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TO: NCASI Operating Committee, NCASI Canadian Steering Committee

CC: Ben Wigley, Kirsten Vice

FROM: Caroline Gaudreault and Reid Miner

SUBJECT: ***Examination of the UK DECC Scenarios and Calculations of the Life Cycle GHG Benefits of Producing Electricity in the UK from Pellets Made from North American Forest Biomass***

In July of 2014, UK Department of Energy & Climate Change (DECC) published *"Life Cycle Impacts of Biomass Electricity in 2020"* (Stephenson and Mackay 2014). The report contains the results of a study of the greenhouse gas emissions associated with pellets produced from North American woody feedstocks (e.g., saw-mill residues, dead trees from natural disturbances, pulpwood) used to produce electricity in the UK. At the same time, UK DECC published a calculator, the "BEAC (Biomass Emissions and Counterfactual) model" (DECC 2014). NCASI has reviewed DECC report and, with input from NCASI's Operating Committee, has identified biomass electricity production scenarios deserving further attention because (a) they represent conditions where the results might be significantly affected by changes to the modeling assumptions, and (b) they appear to be reasonably likely. This includes pellets produced from:

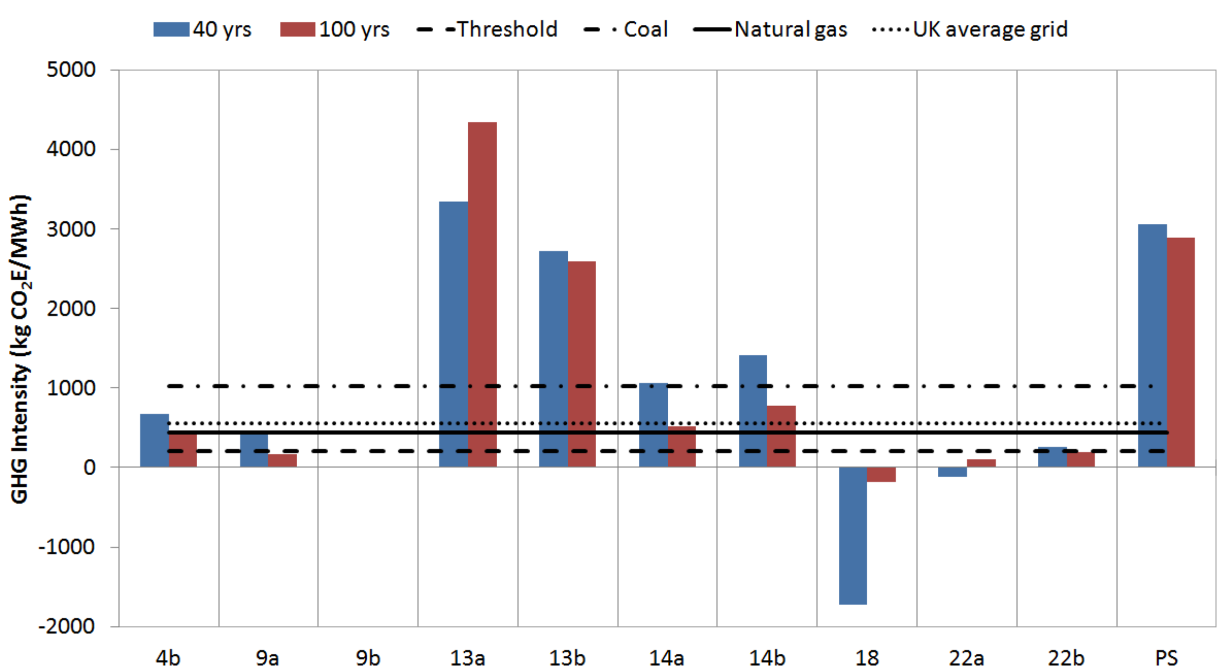
- additional wood from coarse forest residues removed from forest that would otherwise be left to decay on the forest site (Scenario 4b);
- additional wood from salvaged dead trees killed by mountain pine beetle (Scenario 9) ;
- additional roundwood from increased harvest of naturally-regenerated hardwood forest with an actual rotation of 70 years (Scenario 13);
- additional wood from existing intensively-managed pine plantations with an actual rotation of 25 years (Scenarios 14 and 18); and
- additional roundwood from new plantations replacing naturally-regenerated forests with a rotation of 50 years (Scenario 22).

In this review, we have not included a number of reasonably likely scenarios associated with very low net emissions where the results are expected to be insensitive to parameter variation. Generally, the scenarios excluded from the NCASI analysis involve afforestation and avoided deforestation. Wood produced under these conditions will almost always produce low (often negative) net life cycle emissions of GHGs. Finally, the DECC report did not include product substitution scenarios, but the BEAC calculator allows for modeling several of these, some of which were also examined by NCASI. This memorandum describes the draft findings, to date, from examining the UK DECC scenarios and calculations.

Summary of Findings

Quantitative Findings

Figure 1 presents a summary of base case scenario results, developed by DECC (except for product substitution scenarios, which we grouped as PS). Results are presented for two of the time horizons available in the calculator, 40- and 100-years. Detailed sensitivity analyses results can be found in the body of the memorandum.



Scenario descriptions are presented above. In 9a, wood would have been left to decay in the counterfactual and, in 9b, it would have been burned at the roadside. In 13a, the additional wood is obtained by reducing the rotation from 70 to 60 years. In 13b, it is assumed that the additional wood can be obtained by maintaining the rotation at 70 years but that that rotation would increase to 80 years in the absence of the biomass electricity demand. In 14a, it is assumed that the additional wood can be obtained by maintaining the rotation at 25 years but that the rotation would increase to 35 years in the absence of the biomass electricity demand. In 14b, the additional wood is obtained by reducing the rotation from 25 to 20 years. In 18, the additional wood is obtained by maintaining the rotation time at 25 years but increasing the management intensity of medium-intensity plantations. In 22a, the new plantation has a rotation of 25 years and, in 22b, a rotation of 20 years. PS is for average of product substitution scenarios (PS1 to PS8).

Figure 1. Summary of DECC Scenario Base Case Results

It can be seen from Figure 1 that the GHG intensity for biomass electricity, as calculated by the BEaC calculator, is quite variable depending on the source of the biomass used for its production. General findings derived from the results in Figure 1 and from NCASI's sensitivity analyses are summarized below.

- Unless the alternative is pile burning, coarse woody debris (called forest residues in this memorandum) produced in places where decay rates are slow would not meet UK DECC threshold of 200 kg CO_2E/MWh[1] for producing electricity from biomass. However, they would produce a lower GHG intensity than coal. At higher decay rates, such as those used by DECC to model the US South (which are reasonably close to those used by NCASI in the past), coarse woody debris net emissions come close to meeting the threshold only for the 100-year time horizon. According to the report from DECC, fine woody debris meets the UK criteria due to assumed rapid decay rates but NCASI's review and this memorandum do not examine scenarios focused on the use of fine woody debris for energy, and hence, use of the term "forest residues" refers to coarse woody debris only. Of the parameters examined in the sensitivity analysis for forest residues that would be left to decay if not used for energy, decay rate is, by far, the most important. In this case, the calculated GHG intensity is mainly due to the loss of non-soil carbon stocks when residues are removed from the forest site.
- Assuming that salvaged dead trees would be collected and burned if not used for energy always results in calculated GHG intensities lower than the DECC threshold. This is not the case in scenarios where the trees would otherwise be left on-site to decay. Indeed, in this case, the observed GHG intensity is lower than the threshold only over 100 years. The calculated GHG intensity is mainly due to the loss of carbon stocks on the land when dead trees are removed from the forest site in the bioenergy scenario compared to being left to decay in the counterfactual.
- Assumptions regarding forestry yields and growth rates have significant effects on the calculated GHG intensities for scenarios involving roundwood. NCASI was able to confirm that DECC used the growth curve and yield assumptions from US Forest Service (USFS) summaries of the Forest Inventory and Analysis (FIA) data in Smith et al. (2006), but the information in the DECC report and calculator is inadequate to allow NCASI to replicate DECC's approach to using the Smith et al. (2006) data. Discussions with USFS have confirmed, however, that the growth curves in Smith et al. are essentially average values for each age class, across FIA plots and they do not, therefore, reveal the wood outputs from thinnings or the stand-level impacts of thinning, including growth responses. This appears to

[1] The EU Renewable Energy Directive has various GHG thresholds for bioenergy. The "200 kg CO_2E/MWh" threshold applies to biomass power between April 1st 2020 and March 31st 2025. Thresholds to apply between April 1st 2014 and March 31st 2020 are 240 and 285 kg CO_2E/MWh for dedicated biomass power and all other biomass power, respectively. Threshold to apply between April 1st 2025 and March 31st 2030 is 180 kg CO_2E/MWh for both dedicated biomass power and all other biomass power. Only the "200 kg CO_2E/MWh" threshold is discussed in this memorandum.

be, at least in part, why the use of thinnings is not specifically examined by DECC. However, the effect of lack of information on thinnings on the calculated greenhouse gas intensities is unclear, as the impacts of thinning on total wood production and growth rates would apply to both the bioenergy and counterfactual scenarios, except under a scenario where thinning would not occur were it not for the market for biomass electricity.

- Results from the BEAC calculator indicate that increasing the rate of harvest of a naturally-regenerated hardwood (broadleaf) forest to produce biomass electricity would never meet the threshold. In fact, according to the BEACBEAC calculator, this scenario would result in GHG intensities far above those of coal combustion. The calculated GHG intensity is mainly due to the large difference in assumed carbon stocks between longer and shorter rotation periods and the fact that assumed yields for wood production are affected only slightly when the harvesting interval is shortened to every 60 years from every 70 years.
- The GHG benefits of using additional wood from intensively-managed pine plantations in the US South for the production of energy are highly dependent on the assumptions made regarding the counterfactual scenario. For instance, when assuming that the counterfactual involves trees that would be harvested less often in the absence of the bioenergy scenario, the GHG intensity is higher than the threshold because of foregone carbon sequestration. However, in cases where the counterfactual involves tree growing more slowly (e.g., less intensive management) than in the bioenergy scenario, the GHG intensity is much lower in the short-term, even lower than the threshold, and increases over time as the slower-growing trees increase in size in the counterfactual. This is because more carbon is added to the land in the short-term in the bioenergy scenario than in the counterfactual scenario.
- In cases where the demand for wood for energy would cause existing medium-intensity plantations to be managed more intensively, the produced biomass electricity would have GHG intensity of less than zero. This is explained by the fact that DECC assumed higher carbon stocks for more intensively-managed plantations.
- Converting naturally-regenerated pine forests on a 50-year rotation to intensively-managed pine plantations in the US South generally results in GHG intensities lower than the DECC threshold, sometimes in as short as 40 years. The GHG intensities, however, are sensitive to assumed rotation ages and growth curves for intensively-managed planted pine. Where wood is from intensively-managed pine plantations established on land converted from naturally-regenerated hardwood forests, the GHG intensities of the biomass electricity are much higher. The difference is due to the lower non-soil carbon stocks in the bioenergy scenario (intensively-managed pine) compared to that in the counterfactual scenario (naturally-regenerated hardwoods).

- Using wood that would normally be used in wood products for construction to produce biomass electricity, with the exception of medium-density fiberboard (MDF), generally results in GHG intensities significantly higher than threshold, very often significantly higher than coal. This result is due to the fact that according to the BEAC calculator, wood products (except perhaps MDF) produce far fewer GHG emissions than non-wood alternatives, rendering the substitution benefits associated with using wood for construction far greater than those associated with using it for biomass electricity.
- The following parameters have marginal influence on the results:
  - transportation assumptions;
  - assumptions regarding power grid used at pelletizer (other than regional differences);
  - fertilizer usage; and
  - fuel usage in the forest.
- Cofiring produces lower GHG emissions than does dedicated biomass electricity because of greater efficiency in producing the energy.

Potential Methodological Issues Identified by NCASI

NCASI has identified three potentially significant methodological issues in the approach used to model the production of biomass electricity from roundwood.

1. As discussed above, assumptions regarding wood production yields and growth rates have significant effects on the calculated GHG intensities for scenarios involving roundwood. While the information in the DECC report and calculator is inadequate to allow NCASI to exactly replicate DECC's approach to using the Smith et al. (2006) data, we found similar carbon numbers by using Smith et al. data in an attempt to replicate DECC's approach. Discussions with USFS indicate that the growth curves in Smith et al. do not include stand-level effects of thinning because they are average values over a large number of FIA plots. However, the effect of the lack of information on thinnings on the calculated greenhouse gas intensities is unclear as the growth response would apply to both the bioenergy and counterfactual scenarios (unless it is assumed that thinning only occurs in the bioenergy scenario).

2. Another issue is related to assumptions about how sawtimber is used and the methods used to calculate the emissions intensity of biomass electricity produced from smaller diameter logs not suitable for producing lumber. In the scenarios modeled in the DECC report, all additional wood produced in the bioenergy scenarios is used for energy, regardless of size. A more likely outcome, however, is that large diameter trees would be sold for higher value uses, particularly lumber production. Interestingly, in one scenario (Scenario 13), the BEAC calculator allows examination of the effect of using only smaller logs for energy. Due to allocation assumptions in the BEAC calculator, however, modifying Scenario 13 so that biomass electricity is produced only from smaller logs significantly increases the GHG intensity of the biomass electricity produced. Different results are obtained using alternative

allocation assumptions. If allocation is based on mass, the small diameter wood used for energy would have GHG intensity similar to the wood in the scenario where all additional wood beyond the counterfactual is used for energy. If allocation is based on economic value, it is likely that small diameter logs used for energy would have a lower GHG intensity than wood in the scenario where all additional wood is used for energy.

3. The last methodological issue deals with how the pairs of bioenergy and counterfactual scenarios were defined to represent an increase in wood demand, especially related to the use of roundwood where most scenarios assumed that increased demand would be met through a significant reduction in rotation length. Concerns have been raised by the industry and other researchers regarding this simplified modeling approach. In particular, it has been observed that focusing on simplistic rotation length scenarios fails to address the dynamic nature of landowner responses across a region when there is an increase in demand for wood. Examining such scenarios is a reasonable starting place for generating hypotheses on the important factors to consider in modeling the impacts of increased demand, but this approach does not capture the effects of landowner responses to increased demand because these responses are dynamic and interactive over space and time. NCASI has been asked by the Operating Committee to work with experts in modeling timber supply in an attempt to identify a more reasonable, yet workable approach to modeling the carbon impacts of increased demand for roundwood for energy.

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1 Context and Objective

In July of 2014, UK Department of Energy and Climate Change (DECC) published *"Life Cycle Impacts of Biomass Electricity in 2020"* (Stephenson and Mackay 2014). The report contains the results of a study of the greenhouse gas emissions associated with bioelectricity from pellets produced from North American woody feedstocks (e.g., saw-mill residues, dead trees from natural disturbances, pulpwood) used to produce electricity in the UK. At the same time, UK DECC published a calculator, the DECC's BEaC (Biomass Emissions and Counterfactual) model (DECC 2014), that can be used to perform sensitivity analyses on the scenarios investigated in the study report. The scenarios defined in the study are evaluated based on sustainability criteria published by DECC in 2013 (DECC 2013) for biomass feedstocks financially supported under the Renewable Obligation (RO)[2]. According to these criteria, by 2020, electricity from solid biomass subsidized by the RO must be proven to generate electricity with a GHG emission intensity under 200 kg CO_2E/MWh[3], calculated based on the LCA methodology set out in Annex V of the EU Renewable Energy Directive (European Union 2009) and summarized below. This intensity is lower than that of electricity generated from fossil fuels in the UK (e.g., ≈ 437 kg CO_2E/MWh for electricity from natural gas and ≈ 1018 kg CO_2E/MWh for electricity from coal), but higher than that of other renewables.

NCASI has received several requests to critique the UK DECC study and associated calculator. Accordingly, NCASI has undertaken a series of analyses to develop an understanding of the factors influencing the results and the sensitivities of the results to a number of key assumptions. NCASI's analysis, however, did not address the likelihood of the various scenarios examined by DECC.

2 LCA Methodology Employed by UK DECC

2.1 Conceptual Framework Used by DECC to Calculate the GHG Intensity of Biomass Electricity

The objective of DECC was to estimate the overall life cycle GHG intensity of biomass electricity in a way that is directly comparable to that of other pathways (mainly based on fossil fuels) for producing the same form and quantity of energy, while accounting for changes in the carbon stock of a forest, foregone carbon sequestration on land, or indirect impacts on carbon stocks on other land types. Figure 2 shows an example of the conceptual framework, were biomass electricity is compared to energy from coal, that was used in the DECC study to achieve this objective. DECC defined the biomass electricity pathway as the difference between a

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[2] The RO requires licensed UK electricity suppliers to source a specified proportion of the electricity they provide to customers from eligible renewable sources.

[3] The EU Renewable Energy Directive has various GHG thresholds for bioenergy. The "200 kg CO_2E/MWh" threshold applies to biomass power between April 1st 2020 and March 31st 2025. Thresholds to apply between April 1st 2014 and March 31st 2020 are 240 and 285 kg CO_2E/MWh for dedicated biomass power and all other biomass power, respectively. Threshold to apply between April 1st 2025 and March 31st 2030 is 180 kg CO_2E/MWh for both dedicated biomass power and all other biomass power. Only the "200 kg CO_2E/MWh" threshold is discussed in this memorandum.

bioenergy scenario and a counterfactual scenario. The bioenergy scenario accounts for the direct life cycle emissions associated with producing bioenergy. The counterfactual scenario represents what the land would be used for if it were not used to generate the biomass feedstocks. For example, if wood pellets are generated from forest residues that do not have an alternative market, the counterfactuals include leaving the woody residues to decay in the forest after harvest or removing the residues from the forest and burning them at the roadside.

