Technical Appendix 2: General Discussion of Natural Carbon Sequestration In The Land Use Sector

Section A: The Present Situation

1. Data Consistency

These remarks apply to non-food biomass materials including organic carbon. It is often difficult to get consistent figures because reporting conventions are not always specified. Data is presented in numerous different forms, e.g:

- Tonnes of product as generated
- Dried to various degrees, with unspecified water content
- 'Oven-dry tonnes' or dry matter
- Carbon content, often considered 50% of biomass dry weight
- CO_2 equivalent (CO_2e) 44/12 or 3.67 times carbon content

We try to work in CO_2e and unless otherwise specified all figures are in CO_2e. To convert to CO_2e from unspecified wood or other dry biomass products we use a value of 1.2 (MacMath and Fisk, 2000).

2. Balance of Sources and Sinks

In constructing a summary balance of emissions and sinks, there appear to be two sources of biomass

- Indigenous wood and other biomass products from UK
- Imported wood products

and four sinks:

- Soils
- In-situ biomass (in living plants)
- The active UK economy, which we sometimes refer to as the 'technosphere'
- Landfill sites

These are represented in Figure 2.1. The numbers in each box represent an estimate of the total current size of the existing pool in million tonnes CO_2e, derived from a variety of sources (referenced). The bold numbers in brackets are estimates of the existing net sinks in million tonnes CO_2e/ year.

3. Sources

Food products and energy crops are part of a rapid cycle in which they absorb carbon dioxide as they grow and then release it again when metabolised or burned. It is assumed that food products and intermediates are all metabolised in some way and are therefore effectively carbon-neutral apart from any extra emissions that arise from their production (such as emissions from fertiliser). The same applies to energy crops. That leaves "wood products", including paper and pulp, and a small quantity of building materials made from other cellulosic crops such as straw and hemp. The official inputs to the system vary from year to year but are between 50 and 60 million tonnes of wood products, about 9 from UK and ~45 imported (Forestry Commission, 2009). These wood product tonnages are adjusted for likely CO_2e value

