 6).

(h) Sowing rate of 120 kg/ha.a (Ref. 3) and a total carbon requirement of 0.547 kg CO_2/kg of seed based on a ratio of 0.0405 kg CO_2/MJ for oilseed (Ref. 6).

(i) Diesel fuel consumption of 3,801 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 3), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6) and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(k) Land requirement of 0.437 ha.a/t of bioethanol and allocation of 88.2% x 99.9% x 76.3% = 67.2% to bioethanol.

(l) Average round trip distance of 260 km (Ref. 3) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 9).

(m) Harvested wheat grain requirement of 3.499 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(n) Based on pro-rata fuel oil consumption of 305 MJ/t for drying of oilseed rape from 15% to 9% moisture content (Ref. 6), giving fuel oil consumption of 661 MJ/t for drying wheat grain from 16% to 3% moisture content, and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for fuel oil in the UK in 1996 (Ref. 8).

(o) Dried wheat grain requirement of 3.030 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(p) Electricity consumption of 11.6 kWh/t of dried wheat grain for cooling, assumed similar to dried rapeseed cooling in storage (Ref. 6) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 8).

(q) Assuming milling accounts for all electricity consumption of 12.3 kWh/t of dried wheat grain (Ref. 3) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 8).

(r) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with distillation accounting for 54.8% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 8).

(s) Dried wheat grain requirement 3.030 t/t of bioethanol and allocation of 76.3% to bioethanol.

(t) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with dehydration accounting for 0.3% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 8).

(u) Dried wheat grain requirement of 3.030 t/t of bioethanol.

(v) Carbon dioxide output of 6,287 ± 1,116 tonnes CO_2 from construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 9) with a capacity of a 40,000 t/a and a 25 year life, assuming 76.3% contribution to bioethanol by price of co-products.

(w) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 9).

(x) Average round trip distance of 450 km (Ref. 3) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 9).

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1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

2. Annual average price of feed wheat in East Anglia, United Kingdom, 1996/97 from www.hgca.com/c-stats accessed 17 December 2002.

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4. "Overseas Trade Statistics of the United Kingdom with Countries Outside the European Community" Business Monitor MM20, H. M. Customs and Excise, London, December 1996.

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Table R3 Spreadsheet for Methane Outputs from Ethanol Production from Wheat

Functional Unit: :	Bioethanol at point of distribution derived from wheat
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 1.854 tonnes of wheat straw at £25/t (Ref. 1) and 3.499 tonnes of harvested wheat grain at £99/t (Ref. 2), giving a 88.2% allocation to bioethanol, 0.121 tonnes of bran at £10/t (Ref. 3) and 2.909 tonnes of course powder flour at £303/t (Ref. 4), giving a 99.9% allocation to bioethanol, and 1.507 tonnes of animal feed at £80/t (Ref. 3) and 1.000 tonnes of bioethanol at £388/t (Ref. 3), giving a 76.3% allocation to bioethanol.

Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*0.189*	*±0.031*	*0.189*	*±0.031*	(a)
- P Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c, d)
- Insecticide	*ha.a*	-	-	-	-	-	-	(c, e)
- Herbicides	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c, f)
- Fungicide	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c, g)
- Seed	*ha.a*	-	-	-	-	-	-	(c, h)
- Diesel Fuel	*ha.a*	*0.002*	-	*0.078*	*±0.012*	*0.080*	*±0.012*	(c, i)
Reference System:								
- Diesel Fuel	*ha.a*	*- 0.001*	-	*- 0.019*		*- 0.020*	*±0.003*	(c, j)
Sub-Totals	*ha.a*	*0.001*	-	*0.252*	*±0.033*	*0.253*	*±0.033*	
	t be	**-**	**-**	**0.074**	**±0.010**	**0.074**	**±0.010**	(k)
Transport:								
- Diesel Fuel	*t hwg*	-	-	*0.004*	-	*0.004*	-	(l)
	t be	**-**	**-**	**0.011**	**-**	**0.011**	**-**	(m)
Drying:								
- Fuel Oil	*t dwg*	*0.002*	-	*0.013*	*±0.002*	*0.015*	*±0.002*	(c, n)
	t be	**0.005**	**-**	**0.030**	**±0.005**	**0.035**	**±0.005**	(o)
Storage:								
- Electricity	*t dwg*	-	-	*0.017*	*±0.003*	*0.017*	*±0.003*	(c, p)
	t be	**-**	**-**	**- 0.039**	**±0.007**	**0.039**	**±0.007**	(o)
Milling:								
- Electricity	*t dwg*	-	-	*0.018*	*±0.003*	*0.018*	*±0.003*	(c, q)
	t be	**-**	**-**	**0.042**	**±0.007**	**0.042**	**±0.007**	(o)
Hydrolysis, Fermentation and Distillation:								
- Natural Gas	*t dwg*	*0.008*	-	*0.229*	*±0.036*	*0.237*	*±0.036*	(c, r)
	t be	**0.018**	**-**	**0.529**	**±0.083**	**0.547**	**±0.083**	(s)
Dehydration:								
- Natural Gas	*t dwg*	-	-	*0.001*	-	*0.001*	-	(c, t)
	t be	**-**	**-**	**0.004**	**-**	**0.004**	**-**	(u)
Plant Construction	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Plant Maintenance	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Distribution:								
- Diesel Fuel	**t be**	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(x)
Totals	**t be**	**0.023**	**-**	**0.737**	**±0.084**	**0.760**	**±0.084**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t hwg = tonne of harvested wheat grain
t dwg = tonne of dried wheat grain
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 150 kg NH_4NO_3/ha.a, or 52.5 kg N/ha.a assuming 0.35 kg N/kg NH_4NO_3 (Ref. 3) and a total methane requirement for ammonium nitrate of $3.6 \times 10^{-3} \pm 0.6 \times 10^{-3}$ kg CH_4/kg N (Ref. 5).

(b) Phosphate fertiliser application rates of 60 kg P_2O_5/ ha.a (Ref. 3) and a total methane requirement for phosphate fertiliser of 2.3×10^{-5} kg CH_4/kg P_2O_5 (Ref. 6).

(c) Assuming an error bar of ±15% based on similar analyses (Ref. 7).

(d) Potash fertiliser application rate of 60 kg K_2O/ha.a (Ref. 3) and a total methane requirement for potash fertiliser of 2.1×10^{-5} kg CH_4/ kg K_2O (Ref. 6).

(e) Insecticide application rate of 0.14 kg/ha.a (Ref. 3) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8×10^{-4} kg CH_4/kg (Ref. 6).

(f) Herbicide and plant inhibitor application rate of 5.37 kg/ha.a (Ref. 3) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8×10^{-4} kg CH_4/kg (Ref. 6).

(g) Fungicide application rate of 2.9 kg/ha.a (Ref. 3) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8×10^{-4} kg CH_4/kg (Ref. 6).

(h) Sowing rate of 120 kg/ha.a (Ref. 3) and a total methane requirement of 0 kg CH_4/kg of seed, assuming similarity with oilseed (Ref. 6).

(i) Diesel fuel consumption of 3,801 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 3) and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6) and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(k) Land requirement of 0.437 ha.a/t of bioethanol and allocation of 88.2% x 99.9% x 76.3% = 67.2% to bioethanol.

(l) Average round trip distance of 260 km (Ref. 3) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 9).

(m) Harvested wheat grain requirement of 3.499 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(n) Based on pro-rata fuel oil consumption of 305 MJ/t for drying of oilseed rape from 15% to 9% moisture content (Ref. 6), giving fuel oil consumption of 661 MJ/t for drying wheat grain from 16% to 3% moisture content, and a direct methane requirement of 2.6×10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.3×10^{-5} kg CH_4/MJ for fuel oil in the UK in 1996 (Ref. 8).

(o) Dried wheat grain requirement of 3.030 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(p) Electricity consumption of 11.6 kWh/t of dried wheat grain for cooling, assumed similar to dried rapeseed cooling in storage (Ref. 6) and an indirect methane requirement of 4.043×10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 8).

(q) Assuming milling accounts for all electricity consumption of 12.3 kWh/t of dried wheat grain (Ref. 3) and an indirect methane requirement of 4.043×10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 8).

(r) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with distillation accounting for 54.8% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct methane requirement of 3.70×10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083×10^{-4} kg CH_4/MJ and a total methane requirement of 1.12×10^{4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 8).

(s) Dried wheat grain requirement 3.030 t/t of bioethanol and allocation of 76.3% to bioethanol.