As shown in Figure 2, the only function accomplished by the coal pathway is the production of 1 MWh of electricity. The biomass electricity pathway, however, might accomplish multiple functions (e.g., 1 MWh energy, habitat). To be able estimate the emissions associated with the electricity production function of the bioenergy scenario, the other functions (and their emissions) must be subtracted from the calculations. It can been seen from the figure than an inherent assumption in the DECC study is that the other functions delivered by the forest are considered to be equal in the bioenergy and counterfactual scenarios.

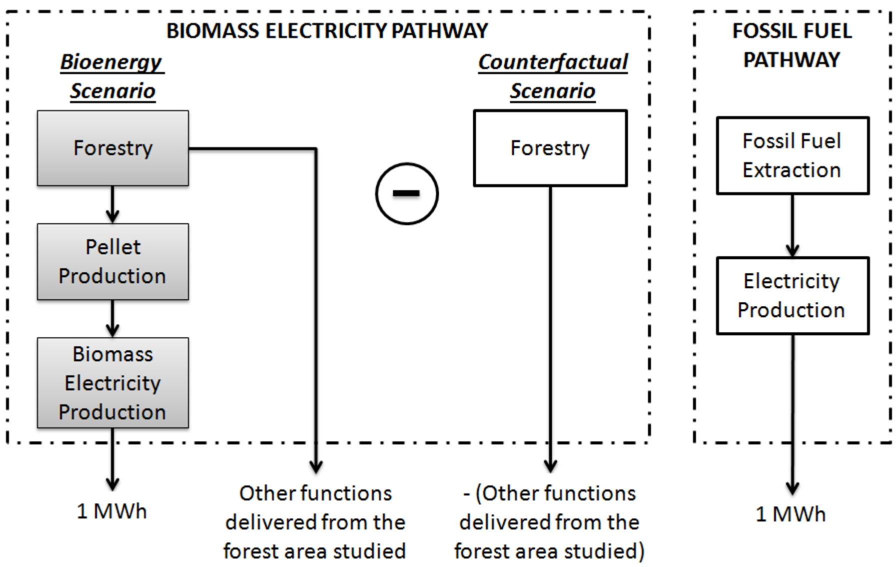

Figure 2. Conceptual Framework Used by DECC to Calculate the GHG Intensity of Biomass Electricity: the Example of Comparison with Fossil Fuel energy

2.2 LCA Methodology Employed by DECC

The detailed LCA methodology employed by DECC is set out in Annex V of the EU Renewable Energy Directive (European Union 2009). As shown in Figure 3, this methodology considers the emissions from forestry (cultivation and harvesting), processing (drying, chipping, and pelletizing), transport of the biomass feedstocks, and energy production. It also includes direct land use change where the land use has changed category since 2008 (e.g., from forest to annual crop land, grassland to annual crop land). However, the Renewable Energy Directive LCA methodology does not account for the following aspects: changes in the carbon stock of a forest, foregone carbon sequestration on land, or indirect impacts on carbon stocks on other land. DECC attempted to address these aspects by examining using an approach where carbon flows over time in defined bioenergy and counterfactual scenarios, and by including scenarios where various indirect effects were included. More details on the definition of the scenarios is provided below.

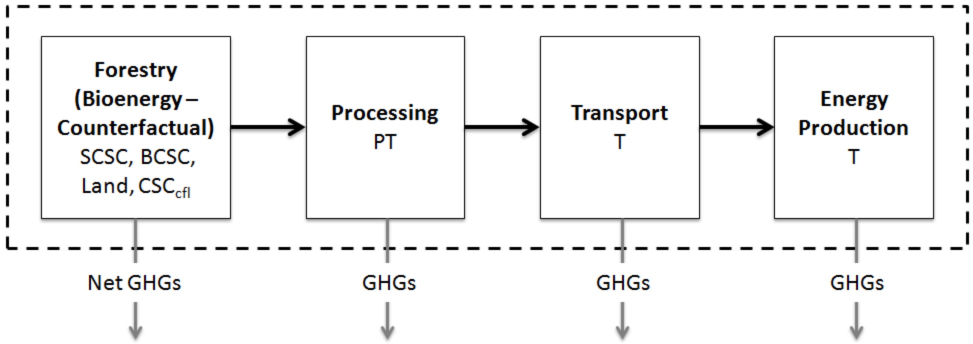

Figure 3. Unit Processes (System Boundary) used by DECC to Compute GHG Intensity of Biomass Electricity
(Detailed nomenclature in Table 1. More detail on the consideration of forestry provided in Figure 2.)

The GHG emission intensity (GHGI) of biomass electricity (production and use of biofuels) is calculated as follows in the DECC study:

$$GHGI = \frac{Life\ Cycle\ GHG\ emissions\ (kg\ CO_2E)}{Total\ delivered\ electricity\ over\ the\ time\ horizon\ (MWh)} \quad \text{[Equation 1]}$$

and the life cycle GHG emissions (LCGHG) are computed as follows (nomenclature provided in Table 1):

$$LCGHG = SCSC + BCSC + Land + PT + T + ET + WP - CSC_{cfl} \quad \text{[Equation 2]}$$

Equation 2, which includes differences in emissions between the bioenergy and counterfactual scenarios, allows for a direct comparison with life cycle GHG emissions from producing the same quantity of energy using fossil fuels.

Table 1. Terms Involved in Calculating the Life Cycle GHG Emissions of Biomass Electricity

Term	Short Name (used in DECC report)	Description
SCSC	Soils C Stock Change	Emissions from the change in the amount of carbon stored in soils for the bioenergy scenario over the time horizon (an increase in stocks is a negative emission, a decrease in stocks is a positive emission).
BCSC	Land Biomass C Stock Change	Emissions from the change in the amount of carbon stored in above- and below-ground biomass for the bioenergy scenario over the time horizon (an increase in stocks is a negative emission, a decrease in stocks is a positive emission).
Land	Land Emissions	Difference in emissions between the bioenergy scenario and counterfactual for the following: • natural GHG emissions flux (e.g., methane production from tropical peat forests); • GHG emissions from crop/tree establishment, fertiliser and pesticide production and use, irrigation and harvest; and • GHG emissions from biomass combustion on the land (e.g., roadside burning of residues).
PT	Pre-treatment (processing)	The treatment of biomass before its final use for energy (includes drying, chipping, and pelletizing)
T	Transport	The transport of biomass by road, rail and ship: • from the farm/forest to the pellet facility; • from the pellet facility to the port; • from the country of origin to the UK port; and • from the UK port to the location of final use.
ET	Energy Technology	The GHG emissions associated with the final energy technology, e.g., combustion for energy and/or heat, production of ethanol etc.
CSC_{cfl}	cfl C Stock Change	Emissions from the change in the amount of carbon stored in soils, and above- and below-ground biomass for the counterfactual scenario (an increase in stocks is a negative emission, a decrease in stocks is a positive emission).
WP	N/A	Emissions from wood product substitution

The life cycle GHG emissions can vary significantly over time. DECC modeled three time horizons: 20 years, 40 years and 100 years. In most cases, the GHG emissions were calculated assuming that the biomass is harvested from the land continuously over the time horizon. IPCC 2007 global warming potentials were used (25 kg CO_2E/kg CH_4 and 298 kg CO_2E/kg N_2O). Carbon stock changes were modeled using data from USFS (Smith et al. 2006) and the C-SORT model. Also, DECC used a landscape-level approach to calculate the change in carbon stocks (i.e., they calculated the average carbon stock in all stands considered). The USFS data provides information on how the harvested wood output, and carbon stocks in the trees, understory, dead wood, forest floor and soil, change over time after a clearcut harvest and re-growth of forests in different forest types of North America. The C-SORT model allows the user to define the tree species, yield class (measure of the growth rate of the tree), soil type, planting density, and time between harvests, to estimate how the carbon stock changes over time in a modelled forest, as well as the amount of saw logs, pulpwood and forest residues that are produced.

DECC modeled several scenarios to represent North American woody feedstocks that are currently used for the production of woody pellets (e.g., pellets from sawmill residues, beetle-killed trees, and pulpwood), as well as potential future scenarios that might occur with an increased demand for biomass fuels. DECC not only modeled plausible or probable scenarios, but also modeled undesirable scenarios to illustrate potential effects of policymaking. In building their scenarios, DECC recognized that an increase in demand for wood pellets could lead to the following conditions, each of which DECC examined separately:

- an increase in the rate of harvest of existing forests, lowering the average age of trees;
- changes in the management practices of current forests;
- the conversion of naturally-regenerated forests to highly productive intensively-managed, genetically-selected plantations;
- the establishment of new plantations on current agricultural land;
- the use of pulpwood for biomass electricity, causing the displacement of non-bioenergy wood uses; or
- the prevention of some productive forests being converted to other uses, such as agricultural land.

In the DECC study report, substitution effects due to displacement of non-wood construction materials were ignored because it was assumed that the amount of non-wood materials used for house construction would not change as a result of wood demand for biomass electricity. Instead, it was considered more likely that increased demand for wood for biomass electricity would result in more wood being harvested for bioenergy. However, the calculator allows for analyzing scenarios in which substitution effects with non-wood products are considered (i.e., fifth condition listed above).

3 NCASI Approach to Examining Selected Scenarios and Model Assumptions

NCASI has reviewed DECC report and has identified scenarios deserving further attention because (a) they represent conditions where the results might be significantly affected by changes to the modeling assumptions and (b) they appear to be reasonably likely. We have not included, however, a number of reasonably likely scenarios associated with very low net emissions where the results are expected to be insensitive to parameter variation. Generally, the scenarios excluded from the NCASI analysis involve afforestation and avoided deforestation. The BEAC calculator allows for modeling several substitution scenarios, some of which were also examined in the NCASI analysis (see Section 5.5 for more details). NCASI used the BEAC calculator and report to investigate these scenarios using the following approach:

- Prepare a summary and analysis of each scenario.
- Review, describe and/or validate the various model parameters, by cross-checking with credible references other than those used by DECC where needed, including:
    - the growth curves (if they appear unrealistic, consider the implications of using other growth curves);

  - for scenarios involving a conversion of natural forest to plantation, the carbon stock assumptions for the pre- and post-conversion conditions (if the assumptions about carbon stocks appear inconsistent with other sources of information, consider the implications of using other sources of information to support assumptions about forest carbon stocks);
  - the decay rates, where applicable; and
  - other process parameters (e.g., forestry yields, fertilizer usage, etc.).
- Understand why some of the results are significantly affected by relatively small changes in rotation time (20- vs. 25-year).
- Investigate, to the extent possible, how the landscape approach was applied. Note that many of the BEAC calculations are embedded within the tool and hence, it was not possible to fully understand the implemented approach.
- Apply a series of sensitivity analyses to understand the effect of key parameters on the results.
- Discuss with key stakeholders to understand assumptions, data used and implications.

The scenarios analyzed by NCASI are summarized in Table 2.

Table 2. Overview of Scenarios Analyzed by NCASI

DECC Scenario #		Description
Wood Residues		
4	b	Additional wood from coarse forest residues removed from forests in Pacific Canada, continuously over the time horizon
9		Additional wood from salvaged dead trees, which have been killed by mountain pine beetle in Pacific Canada for which the counterfactual is:
	a	Leave in the forest to decay
	b	Remove and burn at the roadside
Roundwood from Increased Harvest of Naturally-Regenerated Hardwood Forest		
13	a	Additional wood from increasing the rate of harvest of a naturally-regenerated hardwood (broadleaf) forest in the US South from every 70 years to every 60 years (cfl: the rate of harvest remains at every 70 years)
	b	Additional wood from continuing harvesting a naturally-regenerated hardwood (broadleaf) forest in the US South every 70 years (cfl: the rate of harvest increases at every 80 years)
Roundwood from Existing Intensively-Managed Pine Plantations		
14		Additional wood from intensively-managed pine plantations on a 25 year rotation (currently) in the US South
	a	Accomplished by using 25 year rotation wood (cfl: 35 year rotation with intensive management)
	b	Accomplished by reducing rotation time to 20 years (cfl: 35 year rotation with intensive management)
18		Additional wood by increasing management level of US South 25 year rotation pine plantations from medium-intensity to intensively-managed (cfl: 25 year rotation with medium-intensity management)
Roundwood from New Plantations Replacing Naturally-Regenerated Forests		
22		Additional wood from the conversion of a naturally-regenerated coniferous forest in US South that is harvested every 50 years, to an intensively-managed pine plantation that is harvested...
	a	Every 25 years
	b	Every 20 years
Product Substitution		
PS1-PS8*		Scenarios where additional wood is obtained from wood otherwise used in various wood products (i.e., involving product substitution)

* NCASI nomenclature for additional scenarios modeled by NCASI.

4 Evaluation of DECC Models

4.1 General Evaluation

The distinction between attributional and consequential LCA (ALCA and CLCA) is not always clear. While the results of the scenarios in the UK DECC study are presented in a way that is more consistent with ALCA by presenting GHG intensities, the report relies on CLCA by looking at the potential impacts of increased demand for wood energy and by including indirect effects of that increased demand such as displaced pulpwood, changes in management practices, indirect land use change, etc. Failure to clearly distinguish between CLCA and ALCA or mixing the two can result in a misinterpretation of the results. That said, the overall approach applied in the DECC study seems sound for a study designed around scenario comparisons. NCASI's detailed review of model assumptions and of the sensitivity of the results to these assumptions is presented below.

4.2 Evaluation of Main Modeling Assumptions

The details of the standard assumptions made for all scenarios are presented in the Annex of the DECC report (Stephenson and Mackay 2014, p. 127-130) and summarized in Appendix 1 of this memorandum. NCASI reviewed these standard assumptions, which appear reasonable. Assumptions related to the scenarios that were evaluated by NCASI were reviewed and are discussed below for each scenario.

4.3 Evaluation of Growth Curves and Carbon Stocks

According to DECC, most changes in non-soil carbon stocks were modeled using data from the USDA Forest Service (Smith et al. 2006). The following assumptions were made:

- naturally-regenerated hardwood forests were modeled based on Southeastern US Oak-Hickory forests;
- intensively-managed pine plantations were modeled based on Southeastern US Loblolly pine plantations; and
- naturally-regenerated softwood forests were modeled based on low-productivity naturally-regenerated Southeastern US Loblolly pine forests.

The Smith et al. data for these forest types are included in Appendix 2 below and the carbon data derived from these, according to DECC, are presented in Table 3. While the information in the DECC report and calculator is inadequate to allow NCASI to exactly replicate DECC's approach to using the Smith et al. (2006) data, we found similar carbon numbers by using Smith et al. data in an attempt to replicate DECC's approach. However, discussions with USFS indicate that the growth curves in Smith et al. reflect average carbon stock values, by age class, across a large number of FIA plots. They therefore do not reveal stand-level impacts of thinning (e.g., growth responses in remaining trees). The effect of this on the calculated greenhouse gas intensities is unclear as the impacts of thinning would apply to both the bioenergy and counterfactual scenarios, unless it is assumed that the thinning would not have occurred were it not for the increased demand for biomass electricity. For instance, a plausible scenario could be that an increased demand for pellets might be achieved through a change in thinning regime. It is not clear whether or how one would use the BEAC calculator to model this. The attributes of the Smith et al. (2006) growth curves, however, may explain, at least in part, the lack of attention given to thinnings in the DECC analyses.

Table 3. Average Carbon Stocks Used by UK DECC Described as "Derived from Smith et al."

Scenario #	Average carbon stocks (t C/ha)			
	40 years		100 years	
	Bioenergy	Counterfactual	Bioenergy	Counterfactual
Roundwood from Increased Harvest of Naturally-Regenerated Hardwood Forest				
13a	75.20	84.42	74.02	84.42
13b	84.42	91.06	84.42	93.12
Roundwood from Existing Intensively-Managed Pine Plantations				
14a	80.92	103.01	80.92	103.01
14b	66.53	103.01	66.53	103.01
18	80.92	59.81	80.92	59.81
Roundwood from New Plantations Replacing Naturally-Regenerated Coniferous Forests				
22a	80.92	69.64	80.92	69.64
22a, replacing broadleaf forests (70 yr)	80.92	84.42	80.92	84.42
22b	66.53	69.64	66.53	69.64
22b, replacing broadleaf forests (70 yr)	66.53	84.42	66.53	84.42

4.4 Evaluation of the Landscape Approach Applied

UK DECC used a landscape approach in which the number of stands in the landscape is fixed to the number of years in the rotation. If the rotation is of 25 years, then there are 25 stands in the landscape. Hence, at the scale of a forest or landscape, if the management practice of the forest does not change and the forest consists of stands with a uniform age distribution (referred to by DECC as even-aged), losses of carbon stocks due to harvesting may be counterbalanced by sequestration in the remaining stands which are still growing. In this case, the forest's carbon stock stays at an average value. If the management practice changes, the tree species changes, or harvesting practices are stopped, this average carbon stock also changes.

While this appears reasonable in concept, NCASI was not able to examine some of the details involved in the calculations. For instance, NCASI was not able to check how the calculations address scenarios where the rotation times change, resulting in a different number of plots (i.e., age-cohorts) on the landscape.

