Appendix 1 CO_2 Removals in Residual Combustion Products (charcoal): Basis for Future Methodological Development

Background

Charred materials are the product of the incomplete combustion of vegetation and fossil fuels (Goldberg, 1985). The continuum of combustion products such as char, ash, soot and charcoal are commonly referred to as black carbon (BC). BC is a heterogeneous mixture of residues that have contrasting chemistry and thus resistance to further biological or chemical degradation. Together they occur ubiquitously in soils and other terrestrial sediments, and in marine sediments as well.

A large portion (>80%) of the BC that is produced by a fire event remains proximal to the site where it was formed. It is then incorporated into the soil where it can remain for long periods of time. However, BC can also be transported via fluvial and atmospheric pathways to marine sediments, with the majority moving through the fluvial system. This results in most of the particulate BC transported to the oceans being deposited on the coastal shelves, while a smaller portion continues on to the deeper ocean sediments. Another fraction of the particulate BC produced is dispersed into the atmosphere. With residence times that can exceed 7days, much of this component of BC is transported to the oceans and ultimately contributes to the BC fraction of deep ocean sediments, where it is very stable.

Over the past few decades BC concentrations in the earth's atmosphere and biosphere have become of interest because, in aerosol form, they are strong absorbers of solar radiation. They can provide a record of palaeo-environments in sediment and ice cores, and they may also be a sizable contributor of oxygen to the atmosphere over geological time frames. BC, in particular the charcoal component, is also important because it represents one of the few ways that carbon can be rendered relatively inert, such that it can not easily recombine with oxygen to form CO_2. Hence, there is a strong potential for BC to act as a significant removal (sink) of carbon from the more rapid bio-atmospheric carbon cycle to the slower (long-term) geological carbon cycle (e.g., Graetz and Skjemstad, 2003; Schmidt, 2004; Druffel, 2004).

Role of black carbon in the global C budget

In a recent review of the formation and persistence of BC in terrestrial ecosystems, Forbes *et al.* (2006) provided a revised estimate of the formation of BC from vegetation fires and fossil fuel burning of 50 - 270 Tg yr^{-1}. This is a very large C flux and a key question is thus whether the rate of annual BC formation exceeds the amount of C released from the large pool of BC that is already accumulated in terrestrial and marine ecosystems. Whilst it is currently not possible to definitively answer this question, it is important to continue research that will enable a methodology to be developed in the future for accounting for BC in greenhouse gas inventories, and for better understanding the role of BC in the global C budget.

Forbes *et al.* (2006) also identified a set of important issues to be addressed in order to make development of a reliable methodology possible. They identified the need to describe rates of BC formation in a consistent way and suggested it should be expressed as a percentage of the amount of C consumed (CC) by fire. They found that when expressed this way (BC/CC), the rates of BC formation were <3% for grass and savanna fires, and 4-5% for forest fires. The authors concluded that estimates of BC formation based solely on physical measures are very unreliable (lead to significant over estimates) because they are unable to accurately identify and quantify the BC component of post-fire residues that also contain a range of partly combusted materials.

BC is subject to slow rates of degradation by photochemical processes and by microbial processes in soils and sediments, but knowledge of longer-term rates and of the factors affecting them is very limited. Research such as incubation studies has shown that BC degradation through biological processes is very slow. Other evidence also suggests very slow degradation of BC; BC can comprise up to 40% of the organic C in terrestrial soils and 12-31% of the very large pool of organic C in deep ocean sediments, and has radiocarbon ages in soils in excess of thousands of years. Hence, BC appears to have a significant half-life, in the order of thousands of years and is thus the most stable biomass-derived material in the biospheric C cycle. This relative inertness means that the estimated 3-5% of the carbon converted to BC during forest, savanna and grassland fires, must be considered a significant component of the global carbon cycle with a very slow turnover.

Conclusions

In order to better gauge the influence of BC on the global carbon cycle, an improved understanding of the production and degradation rates of BC are required for those ecosystems exposed to extensive vegetation fires. Further, the assessment of fluvial and aeolian transport of BC needs to be understood at fine scales, and a better understanding gained of degradation rates of BC in land and ocean sediments. This will allow a methodology for

accounting for BC in greenhouse gas inventories to be developed, and for uncertainties and discrepancies regarding estimates of BC fluxes between the atmosphere, biosphere and oceans to be minimised. The result will be a more accurate global black carbon budget, and better understanding of the role of BC as a potential sink in the global C cycle.

References

Druffel, E.R.M. (2004). Comments on black carbon in the global carbon cycle. *Marine Chem.*; **92**:197-200.

Forbes, M.S., Raison, R.J., and Skjemstad, J.O. (2006). Formation, transformation and transport of black carbon (charcoal) in terrestrial and aquatic ecosystems. *Journal of the Science of the Total Environment* (in press).

Goldberg, E.D. (1985). Black Carbon in the Environment: Properties and Distribution. John Wiley and Sons, New York; 198 pp.

Graetz, R.D. and Skjemstad, J.O. (2003). The charcoal sink of biomass burning on the Australian continent. CSIRO Atmospheric Research Technical Paper; no 64.

Schmidt, M.W.I (2004). Carbon budget in the black. *Nature*; **427**:305-306.