(t) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with dehydration accounting for 0.3% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct methane requirement of 3.70×10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083×10^{-4} kg CH_4/MJ and a total methane requirement of 1.12×10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 8).

(u) Dried wheat grain requirement of 3.030 t/t of bioethanol.

(v) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant, assumed to be similar to a biodiesel plant (Ref. 9), with a capacity of a 40,000 t/a and a 25 year life, and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 10), assuming 76.3% contribution to bioethanol by price of co-products.

(w) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 9).

(x) Average round trip distance of 450 km (Ref. 3) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 9).

References

1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

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Table R4 Spreadsheet for Nitrous Oxide Outputs from Ethanol Production from Wheat

Functional Unit: :	Bioethanol at point of distribution derived from wheat
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 1.854 tonnes of wheat straw at £25/t (Ref. 1) and 3.499 tonnes of harvested wheat grain at £99/t (Ref. 2), giving a 88.2% allocation to bioethanol, 0.121 tonnes of bran at £10/t (Ref. 3) and 2.909 tonnes of course powder flour at £303/t (Ref. 4), giving a 99.9% allocation to bioethanol, and 1.507 tonnes of animal feed at £80/t (Ref. 3) and 1.000 tonnes of bioethanol at £388/t (Ref. 3), giving a 76.3% allocation to bioethanol.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*0.189*	*±0.028*	*0.772*	*±0.116*	*0.961*	*±0.119*	(a, b)
- P Fertiliser	*ha.a*	-	-	-	-	-	-	(b, c)
- K Fertiliser	*ha.a*	-	-	*0.001*	-	*0.001*	-	(b, d)
- Insecticide	*ha.a*	-	-	-	-	-	-	(b, e)
- Herbicides	*ha.a*	-	-	*0.008*	*±0.001*	*0.008*	*±0.001*	(b, f)
- Fungicide	*ha.a*	-	-	*0.004*	*±0.001*	*0.004*	*±0.001*	(b, g)
- Seed	*ha.a*	-	-	*0.120*	*±0.018*	*0.120*	*±0.018*	(b, h)
- Diesel Fuel	*ha.a*	*0.002*	-	-	-	*0.002*	-	(b, i)
Reference System:								
- Diesel Fuel	*ha.a*	*- 0.001*	-	-	-	*- 0.001*	-	(b, j)
Sub-Totals	*ha.a*	*0.190*	*±0.028*	*0.905*	*±0.117*	*1.095*	*±0.120*	
	t be	**0.056**	**±0.008**	**0.266**	**±0.034**	**0.322**	**±0.035**	(k)
Transport:								
- Diesel Fuel	*t hwg*	-	-	-	-	-	-	(l)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(m)
Drying:								
- Fuel Oil	*t dwg*	-	-	-	-	-	-	(n)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Storage:								
- Electricity	*t dwg*	-	-	-	-	-	-	(b, p)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Milling:								
- Electricity	*t dwg*	-	-	-	-	-	-	(b, q)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(o)
Hydrolysis, Fermentation and Distillation:								
- Natural Gas	*t dwg*	-	-	-	-	-	-	(b, r)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(s)
Dehydration:								
- Natural Gas	*t dwg*	-	-	-	-	-	-	(b, t)
	t be	**-**	**-**	**-**	**-**	**-**	**-**	(u)
Plant Construction	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(v)
Plant Maintenance	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Distribution:								
- Diesel Fuel	**t be**	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Totals	**t be**	**0.056**	**±0.008**	**0.266**	**±0.034**	**0.322**	**±0.035**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t hwg = tonne of harvested wheat grain
t dwg = tonne of dried wheat grain
t be = tonne of bioethanol

Notes

(a) Nitrogen fertiliser application rate of 150 kg NH_4NO_3/ha.a, or 52.5 kg N/ha.a assuming 0.35 kg N/kg NH_4NO_3 (Ref. 3) and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 5), an indirect nitrous oxide requirement of 0.0147 kg N_2O/kg N (Ref. 6) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 6).

(b) Assuming an error bar of ±15% based on similar analyses (Ref. 7).

(c) Phosphate fertiliser application rates of 60 kg P_2O_5/ ha.a (Ref. 3) and a total nitrous oxide requirement for phosphate fertiliser of 4.2×10^{-5} kg N_2O/kg P_2O_5 (Ref. 5).

(d) Potash fertiliser application rate of 60 kg K_2O/ha.a (Ref. 3) and a total nitrous oxide requirement for potash fertiliser of 9.4×10^{-6} kg N_2O/ kg K_2O (Ref. 5).

(e) Insecticide application rate of 0.14 kg/ha.a (Ref. 3) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.51×10^{3} kg N_2O/kg (Ref. 5).

(f) Herbicide and plant inhibitor application rate of 5.37 kg/ha.a (Ref. 3) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.51×10^{-3} kg N_2O/kg (Ref. 5).

(g) Fungicide application rate of 2.9 kg/ha.a (Ref. 3) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.51×10^{3} kg N_2O/kg (Ref. 5).

(h) Sowing rate of 120 kg/ha.a and a total nitrous oxide requirement of 0.001 kg N_2O/kg of seed (Ref. 3).

(i) Diesel fuel consumption of 3,801 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 3) and a direct nitrous oxide requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60×10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(j) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 5) and a direct nitrous oxide requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60×10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 8).

(k) Land requirement of 0.437 ha.a/t of bioethanol and allocation of 88.2% x 99.9% x 76.3% = 67.2% to bioethanol.

(l) Average round trip distance of 260 km (Ref. 3) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 9).

(m) Harvested wheat grain requirement of 3.499 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(n) Based on pro-rata fuel oil consumption of 305 MJ/t for drying of oilseed rape from 15% to 9% moisture content (Ref. 5), giving fuel oil consumption of 661 MJ/t for drying wheat grain from 16% to 3% moisture content, and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for fuel oil in the UK in 1996 (Ref. 8).

(o) Dried wheat grain requirement of 3.030 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2% to bioethanol.

(p) Electricity consumption of 11.6 kWh/t of dried wheat grain for cooling, assumed similar to dried rapeseed cooling in storage (Ref. 5) and an indirect nitrous oxide requirement of 5.577×10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 8).

(q) Assuming milling accounts for all electricity consumption of 12.3 kWh/t of dried wheat grain (Ref. 3) and an indirect nitrous oxide requirement of 5.577×10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 8).

(r) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with distillation accounting for 54.8% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 8).

(s) Dried wheat grain requirement 3.030 t/t of bioethanol and allocation of 76.3% to bioethanol.

(t) Steam consumption for the complete bioethanol plant of 1,545 kg/t of dried wheat grain (Ref. 3) with dehydration accounting for 0.3% of steam consumption based on pro-rata evaporation requirements between distillation, dehydration and stillage drying, an assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 8).

(u) Dried wheat grain requirement of 3.030 t/t of bioethanol.

(v) Primary energy input of 131,004 ± 23,909 GJ for construction of a bioethanol plant assumed to be similar to a biodiesel plant (Ref. 9) with a capacity of a 40,000 t/a and a 25 year life, assuming an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ of primary energy input to construction (Ref. 10) and a 76.3% contribution to bioethanol by price of co-products.

(w) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 9).

(x) Average round trip distance of 450 km (Ref. 3) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 9).

References

1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

2. Annual average price of feed wheat in East Anglia, United Kingdom, 1996/97 from www.hgca.com/c-stats accessed 17 December 2002.

3. "Alternative Road Transport Fuels – A Preliminary Life-Cycle Study for the UK" by M. P. Gover, S. A. Collings, G. S. Hitchcock, D. P. Moon and G. T. Williams, Report R92, Volume 2, Energy Technology Support Unit, Harwell, United Kingdom, March 1996.

4. "Overseas Trade Statistics of the United Kingdom with Countries Outside the European Community" Business Monitor MM20, H. M. Customs and Excise, London, December 1996.

5. "Nachwachsende Energieträger – Grundlagen, Verfaben, Ökologische Bilanzierung" (Renewable Energy Sources, Basis, Processes and Ecological Balance) by M. Kaltschmitt and G. A. Reinhardt (eds), Vieweg, Braunschweig/Weisbaden, Germany, 1997.

6. "Evaluation of the Comparative Energy, Global Warming and Social Costs and Benefits of Biodiesel" by N. D. Mortimer, P. Cormack, M. A. Elsayed and R. E. Horne, Resources Research Unit, Sheffield Hallam University, United Kingdom, January 2003.