5 Evaluation of DECC Scenarios

5.1 Wood Residues

5.1.1 Description of Scenarios and Proposed Sensitivity Analyses

Scenario 4b analyzed the GHG emissions associated with pellets produced from removing coarse woody debris from Pacific Canada, where decay rates are relatively slow for the production of electricity in dedicated biomass electricity facilities in UK. In the counterfactual, the debris is left on the forest site to decay. According to DECC, the use of forest residues for pellets has been limited, mainly because of high transport costs. However, DECC mentions that the pellet industry reports that these resources are expected to be used to a greater extent in the future for pellet manufacture (AEBIOM et al., 2013) but that the lack of homogeneity and predictability of combustion characteristics of the resource might be a barrier. Another barrier could be the use of forest residues domestically, hence reducing the quantity available for export.

Scenario 9 analyzed the GHG emissions associated with pellets produced from salvaged dead trees, which have been killed by the mountain pine beetle in Pacific Canada, for the production of electricity in dedicated biomass electricity facilities in the UK. In Scenario 9a, the counterfactual involved leaving the dead trees in the forest, and in Scenario 9b, removing the dead trees and burning them without recovering the energy. Trees killed from natural disturbances are already used as a feedstock for biomass pellets. According to DECC, there are likely to be significant quantities of this resource available in the future but the annualized volumes within a designated landscape are inconsistent and costly to recover and use.

NCASI's evaluation of the main assumptions pertaining to Scenarios 4b, 9a and 9b is presented in Table 4.

Table 4. NCASI's Review of Main Assumptions Pertaining to Wood Residues Scenarios

Parameter	Model assumption	NCASI evaluation
Scenario 4b		
Decay of residues in forest	Decay rate: 0.028 yr^{-1}.	The decomposition rates of residues are highly variable and depend on characteristics of the residue itself (e.g., wood species and diameter), climate, and other site and management factors. NCASI compiled estimates of the decay rated for coarse woody debris from forests in North America (NCASI 2004, p. 18). Decay rate estimate for western forests were in the range of < 0.003 to 0.231 yr^{-1}, with most estimates in the range of 0.008 to 0.034 yr^{-1} (median was approximately 0.023 yr^{-1}). DECC value is within the range found by NCASI.
	All released into CO_2 i.e., releases of CH_4 are negligible.	Literature is lacking information on the amounts of methane generation from decaying forest residues. In general, as also assumed by DECC, it is assumed that there is no methane releases from residues left to decay in the forest. Note, however, that there are examples in the literature that suggest the potential for methane releases from the decomposition of forest residuals (e.g., Mann and Spath 2001, Pier and Kelly 1997).
Scenario 9		
Decay of dead trees	Decay rate: 0.028 yr^{-1}.	See above.
	All released into CO_2 i.e., releases of CH_4 are negligible.	See above.

Sensitivity analyses for Scenarios 4b and 9 are presented in Table 5.

Where the base case parameter choices are combined with a "0", for instance, analysis 4b-0, the information describes the results for the scenario (e.g., Scenario 4b) under base case conditions i.e., those analyzed by DECC. This nomenclature is applied throughout this document. Note that few sensitivity analyses were performed on Scenario 9 because the effect of different parameters was directionally similar to analyses performed for Scenario 4b.

Table 5. Sensitivity Analyses for Scenarios 4b and 9

<table>
<tr><th rowspan="2">#</th><th rowspan="2">Biomass use</th><th colspan="2">Land use</th><th rowspan="2">Decay rate (yr^{-1})</th><th rowspan="2">Region</th><th rowspan="2">Power grid for pelletizer</th><th rowspan="2">Transport</th></tr>
<tr><th>Bioenergy</th><th>Counterfactual (cfl)</th></tr>
<tr><td colspan="8">Scenario 4b</td></tr>
<tr><td>4b-0</td><td rowspan="8">Coarse woody debris used for dedicated biomass electricity</td><td rowspan="8">Remove woody debris from land in long rotation forestry (LRF)</td><td>Leave residues to decay</td><td>0.028</td><td rowspan="2">Pacific Canada</td><td rowspan="2">Predicted 2020[a]</td><td rowspan="6">Predicted 2020</td></tr>
<tr><td>4b-1</td><td>Remove from land and burn</td><td>N/A</td></tr>
<tr><td>4b-2</td><td rowspan="7">Leave residues to decay</td><td>0.028</td><td>North West US</td><td>Predicted 2020[b]</td></tr>
<tr><td>4b-3</td><td>0.083</td><td>South US</td><td>Predicted 2020[c]</td></tr>
<tr><td>4b-4</td><td>0.034[d]</td><td rowspan="5">Pacific Canada</td><td>Predicted 2020[a]</td></tr>
<tr><td>4b-5</td><td rowspan="4">0.028</td><td>2013[e]</td></tr>
<tr><td>4b-6</td><td rowspan="3">Predicted 2020[a]</td><td>Best case</td></tr>
<tr><td>4b-7</td><td>Worst case</td></tr>
<tr><td>4b-8</td><td>Coarse woody debris used for cofiring</td><td>Remove woody debris from land in LRF</td><td>Predicted 2020</td></tr>
<tr><td colspan="8">Scenario 9</td></tr>
<tr><td>9a-0</td><td rowspan="2">Dead trees used for dedicated biomass electricity</td><td rowspan="2">Remove dead tree from land and allow natural regeneration</td><td>Leave in forest</td><td>0.028</td><td>Pacific Canada</td><td>Predicted 2020[a]</td><td>Predicted 2020</td></tr>
<tr><td>9b-0</td><td>Remove and burn at the roadside</td><td>N/A</td><td>Pacific Canada</td><td>Predicted 2020[a]</td><td>Predicted 2020
N/A</td></tr>
</table>

[a]148 kg CO_2E/MWh. [b]439 kg CO_2E/MWh. [c]439 kg CO_2E/MWh. [d] Higher end of the range for Pacific Canada. [e]180 kg CO_2E/MWh. [f]Frequent natural disturbance means no foregone carbon sequestration while no natural disturbance means maximum foregone carbon sequestration.

5.1.2 Results

The base case as well as sensitivity analyses for Scenarios 4b, 9a and 9b are presented in the next sections.

5.1.2.1 Scenario 4b

Figure 4 shows base case results for Scenario 4b (forest residues from Pacific Canada that would otherwise be left on the forest site to decay). The calculated GHG intensity of biomass electricity is lower than that of energy from coal and exceeds the threshold of 200 kg CO_2E/MWh. The GHG intensity is mainly attributable to emissions from the change in the amount of carbon stored in above-ground biomass for the bioenergy scenario over the time horizon; in this case, foregone carbon storage in residues that were removed. The GHG intensity is lower at 100 years than at 40 years because this change in carbon (i.e., foregone storage) is lower at 100 years than at 40 years.

Table 6 presents results of sensitivity undertaken for Scenario 4b. It can be seen from this table that only two parameters have a significant effect on the results for the use of forest residues in slow decay conditions: 1) assumption regarding the counterfactual, and 2) assumed decay rate.

Assuming that forest residues would be removed from the land and burned anyway is the only case in which forest residues in slow decay conditions present a GHG intensity that is below the threshold.

In cases where the counterfactual would be to leave the forest residues to decay in the forest, the assumed decay rate has significant effect on the calculated GHG intensity. For instance, in the conditions tested in this study, a 21% increase in decay rate would produce a reduction in GHG intensity of 12% over 100 years. However, when testing possible decay rates for slow decay conditions (e.g., Pacific Canada and North West US), faster decay rates are not sufficient to produce GHG intensities below the threshold. Indeed, Figure 45 shows the observed GHG intensity as a function of the assumed decay rate for forest residues left in the forest to decompose. It can be seen that, for the calculated GHG intensity to be equal or lower than the UK DECC threshold, the decay rate needs to be greater than 0.1 yr^{-1}. Although this is within the range of estimated decay rate for western forest reported in a review by NCASI (2004, p. 18), most of the decay rates in the literature reviewed by NCASI were in the range of 0.008 to 0.034 yr^{-1}. Indeed, a decay rate of 0.1 yr^{-1} is higher than the decay rate used by DECC to represent the US South, as well as the values usually used by NCASI for the US South, an area of relatively high decay rates.

Other parameters tested in sensitivity analyses showed marginal effect on the results.

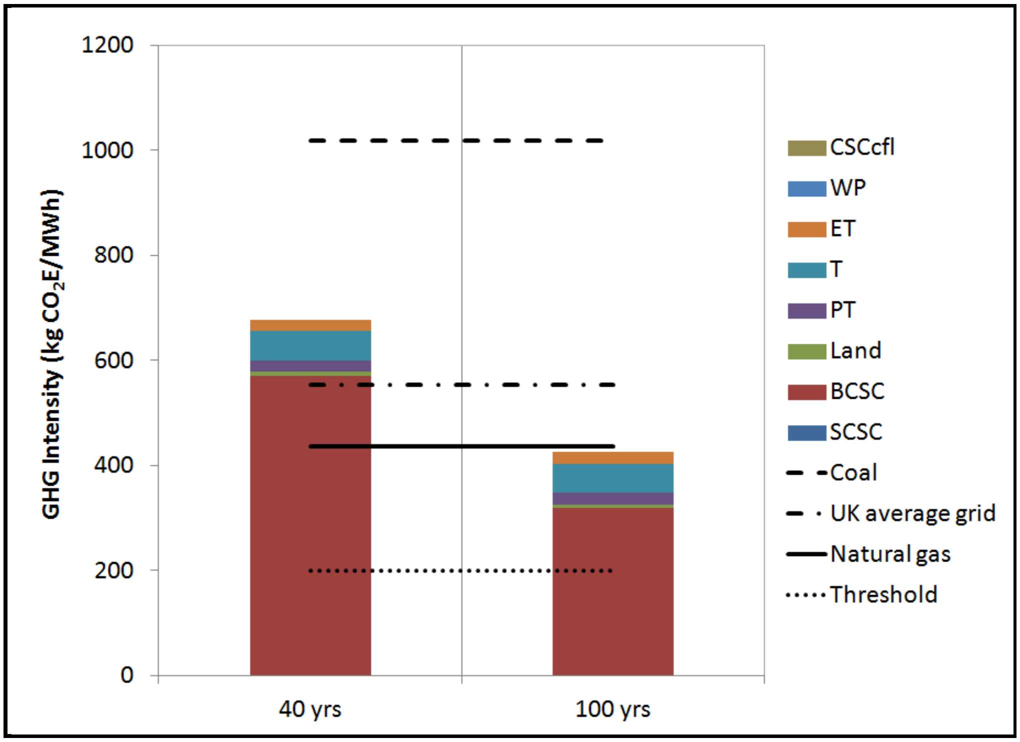

Figure 4. Detailed Base Case Results for Scenario 4b
(Nomenclature is provided in Table 1)

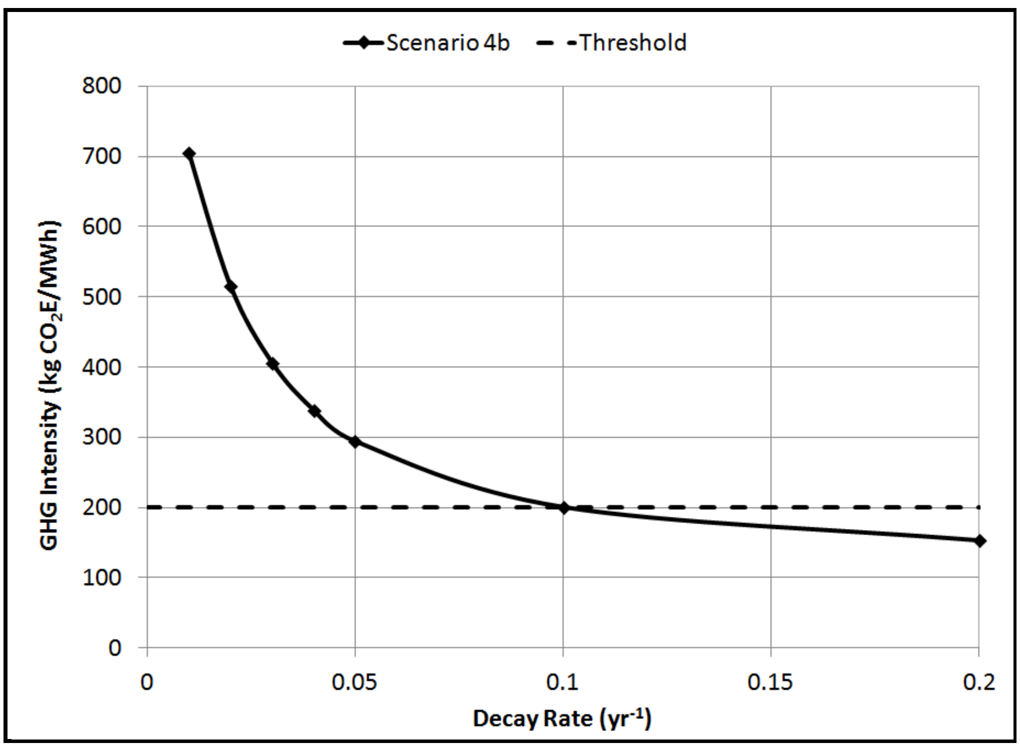

Figure 5. GHG Intensity as a Function of the Assumed Decay Rate for Scenario 4b

Table 6. Sensitivity Analysis Results for Scenario 4b

#	Main characteristic compared to base case	GHG Intensity ($kg\ CO_2E/MWh$)		Explanation of the difference w/ base case
		40 years	100 years	
4b-0	N/A	677	425	N/A
4b-1	cfl is remove from land and burn	0.7	0.7	When the counterfactual involves the removal of residues from the land and burning, the carbon is rapidly returned to the atmosphere both in the bioenergy and counterfactual scenario in contrast to a slower return where it is assumed the residues would be left on the forest floor to decay.
4b-2	Region is North West US	709	457	Pre-treatment emissions are greater for North West US than for Pacific Canada. The reason is the high electricity grid intensity assumed for North West US
4b-3	Region is South US	389	228	Decay rate is higher hence there are higher emissions in the counterfactual.
4b-4	Higher decay rate	625	376	More of the residues would have decayed in the counterfactual scenarios when assuming higher decay rates.
4b-5	Grid intensity 2013	681	428	GHG intensity of electricity used for producing the pellets is slightly higher in 2013 than predicted in 2020.
4b-6	Best case transport	669	417	The effect of transportation scenarios on the results is marginal.
4b-7	Worst case transport	690	437	
4b-8	Cofiring	601	377	Cofiring produces less GHG emissions than dedicated bioelectricity because of greater efficiency in producing the energy and thus more biomass electricity is produced for the same quantity of biomass output.

NOTE: In this table, the sensitivity analyses for which the GHG intensity is above the threshold are shown in light gray.

5.1.2.2 Scenario 9

Base case results for Scenarios 9a and 9b are depicted in Figure 6. Over the long-term, both bioenergy scenarios offer benefits compared to coal, natural gas and UK average grid in 2013, and produce GHG intensities lower than the threshold.

In Scenario 9a, it was assumed that the dead trees would be harvested, after which the land would undergo natural regeneration in the bioenergy scenario and that they would have decayed in the forest in the counterfactual scenario, while the land is naturally regenerated. It was assumed that the increase in the forest carbon stock by natural regeneration would occur at the same rate in both cases. In these conditions, the use of dead trees would meet the GHG intensity threshold in 100 years but not in 40. UK DECC notes that, in reality, future stand development and natural disturbances might be different for a harvested stand of dead trees, and a stand which has been left untreated, which could affect the results.

Surprisingly, although the same decay rate is assumed for beetle-killed trees (9a) as for coarse woody debris (4b), the GHG intensity for using beetle-killed trees is far lower than that of coarse woody debris (40% lower at 40 years and 60% lower at 100 years). It appears that this is because, in the case of forest residues, the counterfactual involves ongoing additions of carbon to residues (every time a plot is harvested) whereas in the case of standing dead wood, there are no additions to stocks of carbon in standing dead wood over time in the counterfactual.

When assuming that wood would be burned at the roadside if not collected for energy production (Scenario 9b), this results in no net emissions.