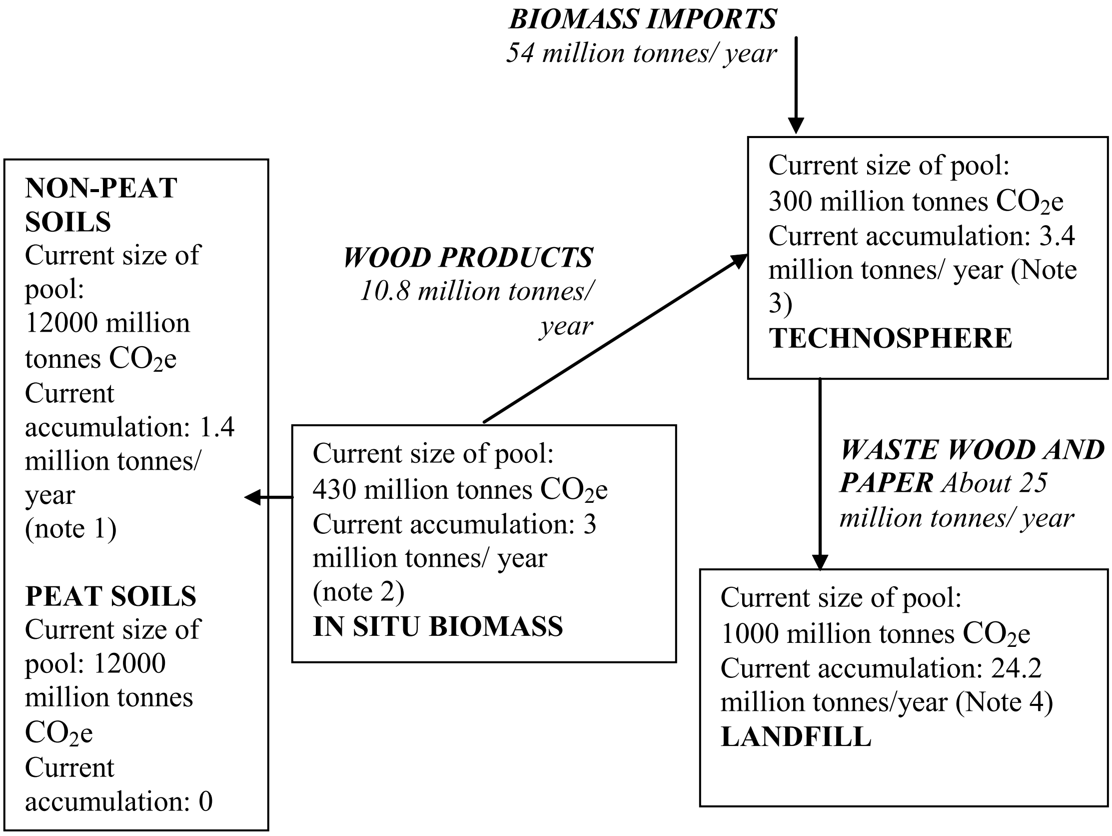

Figure 2.1: Current principle sinks, accumulation rates and flows
Boxes show principal sinks and reported or estimated sizes and accumulation rates. Arrows represent flows. CO_2 is constantly being released from all parts of the system, assumed to be biogenic and therefore 'neutral'.

by a coefficient of 1.2 (MacMath and Fisk, 2000).

4. Sinks
Soils are a small net sink, and newly-planted UK forests are reported as sequestering about 3 million tonnes in above-ground biomass in the UK submission to the UNFCCC. It is almost certain that existing and new forests currently absorb more than this (FAO, 2010) but exact figures are disputed.

Of these, 2.8 million tonnes (adjusted to 3.4 for CO_2e absorbed) are reported as accumulating in human artefacts, which we have sometimes described as the "technosphere" (TRADA, 2005). This is likely to be an underestimate, but is adopted faute de mieux. A far greater quantity (24.2 million tonnes) accumulates in landfills (Fawcett *et al*., 2002) but this is ignored in official carbon accounting.

If landfill sequestration is ignored, the baseline rate of sequestration is 8 million tonnes CO_2e/ year, represented in Figure 2.1. This implies that the balance (57+ million tonnes) does not accumulate, but is decomposed in various ways, by combustion or by biological processes. This can be assumed to be carbon-neutral unless some of the decomposition produces un-combusted methane. This is possible in the case of some classes of paper in a poorly-controlled landfill situation, and indeed currently occurs. For the purposes of the exercise we have assumed that at present fugitive methane emissions cancel out the sequestration value of wood products in landfill. It is notable however that if landfill sequestration were included the present rate would be over 32 million tonnes CO_2e/ year.

5. Further Discussion of Figure 2.1

Note 1: Soil
The figure for the current size of the pool is taken from Emmet *et al.* (2010), with peat soils (mostly in Scotland), assumed to be about half the total.

Soil emissions and sequestration are notoriously difficult to estimate reliably. Emmett *et al*. (2010) report no net change in soil carbon 1978 - 2007, although there were gains in forested area and bracken, and some losses in cropland. In the official figures the two are assumed to approximately cancel out.

There is some evidence, however, of a small 'background' accumulation in European forest soils of 11-19g C/m^2/year (Liski *et al*., 2002, Nabuurs *et al*., 2003). If we take say 15g C/m^2/year and convert it, that gives us 0.55 tonnes/ha/year multiplied by 2.6 (area of forest) hence 1.43 million tonnes CO_2e/year. We assume, following Emmett *et al*. (2010) that there is no other net gain or loss.

Note 2: In situ biomass
The figure for the size of the current pool is from Milne and Brown (1997) converted to CO_2e. The in-situ sequestration value is that reported for the 'Kyoto forests' planted since 1990 (FAO 2010). This is definitely an under-estimate but other values in the literature vary a great deal.

Note 3: The technosphere
The figure of 300 million tonnes for the current pool is taken from Broadmeadow and Matthews (2003). The 3.4 million tonnes/year added to the UK is from TRADA (2005). They report 2.8 million tonnes/year as 'products', taken as air-dried tonnes and converted at 1.2.

Note 4: Landfill
The figure of 24 million tonnes in landfill is from Fawcett *et al*. (2002), summarised in the following table:

	Raw tonnes (million tonnes)	**Carbon content (total, million tonnes)**	**Carbon remaining landfill (total, million tonnes)**
paper	14.5	6.3	4.6
wood	4.1	2.1	2.0
total	**18.6**	**8.3**	**6.6**

6.6 million tonnes carbon multiplied by 44/12 = 24.2.

Although the figure of 24.2 million tonnes/year appears large at first sight, it is plausible because the longevity of wood and paper in landfills is well-established (Rathje, 2001, Ximenes *et al*., 2008). It implies both a large sink and a growing reservoir. Obviously 24 million tonnes per year for 40 years is a large quantity (968 million tonnes) but the landfills have been in operation for far longer than this, so presumably they are already reservoirs containing thousands of gigatonnes of fixed carbon. This is an important factor that has received too little attention.