7. "Comparison of Transport Fuels: Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles" by. T. Beer, T. Grant, G. Morgan, J. Lapszewicz, P. Anyon, J. Edwards, P. Nelson, H. Watson and D. Williams, CSIRO, Aspendale, Australia, 2002.

8. "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

9. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

10. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

Table R5 Spreadsheet for Greenhouse Gas Outputs from Ethanol Production from Wheat

Functional Unit: :	Bioethanol at point of distribution derived from wheat
Final Unit of Measurement:	1 tonne of bioethanol
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 1.854 tonnes of wheat straw at £25/t (Ref. 1) and 3.499 tonnes of harvested wheat grain at £99/t (Ref. 2), giving a 88.2% allocation to bioethanol, 0.121 tonnes of bran at £10/t (Ref. 3) and 2.909 tonnes of course powder flour at £303/t (Ref. 4), giving a 99.9% allocation to bioethanol, and 1.507 tonnes of animal feed at £80/t (Ref. 3) and 1.000 tonnes of bioethanol at £388/t (Ref. 3), giving a 76.3% allocation to bioethanol.

Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*60*	*±9*	*352*	*±40*	*412*	*±41*	(a)
- P Fertiliser	*ha.a*	-	-	*42*	*±6*	*42*	*±6*	(a)
- K Fertiliser	*ha.a*	-	-	*27*	*±4*	*27*	*±4*	(a)
- Insecticide	*ha.a*	-	-	*1*	-	*1*	-	(a)
- Herbicides	*ha.a*	-	-	*29*	*±4*	*29*	*±4*	(a)
- Fungicide	*ha.a*	-	-	*15*	*±2*	*15*	*±2*	(a)
- Seed	*ha.a*	-	-	*104*	*±12*	*104*	*±12*	(a)
- Diesel Fuel	*ha.a*	*262*	*±42*	*33*	*±14*	*295*	*±44*	(a)
Reference System:								
- Diesel Fuel	*ha.a*	*- 63*	*±10*	*- 8*	*±3*	*- 71*	*±11*	(a)
Sub-Totals	*ha.a*	*259*	*±44*	*595*	*±45*	*854*	*±63*	
	t be	**76**	**±13**	**175**	**±13**	**251**	**±19**	(b)
Transport:								
- Diesel Fuel	*t hwg*	*15*	*±1*	*4*	-	*19*	*±1*	(a)
	t be	**40**	**±3**	**11**	**-**	**51**	**±3**	(c)
Drying:								
- Fuel Oil	*t dwg*	*48*	*±8*	*5*	*±2*	*53*	*±8*	(a)
	t be	**111**	**±18**	**12**	**±5**	**123**	**±18**	(c)
Storage:								
- Electricity	*t dwg*	-	-	*6*	*±1*	*6*	*±1*	(a)
	t be	**-**	**-**	**14**	**±2**	**14**	**±2**	(c)
Milling:								
- Electricity	*t dwg*	-	-	*7*	*±1*	*7*	*±1*	(a)
	t be	**-**	**-**	**16**	**±2**	**16**	**±2**	(d)
Hydrolysis, Fermentation and Distillation:								
- Natural Gas	*t dwg*	*110*	*±17*	*10*	*±1*	*120*	*±17*	(a)
	t be	**254**	**±39**	**23**	**±2**	**277**	**±39**	(d)
Dehydration:								
- Natural Gas	*t dwg*	*1*	-	-	-	*1*	-	(a)
	t be	**3**	**-**	**-**	**-**	**3**	**-**	(e)
Plant Construction	**t be**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a, e)
Plant Maintenance	**t be**	**-**	**-**	**3**	**±1**	**3**	**±1**	(a, e)
Distribution:								
- Diesel Fuel	**t be**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(a, e)
Totals	**t be**	**509**	**±45**	**266**	**±14**	**775**	**±47**	

Biofuel Specifications

Density of bioethanol = 0.79 kg/l
Net calorific value of bioethanol = 26.72 MJ/kg
Gross calorific value of bioethanol = 29.74 MJ/kg

Abbreviations

ha.a = hectare year
t hwg = tonne of harvested wheat grain
t dwg = tonne of dried wheat grain
t be = tonne of bioethanol

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 0.437 ha.a/t of bioethanol and allocation of 88.2% x 99.9% x 76.3% = 67.2% to bioethanol.

(c) Harvested wheat grain requirement of 3.499 t/t of bioethanol and allocation of 99.9% x 76.3% = 76.2 % to bioethanol.

(d) Dried wheat grain requirement 3.030 t/t of bioethanol and allocation of 76.3% to bioethanol.

(e) Dried wheat grain requirement of 3.030 t/t of bioethanol.

References

1. "A Review of the Potential of Biodiesel as a Transport Fuel" by F. Culshaw and C. Butler, ETSU-R-71, Energy Technology Support Unit, Harwell, United Kingdom, September 1992.

2. Annual average price of feed wheat in East Anglia, United Kingdom, 1996/97 from www.hgca.com/c-stats accessed 17 December 2002.

3. "Alternative Road Transport Fuels – A Preliminary Life-Cycle Study for the UK" by M. P. Gover, S. A. Collings, G. S. Hitchcock, D. P. Moon and G. T. Williams, Report R92, Volume 2, Energy Technology Support Unit, Harwell, United Kingdom, March 1996.

4. "Overseas Trade Statistics of the United Kingdom with Countries Outside the European Community" Business Monitor MM20, H. M. Customs and Excise, London, December 1996.

APPENDIX S: Small-Scale Heat Production by Combustion of Wood Chips

Figure S1 Flow Chart for the Small Scale Production of Heat from Wood Chips

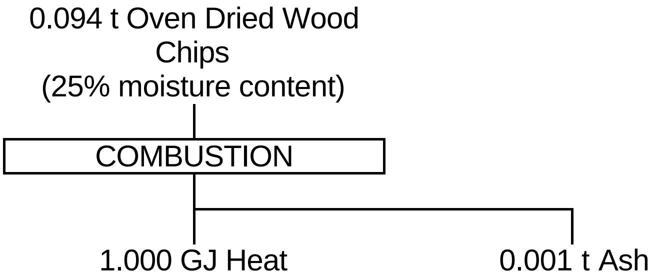

Table S1 Spreadsheet for Primary Energy Inputs to Small-Scale Production of Heat by Combustion of Wood Chips

Functional Unit:	Heat at point of production from combustion of wood chips									
Final Unit of Measurement:	1 GJ of heat									
Relevant Location:	United Kingdom									
Relevant Period:	2001									
Allocation Procedures:	None required									
Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**1**	**-**	**35**	**±4**	**-**	**-**	**36**	**±4**	(b)
Plant Maintenance:	**GJ**	**1**	**-**	**22**	**±3**	**-**	**-**	**23**	**±3**	(b, c)
Ash Disposal:		-	-	-	-	-	-	-	-	(d)
	GJ	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	(e)
Plant Decommission:	**GJ**	**1**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	(b, f)
Totals	**GJ**	**3**	**-**	**57**	**±5**	**-**	**-**	**60**	**±5**	

Abbreviation

GJ = GJ of heat.

Notes

(a) Not specified.

(b) Primary energy input of 708 ± 81 GJ for construction of a small-scale wood-fired only plant consuming 89 oven dried tonnes (25% moisture content) of wood chip per year, with a net output rating of 50 kW, an average load factor of 50%, a thermal efficiency of 60% and a 25 year life (Ref. 1).

(c) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 1).

(d) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 2) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 1).

(e) Ash output of 1.5% of oven dried wood chip input, or 1.686 kg/GJ of heat (Ref. 2).

(f) Primary energy input to plant decommissioning assumed to be 4% ±1% of the primary energy input to plant construction (Ref. 1).

References

1. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

2. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table S2 Spreadsheet for Carbon Dioxide Outputs from Small-Scale Heat Production by Combustion of Wood Chips

Functional Unit:	Heat at point of production by combustion of wood chips
Final Unit of Measurement:	1 GJ of heat
Relevant Location:	United Kingdom
Relevant Period:	2001
Allocation Procedures:	None required

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**2**	**-**	**2**	**-**	(b)
Plant Maintenance:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b, c)
Ash Disposal:		-	-	-	-	-	-	(d)
	GJ	**-**	**-**	**-**	**-**	**-**	**-**	(e)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b, f)
Totals	**GJ**	**-**	**-**	**3**	**-**	**3**	**-**	

Abbreviation

GJ = GJ of heat.