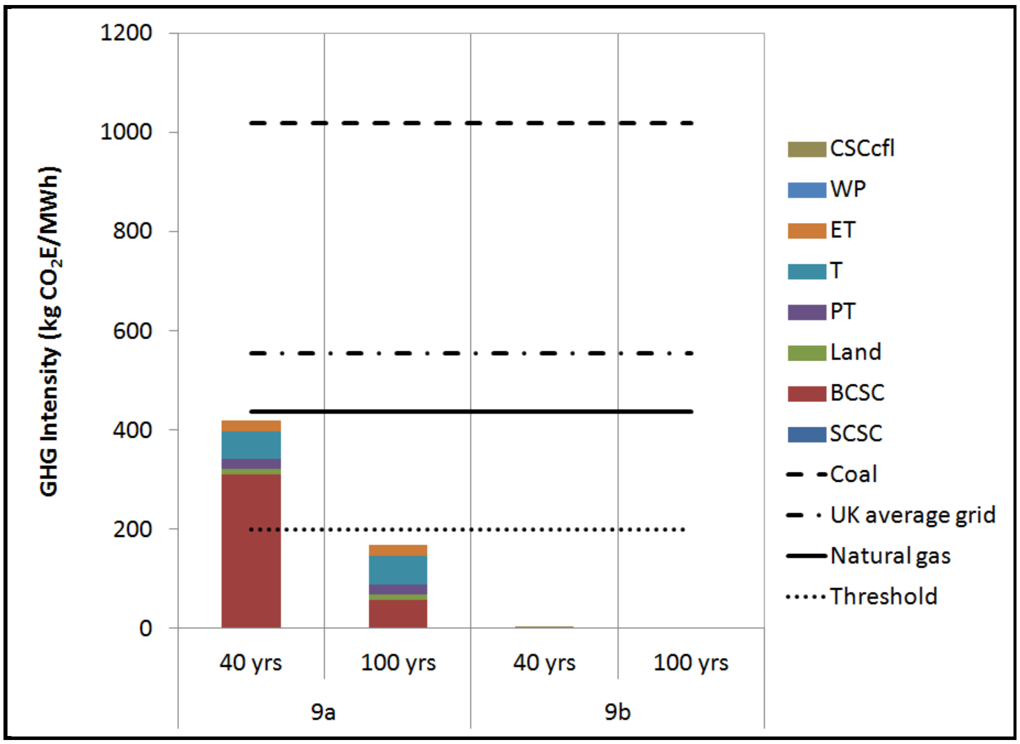

Figure 6. Detailed Base Case Results for Scenario 9
(Nomenclature is provided in Table 1)

5.2 Roundwood from Increased Harvest of Naturally-Regenerated Hardwood Forest

5.2.1 Description of Scenarios and Proposed Sensitivity Analyses

Scenario 13a aims at investigating the impact of increasing the rate of harvest of a naturally-regenerated hardwood (broadleaf) forest, with the counterfactual being leaving the forest under the previous management regime. Additional wood (in comparison to the counterfactual) is generated by increasing the frequency of harvest of a naturally-regenerated hardwood forest in South US from every 70 years to every 60 years. In the counterfactual, harvesting continues to occur every 70 years. Scenario 13b addresses the impact of continuing to harvest a naturally-regenerated hardwood forest in the US every 70 years, with the counterfactual being that the forest would be harvested less frequently. More specifically, additional wood (in comparison to the counterfactual) is generated by continuing harvesting a naturally-regenerated hardwood forest in South US every 70 years assuming that in the counterfactual the rate of harvest would be reduced to every 80 years.

The UK DECC rationale for Scenarios 13a and 13b is that naturally-regenerated hardwood forests are already used to produce biomass feedstocks in South US. These scenarios are intended to represent cases where the demand for pulpwood is stable or increasing. In these cases, additional demand for hardwood pulpwood for pellet production could result in a greater area of hardwood forest being harvested each year in the region in comparison to the counterfactual.

NCASI's evaluation of the main assumptions pertaining to Scenario 13 is presented in Table 7.

Table 7. NCASI Review of Main Assumptions Pertaining to Scenarios on Roundwood from Increased Harvest of Hardwood Naturally-Regenerated Forest (Scenario 13)

Parameter			Model assumption	NCASI evaluation
Type of biomass used for biomass electricity			All additional roundwood, including saw logs	At this time, it is not realistic to assume that all additional roundwood would be used for biomass electricity. A more likely outcome is that large diameter trees would be sold for higher value uses, particularly sawtimber. Also, another limitation affecting NCASI's ability to dissect DECC's calculations is the inability to know exactly how DECC used (or did not) Smith et al. data on the fraction of growing-stock that is saw log size and the composition of the remaining fraction (pulpwood, thinnings, etc.).[a]
Soil organic carbon (SOC)			No difference in SOC between bioenergy scenario and land counterfactual	Highly variable soil C responses to management practices and the difficulty in detecting changes that do occur would seem to support the use of a soil carbon no-change default value unless site- and management-specific response data are available (e.g., Nave et al. 2010, Thiffault et al. 2011).
Average wood production over time horizon	13a	Bio	<u>40 years</u>: 1.668 odt/ha/yr <u>100 years</u>: 1.563 odt/ha/yr	For naturally-regenerated Northeast/North central hardwood[b], the Consortium for Research on Renewable Industrial Materials (CORRIM) reports wood production that vary between 1.62 and 1.76 odt/ha/yr[c] (Oneil et al. 2010). DECC numbers are of the same order of magnitude.
		cfl	1.508 odt/ha/yr	
	13b	Bio	1.508 odt/ha/yr	
		cfl	<u>40 years</u>: 1.365 odt/ha/yr <u>100 years</u>: 1.430 odt/ha/yr	

NOTE: Bio is for bioenergy scenario and cfl for counterfactual scenario.
[a]Sensitivity analysis on the biomass used for biomass electricity has been performed. [b]CORRIM does not report data specific to the Southeast for hardwood. [c]Assuming 624 kg/m^3

Proposed sensitivity analyses for Scenario 13a are presented in Table 8. No further sensitivity analyses were proposed for Scenario 13b because the effect on the results would have been directionally equivalent to that applied to Scenario 13a.

One of the sensitivity analyses performed by NCASI, and listed in Table 8, addresses the assumption that all additional wood is used for energy, regardless of size. Although not addressed in the DECC report, for this scenario the DECC calculator allows examination of emissions under conditions where only small logs are used for energy while larger logs are used for lumber production. Neither the DECC calculator nor the report, however, explain exactly how the Smith et al. 2006 data were used to allocate harvested wood into different size classes or whether/how this calculation captures thinning.

Table 8. Sensitivity Analyses for Scenario 13a

<table>
<tr><th rowspan="2">#</th><th rowspan="2">Use of biomass</th><th colspan="2">Land use</th><th rowspan="2">Growth curve</th><th rowspan="2">Power grid for pelletizer</th><th rowspan="2">Transport</th></tr>
<tr><th>Bioenergy</th><th>Counterfactual (cfl)</th></tr>
<tr><td>13a-0</td><td rowspan="5">All additional wood is used for dedicated bio-electricity</td><td rowspan="6">LRF Broadleaf for wood products and biomass electricity, rotation length reduced to 60y</td><td rowspan="7">LRF Broadleaf for wood products, rotation length remains at 70y, residues unused</td><td rowspan="4">Oak-Hickory</td><td>Predicted 2020[a]</td><td rowspan="2">Predicted 2020</td></tr>
<tr><td>13a-1</td><td>2013[b]</td></tr>
<tr><td>13a-2</td><td rowspan="5">Predicted 2020[a]</td><td>Best case</td></tr>
<tr><td>13a-3</td><td>Worst case</td></tr>
<tr><td>13a-4</td><td>Oak-Gum-Cypress</td><td rowspan="3">Predicted 2020</td></tr>
<tr><td>13a-5</td><td>All additional wood is used for cofiring</td><td rowspan="2">Oak-Hickory</td></tr>
<tr><td>13a-6</td><td>All additional small logs used for bioelectricity. Largeer logs to construction (window frame).</td><td>LRF Broadleaf, for wood products and biomass electricity, rotation length reduced to 60y, additional large logs to construction, remainder to biomass electricity</td></tr>
</table>

[a]439 kg CO_2E/MWh. [b]520 kg CO_2E/MWh.

5.2.2 Results

Base case results for Scenarios 13a and 13b are depicted in Figure 7. Scenario 13 assumes that a potential consequence of increased demand for biomass electricity is that forests are harvested more frequently in comparison to the counterfactual, meaning that a greater area of forest is harvested each year. The main effect is to reduce the non-soil carbon stored in the forest in a way that would make the calculated GHG intensity significantly above the threshold, and greater than coal. This is depicted in Figure 7 by the large bars that can be seen under "BCSC" and "CSCcfl", for Scenarios 13a and 13b, respectively. For Scenario 13a, the observed difference is greater at 100 years than at 40 years. This mostly can be explained by the fact that bigger trees are harvested until the transition between rotation lengths is completed, and hence the carbon impacts are distributed across a greater amount of biomass electricity. This phenomenon is not observed in Scenario 13b because the rotation length is increased in the absence of the additional demand for wood.

Results depicted in Figure 7 also show that assuming that the demand for biomass electricity would cause the rotation length to drop to 60 years in the bioenergy scenario compared to 70 years in the counterfactual would have higher net emissions than assuming that the bioenergy scenario could be achieved using a 70-year rotation with a counterfactual assumption that the rotation cycle would extend to 80 years. This is likely due to the fact that growth between 60 and 70 years (12% increase in non-soil C stocks for Oak-Hickory stands according to Smith et al. 2006) is greater than the growth between 70 and 80 years (9% according to Smith et al. 2006). The shapes of the Smith et al. growth curves between 60 and 80 years (see Appendix 2 below) for Oak-Gum-Cypress stands suggest that the difference between 13a and 13b would be somewhat greater for Oak-Gum-Cypress than shown in Figure 5 for Oak-Hickory stands, while the curves for Oak-Pine stands suggest a smaller difference between Scenarios 13a and 13b than shown in Figure 5. Also, the specific method used to model the landscape could conceivably affect calculations involving changes to rotation time, but NCASI was unable to discern the details of how such scenarios were modeled by DECC and was therefore unable to examine this possible effect.

The results discussed above assume that changing the rotation length as no effect on soil carbon. However, DECC highlights that some authors have shown that reduced rotation length is sometimes associated with lower soil carbon. This would have the effect of elevating the results of Scenario 13 even higher above the threshold.

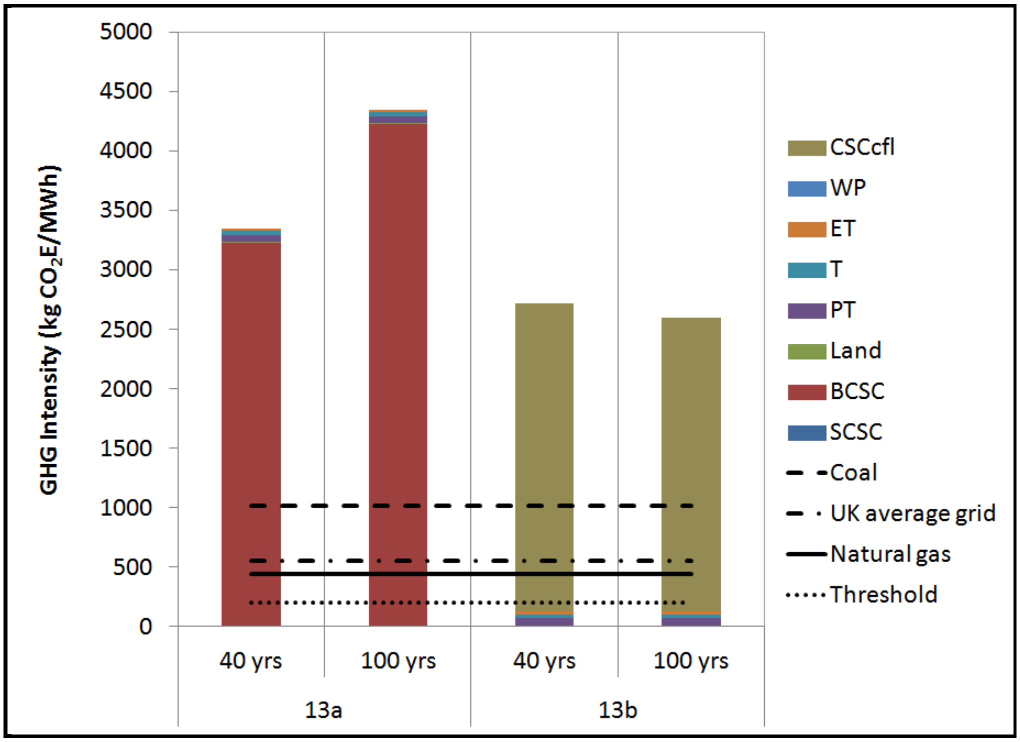

Figure 7. Detailed Base Case Results for Scenario 13
(Nomenclature is provided in Table 1)

Sensitivity analysis results for Scenario 13 are presented in Table 10. It can be seen from the results presented in this table that the calculated GHG intensity from using wood derived from increasing the rate of harvest of a naturally-regenerated hardwood (broadleaf) forest with the counterfactual being leaving the forest under the previous management regime for biomass electricity production is always above the threshold, at least for the parameters tested here.

DECC assumed that all additional wood from increasing the rate of harvest of a naturally-regenerated hardwood (broadleaf) forest, regardless of size, would be used for energy. Instead, one could assume that only smaller logs would be used for energy and that larger logs would be used for lumber production. Sensitivity analysis#13a-6 shows the effect of this alternative assumption on the calculated results. It is shown in Table 10 that analysis #13a-6 produces higher GHG intensity than #13a-0 where all additional wood is used for biomass electricity. This is because in the DECC calculator the change in non-soil carbon stocks caused by the increased harvest is distributed to a lesser quantity of energy in 13a-6 (same change of carbon stocks, same quantity of biomass output, but less biomass used for biomass electricity). This is further discussed below. Note that some benefits from substituting PVC window frames with wood are observed as depicted in Figure 8 by "WP".

Table 9. Sensitivity Analysis Results for Scenario 13

#	Main characteristic compared to base case	GHG Intensity ($kg\ CO_2E/MWh$)		Explanation of the difference w/ base case
		40 years	100 years	
13a-0	N/A	3346	4348	Difference between 13a-0 and 13b-0 is that in the first case the rotation goes from 70 years in the cfl to 60 years in the bioenergy scenario while in the second case, it is assumed that 70 years is appropriate for biomass electricity production but that in the cfl the rotation would increase to 80 years. The difference in results is mostly dependent on the difference in carbon stocks assumed for different rotation lengths.
13b-0	N/A	2717	2594	
13a-1	Grid intensity 2013	3356	4358	GHG intensity of electricity used for producing the pellets is slightly higher in 2013 than predicted in 2020.
13a-2	Best case transport	3340	4343	The effect of transportation scenarios on the results is marginal.
13a-3	Worst case transport	3353	4354	
13a-4	Cofiring	2969	3858	Cofiring produces lower GHG emissions than dedicated biomass electricity because of greater efficiency in producing the energy and thus more electricity is produced for the same quantity of biomass.
13a-5	Only small logs used for biomass electricity, large logs used for construction	4116	5996	Despite the fact that in analysis 13a-7, large logs are used to substitute for steel window frames, this is not enough to offset a greater reduction in non-soil carbon stocks per unit of energy than in the base case. The reason is that the change in carbon stocks is fully allocated to the biomass electricity demand, meaning that the same quantity of change in carbon stocks is distributed across a smaller quantity of biomass electricity output.

NOTE: In this table, the sensitivity analyses for which the GHG intensity is above the threshold are shown in light gray.

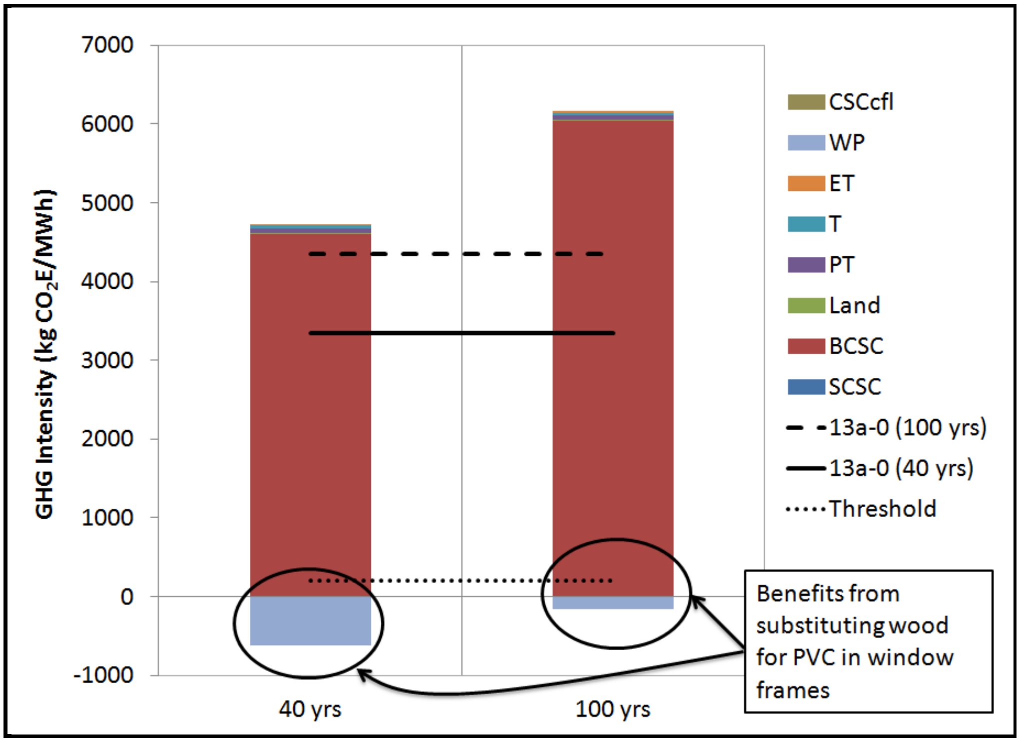

Figure 8. Detailed Results for Analysis 13a-5
(Nomenclature is provided in Table 1)

As mentioned above and depicted in Table 10, assuming that less wood is available for biomass electricity, given a fixed amount of wood harvested, and assigning the entire stock change to biomass electricity, results in more carbon stock change to be attributed to each unit of energy. This is an artifact of the methodology employed by DECC. The methodology reflects DECC's decision to credit the biomass electricity system with substitution benefits associated with using some of the wood for construction materials. In other words, both the substitution benefits of the wood used for construction as well as the loss of carbon stocks associated with this wood are attributed to the biomass electricity system. Conceptually, however, this approach makes sense only if it can be assumed that the biomass electricity demand is responsible for the increased harvesting of the land and additional wood for construction is a side effect of this demand. In the case where demand for both biomass electricity and wood products are responsible for the increased harvesting, a different approach would be required. Indeed, it would necessary to allocate (i.e., distribute) the change in carbon stocks between the biomass electricity and construction products. Several methods exist to do so, from which the most straightforward would be to perform this allocation based on the mass of feedstock used in both type of products. The results of applying such an allocation approach are included in Table 10. Using this approach, the biomass electricity would not be granted any of the benefits from wood product substitution but would also not be responsible for the carbon impacts of harvesting wood destined for construction materials. It can be seen from the results in Table 10 that if allocation was based on mass, the smaller logs used for energy would have similar GHG intensity to the wood in the scenario where all additional wood is used for energy. If allocation was based on economic value, it is likely that wood used for energy would have a lower GHG intensity where the only wood used is that not suited for use in saw mills because, at this time, the economic value of wood used in biomass electricity is significantly lower than that of wood used to produce lumber.