Section B: Sinks in the Zero Carbon Scenario

6. Limitations of Sinks

The physical problem with carbon sequestration is that the sinks tend to fill up: they cannot be expanded indefinitely. In a sense, this is a measure of just how deviant the present fossil-fuel age is from the pre-industrial era: before, the sinks were entirely adequate while now they are strained to the limit.

Our task is to show a near-zero state at around 2030, but it is important that this is not achieved at the cost of failing to maintain the near-zero state in the future. To this end we have accepted the concept of a 'window of opportunity' stretching across the next 20-30 years (Smith, 2004; Azeez, 2009). The 'window' seizes opportunities that will buy time for the development of larger-scale, longer-term, world-wide procedures that can deliver a permanent low-carbon world economy.

The scenario seeks policies that will provide net-negative processes or carbon sinks in the period 2015-2050. Thereafter the carbon sinks would need to be maintained but would probably decline in effectiveness, and other net-negative methods would be required if there were still residual greenhouse gas emissions.

7. Inputs

The scenario incorporates the assumption that the land-use system in Britain generates biomass for structural and material purposes equivalent to about 41 million tonnes CO_2e. There might well be imports (for example of structural timber, which we are less well suited to growing) but these are balanced by exports of other products with the same embodied carbon.

8. Sequestration:

a) Soils

Further discussion is found in Technical Appendix 5.

Peat soils:

It is important to distinguish peat soils that are already extremely carbon-rich from non-peat mineral soils that have variable levels of soil organic matter. Lengthier discussion can be found in Technical Appendix 5.

Across Britain as a whole, peat soils are assumed to be able to sequester 0.5 million tonnes a year with appropriate management, which gives a total value of 0.68 million tonnes for all of the peat soils in the UK.

Non-peat soils:

The very large size of the non-peat soil reservoir should be noted. Addition of, say, 50 million tonnes CO_2e per year for 50 years would increase the stock by around 20%. Given the enormous range of soil carbon concentrations, this cannot be regarded as physically impossible, even though the build-up of stable soil carbon is a slow process. Each soil/vegetation type has its own characteristics.

Woodland soils

Technical Appendix 5 shows calculations for expected soil sequestration in the 'window' 2015-2035. The total in Great Britain amounts to 1 million tonnes CO_2e/y for soils in optimally-managed existing forests and 4.48 million tonnes CO_2e/y for new woodland, a total of 5.48 million tonnes.

Grassland soils

Optimum management of the grassland in the scenario for soil-sequestration is calculated to be able to provide 5.65 million tonnes CO_2e/y, in total, in the 'window'.

Cropland soils

Adopting practices recommended for building soil carbon in arable land, it is estimated that good practice could deliver a total of 4 million tonnes CO_2e/y in the 'window'.

The total for all soil sequestration in the scenario is 15.8 million tonnes CO_2e.

To this is added 16 million tonnes sequestered by biochar (Sohi, 2010; see also Technical Appendix 7).