Notes

(a) Not specified.

(b) Carbon dioxide output of 34 ± 4 tonnes of CO_2 for construction of a small-scale wood-fired only plant consuming 89 oven dried tonnes (25% moisture content) of wood chip per year, with a net output rating of 50 kW, an average load factor of 50%, a thermal efficiency of 60% and a 25 year life (Ref. 1).

(c) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output from plant construction (Ref. 1).

(d) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 2) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 1).

(e) Ash output of 1.5% of oven dried wood chip input, or 1.686 kg/GJ of heat (Ref. 2).

(f) Carbon dioxide output from plant decommissioning assumed to be 4% ±1% of the carbon dioxide output from plant construction (Ref. 1).

References

1. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

2. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table S3 Spreadsheet for Methane Outputs from Small-Scale Heat Production by Combustion of Wood Chips

Functional Unit:	Heat at point of production from combustion of wood chips							
Final Unit of Measurement:	1 GJ of heat							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Methane Output (kg CH_4)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Direct Emissions	**GJ**	**0.017**	**-**	**-**	**-**	**0.017**	**-**	(b)
Plant Construction:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c)
Plant Maintenance:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, d)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(e) (f)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(c, g)
Totals	**GJ**	**0.017**	**-**	**-**	**-**	**0.017**	**-**	

Abbreviation

GJ = GJ of heat.

Notes

(a) Not specified.

(b) Direct emissions of 0.010 g CH_4/MJ of wood chips (Ref. 1).

(c) Primary energy input of 708 ± 81 GJ for construction of a small-scale wood-fired only plant consuming 89 oven dried tonnes (25% moisture content) of wood chip per year, with a net output rating of 50 kW, an average load factor of 50%, a thermal efficiency of 60% and a 25 year life (Ref. 2), and an estimated total methane requirement of 1.192×10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 3).

(d) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 2).

(e) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref.2).

(f) Ash output of 1.5% of oven dried wood chip input, or 1.686 kg/GJ of heat (Ref. 4).

(g) Methane output from plant decommissioning assumed to be 4% ±1% of the methane output from plant construction (Ref. 2).

References

1. Private communication with G. Jungmeier, Joanneum Research, Austria, 15 January 2003.

2. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

3. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

4. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table S4 Spreadsheet for Nitrous Oxide Outputs from Small-Scale Heat Production by Combustion of Wood Chips

Functional Unit:	Heat at point of production from combustion of wood chips							
Final Unit of Measurement:	1 GJ of heat							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	-	-	-	-	-	-	(a)
Direct Emissions	**GJ**	**0.005**	-	-	-	**0.005**	-	(b)
Plant Construction:	**GJ**	-	-	-	-	-	-	(c)
Plant Maintenance:	**GJ**	-	-	-	-	-	-	(c, d)
Ash Disposal:	**GJ**	- -	- -	- -	- -	- -	- -	(e) (f)
Plant Decommission:	**GJ**	-	-	-	-	-	-	(c, g)
Totals	**GJ**	**0.005**	-	-	-	**0.005**	-	

Abbreviation

GJ = GJ of heat.

Notes

(a) Not specified.

(b) Direct emissions of 0.003 g N_2O/MJ of wood chips (Ref. 1).

(c) Primary energy input of 708 ± 81 GJ for construction of a small-scale wood-fired only plant consuming 89 oven dried tonnes (25% moisture content) of wood chip per year, with a net output rating of 50 kW, an average load factor of 50%, a thermal efficiency of 60% and a 25 year life (Ref. 2), and an estimated total nitrous oxide requirement of 1.866×10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 3).

(d) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of nitrous oxide output from plant construction (Ref. 2).

(e) Ash sent for spreading as a fertiliser on fields at an average round trip distance of 70 km (Ref. 4) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 2).

(f) Ash output of 1.5% of oven dried wood chip input, or 1.686 kg/GJ of heat (Ref. 4).

(g) Nitrous oxide output from plant decommissioning assumed to be 4% ±1% of the nitrous oxide output from plant construction (Ref. 2).

References

1. Private communication with G. Jungmeier, Joanneum Research, Austria, 15 January 2003.

2. "Carbon and Energy Modelling of Biomass Systems: Conversion Plant and Data Updates" by N. D. Mortimer and M. A. Elsayed, ETSU Report B/U1/00644/00/00REP, Energy Technology Support Unit, Harwell, United Kingdom, August 2001.

3. "Digest of United Kingdom Energy Statistics, 1999" Department of Trade and Industry, HMSO, London, United Kingdom, 2000.

4. "Estimation of Carbon Dioxide and Energy Budgets of Wood-Fired Electricity Generation Systems" by R. Matthews and N. D. Mortimer, ETSU B/U1/00601/05/REP, Energy Technology Support Unit, Harwell, United Kingdom, 2000.

Table S5 Spreadsheet for Greenhouse Gas Outputs from Small-Scale Heat Production by Combustion of Wood Chips

Functional Unit:	Heat at point of production from combustion of wood chips							
Final Unit of Measurement:	1 GJ of heat							
Relevant Location:	United Kingdom							
Relevant Period:	2001							
Allocation Procedures:	None required							
Contribution	Per Unit	Total Greenhouse Gas Output (kg eq CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Start-Up Fuel:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(a)
Direct Emissions	**GJ**	**2**	**-**	**-**	**-**	**2**	**-**	(a)
Plant Construction:	**GJ**	**-**	**-**	**2**	**-**	**2**	**-**	(b)
Plant Maintenance:	**GJ**	**-**	**-**	**1**	**-**	**1**	**-**	(b)
Ash Disposal:	 **GJ**	- **-**	- **-**	- **-**	- **-**	- **-**	- **-**	(b) (c)
Plant Decommission:	**GJ**	**-**	**-**	**-**	**-**	**-**	**-**	(b)
Totals	**GJ**	**2**	**-**	**3**	**-**	**5**	**-**	

Abbreviation

GJ = GJ of heat.

Notes

(a) Not specified.

(b) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(c) Ash output of 1.5% of oven dried wood chip input, or 1.686 kg/GJ of heat.

APPENDIX T: Production of Rapeseed Oil from Oilseed Rape

Figure T1 Flow Chart for the Production of Rapeseed Oil from Oilseed Rape

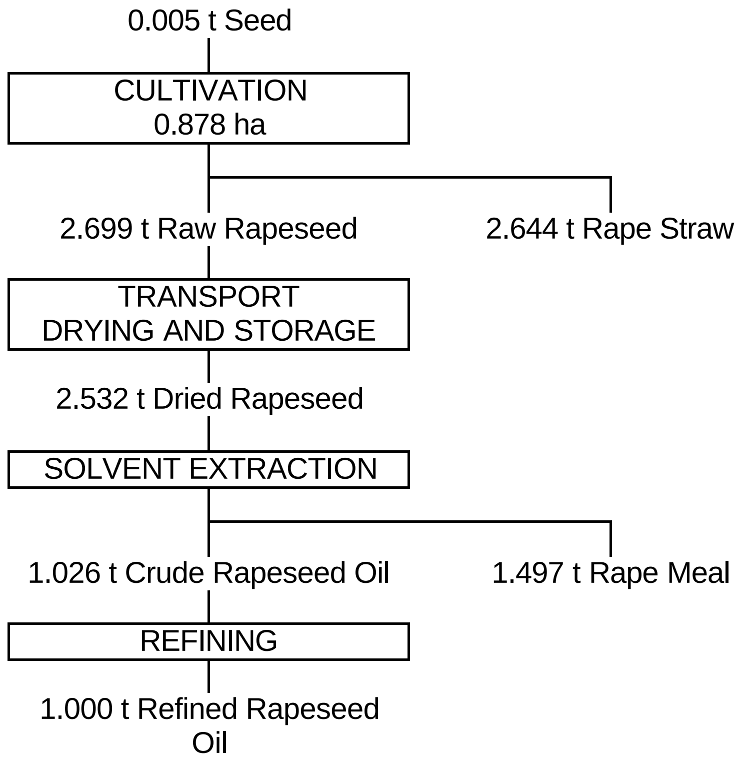

Table T1 Spreadsheet for Primary Energy Inputs to Rapeseed Oil Production from Oilseed Rape Using Solvent Extraction

Functional Unit:	Rapeseed Oil at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of refined rapeseed oil
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to rapeseed oil, and 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 – 2000 average; Ref. 2), giving a 72% allocation to rapeseed oil.