Table 10. Explanation of the Differences between 13a-0 and 13a-6 (40-Year Timeframe)

	Unit	BEaC method		Allocation method	
		13a-0	**13a-6**	**13a-0**	**13a-6**
Total additional biomass output	odt/ha/yr	0.160	0.160	0.160	0.160
Additional biomass output used for biomass electricity	odt/ha/yr	0.160	0.112	0.160	0.112
Additional biomass output used for construction	odt/ha/yr	0	0.048	0	0.048
Biomass electricity produced	MWh/ha/yr	0.26	0.18	0.26	0.18
Total change in non-soil carbon stocks	t CO_2/ha/yr	0.85	0.85	0.85	0.85
Total change in non-soil carbon stocks allocated to biomass electricity	t CO_2/ha/yr	0.85	0.85	0.85	0.59
Total change in non-soil carbon stocks per unit of biomass electricity	kg CO_2/MWh	3223	4605	3223	3223
Benefits from wood product substitution attributed to biomass electricity	kg CO_2/MWh	0	-615	0	0
Other GHG impacts	kg CO_2/MWh	122	126	122	126
Observed GHG intensity	kg CO_2/MWh	3345	4116	3345	3349

NOTES: Numbers from this table were rounded from numbers obtained directly from the BEaC Calculator. Gray cells illustrate the main difference between the BEaC method and allocation method.

5.2.3 Additional Aspects of Concern not Tested in Sensitivity Analysis

Naturally-regenerated hardwood forests were modeled based on the growth curves for Southeastern US Oak-Hickory forests. Other curves could have been used, for instance Smith et al. derived growth curves for Oak-Gum-Cypress. Because the GHG intensities are almost entirely driven by the difference in carbon stocks, the chosen curves can have a potentially significant effect on the results. For instance, the difference in carbon stocks between 70 and 60 years for Oak-Hickory forests in Smith et al. is -11% while the difference for Oak-Gum-Cypress is -13%. This indicates that selecting the Oak-Gum-Cypress curves would have given higher (worse) GHG intensities. Another choice would have given a different result.

In addition, NCASI identified a methodological issue with how the pairs of bioenergy and counterfactual scenarios were defined by DECC to represent an increase in wood demand related to the use of roundwood where it was assumed that increased demand would be met through a significant reduction in rotation length. Questions have been raised by the industry and other researchers as to whether this assumption is realistic. In particular, it has been observed that focusing on simplistic rotation length scenarios fails to address the dynamic nature of landowner responses across a region when there is an increase in demand for wood. Examining such simplistic scenarios is a reasonable starting place for generating hypotheses on the important factors to consider in modeling the impacts of increased demand, but it does not capture the effects of landowner responses to increased demand because these responses are dynamic and interactive over space and time.

5.3 Roundwood from Existing Intensively-Managed Pine Plantations

5.3.1 Description of Scenarios and Proposed Sensitivity Analyses

Scenario 14 focuses on the impacts of using additional wood from intensively-managed pine plantations in the US South for the production of wood pellets. Additional wood (in comparison to the counterfactual) is obtained from intensively-managed pine plantations in the US South. Scenario 14a assumes that wood continues to be harvested every 25 years, and Scenario 14b that the increased demand for pulpwood results in the rotation time being reduced to 20 years. Other than harvesting frequency, forest management intensity and productivity are assumed to be unchanged. For both cases, the counterfactual assumes a reduction of the frequency of harvest (i.e., an increase in rotation time) from 25 to 35 years. Scenario 14 is meant to represent conditions in which the regional demand for roundwood is low and hence, wood from some plantations could be harvested for biomass electricity, without impacting other markets. It is assumed that without demand for wood for pellets, less biomass would be harvested, and more biomass would be stored in the above-ground biomass of the forest. This scenario is intended to reflect the situation following the recession, where fewer trees were cut, and the forest inventory increased. According to DECC, this scenario could also represent a case where initiatives encourage forest owners to extend their rotation time, in order to increase carbon storage.

Given that DECC intends this scenario to reflect the situation following the recession, it could be important to note that (a) roundwood suitable for energy production is more likely of pulpwood size than saw timber or chip-n-saw size, and (b) while lumber production in the four years following 2008 was 35% below that in the four years before 2008, pulp production was only 8% lower (AF&PA 2012 and 2007 statistics reports and FAOSTAT data at www.faostat3.fao.org). Indeed, DECC created the following scenario (18) to address the fact that despite the recession, pulpwood demand remains strong.

Scenario 18 also focuses on the impacts of using wood from plantations in the US South for the production of wood pellets. In this case, however, it is assumed that before additional demand is applied, these plantations are managed at medium-intensity and that the increase in demand causes the management intensity to increase. More specifically, it is assumed that the overall yield increases by 35%, achieving 74% of the yield of an intensively-managed plantation. This is accomplished by more intensive management of medium-intensity plantations, assuming that this increase in intensity would be applied to those plantations that are not currently managed optimally. The additional wood (in comparison to the counterfactual) is obtained from increasing the management intensity of a pine plantation in the US South that is harvested every 25 years (e.g., adopting optimal thinning practices[4] and increasing initial planting densities) and the

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[4] Although thinning practices are identified as a management tool, DECC does not indicate whether or how the timing or quantity of thinnings influenced the calculation of net GHG emissions.

counterfactual scenario involves continuing the previous management regime (medium-intensity management practices, harvested every 25 years). In both cases, all of the additional wood is used for biomass electricity. DECC intends Scenario 18 to apply in cases where the regional demand for roundwood for other uses is high and landowners respond by producing more wood from the plantations in order to meet both historic and new demands. DECC argues that Scenario 18 is more likely than Scenario 14 because the removal of softwood pulpwood in US South increased between the years 2000 and 2009 and competition is high (with prices increasing).

NCASI's evaluation of the main assumptions pertaining to Scenarios 14 and 18 is presented in Table 11.

Table 11. NCASI Review of Main Assumptions Pertaining to Scenarios on Roundwood from Existing Intensively-Managed Pine Plantation

Parameter	Model assumption	NCASI Evaluation
General		
Biomass used for biomass electricity	All additional roundwood, including large saw logs	At this time, it is not realistic to assume that all additional roundwood would be used for biomass electricity. A more likely outcome is that large diameter trees would be sold for higher value uses, particularly lumber production. Also, another limitation affecting NCASI's ability to dissect DECC's calculations is the inability to know exactly how DECC used (or did not) Smith et al. data on the fraction of growing-stock that is saw log size and the composition of the remaining fraction (pulpwood, thinnings, etc.).[a]
Soil carbon stocks	No difference in SOC between bioenergy scenario and land counterfactual	Highly variable soil C responses to management practices and the difficulty in detecting changes that do occur would seem to support the use of a soil carbon no-change default value unless site- and management-specific response data are available (e.g., Nave et al. 2010, Thiffault et al. 2011).
Fuel consumption pre-harvest	Medium intensity: 168 L diesel/ha High intensity: 421 L diesel/ha	CORRIM reports the following fuel consumptions (Puettmann et al. 2013a): Medium intensity: 132 L diesel/ha; and High intensity: 272 L diesel/ha. DECC's values are higher than CORRIM's.[b]
Fuel consumption at harvest	3.42 L diesel/odt of wood harvested	CORRIM reports approximately 5.75 L diesel/odt[b] for harvesting (Puettmann et al. 2013a). DECC values are lower than CORRIM's.[c]

(Continued on next page. Notes at the end of table.)

Table 11. (Cont'd)

Parameter			Model assumption	NCASI Evaluation
Scenario 14				
Fertilizer			Medium intensity: 54.6 kg P/ha and 191 kg N/ha over the rotation High intensity: Application of 54.7 kg P/ha at planting, then 27.3 kg P/ha and 191 kg N/ha at ages 7, 14 and 21 years; that is 136 kg P/ha and 573 kg N/ha over the rotation	CORRIM reports the following fertilizer consumption over the rotation (Puettmann et al. 2013a): Medium intensity: 72.9 kg P/ha and 265 kg N/ha; and High intensity: 129 kg P/ha and 713 kg N/ha. At medium intensity, P and N values from DECC are higher than CORRIM's; at high intensity, N value used by DECC is lower than CORRIM's.[d]
Average wood production over time horizon	14a	Bio	40 years: 5.913 odt/ha/yr 100 years: 5.913 odt/ha/yr	CORRIM reports the following average wood production for medium and high management intensities for Southeast forests (Puettmann et al. 2013a, 25-year rotation): Medium intensity: 4.86 odt/ha/yr; and High intensity: 6.58 odt/ha/yr. Yields assumed by DECC are lower than CORRIM's.[e]
		cfl	40 years: 4.608 odt/ha/yr 100 years: 4.669 odt/ha/yr	
	14b	Bio	40 years: 6.188 odt/ha/yr 100 years: 5.917 odt/ha/yr	
		cfl	40 years: 4.608 odt/ha/yr 100 years: 4.669 odt/ha/yr	
Scenario 18				
Yield			Loblolly pine plantation, managed to a medium-intensity, achieving 74% of the yield of an intensively-managed plantation	DECC did not justify the 74%. Different increase in yield will lead to different results.
Average wood production over time horizon		Bio	40 years: 4.949 odt/ha/yr 100 years: 5.528 odt/ha/yr	See above.
		cfl	40 years: 4.371 odt/ha/yr 100 years: 4.371 odt/ha/yr	

NOTE: Bio is for bioenergy scenario and cfl for counterfactual scenario.
[a]NCASI was unable to perform a sensitivity analysis on this using the BEAC calculator. [b]Pre-harvest fuel consumption for medium and high intensities were tested in sensitivity analyses. [c]Harvesting fuel consumption were tested in a sensitivity analyses. [d]N fertilizer quantities were tested in sensitivity analyses. [e]Yields were tested in sensitivity analyses.

Sensitivity analyses for Scenario 14 are presented in Table 12. When a given analysis was expected to have a similar effect in multiple scenarios, it was undertaken only once. No sensitivity analysis was performed on Scenario 18 because change in parameters was either expected to (1) have marginal effect on the results, (2) have an effect similar to that observed for Scenario 14, (3) deemed reasonable as proposed, or (4) not possible. In fact, in itself, Scenario 18 could be seen as a variation of Scenario 14.

Table 12. Sensitivity Analyses for Scenarios 14 and 18

#	Use of the biomass	Land use: Bioenergy	Land use: Counterfactual	Yield (Bio)	Fertilizer (Bio)[1]	Pre-harvest fuel	Harvest fuel
Scenario 14							
14a-0	All additional wood is used for dedicated bioelectricity	Intensely managed SRF Conifer, rotation time remains at 25 years	Intensely managed SRF Conifer, rotation time increasing from 25 to 35 years	5.91 odt/ha/yr	22.97 kg N/ha/yr	421 L diesel/ha	3.42 L diesel/odt
14a-1			Intensely managed SRF Conifer, rotation time increasing from 25 to 35 years (for a period of 15 years, then wood extraction increases				
14a-2			Intensely managed SRF Conifer, "about to be managed less intensively as natural Loblolly stand"[2]				
14a-3			Intensely managed SRF Conifer, about to be harvested then left to regenerate naturally, without future harvesting				
14a-4			Intensely managed SRF Conifer, rotation time increasing from 25 to 35 years	6.58 odt/ha/yr			
14a-5				5.91 odt/ha/yr	28.6 kg N/ha/yr		
14a-6					22.97 kg N/ha/yr	272 L diesel/ha	
14a-7						421 L diesel/ha	5.75 L diesel/odt
14a-8	All additional wood is used in cofiring	Intensely managed SRF Conifer, rotation time remains at 25 years					3.42 L diesel/odt

(Continued on next page. Notes at the end of table.)

Table 12. (Cont'd)

#	Use of the biomass	Land use		Yield (Bio)	Fertilizer[1]	Pre-harvest fuel	Harvest fuel
		Bioenergy	Counterfactual				
Scenario 14 (Cont'd)							
14b-0	All additional wood is used for dedicated bioelectricity	Intensely managed SRF Conifer, rotation length reduced from 25 to 20 years	Intensely managed SRF Conifer, rotation time increasing from 25 to 35 years	40 years: 6.188 odt/ha/yr 100 years: 5.917 odt/ha/yr	22.97 kg N/ha/yr	421 L diesel/ha	3.42 L diesel/odt
14b-1			Intensely managed SRF Conifer, rotation time increasing from 25 to 35 years (for a period of 15 years, then wood extraction increases)				
14b-2			Intensely managed SRF Conifer, about to be managed less intensively as natural Loblolly stand				
14b-3			Intensely managed SRF Conifer, about to be harvested then left to regenerate naturally, without future harvesting				
14b-4			Intensely managed SRF Conifer, rotation time increasing from 25 to 35 years	40 years: 6.58 odt/ha/yr 100 years: 6.58 odt/ha/yr			
Scenario 18							
18-0	All additional wood is used for dedicated bioelectricity	SRF Conifer, increased management intensity, 25-year rotation	Medium intensity managed SRF Conifer, rotation time 25 years	40 years: 4.949 odt/ha/yr 100 years: 5.528 odt/ha/yr	18.19kg N/ ha/yr	421 L diesel/ha	3.42 L diesel/odt

NOTE: Bio is for bioenergy scenario. SRF is for short rotation forestry.
[1]Not considering any change in yields, which were addressed separately. [2]The actual meaning of this scenario is not defined in the study.

5.3.2 Results

Detailed results for Scenarios 14a, 14b and 18 are presented in Figure 9.

In the case of Scenario 14, over 100 years, biomass electricity produces net emissions comparable to, or somewhat above, the UK average grid in 2013, and the life cycle emissions always exceed the 200 kg CO_2E/MWh threshold. At 40 years, the net emissions are even higher. The high net emissions are due to assumptions that, in the absence of harvesting for biomass electricity, rotation times are longer while yields are unchanged, and that carbon stocks are higher in less frequently disturbed forests.

If the demand for wood for energy causes medium-intensity plantations to be managed more intensively (Scenario 18), with the yield increasing by 35% (which, it is assumed, would not happen otherwise), and the time between harvests stays at 25 years, the produced biomass electricity would have a GHG intensity of less than zero (over time horizons of 40 and 100 years, respectively, using the default key parameters). The calculated GHG intensity is lower at 40 years than at 100 years because to produce 35% more wood on the same rotation, more biomass is needed on the land every year, compared to the counterfactual. As a result, during the conversion of the landscape to higher yield, there is get a gradual, but one-time increase in the carbon stocks on the landscape. If this one-time increase were spread over a longer time (and over more MWh) its impact would diminish.