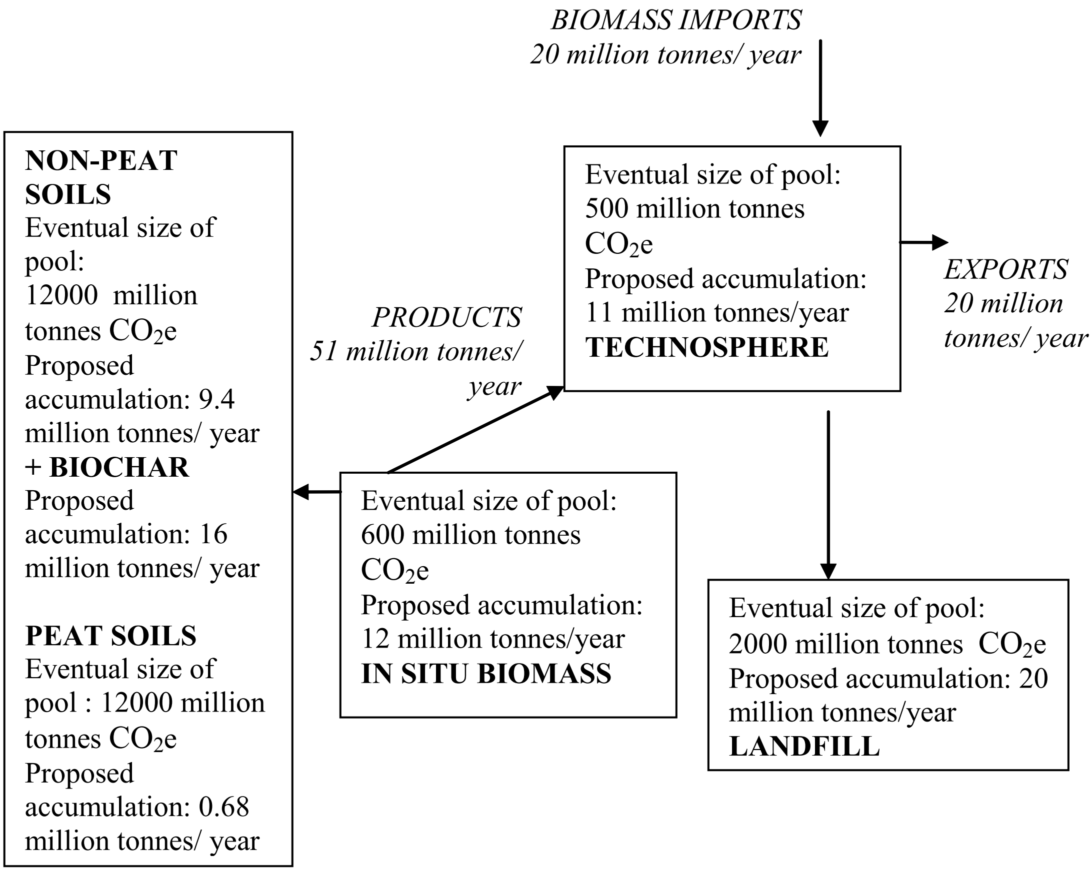

Figure 2.2: Proposed pools (million tonnes) and flows (million tonnes/year) of CO_2e.

Boxes represent principal sinks and reported or estimated sizes. Arrows represent flows. Imports and exports are designed to cancel out in carbon terms. CO_2 released from all parts of the system is assumed neutral.

Although the use of biochar is a process still under development and there are many unknowns, it is felt that this quantity could reasonably be absorbed by British soils without great risk in the next 20 years. It is worth noting that there is no obvious limit to the amount of biochar that can be added to soils, so this could represent a very large sink on the other side of the 'window'. It could also be used as an active component of landfill sequestration, where it might serve to adsorb methane (Rondon *et al*., 2007).

b) In-situ Biomass
Nearly all the accumulation of above-ground biomass is in trees. Data derived from Read *et al*. (2009) suggest that appropriate new planting and forest management in the areas designated by the scenario could sequester 13.7 million tonnes CO_2e/y in the 'window'.

This allows for a certain amount of harvested material removed from the woodland systems.

c) Accumulating in human artefacts: the 'technosphere'
The scenario incorporates a completely different approach to new structures, which would be designed in order to incorporate as much permanent biomass as possible. It is difficult to estimate what the ultimate size of this sink could be, or how much could be deposited in it for how long. We have estimated a sustained sink of 11 million tonnes for 30 years, implying an eventual sink size of about 400 million tonnes.

d) Landfill
Although in ***zero****carbon****britain****2030* there is likely to be less 'waste' in the ordinary sense, there is no reason why landfill or similar sites should not continue to be used, but for new and more benign purposes, especially if they serve a useful function. At a carbon price of >£200 a tonne, there would be negative gate-fees. We propose that this existing function continues at somewhat less than its present rate of 24 million tonnes CO_2e/y.

It might be clearer if instead of 'landfill', we speak of dedicated biomass storage sites or 'silos' (cf. Zeng, 2008). In terms of areas required, if one tonne of sequestered carbon is about 1.4m^3 in volume, then the volume of 1000 million tonnes is 1.4e9m^3. If a typical storage site is similar to landfill site practice at (say) 200m deep, the total area required is about 70 thousand hectares and the sequestration density is about 14 thousand tonnes/hectare, several orders of magnitude greater than other sinks. This process seems bizarre at first sight, comparable with the suggestion by Strand and Benford (2009) that carbon be sequestered by dumping biomass in the ocean, but we live in bizarre times and all options have to be on the table. Useful calculations are given by Zeng (op cit).

9. The Overall Balance
In the scenario the engineered sequestration rate in 2030 is 67.9 million tonnes CO_2e/y including dedicated biomass sequestration. As described, today's level is 32 million tonnes CO_2e/y if landfill sequestration is included. Hence 68 million tonnes CO_2e/y gives us an additional 36 million tonnes CO_2e sequestration with which we can offset residual emissions in the land-use and other sectors.

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