Contribution	Per Unit	Primary Energy Input (MJ)								
		Direct		Indirect		Feedstock		Total		Notes
		Value	Range	Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:										
- N Fertiliser	ha.a	-	-	2,747	±1,097	5,213	±208	7,960	±1,117	(a)
- Other Fertiliser	ha.a	-	-	1,276	±191	-	-	1,276	±191	(b)
- Pesticides	ha.a	-	-	767	±115	-	-	767	±115	(c)
- Seeds	ha.a	-	-	39	±6	-	-	39	±6	(d)
- Diesel Fuel	ha.a	2,385	±377	262	±124	-	-	2,647	±397	(e)
Reference System:										
- Diesel Fuel	ha.a	- 922	±145	- 101	±49	-	-	-1,023	±153	(f)
Sub-Totals	ha.a	1,463	±404	4,990	±1,127	5,213	±208	11,666	±1,216	
	t rro	**793**	**±219**	**2,704**	**±611**	**2,824**	**±113**	**6,321**	**±659**	(g)
Transport:										
- Diesel Fuel	t ros	213	±8	74	±9	-	-	287	±12	(h)
	t rro	**414**	**±16**	**144**	**±17**	**-**	**-**	**558**	**±23**	(i)
Drying:										
- Fuel Oil	t dos	305	±48	34	±17	-	-	339	±51	(j)
	t rro	**556**	**±88**	**62**	**±31**	**-**	**-**	**618**	**±93**	(k)
Storage:										
- Electricity	t dos	42	±6	87	±9	-	-	129	±11	(l)
	t rro	**77**	**±11**	**159**	**±16**	**-**	**-**	**236**	**±20**	(k)
Solvent Extraction:										
- Natural Gas	t cro	2,237	±336	246	±111	-	-	2,483	±354	(m)
- Electricity	t cro	302	±45	629	±15	-	-	931	±47	(n)
- Hexane	t cro	-	-	129	±19	-	-	129	±19	(o)
Sub-Totals	t cro	2,539	±339	1,004	±114	-	-	3,543	±358	
	t rro	**1,875**	**±250**	**741**	**±84**	**-**	**-**	**2,616**	**±264**	(p)
Refining:										
- Electricity	t rro	11	±2	23	±5	-	-	34	±5	(q)
- Natural Gas	t rro	178	±27	20	±8	-	-	198	±28	(r)
- Heavy Fuel Oil	t rro	20	±3	3	-	-	-	23	±3	(s)
- Light Fuel Oil	t rro	152	±23	16	±7	-	-	168	±24	(t)
- Phosph. Acid	t rro	-	-	11	±2	-	-	11	±2	(u)
- Smectite	t rro	-	-	15	±2	-	-	15	±2	(v)
Sub-Totals	**t rro**	**361**	**±36**	**88**	**±12**	**-**	**-**	**449**	**±37**	
Plant Construct.	**t rro**	**2**	**-**	**72**	**±16**	**-**	**-**	**74**	**±16**	(w)
Plant Maintain.	**t rro**	**-**	**-**	**46**	**±10**	**-**	**-**	**46**	**±10**	(x)
Distribution:										
- Diesel Fuel	**t rro**	**369**	**±14**	**129**	**±16**	**-**	**-**	**498**	**±21**	(y)
Totals	**t rro**	**4,447**	**±347**	**4,145**	**±619**	**2,824**	**±113**	**11,416**	**±719**	

Biofuel Specifications

Density of rapeseed oil = 0.92 kg/l
Net calorific value of rapeseed oil = 39.20 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a direct and indirect energy requirement of 14.013 ± 5.599 MJ/kg N and a feedstock energy requirement of 26.595 ± 1.060 MJ/kg N for ammonium nitrate (Ref. 4).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 5), and for lime of 18.9 kg CaO (Ref. 6), with total energy requirements for phosphate fertiliser of 15.8 MJ/kg P_2O_5 , for potash fertiliser of 9.3 MJ/ kg K_2O, and for lime of 2.1 MJ/kg CaO (Ref. 6).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total energy requirement for general pesticides, herbicides and fungicides of 274.1 MJ/kg (Ref. 6).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total energy requirement of 7.8 MJ/kg of seed (Ref. 6).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.878 ha.a/t of refined rapeseed oil and allocation of 86% x 72% = 61.92% to refined rapeseed oil.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.699 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.532 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 6), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total energy requirement of 5.05 MJ/kg of hexane (Ref. 6).

(p) Crude rapeseed oil requirement of 1.026 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 6) and a gross energy requirement of 3.083 MJ/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 6) and a gross energy requirement of 1.110 MJ/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total energy requirement of 11.4 MJ/kg for phosphoric acid (Ref. 6).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total energy requirement of 2.55 MJ/kg for smectite (Ref. 6).

(w) Primary energy input of 108,309 ± 23,345 GJ for construction of an oilseed mill, assumed to be similar to a solvent extraction plant (Ref. 11), with a capacity of a 42,080 t/a and a 25 year life, and 72% contribution to rapeseed oil by price of co-products.

(x) Primary energy input of annual plant maintenance assumed to be 2.5% of primary energy input to plant construction (Ref. 11).

(y) Average round trip distance of 450 km similar to biodiesel (Ref. 10) by bulk road carrier transport with a direct energy requirement of 0.8196 ± 0.0310 MJ/t-km, an indirect energy requirement of 0.2857 ± 0.0352 MJ/t-km and a total energy requirement of 1.1053 ± 0.0469 MJ/t-km (Ref. 11).

References

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Table T2 Spreadsheet for Carbon Dioxide Outputs from Rapeseed Oil Production from Oilseed Rape using Solvent Extraction

Functional Unit: :	Rapeseed oil at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of refined rapeseed oil
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to rapeseed oil, and 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to rapeseed oil.

Contribution	Per Unit	Carbon Dioxide Output (kg CO_2)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*373*	*±54*	*373*	*±54*	(a)
- Other Fertiliser	*ha.a*	-	-	*60*	*±9*	*60*	*±9*	(b)
- Pesticides	*ha.a*	-	-	*14*	*±2*	*14*	*±2*	(c)
- Seeds	*ha.a*	-	-	*2*	-	*2*	-	(d)
- Diesel Fuel	*ha.a*	*164*	*±25*	*19*	*±3*	*183*	*±25*	(e)
Reference System:								
- Diesel Fuel	*ha.a*	*- 64*	*±9*	*- 7*	*±1*	*- 71*	*±9*	(f)
Sub-Totals	*ha.a*	*100*	*±27*	*461*	*±55*	*561*	*±61*	
	t rro	**54**	**±15**	**251**	**±30**	**305**	**±34**	(g)
Transport:								
- Diesel Fuel	*t ros*	*15*	*±1*	*4*	-	*19*	*±1*	(h)
	t rro	**29**	**±2**	**8**	**±1**	**37**	**±2**	(i)
Drying:								
- Fuel Oil	*t dos*	*22*	*±3*	*2*	-	*24*	*±3*	(j)
	t rro	**40**	**±5**	**4**	**±1**	**44**	**±5**	(k)
Storage:								
- Electricity	*t dos*	-	-	*6*	*±1*	*6*	*±1*	(l)
	t rro	**-**	**-**	**11**	**±2**	**11**	**±2**	(k)
Solvent Extraction:								
- Natural Gas	*t cro*	*117*	*±18*	*4*	-	*121*	*±18*	(m)
- Electricity	*t cro*	-	-	*45*	*±7*	*45*	*±7*	(n)
- Hexane	*t cro*	-	-	*1*	-	*1*	-	(o)
Sub-Totals	*t cro*	*117*	*±18*	*50*	*±7*	*167*	*±19*	
	t rro	**86**	**±13**	**37**	**±5**	**123**	**±14**	(p)
Refining:								
- Electricity	*t rro*	-	-	*2*	-	*2*	-	(q)
- Natural Gas	*t rro*	*9*	*±1*	*1*	-	*10*	*±1*	(r)
- Heavy Fuel Oil	*t rro*	*2*	-	-	-	*2*	-	(s)
- Light Fuel Oil	*t rro*	*11*	*±2*	*1*	-	*12*	*±2*	(t)
- Phosph. Acid	*t rro*	-	-	*1*	-	*1*	-	(u)
- Smectite	*t rro*	-	-	*1*	-	*1*	-	(v)
Sub-Totals	**t rro**	**22**	**±2**	**6**	**-**	**28**	**±2**	
Plant Construction	**t rro**	**-**	**-**	**4**	**±1**	**4**	**±1**	(w)
Plant Maintenance	**t rro**	**-**	**-**	**2**	**±1**	**2**	**±1**	(x)
Distribution:								
- Diesel Fuel	**t rro**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(y)
Totals	**t rro**	**256**	**±21**	**330**	**±31**	**586**	**±37**	