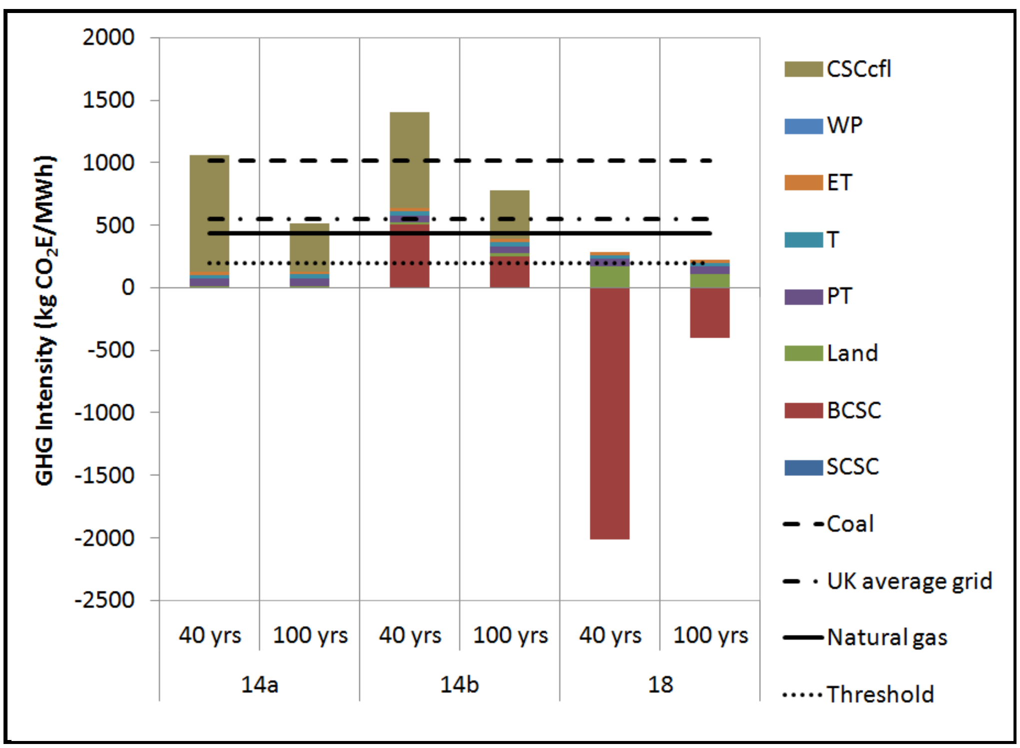

Figure 9. Detailed Base Case Results for Scenarios 14 and 18 (Nomenclature is provided in Table 1)

Sensitivity analysis results for Scenarios 14 and 18 are presented in Table 13. It can been seen from this table that the GHG intensity of using additional wood from intensively-managed pine plantations in the US South for the production of energy is highly dependent on the assumptions made regarding the counterfactual scenario. For instance, in the case where the counterfactual involves trees being harvested less frequently than in the bioenergy scenario (e.g., 14a-0), the GHG intensity is higher than that of the DECC threshold. However, in sensitivity analyses where the counterfactual involves converting an intensively-managed pine plantation to natural regeneration with trees growing more slowly in the future than in the bioenergy scenario (e.g., 14a-2 and 14a-3), the GHG intensity is much lower in the short-term, even lower than the DECC threshold. In these cases, the GHG intensity increases over time as the slower-growing trees grow back in the counterfactual because the naturally-regenerated forest is assumed to eventually grow to carbon stocks that exceed the stocks in the managed forest.

Another observation is that assumptions on yield have significant effects on the results. Indeed, an increase in yield of approximately 10% (sensitivity analyses 14a-4 and 14b-4) reduces the GHG intensity by approximately 20 to 30%. Other parameters have a low-to-marginal effect on the results.

Scenarios 14 and 18 assume that all additional wood, including saw logs, is used for energy. The sensitivity analyses on Scenario 13 above (13-6) showed that using only smaller diameter logs for energy gives significantly greater GHG intensities assuming large logs would displace non-wood products and allocating all the carbon impact to biomass electricity (i.e., the method used in the BEAC calculator). As discussed above, other allocation methods give different results. One could expect a similar effect for Scenarios 14 and 18; however, it was not possible to test this choice within the calculator.

In addition, as discussed above for Scenario 13, it was assumed by DECC that increased demand would be met through a significant reduction in rotation length. Focusing on simplistic rotation length scenarios fails to address the dynamic nature of landowner responses across a region when there is an increase in demand for wood.

Table 13. Sensitivity Analysis Results for Scenarios 14 and 18

#	Main characteristic compared to base case	GHG Intensity ($kg\ CO_2E/MWh$)		Explanation of the difference w/ base case (14a-x compared with 14a-0, 14b-x compared with 14b-0, 18-0 compared with 14a-0)
		40 years	100 years	
Scenario 14				
14a-0	N/A	1059	518	N/A.
14b-0	N/A	1406	777	Compared to 14a-0, 14b-0 involves shorter rotation and hence less carbon stock per hectare.
14a-1	After 15 years, wood extraction increases in the cfl as well	668	245	Assuming that wood extraction would also increase in the cfl reduces the difference in carbon stocks between the bioenergy and cfl scenarios.
14b-1		1465	1701	
14a-2	Cfl involves less intensively-managed forestry	-178	86.2	Assuming a counterfactual in which the trees regrow more slowly results in carbon benefits in the short term from an intensively-managed plantation.
14b-2		461	202	
14a-3	Cfl involves harvest followed by natural regeneration, without future harvesting	44.3	488	Assuming a counterfactual in which the trees regrow more slowly results in carbon benefits in the short-term from an intensively-managed plantation.
14b-3		375	561	
14a-4	Increase in yield	739	376	Higher yield means more wood obtained from the same land can be used for biomass electricity and thus, the changes in carbon stocks are spread across more MWh.
14b-4		1145	547	
14a-5	Increase in N fertilizer usage	1091	552	Marginal effect, higher emissions from producing the fertilizer
14a-6	Decrease in pre-harvest fuel consumption	1056	515	Marginal effect, lower emissions from fuel production and combustion
14a-7	Increase in harvest fuel consumption	1063	522	Marginal effect, higher emissions from fuel production and combustion
14a-8	Cofiring	939	460	Cofiring produces lower GHG emissions than does dedicated biomass electricity because of greater efficiency in producing the energy and thus more biomass electricity is produced for the same quantity of biomass.
18-0	N/A	-1730	-179	Compared to 14a-0: Higher management intensity means more biomass per hectare, and hence more electricity is produced, despite the same change in carbon stocks. Therefore the carbon stock change is spread across a greater quantity of electricity. Since rotation age is unchanged, it also means that there is more carbon on the landscape when yield is increased.

NOTE: In this table, the sensitivity analyses for which the GHG intensity is above the threshold are shown in light gray.

5.4 Roundwood from New Pine Plantations Replacing Naturally-Regenerated Forests

5.4.1 Description of Scenarios and Proposed Sensitivity Analyses

Scenario 22 focuses on additional wood obtained from new intensively-managed pine plantations established on naturally-regenerated coniferous forest in the US South. The original forest types were chosen by UK DECC to represent typical productive naturally-regenerated timberlands in the US South, which are already harvested regularly. DECC assumed that the naturally-regenerated forest was harvested every 50 years. After conversion, the intensively-managed pine plantation is harvested every 25 years in Scenario 22a, and every 20 years in Scenario 22b. In both cases, the counterfactual consists of ccontinuing to harvest every 50 years followed by natural regeneration. DECC justifies these scenarios by observing that the increased demand for wood for biomass electricity could result in the establishment of new plantations. DECC indicates that this is consistent with USDA projections suggesting that increased demand for biomass for energy in the future could result in increased areas of pine plantations in the US South, often displacing natural pine forests. During the period 1990 to 2010, the area of plantations in this region increased by approximately by 40%.

At the request of the Operating Committee, NCASI has also examined a scenario where pine plantations are established on land previously occupied by naturally regenerating hardwood forests harvested every 70 years to produce wood products. This was performed by modifying Scenario 22 in the BEaC calculator.

NCASI's evaluation of the main assumptions pertaining to Scenario 22 is presented in Table 14.

Table 14. NCASI Review of Main Assumptions Pertaining to Scenarios on Roundwood from New Pine Plantations Replacing Naturally-Regenerated Forests

Parameter			Model assumption	NCASI evaluation
Scenario 22				
Biomass used for biomass electricity			All additional roundwood, including large logs	At this time, it is not realistic to assume that all additional roundwood would be used for biomass electricity. A more likely outcome is that large diameter trees would be sold for higher value uses, particularly lumber production. Also, another limitation affecting NCASI's ability to dissect DECC's calculations is the inability to know exactly how DECC used (or did not) Smith et al. data on the fraction of growing-stock that is useable for lumber and the composition of the remaining fraction (pulpwood, thinning, etc.).[a]
Soil carbon stocks			No difference in SOC between bioenergy scenario and land counterfactual	Highly variable soil C responses to management practices and the difficulty in detecting changes that do occur would seem to support the use of a soil carbon no-change default value unless site- and management-specific response data are available (e.g., Nave et al. 2010, Thiffault et al. 2011).
Fuel and fertilizer consumption for pine plantations			See Table 11.	
Average wood production over time horizon	22a	Bio	40 years: 3.771 odt/ha/yr 100 years: 5.056 odt/ha/yr	CORRIM reports the following average wood production (Oneil et al. 2010, Puettmann et al. 2013a): Intensively-managed pine plantations: 6.58 odt/ha/yr (25-year rotation); and Naturally-regenerated hardwood forests: 1.62 and 1.76 odt/ha/yr[c]. IPCC (2006) reports between 2 and 7 odt/ha/yr for naturally subtropical humid forest. Yield assumed by DECC are lower than CORRIM's and IPCC's.[d]
		cfl	40 years: 1.795 odt/ha/yr 100 years: 1.795 odt/ha/yr	
	22b	Bio	40 years: 4.281 odt/ha/yr 100 years: 5.157 odt/ha/yr	
		cfl	40 years: 1.795 odt/ha/yr 100 years: 1.795 odt/ha/yr	
	22a-1[b]	Bio	40 years: 3.742 odt/ha/yr 100 years: 5.045 odt/ha/yr	
		cfl	40 years: 1.508 odt/ha/yr 100 years: 1.508 odt/ha/yr	
	22b-1[b]	Bio	40 years: 4.278 odt/ha/yr 100 years: 5.156 odt/ha/yr	
		cfl	40 years: 1.508 odt/ha/yr 100 years: 1.508 odt/ha/yr	

NOTE: Bio is for bioenergy scenario and cfl for counterfactual scenario.
[a]NCASI was unable to perform a sensitivity analysis on that using the BEAC calculator. [b]Scenario 22 modified so the counterfactual is naturally-regenerated hardwood forests (see below) and this table provides DECC assumptions given this modification. [c]Data for Northeast/Northcentral, assuming 624 kg/m^3 (Bergman and Bowe 2010). [d]Yields were tested in sensitivity analyses.

Proposed sensitivity analyses for Scenario 14 are presented in Table 15.

Table 15. Sensitivity Analyses for Scenario 22

#	Use of biomass	Land use		Yield (Bio, 100 years)[a]
		Bioenergy	**Counterfactual**	
22a-0	All additional wood is used for dedicated bioelectricity	Conversion of LRF Conifer to intensively-managed SRF plantation, 25-year rotation	LRF Conifer for wood products, residues unused	5.056 odt/ha/yr
22a-1		Conversion of LRF Broadleaf to intensively-managed SRF plantation, 25-year rotation	LRF Broadleaf for wood products, residues unused	5.045 odt/ha/yr
22a-2		Conversion of LRF Conifer to intensively-managed SRF plantation, 25-year rotation	LRF Conifer for wood products, residues unused	5.97 odt/ha/yr[b]
22a-3	All additional wood is used in cofiring			5.056 odt/ha/yr
22b-0	All additional wood is used for dedicated bioelectricity	Conversion of LRF Conifer to intensively-managed SRF plantation, 20-year rotation	LRF Conifer for wood products, residues unused	5.157 odt/ha/yr
22b-1		Conversion of LRF Broadleaf to intensively-managed SRF plantation, 20-year rotation	LRF Broadleaf for wood products, residues unused	5.156 odt/ha/yr

NOTE: Bio is for bioenergy scenario. [a]Except when noted otherwise, all yields are from the BEAC calculator. [b]Assuming 40 years at 5.045 odt/ha/yr (from DECC) and 60 years at 6.48 odt/ha/yr (from CORRIM).

5.4.2 Results

Detailed results for Scenarios 22a and 22b are presented in Figure 10. For the case of converting a naturally-regenerated Loblolly Pine forest that is harvested every 50 years, to an intensively-managed plantation that is harvested every 25 years (22a), the carbon accumulations curves used by DECC (i.e., Smith et al. 2006) suggest that carbon stored in the forest can increase, resulting in a GHG intensity of the produced biomass electricity of less than zero. However, if the forest is converted to a plantation that is harvested every 20 years (22b), the GHG intensities are shown to be significantly greater than zero but generally lower than those of fossil fuels. In the case of the 20-year rotation, the full 100 years is required to fall below the 200 kg CO_2E/MWh threshold. The apparent reason for the 20-year rotation looking so much worse than the 25 year rotation is the carbon stocks on the land in the bioenergy scenarios relative to those in the counterfactual scenarios. For the 25-year rotation, DECC found that average carbon stocks are higher than the average for naturally regenerating pine with a 50-year rotation. With a 20-year rotation, however, DECC found that the intensively-managed pine landscape has lower stocks than a landscape of naturally-regenerated pine on a 50-year rotation. NCASI has not been able to replicate these findings. Indeed, NCASI's analysis of the Smith et al. 2006 data (see Appendix 2) suggests that in the case of both 20- and 25-year rotations, the average carbon stocks in intensively-managed pine plantations over a rotation are equal to or higher than those for naturally regenerating pine on a 50-year rotation. The difference may be due to NCASI not having a detailed description of the specific method used by DECC analyze the Smith et al. (2006) data and, in particular, the method used by DECC to model landscapes when rotation times are changed. The effect of changing the forest from naturally-regenerated to intensively-managed decreases over time because the initial one-time change in carbon stocks from converting the forest is split across more biomass electricity produced. Indeed, over time, more biomass per hectare, and hence more electricity, is produced that shares that initial one-time change in carbon stocks.

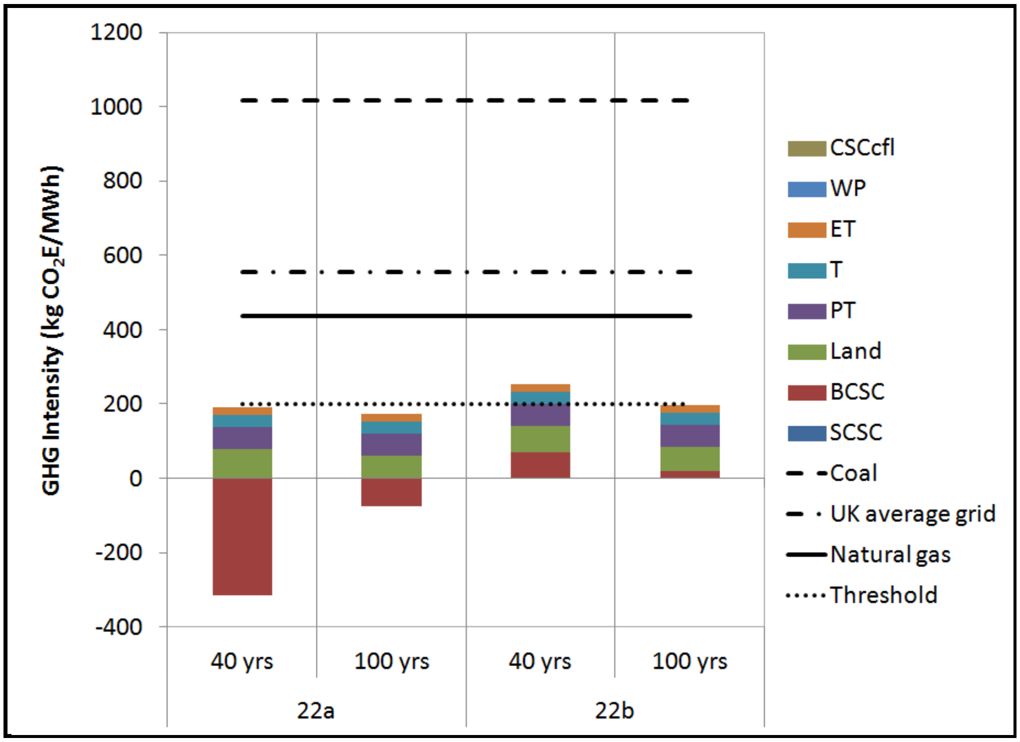

Figure 10. Detailed Base Case Results for Scenario 22
(Nomenclature is provided in Table 1)

Sensitivity analysis results for Scenario 22 are presented in Table 16. It can be seen from these results that, based on the carbon accumulation curves used by DECC (from Smith et al. 2006) the loss of carbon stocks from converting a naturally-regenerated hardwood forest to a pine plantation is greater than when converting a naturally-regenerated softwood forest, and thus the GHG intensity of the biomass energy is greater. It is also observed from this table that the assumed yield has a significant effect on the results.

Also, the assumptions made by DECC regarding the size of the wood used for biomass electricity and the related allocation decision (as discussed above for Scenario 13) potentially have an effect on the results that was not possible to test in sensitivity analyses because these options are not included in the BEaC tool.

Table 16. Sensitivity Analysis Results for Scenario 22

#	Main characteristic compared to base case	GHG Intensity ($kg\ CO_2E/MWh$)		Explanation of the difference w/ base case
		40 years	100 years	
22a-0	N/A	-123	97.3	N/A
22a-1	Broadleaf forest is converted to pine plantation	272	193	DECC shows the loss of carbon stocks from converting a naturally-regenerated hardwood forest to a pine plantation to be greater than when converting a naturally-regenerated softwood forest. This results from the growth curves in Smith et al. 2006 as used by DECC.
22a-2	Higher yield at 100 years	N/A	101	Higher yield translates into more biomass electricity from the same change in carbon stocks.
22a-3	Cofiring	-109	86.3	Normally cofiring produces lower GHG emissions than dedicated biomass electricity because of greater efficiency in producing the energy and thus more biomass electricity is produced for the same quantity of biomass output. However, in the case of Scenario 22, at 40 years a significant carbon stock benefit (negative emission) offsetting GHG emissions is also observed. Therefore, this benefit is also divided across more units of energy and thus lower per unit of energy.
22b-0	N/A	253	196	N/A
22b-1	Broadleaf forest is converted to pine plantation	535	281	See 22a-1.

NOTE: In this table, the sensitivity analyses for which the GHG intensity is above the threshold are shown in light gray.