Biofuel Specifications

Density of rapeseed oil	= 0.92 kg/l
Net calorific value of rapeseed oil	= 39.20 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a total carbon requirement for ammonium nitrate of 1.904 ± 0.275 kg CO_2/kg N (Ref. 4).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 5), and for lime of 18.9 kg CaO (Ref. 6), with total carbon requirements for phosphate fertiliser of 0.700 kg CO_2/kg P_2O_5 , for potash fertiliser of 0.453 kg CO_2/ kg K_2O, and for lime of 0.179 kg CO_2/kg CaO (Ref. 6).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total carbon requirement for general pesticides, herbicides and fungicides of 4.921 kg CO_2/kg (Ref. 6).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total carbon requirement of 0.316 kg CO_2/kg of seed (Ref. 6).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 6), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6), and a direct carbon requirement of 0.0686 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0767 kg CO_2/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.878 ha.a/t of refined rapeseed oil and allocation of 86% x 72% = 61.92% to refined rapeseed oil.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 kg CO_2/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 kg CO_2/t-km and a total carbon requirement of 0.0723 ± 0.0027 kg CO_2/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.699 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 6), and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.532 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 6), and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 6), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 6) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total carbon requirement of 0.543 kg CO_2/kg of hexane (Ref. 6).

(p) Crude rapeseed oil requirement of 1.026 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 6) and an indirect carbon requirement of 0.1504 kg CO_2/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 6) and a direct carbon requirement of 0.0522 kg CO_2/MJ, an indirect carbon requirement of 0.0017 kg CO_2/MJ and a total carbon requirement of 0.0539 kg CO_2/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 6) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 6) and a direct carbon requirement of 0.0730 kg CO_2/MJ, an indirect carbon requirement of 0.0081 kg CO_2/MJ and a total carbon requirement of 0.0811 kg CO_2/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total carbon requirement of 0.768 kg CO_2 /kg for phosphoric acid (Ref. 6).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total carbon requirement of 0.197 kg CO_2 /kg for smectite (Ref. 6).

(w) Carbon dioxide output of 5,132 ± 1,087 tonnes CO_2 for construction of an oilseed mill, assumed to be similar to a solvent extraction plant (Ref. 11), with a capacity of a 42,080 t/a and a 25 year life, and 72% contribution to rapeseed oil by price of co-products.

(x) Carbon dioxide output of annual plant maintenance assumed to be 2.5% of carbon dioxide output of plant construction (Ref. 11).

(y) Average round trip distance of 450 km similar to biodiesel (Ref. 10) by bulk road carrier transport with a direct carbon requirement of 0.0562 ± 0.0021 MJ/t-km, an indirect carbon requirement of 0.0161 ± 0.0017 MJ/t-km and a total carbon requirement of 0.0723 ± 0.0027 MJ/t-km (Ref. 11).

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Table T3 Spreadsheet for Methane Outputs from Rapeseed Oil Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Rapeseed oil at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of refined rapeseed oil
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to rapeseed oil, and 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to rapeseed oil.

Contribution	Per Unit	Methane Output (kg CH_4)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	-	-	*0.706*	*±0.118*	*0.706*	*±0.118*	(a)
- Other Fertiliser	*ha.a*	-	-	*0.002*	-	*0.002*	-	(b)
- Pesticides	*ha.a*	-	-	*0.001*	-	*0.001*	-	(c)
- Seeds	*ha.a*	-	-	-	-	-	-	(d)
- Diesel Fuel	*ha.a*	*0.001*	-	*0.049*	*±0.007*	*0.050*	*±0.007*	(e)
Reference System:								
- Diesel Fuel	*ha.a*	*-0.001*	-	*-0.019*	*±0.003*	*-0.020*	*±0.003*	(f)
Sub-Totals	*ha.a*	-	-	*0.739*	*±0.118*	*0.739*	*±0.118*	
	t rro	**-**	**-**	**0.402**	**±0.064**	**0.402**	**±0.064**	(g)
Transport:								
- Diesel Fuel	*t ros*	-	-	*0.004*	*±0.001*	*0.004*	*±0.001*	(h)
	t rro	**-**	**-**	**0.008**	**±0.002**	**0.008**	**±0.002**	(i)
Drying:								
- Fuel Oil	*t dos*	*0.001*	-	*0.006*	*±0.001*	*0.007*	*±0.001*	(j)
	t rro	**0.002**	**-**	**0.011**	**±0.002**	**0.013**	**±0.002**	(k)
Storage:								
- Electricity	*t dos*	-	-	*0.017*	*±0.003*	*0.017*	*±0.003*	(l)
	t rro	**-**	**-**	**0.031**	**±0.005**	**0.031**	**±0.005**	(k)
Solvent Extraction:								
- Natural Gas	*t cro*	*0.008*	*±0.001*	*0.242*	*±0.036*	*0.250*	*±0.036*	(m)
- Electricity	*t cro*	-	-	*0.122*	*±0.018*	*0.122*	*±0.018*	(n)
- Hexane	*t cro*	-	-	*0.002*	-	*0.002*	-	(o)
Sub-Totals	*t cro*	*0.008*	*±0.001*	*0.366*	*±0.040*	*0.374*	*±0.040*	
	t rro	**0.006**	**±0.001**	**0.270**	**±0.030**	**0.276**	**±0.030**	(p)
Refining:								
- Electricity	*t rro*	-	-	*0.005*	*±0.001*	*0.005*	*±0.001*	(q)
- Natural Gas	*t rro*	*0.001*	-	*0.019*	*±0.003*	*0.020*	*±0.003*	(r)
- Heavy Fuel Oil	*t rro*	-	-	-	-	-	-	(s)
- Light Fuel Oil	*t rro*	-	-	*0.003*	*±0.001*	*0.003*	*±0.001*	(t)
- Phosph. Acid	*t rro*	-	-	*0.001*	-	*0.001*	-	(u)
- Smectite	*t rro*	-	-	-	-	-	-	(v)
Sub-Totals	**t rro**	**0.001**	**-**	**0.028**	**±0.003**	**0.029**	**±0.003**	
Plant Construction	**t rro**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Plant Maintenance	**t rro**	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Distribution:								
- Diesel Fuel	**t rro**	**-**	**-**	**0.008**	**-**	**0.008**	**-**	(y)
Totals	**t rro**	**0.009**	**±0.001**	**0.758**	**±0.071**	**0.767**	**±0.071**	

Biofuel Specifications

Density of rapeseed oil = 0.92 kg/l
Net calorific value of rapeseed oil = 39.20 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a total methane requirement for ammonium nitrate of $3.6 \times 10^{-3} \pm 0.6 \times 10^{-3}$ kg CH_4/kg N (Ref. 4).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 5), and for lime of 18.9 kg CaO (Ref. 6), with total carbon requirements for phosphate fertiliser of 2.3×10^{-5} kg CH_4/kg P_2O_5 , for potash fertiliser of 2.1×10^{-5} kg CH_4/ kg K_2O, and for lime of 3.9×10^{-6} kg CH_4/kg CaO (Ref. 6).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total methane requirement for general pesticides, herbicides and fungicides of 1.8×10^{-4} kg CH_4/kg (Ref. 6).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total methane requirement of 0 kg CH_4/kg of seed (Ref. 6).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 6), and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 6), and a direct methane requirement of 6.0×10^{-7} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.1×10^{-5} kg CH_4/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.878 ha.a/t of refined rapeseed oil and allocation of 86% x 72% = 61.92% to refined rapeseed oil.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct methane requirement of $4.900 \times 10^{-7} \pm 2.000 \times 10^{-8}$ kg CH_4/t-km, an indirect methane requirement of $1.672 \times 10^{-5} \pm 6.3 \times 10^{-7}$ kg CH_4/t-km and a total methane requirement of $1.721 \times 10^{-5} \pm 6.5 \times 10^{-7}$ kg CH_4/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.699 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 6), and a direct methane requirement of 2.6×10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04×10^{-5} kg CH_4/MJ and a total methane requirement of 2.3×10^{-5} kg CH_4/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.532 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 6), and an indirect methane requirement of 4.043×10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 6), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct methane requirement of 3.70×10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083×10^{-4} kg CH_4/MJ and a total methane requirement of 1.12×10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 6) and an indirect methane requirement of 4.043×10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total carbon requirement of 6.73×10^{-4} kg CH_4/kg of hexane (Ref. 6).

(p) Crude rapeseed oil requirement of 1.026 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 6) and an indirect methane requirement of 4.043×10^{-4} kg CH_4/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 6) and a direct methane requirement of 3.70 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 1.083 x 10^{-4} kg CH_4/MJ and a total methane requirement of 1.12 x 10^{-4} kg CH_4/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 6) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 6) and a direct methane requirement of 2.6 x 10^{-6} kg CH_4/MJ, an indirect methane requirement of 2.04 x 10^{-5} kg CH_4/MJ and a total methane requirement of 2.3 x 10^{-5} kg CH_4/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total methane requirement of 1.23 x 10^{-3} kg CH_4 /kg for phosphoric acid (Ref. 6).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total methane requirement of 3.7 x 10^{-5} kg CH_4 /kg for smectite (Ref. 6).

(w) Primary energy input of 108,309 ± 23,345 GJ for construction of an oilseed mill, assumed to be similar to a solvent extraction plant (Ref. 11), with a capacity of a 42,080 t/a and a 25 year life, and an estimated total methane requirement of 1.192 x 10^{-7} kg CH_4/MJ primary energy input to construction (Ref. 12) and 72% contribution to rapeseed oil by price of co-products.

(x) Methane output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 11).

(y) Average round trip distance of 450 km similar to biodiesel (Ref. 10) by bulk road carrier transport with a direct methane requirement of 4.900 x 10^{-7} ± 2.000 x 10^{-8} kg CH_4/t-km, an indirect methane requirement of 1.672 x 10^{-5} ± 6.3 x 10^{-7} kg CH_4/t-km and a total methane requirement of 1.721 x 10^{-5} ± 6.5 x 10^{-7} kg CH_4/t-km (Ref. 11).

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Table T4 Spreadsheet for Nitrous Oxide Outputs from Rapeseed Oil Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Rapeseed oil at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of refined rapeseed oil
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to rapeseed oil, and 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to rapeseed oil.

Contribution	Per Unit	Nitrous Oxide Output (kg N_2O)						
		Direct		Indirect		Total		Notes
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*0.706*	*±0.106*	*2.881*	*±0.432*	*3.587*	*±0.445*	(a)
- Other Fertiliser	*ha.a*	-	-	*0.003*	-	*0.003*	-	(b)
- Pesticides	*ha.a*	-	-	*0.004*	-	*0.004*	-	(c)
- Seeds	*ha.a*	-	-	*0.005*	-	*0.005*	-	(d)
- Diesel Fuel	*ha.a*	*0.001*	-	-	-	*0.001*	-	(e)
Reference System:								
- Diesel Fuel	*ha.a*	*-0.001*	-	-	-	*-0.001*	-	(f)
Sub-Totals	*ha.a*	*0.706*	*±0.106*	*2.893*	*±0.432*	*3.599*	*±0.445*	
	t rro	**0.384**	**±0.058**	**1.573**	**±0.235**	**1.957**	**±0.242**	(g)
Transport:								
- Diesel Fuel	*t ros*	-	-	-	-	-	-	(h)
	t rro	**-**	**-**	**-**	**-**	**-**	**-**	(i)
Drying:								
- Fuel Oil	*t dos*	-	-	-	-	-	-	(j)
	t rro	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Storage:								
- Electricity	*t dos*	-	-	-	-	-	-	(l)
	t rro	**-**	**-**	**-**	**-**	**-**	**-**	(k)
Solvent Extraction:								
- Natural Gas	*t cro*	-	-	-	-	-	-	(m)
- Electricity	*t cro*	-	-	*0.002*	-	*0.002*	-	(n)
- Hexane	*t cro*	-	-	-	-	-	-	(o)
Sub-Totals	*t cro*	-	-	*0.002*	-	*0.002*	-	
	t rro	**-**	**-**	**0.001**	**-**	**0.001**	**-**	(p)
Refining:								
- Electricity	*t rro*	-	-	-	-	-	-	(q)
- Natural Gas	*t rro*	-	-	-	-	-	-	(r)
- Heavy Fuel Oil	*t rro*	-	-	-	-	-	-	(s)
- Light Fuel Oil	*t rro*	-	-	-	-	-	-	(t)
- Phosph. Acid	*t rro*	-	-	-	-	-	-	(u)
- Smectite	*t rro*	-	-	-	-	-	-	(v)
Sub-Totals	**t rro**	**-**	**-**	**-**	**-**	**-**	**-**	
Plant Construction	**t rro**	**-**	**-**	**-**	**-**	**-**	**-**	(w)
Plant Maintenance	**t rro**	**-**	**-**	**-**	**-**	**-**	**-**	(x)
Distribution:								(y)
- Diesel Fuel	**t rro**	**-**	**-**	**-**	**-**	**-**	**-**	
Totals	**t rro**	**0.351**	**±0.053**	**1.443**	**±0.215**	**1.794**	**±0.222**	

Biofuel Specifications

Density of rapeseed oil = 0.92 kg/l
Net calorific value of rapeseed oil = 39.20 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil

Notes

(a) Ammonium nitrate fertiliser application rate of 196 kg N/ha.a based on a 4 year average for the UK between 1997 and 2000 (Ref. 3) and a direct nitrous oxide requirement of 0.0036 kg N_2O/kg N (Ref. 4), an indirect nitrous oxide requirement of 0. 147 kg N_2O/kg N (Ref. 5) and a total nitrous oxide requirement for ammonium nitrate of 0.0183 kg N_2O/kg N (Ref. 5).

(b) Other fertiliser application rates for phosphate of 50 kg P_2O_5/ ha.a and for potash of 48 kg K_2O/ha.a (Ref. 6), and for lime of 18.9 kg CaO (Ref. 4), with total nitrous oxide requirements for phosphate fertiliser of 4.2×10^{-5} kg N_2O/kg P_2O_5 , for potash fertiliser of 9.4×10^{-6} kg N_2O/ kg K_2O, and for lime of 1.6×10^{-5} kg N_2O/kg CaO (Ref. 4).

(c) Application rate for a mixture of pesticides, herbicides and fungicides of 2.8 kg/ha.a (Ref. 7) and a total nitrous oxide requirement for general pesticides, herbicides and fungicides of 1.51×10^{-3} kg N_2O/kg (Ref. 4).

(d) Sowing rate of 5 kg/ha.a (Ref. 8) and a total nitrous oxide requirement of 0.001 kg N_2O/kg of seed (Ref. 4).

(e) Diesel fuel consumption of 2,385 MJ/ha.a used by agricultural machinery for ploughing, sowing, spreading fertilisers, pesticides, herbicides and fungicides, and harvesting (Ref. 4), and a direct nitrous oxide requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60×10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(f) Reference system consisting of fallow set-aside with a diesel fuel consumption of 922 MJ/ha.a for mowing (Ref. 4), and a direct nitrous oxide requirement of 5.64×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.60×10^{-8} kg N_2/MJ and a total nitrous oxide requirement of 5.90×10^{-7} kg N_2O/MJ for diesel fuel in the UK in 1996 (Ref. 9).

(g) Land requirement of 0.878 ha.a/t of refined rapeseed oil and allocation of 86% x 72% = 61.92% to refined rapeseed oil.

(h) Average round trip distance of 260 km (Ref. 10) by bulk road carrier transport with a direct nitrous oxide requirement of $4.6 \times 10^{-7} \pm 1.7 \times 10^{-8}$ kg N_2O/t-km, an indirect nitrous oxide requirement of $2.1 \times 10^{-8} \pm 8 \times 10^{-10}$ kg N_2O/t-km and a total nitrous oxide requirement of $4.8 \times 10^{-7} \pm 1.8 \times 10^{-8}$ kg N_2O/t-km (Ref. 11).

(i) Raw oilseed requirement of 2.699 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(j) Fuel oil consumption of 305 MJ/t of dried oilseed for drying (Ref. 4), and a direct nitrous oxide requirement of 5.74×10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6×10^{-7} kg N_2O/MJ for fuel oil in the UK in 1996 (Ref. 9).

(k) Dried oilseed requirement of 2.532 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(l) Electricity consumption of 11.6 kWh/t of dried oilseed for cooling (Ref. 4), and an indirect nitrous oxide requirement of 5.577×10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(m) Steam consumption of 716 kg/t of crude rapeseed oil (Ref. 4), with assumed boiler efficiency of 80% giving natural gas consumption of 2.5 MJ/kg steam, and a direct nitrous requirement of 8.9×10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1×10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0×10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 9).