5.5 Product Substitution Scenarios

5.5.1 Description of Scenarios

The study report by UK DECC does not include any wood product substitution scenarios. In the report, in those scenarios involving wood products the output of wood products is assumed to be unchanged by the additional production of pellets, allowing the substitution effect to be ignored. However, the BEAC Calculator allows examination of scenarios where forest products substitution effects occur. Scenarios listed in Table 17 were run by NCASI for US South conditions. The calculator includes the following possibly substituted wood products: particleboard, MDF, fencing, and combinations. NCASI studied particleboard, MDF and combinations involving fencing. Wood studs and framing were not an option within the calculator.

Table 17. Additional Product Substitution Scenarios

#	Use of biomass	Land use and product substitution		Product substitution	
		Bioenergy	Counterfactual	Bioenergy	Counterfactual
PS1	Small roundwood used in dedicated bioelectricity	LRF Conifer for biomass electricity	LRF Conifer for wood products, residues unused	Breeze blocks	Particleboard
PS2				Concrete fencing and breeze blocks	Wood fencing and off-cuts particleboard
PS3				Plaster work	MDF
PS4				Concrete fencing and plaster work	Wood fencing Off-cuts MDF
PS5	Small roundwood used in cofiring	LRF Conifer for biomass electricity	LRF Conifer for wood products, residues unused	Breeze blocks	Particle board
PS6				Plaster work	MDF
PS7	Sawmill residues used in dedicated bioelectricity	LRF Conifer for biomass electricity	LRF Conifer for wood products, residues unused	Breeze blocks	Particle board
PS8				Plaster work	MDF

NOTE: Scenarios PS1to PS6 were built by NCASI using DECC Scenario 13 described above, and Scenarios PS7 and PS8 were built using DECC Scenario 2 (sawmill residues dried from 25% to 10% moisture in the US South).

Table 18. NCASI Review of Main Assumptions Pertaining to Product Substitution Scenarios

Parameter	Model assumption	NCASI evaluation	
Processing and transport emissions			
Particleboard	403 kg CO_2E/m^3	CORRIM reports 376 kg CO_2E/m^3 for US average particleboard (Puettmann et al. 2013c).	OK
MDF	791 kg CO_2E/ m^3	CORRIM reports 569 kg CO_2E/m^3 for US average MDF (Puettmann et al. 2013b).	[a]
Concrete floor	425 kg CO_2E/m^3	ecoinvent v3 reports 425 kg CO_2E/m^3 for world average concrete (ecoinvent Centre 2013, default allocation).	OK
Blockwork	49 kg CO_2E/m^2	ecoinvent v3 reports between 39.9 and 188 kg CO_2E/m^3 for world average lightweight concrete blocks (ecoinvent Centre 2013, default allocation)[b].	OK
Plasterboard	5 kg CO_2E/m^2	ecoinvent v3 reports 2.17 kg CO_2E/m^3 for world average gypsum plasterboard (ecoinvent Centre 2013, default allocation)[c].	OK
Displacement Factors unit			
Concrete floor	8.00 m^3/t wood	This assumes that you need approximately 3 in. of concrete to perform the same function as 1 in. of wood.	[d]
Blockwork	41.7 m^2/m^3 wood	This means that 8 in. blocks perform the same function as MDF panels of 1 in.	[d]
Plasterboard	80 m^2/m^3 MDF	Assuming a thickness on 0.5 in. and the same thickness for MDF and plasterboard, this number makes sense.	OK

[a]Value higher than other literature source. Sensitivity analysis was performed. [b]Assuming 16 x 8 x 8 in. and 134 kg/m^2. [c]Assuming 1/2 in. and 9.8 kg/m^2. [d]Displacement factors used by DECC cannot easily be checked. Hence, NCASI only checked the sensitivity of the results to theirs.

Table 19. Proposed Sensitivity Analyses on Substitution Scenarios

#	Parameter	Original Value	Revised value
PS1-1	Displacement factor	41.7 m^2/m^3 wood	37.53 m^2/m^3 wood
PS3-1		80 m^2/m^3 MDF	72 m^2/m^3 MDF
PS3-2, PS4-2, PS6-1	Emission from MDF production	791 kg CO_2E/m^3	569 kg CO_2E/m^3

5.5.2 Results

Observed GHG intensities for product substitution scenarios listed in Table 17 are depicted in Figure 11, Figure 12 and Figure 13. It can be seen from these figures that using wood that would otherwise be used in wood products, with the occasional exception of MDF, to produce biomass electricity generally results in GHG intensities well above the threshold and most often well above that observed for energy from coal. This is due to the emissions associated with switching to non-wood products when the wood is not available for wood products. In the case where biomass electricity requires wood that would otherwise be used for MDF, the sensitivity analysis (see Table 20) indicates that the GHG intensity of biomass electricity is sensitive to the assumed emissions from production of MDF, with lower assumed MDF emissions resulting in higher calculated GHG intensity for biomass electricity.

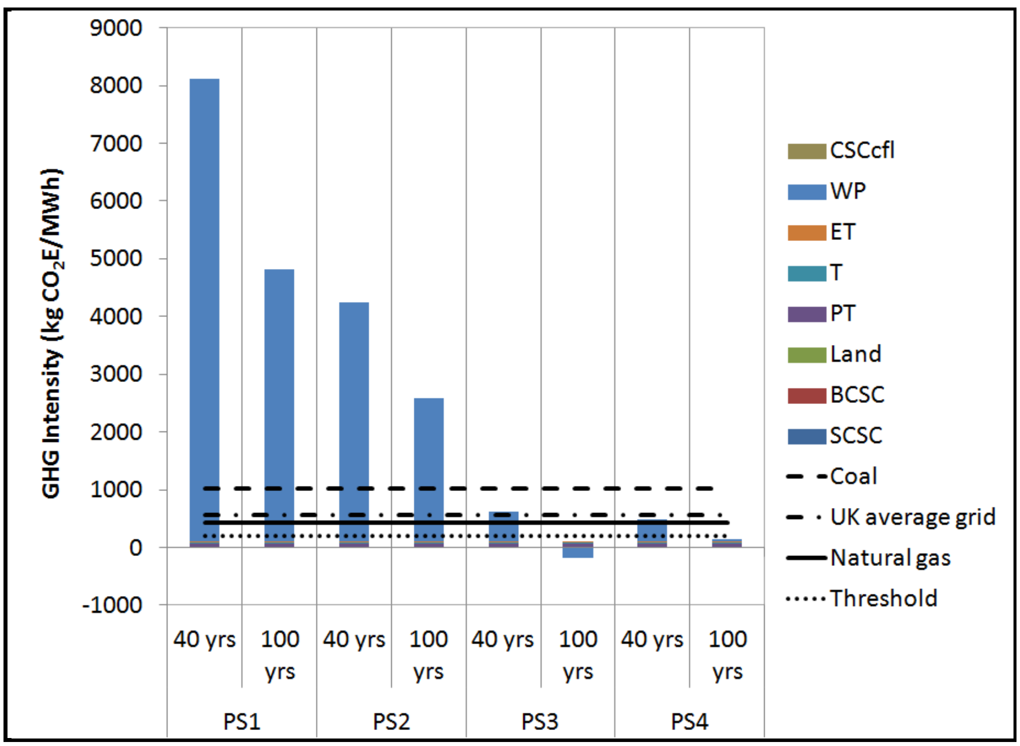

Figure 11. Results from Scenarios in Which Dedicated Biomass Electricity is Produced from Small Roundwood Otherwise Used for Wood Products
(Nomenclature is provided in Table 1)

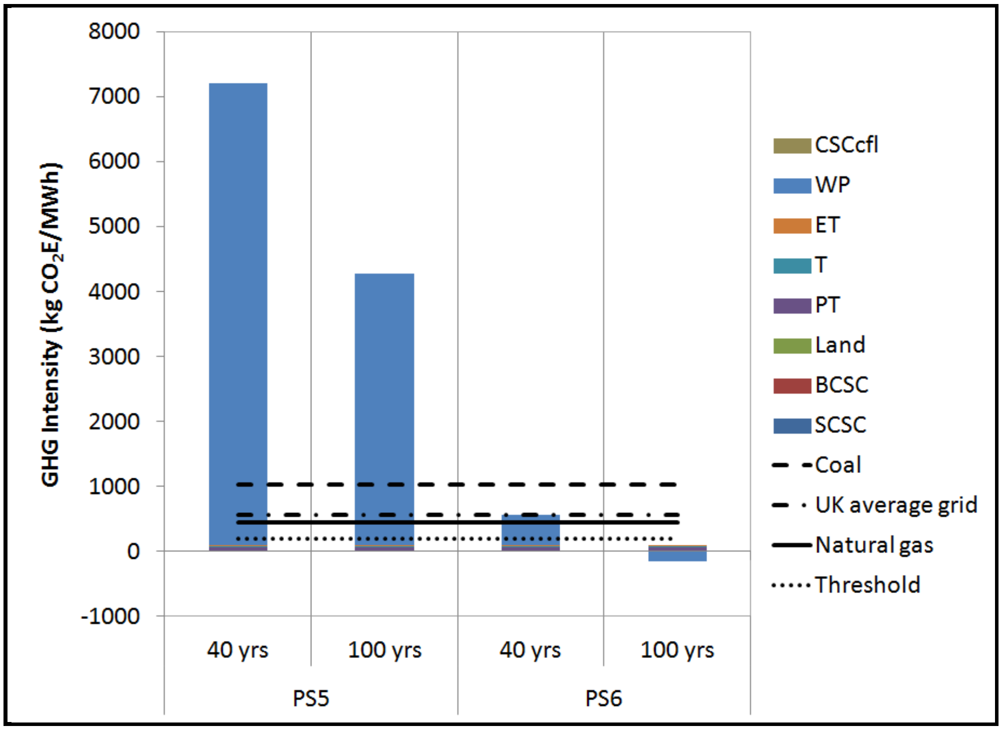

Figure 12. Results from Scenarios in Which Cofired Biomass Electricity is Produced from Small Roundwood Otherwise Used for Wood Products
(Nomenclature is provided in Table 1)

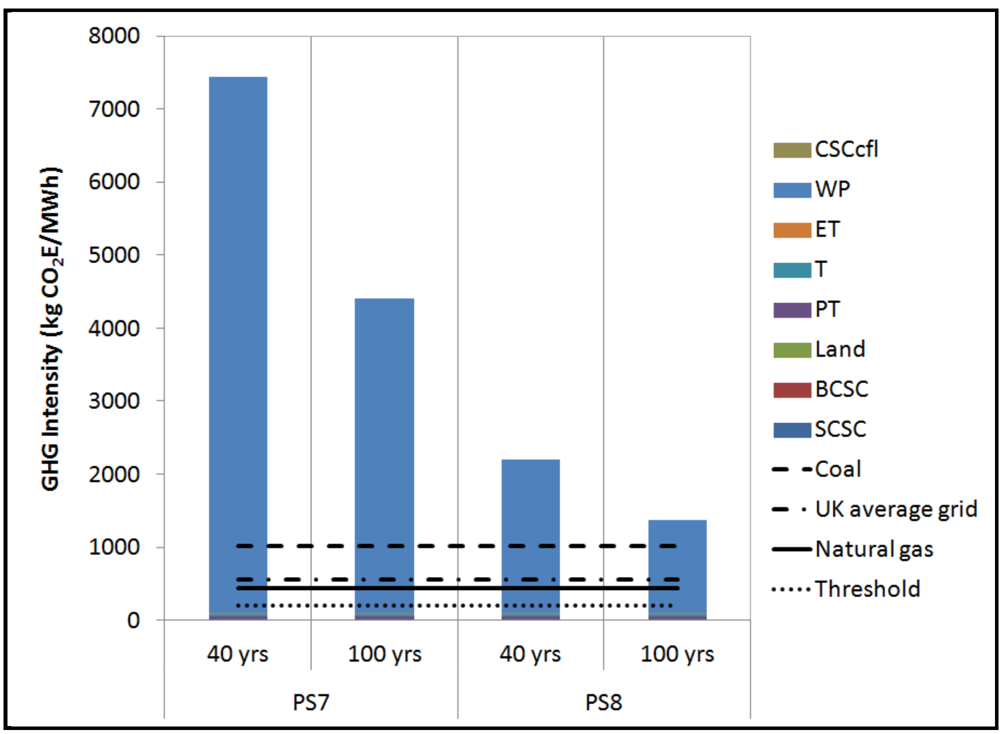

Figure 13. Results from Scenarios in Which Dedicated Biomass Electricity is Produced from Sawmill Residues Otherwise Used for Wood Products
(Nomenclature is provided in Table 1)

NCASI was not able to check the non-wood to wood product displacement factors used by DECC but performed a sensitivity analysis on them. The results showed that increasing the quantity of non-wood product that can be substituted by a given quantity of wood product would increase the calculated GHG intensities for the reason noted above. It was observed that decreasing the displacement factors by 10% would decrease the GHG intensities by 2 to 17%, indicating that the results of the substitution scenarios are potentially significantly affected by the displacement factor assumptions. That said, the GHG intensities for these scenarios are sufficiently high that decreasing the displacement factors alone would be unlikely to result in GHG intensities below the threshold.

Given the variability in MDF-related life cycle GHG emissions reported in the literature, more analyses would be required to fully understand the tradeoff between MDF and biomass electricity. The results from this NCASI analysis are, however, broadly consistent with many other studies that suggest the substitution benefits from using wood for construction are usually greater, and often far greater, than those associated with using the same wood for energy.

Table 20. Sensitivity Analysis Results for Product Substitution Scenarios

#	**Main characteristic compared to base case**	**GHG Intensity ($kg\ CO_2E/MWh$)**		**Explanation of the difference w/ base case**
		40 years	**100 years**	
PS1-0	N/A	8122	4807	N/A
PS1-1	Displacement factor decreased by 10%	7537	4222	Decreasing the quantity of non-wood product displaced by a given quantity of wood product results in lower emissions from the bioenergy scenario.
PS3-0	N/A	621	-71.2	N/A
PS3-1	Displacement factor decreased by 10%	608	-83.7	Decreasing the quantity of non-wood product displaced by a given quantity of wood product results in lower emissions from the bioenergy scenario.
PS3-2	Lower emissions from producing MDF	715	14.1	Lower emissions from MDF production makes it less advantageous to use the wood for biomass electricity instead.
PS4-0	N/A	492	146	N/A
PS4-2	Lower emissions from producing MDF	560	210	Lower emissions from MDF production makes it less advantageous to use the wood for biomass electricity instead.
PS6-0	N/A	551	-63.2	N/A
PS6-1	Lower emissions from producing MDF	634	13.2	Lower emissions from MDF production makes it less advantageous to use the wood for biomass electricity instead.

NOTE: In this table, the sensitivity analyses for which the GHG intensity is above the threshold are shown in light gray.

6 Conclusions

NCASI has reviewed and investigated the UK DECC report and calculator and has identified scenarios deserving further attention because (a) they represent conditions where the results might be significantly affected by changes to the modeling assumptions, and (b) they appear to be reasonably likely. For these scenarios, the results from DECC showed that the GHG intensity for biomass electricity is quite variable depending on the source of the biomass used for its production. Biomass obtained from salvaged dead trees, from increased management intensity of US South pine plantations, and from establishing intensively-managed pine plantations on naturally-regenerating pine forest resulted in the lowest calculated GHG intensities, usually lower than the threshold, at least in 100 years. Several DECC scenarios not examined by NCASI, particularly those involving afforestation and avoided deforestation, also yield results lower than the DECC threshold. Biomass obtained from increased harvest of naturally-regenerated forests and from wood normally used in wood products (product substitution scenarios, with the occasional exception of MDF), however, results in the greatest observed GHG intensities, usually greater than that of coal. Biomass obtained from forest residues and from existing intensively-managed pine plantations give GHG intensities between these extremes, generally lower than that of coal, sometimes higher, and sometimes lower than the threshold. NCASI showed that, in the case of roundwood, assumptions made concerning the counterfactual scenario and assumed yields have significant effects on the results. For forest residues, NCASI sensitivity analyses showed that results are significantly affected by assumed counterfactual scenarios and decay rates. Assumptions regarding transportation, power grid used at pelletizer (other than regional differences), fertilizer usage and fuel usage in the forest have a marginal effect on the results.

NCASI has identified three potentially significant methodological issues in the approach used to model the production of biomass electricity from roundwood. First, DECC indicates it used growth curves from USFS (Smith et al. 2006) in calculating changes in carbon stocks. These curves reflect the average biomass for each age class on a large number of FIA plots and therefore the curves do not show the production of thinnings and do not reveal the stand-level impacts of thinning on growth. The effect of this on the calculated greenhouse gas intensities is unclear as the impact on growth would apply to both the bioenergy and counterfactual scenarios, except in the case where it is assumed that thinnings would not be produced were it not for the demand for biomass electricity. Second, DECC assumed that all additional wood produced in the bioenergy scenarios is used for energy, regardless of size. A more likely outcome is that large diameter trees would be sold for higher value uses, particularly lumber production. The potential effect of this assumption strongly depends on the method used to allocate carbon stock changes to the wood used in biomass electricity versus higher value use. Finally, the modeling of increased use of roundwood was done using scenarios that assumed a step change in rotation lengths with the results of the modeling being primarily driven by the specific carbon accumulation curves used in the scenarios. The use of these types of simplified scenarios paired with counterfactuals, however, fails to capture the interactive, location-dependent and dynamic nature of forest and landowner responses to increased demand for wood. In these cases, a different modeling approach could give significantly different results.