(n) Electricity consumption of 84 kWh/t of crude rapeseed oil (Ref. 4) and an indirect nitrous oxide requirement of 5.577×10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(o) Hexane consumption of 2.5 kg/t of crude rapeseed oil and a total nitrous oxide requirement of 1.35×10^{-5} kg N_2O/kg of hexane (Ref. 4).

(p) Crude rapeseed oil requirement of 1.026 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(q) Electricity consumption of 3.1 kWh/t refined rapeseed oil (Ref. 4) and an indirect nitrous oxide requirement of 5.577×10^{-6} kg N_2O/MJ for electricity in the UK in 1996 (Ref. 9).

(r) Natural gas consumption of 178 MJ/t of refined rapeseed oil (Ref. 4) and a direct nitrous requirement of 8.9 x 10^{-8} kg N_2O/MJ, an indirect nitrous oxide requirement of 1.1 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 1.0 x 10^{-7} kg N_2O/MJ for natural gas in the UK in 1996 (Ref. 9).

(s) Heavy fuel oil consumption of 20 MJ/t of refined rapeseed oil (Ref. 4) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for heavy fuel oil in the UK in 1996 (Ref. 9).

(t) Light fuel oil consumption of 152 MJ/t of refined rapeseed oil (Ref. 4) and a direct nitrous oxide requirement of 5.74 x 10^{-7} kg N_2O/MJ, an indirect nitrous oxide requirement of 2.6 x 10^{-8} kg N_2O/MJ and a total nitrous oxide requirement of 6 x 10^{-7} kg N_2O/MJ for light fuel oil in the UK in 1996 (Ref. 9).

(u) Phosphoric acid consumption of 1 kg/t of refined rapeseed oil and a total nitrous oxide requirement of 2 x 10^{-5} kg N_2O /kg for phosphoric acid (Ref. 4).

(v) Smectite consumption of 6 kg/t of refined rapeseed oil and a total carbon requirement of 6.5 x 10^{-6} kg N_2O /kg for smectite (Ref. 4).

(w) Primary energy input of 108,309 ± 23,345 GJ for construction of an oilseed mill, assumed to be similar to a solvent extraction plant (Ref. 11), with a capacity of a 42,080 t/a and a 25 year life, and an estimated total nitrous oxide requirement of 1.866 x 10^{-9} kg N_2O/MJ primary energy input to construction (Ref. 12) and 72% contribution to rapeseed oil by price of co-products.

(x) Nitrous oxide output of annual plant maintenance assumed to be 2.5% of methane output from plant construction (Ref. 11).

(y) Average round trip distance of 450 km similar to biodiesel (Ref. 10) by bulk road carrier transport with a direct nitrous oxide requirement of 4.6 x 10^{-7} ± 1.7 x 10^{-8} kg N_2O/t-km, an indirect nitrous oxide requirement of 2.1 x 10^{-8} ± 8 x 10^{-10} kg N_2O/t-km and a total nitrous oxide requirement of 4.8 x 10^{-7} ± 1.8 x 10^{-8} kg N_2O/t-km (Ref. 11).

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Table T5 Spreadsheet for Greenhouse Gas Outputs from Rapeseed Oil Production from Oilseed Rape Using Solvent Extraction

Functional Unit: :	Rapeseed at point of distribution derived from oilseed rape using solvent extraction
Final Unit of Measurement:	1 tonne of refined rapeseed oil
Relevant Location:	United Kingdom
Relevant Period:	1996
Allocation Procedures:	Based on average market prices, assuming 2.782 tonnes of rape straw at £25/t (UK 1992; Ref. 1) and 2.839 tonnes of raw oilseed at £152/t (UK 1997 - 2000 average; Ref. 2), giving a 86% allocation to rapeseed oil, and 1.575 tonnes of rape meal at £84/t (UK 1997 - 2000 average; Ref. 2) and 1.079 tonnes of crude rapeseed oil at £323 per tonne (UK 1997 - 2000 average; Ref. 2), giving a 72% allocation to rapeseed oil.

Contribution	Per Unit	Greenhouse Gas Output (kg eq CO_2)						Notes
		Direct		Indirect		Total		
		Value	Range	Value	Range	Value	Range	
Cultivation and Harvesting:								
- N Fertiliser	*ha.a*	*226*	*±34*	*1,314*	*±148*	*1,538*	*±152*	(a)
- Other Fertiliser	*ha.a*	-	-	*61*	*±9*	*61*	*±9*	(a)
- Pesticides	*ha.a*	-	-	*15*	*±2*	*15*	*±2*	(a)
- Seeds	*ha.a*	-	-	*4*	-	*4*	-	(a)
- Diesel Fuel	*ha.a*	*164*	*±25*	*20*	*±3*	*184*	*±25*	(a)
Reference System:								
- Diesel Fuel	*ha.a*	*-64*	*±9*	*-7*	*±1*	*-71*	*±9*	(a)
Sub-Totals	*ha.a*	*326*	*±43*	*1,407*	*±148*	*1,731*	*±155*	
	t rro	**177**	**±23**	**765**	**±80**	**942**	**±83**	(b)
Transport:								
- Diesel Fuel	*t ros*	*15*	*±1*	*4*	-	*19*	*±1*	(a)
	t rro	**29**	**±2**	**8**	**±1**	**37**	**±2**	(c)
Drying:								
- Fuel Oil	*t dos*	*22*	*±3*	*2*	-	*24*	*±3*	(a)
	t rro	**40**	**±5**	**4**	**±1**	**44**	**±5**	(d)
Storage:								
- Electricity	*t dos*	-	-	*6*	*±1*	*6*	*±1*	(a)
	t rro	**-**	**-**	**11**	**±2**	**11**	**±2**	(d)
Solvent Extraction:								
- Natural Gas	*t cro*	*117*	*±18*	*10*	*±1*	*127*	*±18*	(a)
- Electricity	*t cro*	-	-	*49*	*±7*	*49*	*±7*	(a)
- Hexane	*t cro*	-	-	*1*	-	*1*	-	(a)
Sub-Totals	*t cro*	*117*	*±18*	*60*	*±7*	*177*	*±19*	
	t rro	**86**	**±13**	**44**	**±5**	**130**	**±14**	(e)
Refining:								
- Electricity	*t rro*	-	-	*2*	-	*2*	-	(a)
- Natural Gas	*t rro*	*9*	*±1*	*1*	-	*10*	*±1*	(a)
- Heavy Fuel Oil	*t rro*	*2*	-	-	-	*2*	-	(a)
- Light Fuel Oil	*t rro*	*11*	*±2*	*1*	-	*12*	*±2*	(a)
- Phosph. Acid	*t rro*	-	-	*1*	-	*1*	-	(a)
- Smectite	*t rro*	-	-	*1*	-	*1*	-	(a)
Sub-Totals	**t rro**	**22**	**±2**	**6**	**-**	**28**	**±2**	
Plant Construction	**t rro**	**-**	**-**	**5**	**±1**	**5**	**±1**	(a)
Plant Maintenance	**t rro**	**-**	**-**	**2**	**±1**	**2**	**±1**	(a)
Distribution:								
- Diesel Fuel	**t rro**	**25**	**±1**	**7**	**±1**	**32**	**±1**	(a)
Totals	**t rro**	**379**	**±27**	**852**	**±80**	**1,230**	**±84**	

Biofuel Specifications

Density of rapeseed oil = 0.92 kg/l
Net calorific value of rapeseed oil = 39.20 MJ/kg

Abbreviations

ha.a = hectare year
t ros = tonne of raw rapeseed
t dos = tonne of dried rapeseed
t cro = tonne of crude rapeseed oil
t rro = tonne of refined rapeseed oil

Notes

(a) Summation of results from previous spreadsheets with conversion using a global warming potential for methane of 24.5 kg eq CO_2/kg CH_4 and a global warming potential for nitrous oxide of 320 kg eq CO_2/kg N_2O.

(b) Land requirement of 0.878 ha.a/t of refined rapeseed oil and allocation of 86% x 72% = 61.92% to refined rapeseed oil.

(c) Raw oilseed requirement of 2.699 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(d) Dried oilseed requirement of 2.532 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.

(e) Crude rapeseed oil requirement of 1.026 t/t of refined rapeseed oil and allocation of 72% to refined rapeseed oil.