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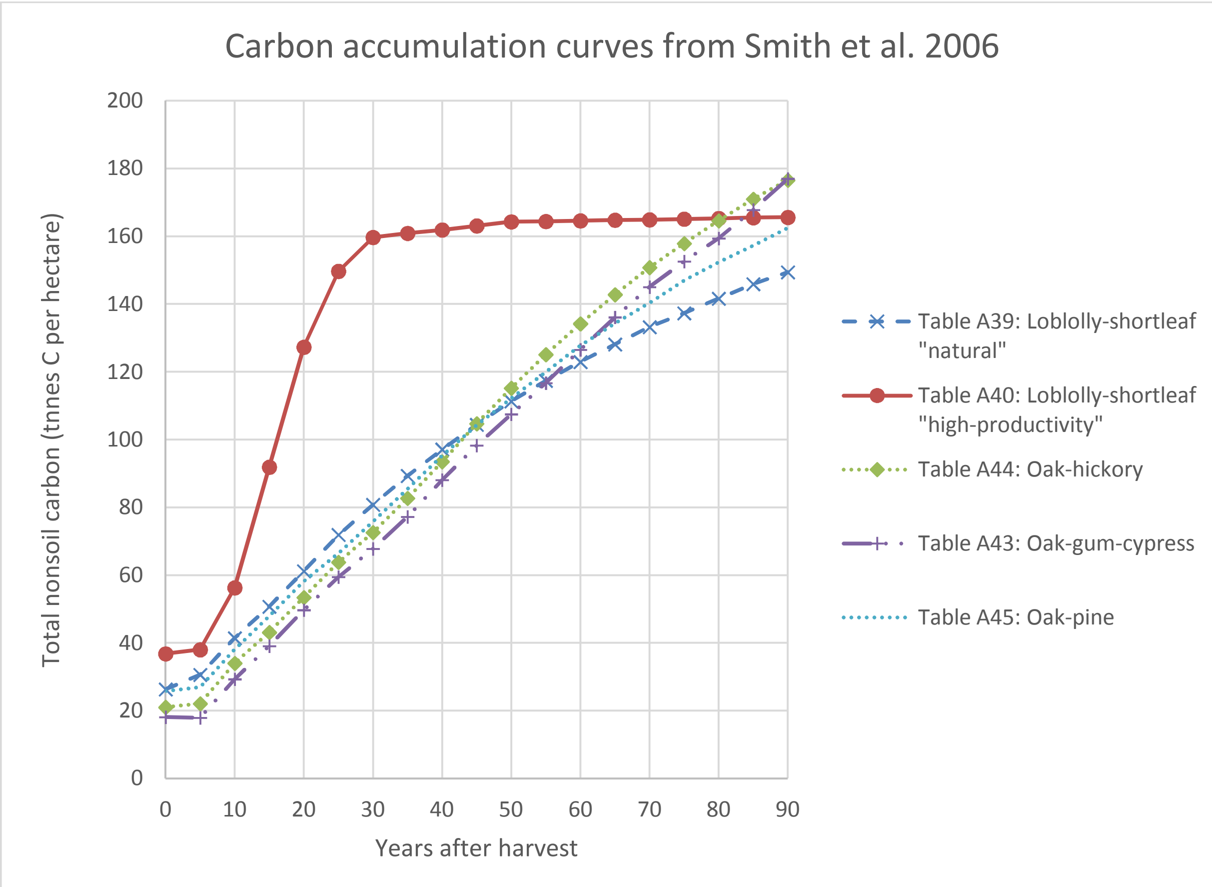
Appendix 1: List of General Assumptions

Details	Assumption
Biomass carbon content	47%
Dry biomass lower heating value	Softwood: 19.2 MJ/kg Hardwood: 19.0 MJ/kg SRC willow: 18.4 MJ/kg
Biomass moisture content	Harvested roundwood: 50 wt% Harvested forest residues and deadwood: 25 wt% Saw mill residues: 10 to 50 wt% Wood pellets: 7 wt%
Drying fuel prior to wood pelletization	Default: Biomass Low: Biomass High: Natural Gas
Drying fuel requirements prior to pelletization, using biomass	Initial moisture content 10 wt%: no drying Initial moisture content 25 wt%: 130 kWh/t output Initial moisture content 50 wt%: 519 kWh/t output
Drying fuel requirements prior to pelletization, using natural gas	Initial moisture content 10 wt%: no drying Initial moisture content 25 wt%: 133 kWh/t output Initial moisture content 50 wt%: 532 kWh/t output
Pelletizing electrical requirement (excluding drying)	Default: 190 kWh per tonne of pellets Low: 100 kWh per tonne of pellets High: 239 kWh per tonne of pellets
Combust in dedicated biomass power station	Default: Efficiency 35.5% based on the lower heating value of fuel (LHV) Low: Efficiency 30% based on LHV High: Efficiency 40% based on LHV
Surface transport methods and distances	Default: Transport wood 50 km from forest to pellet facility by truck, pellets 100 km from pellet facility to the port by truck (apart from pellets from Interior-West Canada, which are transported 630 km by rail), and 100 km from port to plant by rail Low: Transport wood 25 km from forest to pellet facility by truck, pellets 75 km from pellet facility to the port by truck (apart from pellets from Interior-West Canada, which are transported 320 km by rail), and 75 km from port to plant by rail High: Transport wood 75 km from forest to pellet facility by truck, pellets 150 km from pellet facility to the port by truck (apart from pellets from Interior-West Canada, which are transported 1600 km by rail), and 150 km from port to plant by rail

Details	Assumption
Shipping distances	South USA to UK: 7200 km Pacific Canada to UK: 16300 km Interior-West Canada to UK: 16300 km North West USA to UK:16000 km East Canada to UK: 4900 km Northeast USA: 5800 km Brazil to Southeast USA: 5200 km Pacific Canada to Southeast USA: 10500 km
Rail emissions and energy requirements	Default: Pellet rail emissions would reduce by 15% between 2013 and 2020, from 0.017 to 0.015 kg CO2E/t km, and energy consumption would reduce by 7.5% from 0.054 to 0.050 kWh/t km Low: Pellet rail emissions would reduce by 15% between 2013 and 2020, from 0.017 to 0.015 kg CO2E/t km, and energy consumption would reduce by 7.5% from 0.054 to 0.050 kWh/t km High: Pellet rail emissions and energy consumption in 2020 would stay the same as in 2013, at 0.017 kg CO2E/t km
Truck emissions and energy requirements	Default: Pellet truck emissions and energy consumption would reduce by 12.35% between 2013 and 2020. Emissions would reduce from 0.110 kg CO2E/t km to 0.096 kg CO2E/t km, and energy consumption would reduce from 0.339 to 0.297 kWh/t km Low: Pellet truck emissions and energy consumption would reduce by 12.35% between 2013 and 2020. Emissions would reduce from 0.110 kg CO2E/t km to 0.096 kg CO2E/t km, and energy consumption would reduce from 0.339 to 0.297 kWh/t km High: Pellet truck emissions and energy consumption in 2020 would stay the same as in 2013, at 0.110 kg CO2E/t km, and 0.339 kWh/t km, respectively
Shipping emissions and energy requirements	Default: Pellet shipping emissions would reduce by 20% between 2013 and 2020, from 0.006 to 0.005 kg CO2E/t km, and energy consumption would reduce by 10% from 0.018 to 0.016 kWh/t km Low: Pellet shipping emissions would reduce by 20% between 2013 and 2020, from 0.006 to 0.005 kg CO2E/t km, and energy consumption would reduce by 10% from 0.018 to 0.016 kWh/t km High: Pellet shipping emissions and energy consumption in 2020 would stay the same as in 2013, at 0.006 kg CO2E/t km, and 0.018 kWh/t km, respectively
US electrical grid	US grid GHG intensity (in kg CO2E/MWh) would reduce by 16% between 2013 and 2020, from 520 to 439 kg CO2E/MWh
Canadian electrical grid	Canadian grid GHG intensity (in kg CO2E/MWh) would reduce by 18% between 2013 and 2020, from 180 to 148 kg CO2E/MWh
Industrial-scale electricity generation methane emissions	Methane emissions from electricity generation assumed to be 30 g CH4/GJ (based on HHV in feedstock), equivalent to 0.0029 kg CO2E/kWh (based on LHV in feedstock)

Details	Assumption
Industrial-scale electricity generation nitrous oxide emissions	Nitrous oxide emissions from electricity generation assumed to be 4 g N_2O/GJ (based on HHV in feedstock), equivalent to 0.0046 kg CO_2E/kWh (based on LHV in feedstock)
Losses of feedstock per transport leg.	Truck: 0.1 wt% Rail: 0.1 wt% Ship: 0.1 wt%

Appendix 2: Smith et al. Data Used in the Investigated Scenarios
(Note: Table numbers are from Smith et al. 2006)



A39— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the Southeast

		Mean carbon density (tonnes C per hectare)						
Age	Mean volume (m3/hectare)	Live tree	Standing dead tree	Understory	Dow dead wood	Forest floor	Soil organic	Total nonsoil
0	0	0	0	4.2	9.9	12.2	72.9	26.3
5	0	11.1	0.7	4	8.4	6.5	72.9	30.6
10	19.1	22.6	1.3	3.6	7.5	6.4	72.9	41.4
15	36.7	31.3	1.6	3.4	6.8	7.5	72.9	50.7
20	60.4	40.8	1.9	3.2	6.6	8.7	72.9	61.2
25	85.5	50.3	2.1	3.1	6.5	9.8	72.9	71.9
30	108.7	58.2	2.3	3.1	6.6	10.7	72.9	80.8
35	131.2	65.6	2.4	3	6.7	11.5	72.9	89.3
40	152.3	72.5	2.5	3	6.9	12.2	72.9	97.1
45	172.3	78.9	2.7	2.9	7.2	12.7	72.9	104.4
50	191.4	85	2.7	2.9	7.5	13.2	72.9	111.3
55	208.4	90.3	2.8	2.9	7.8	13.7	72.9	117.4
60	223.9	95.1	2.9	2.8	8.1	14.1	72.9	122.9
65	238.4	99.6	2.9	2.8	8.3	14.4	72.9	128.1
70	252.9	104	3	2.8	8.6	14.7	72.9	133.2
75	264.6	107.6	3	2.8	8.9	15	72.9	137.3
80	277.1	111.4	3.1	2.8	9.1	15.2	72.9	141.6
85	289.5	115.1	3.1	2.8	9.4	15.5	72.9	145.9
90	299.6	118.2	3.2	2.7	9.6	15.7	72.9	149.4

A40— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the Southeast; volumes are for high-productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

		Mean carbon density (tonnes C per hectare)						
Age	Mean volume (m3/hectare)	Live tree	Standing dead tree	Understory	Dow dead wood	Forest floor	Soil organic	Total nonsoil
0	0	0	0	4.1	20.4	12.2	72.9	36.8
5	0	11	0.7	4	15.9	6.5	72.9	38
10	47.7	31.9	1.4	3.8	12.9	6.4	72.9	56.3
15	146.5	67.4	1.9	3.7	11.4	7.5	72.9	91.9
20	244.8	102.3	2.1	3.7	10.5	8.7	72.9	127.3
25	315.2	124.2	2.3	3.7	9.7	9.8	72.9	149.7
30	347.3	134.1	2.4	3.7	8.8	10.7	72.9	159.7
35	351.5	135.4	2.4	3.7	8	11.5	72.9	160.9
40	355	136.5	2.4	3.7	7.3	12.2	72.9	161.9
45	358.5	137.5	2.4	3.6	6.8	12.7	72.9	163.1
50	362	138.6	2.4	3.6	6.4	13.2	72.9	164.3
55	362	138.6	2.4	3.6	6.1	13.7	72.9	164.4
60	362	138.6	2.4	3.6	5.9	14.1	72.9	164.6
65	362	138.6	2.4	3.6	5.7	14.4	72.9	164.8
70	362	138.6	2.4	3.6	5.6	14.7	72.9	164.9
75	362	138.6	2.4	3.6	5.5	15	72.9	165.1
80	362	138.6	2.4	3.6	5.4	15.2	72.9	165.3
85	362	138.6	2.4	3.6	5.4	15.5	72.9	165.5
90	362	138.6	2.4	3.6	5.3	15.7	72.9	165.6

A43.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands on forest land after clearcut harvest in the Southeast

		Mean carbon density (tonnes C per hectare)						
Age	Mean volume (m3/hectare)	Live tree	Standing dead tree	Understory	Dow dead wood	Forest floor	Soil organic	Total nonsoil
0	0	0	0	1.8	10.2	6	158	18.1
5	0	6.7	0.7	1.9	6.2	2.4	158	17.9
10	9.8	18.8	1.9	1.8	4.5	2.4	158	29.3
15	19.9	28.3	2.4	1.7	3.7	3	158	39.1
20	32.7	38	2.8	1.7	3.5	3.8	158	49.7
25	45.4	46.8	3.1	1.6	3.6	4.4	158	59.5
30	58.1	54	3.4	1.6	3.8	5	158	67.8
35	73.4	62.3	3.6	1.6	4.2	5.5	158	77.2
40	92.2	71.9	3.9	1.6	4.7	6	158	88.1
45	110.7	80.9	4.2	1.6	5.2	6.4	158	98.3
50	128.1	89	4.4	1.5	5.7	6.8	158	107.5
55	146.3	97.3	4.6	1.5	6.2	7.2	158	116.7
60	166.1	105.9	4.7	1.5	6.7	7.5	158	126.5
65	186.4	114.5	4.9	1.5	7.3	7.8	158	136.1
70	205.7	122.5	5.1	1.5	7.8	8.1	158	145
75	222.5	129.3	5.2	1.5	8.2	8.4	158	152.6
80	237.9	135.4	5.3	1.5	8.6	8.6	158	159.4
85	257.3	142.9	5.5	1.5	9.1	8.9	158	167.8
90	278.9	151.2	5.6	1.5	9.6	9.1	158	177

A44— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Southeast

		Mean carbon density (tonnes C per hectare)						
Age	Mean volume (m3/hectare)	Live tree	Standing dead tree	Understory	Dow dead wood	Forest floor	Soil organic	Total nonsoil
0	0	0	0	4.2	10.8	6	45.3	21
5	0	8.1	0.8	4.2	6.7	2.4	45.3	22.1
10	11.7	21	2.1	3.8	4.8	2.4	45.3	34
15	21.2	30.3	2.5	3.5	3.8	3	45.3	43.1
20	33.8	40	2.8	3.3	3.5	3.8	45.3	53.4
25	46.6	49.5	3	3.2	3.6	4.4	45.3	63.8
30	60.2	57.5	3.2	3.1	3.8	5	45.3	72.6
35	76.3	66.6	3.4	3	4.2	5.5	45.3	82.7
40	94.3	76.2	3.6	2.9	4.6	6	45.3	93.5
45	114.1	86.4	3.8	2.9	5.2	6.4	45.3	104.7
50	133	95.8	4	2.8	5.7	6.8	45.3	115.2
55	151.4	104.8	4.1	2.8	6.2	7.2	45.3	125.1
60	168.9	113	4.2	2.7	6.7	7.5	45.3	134.2
65	185.6	120.8	4.3	2.7	7.2	7.8	45.3	142.8
70	201.5	128	4.4	2.7	7.6	8.1	45.3	150.8
75	215.7	134.4	4.5	2.6	8	8.4	45.3	157.9
80	229.4	140.5	4.6	2.6	8.3	8.6	45.3	164.6
85	242.5	146.2	4.6	2.6	8.7	8.9	45.3	171
90	254.1	151.3	4.7	2.6	9	9.1	45.3	176.6

A45.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Southeast

		Mean carbon density (tonnes C per hectare)						
Age	Mean volume (m3/hectare)	Live tree	Standing dead tree	Understory	Dow dead wood	Forest floor	Soil organic	Total nonsoil
0	0	0	0	4.2	11.3	10.3	61.4	25.8
5	0	7.4	0.6	4.1	9	5.8	61.4	26.9
10	13.6	19.6	1.2	3.6	7.7	5.9	61.4	38
15	27.8	29.3	1.6	3.5	6.7	6.8	61.4	47.9
20	43.9	39	1.9	3.4	6.2	7.7	61.4	58.2
25	59.3	46.8	2.1	3.3	5.8	8.6	61.4	66.5
30	77.2	55.4	2.3	3.2	5.6	9.2	61.4	75.8
35	96.8	64.4	2.5	3.2	5.7	9.8	61.4	85.5
40	117.2	73.4	2.7	3.1	5.9	10.2	61.4	95.3
45	136.4	81.6	2.8	3.1	6.1	10.6	61.4	104.2
50	154.1	88.9	2.9	3.1	6.3	11	61.4	112.2
55	171.4	96	3	3	6.6	11.3	61.4	119.9
60	189.6	103.2	3.1	3	6.9	11.5	61.4	127.8
65	204.5	109.1	3.2	3	7.2	11.8	61.4	134.3
70	218.8	114.6	3.3	3	7.5	12	61.4	140.3
75	234.5	120.6	3.4	2.9	7.8	12.1	61.4	146.9
80	247.6	125.5	3.5	2.9	8.1	12.3	61.4	152.3
85	259.4	129.9	3.5	2.9	8.3	12.5	61.4	157.2
90	272.3	134.7	3.6	2.9	8.6	12.6	61.4	162.4