UKBRC

Biochar:

An Emerging Technology for Climate Change Mitigation?

Workshop proceedings, 1st April 2009

Saran Sohi, Simon Shackley, Mandy Meikle, Kimberley Pratt, Elisa Lopez-Capel, Stuart Haszeldine, John Gaunt, Ondřej Mašek, David Manning and Sarah Carter

April 2009

UKBRC Working Paper 1:

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UKBRC

www.biochar.org.uk

UK Biochar Research Centre

Reducing and removing CO_2 while improving soils: a significant and sustainable response to climate change.

Biochar: An Emerging Technology for Climate Change Mitigation?

1 April 2009, George Square, University of Edinburgh

Introduction: Biochar has emerged as a carbon mitigation option of potentially global significance. But many key questions remain to be addressed before we can be confident that biochar can be a major part of the move to a sustainable zero-carbon economy.

Aims of the Workshop:

- to map out the key research needs in establishing what role biochar may have in limiting atmospheric concentrations of CO_2 and other greenhouse gases;
- to identify the key research needs in deployment of biochar for carbon storage and as a soil amendment;
- to review and assess the role that the UK research community can and should have in addressing the above-identified research needs;
- to share information and to discuss how UK researchers can work together in meeting these research needs.

Contents

Programme

10.00 -10.55 am - Registration - Coffee/Tea on the balcony

Morning Chair: Professor David Manning, Newcastle University

11.00 -11.10 am – Welcome & Introduction – **Professor Stuart Haszeldine**, Scottish Centre for Carbon Storage, University of Edinburgh

11.15 – 11.45 am – **Keynote Presentation** - **The Biochar Landscape, Dr John Gaunt** Adjunct Associate Professor, College of Agriculture and Life Sciences, Cornell University

11.50 – 12.30 am – Key Biochar Research Needs. **Dr Saran Sohi**, UKBRC

12.35 – 1.00 pm – Engineering Principles in Biochar Production, **Dr Ondřej Mašek,** UKBRC

1.05 – 1.55 pm – Lunch – balcony

Afternoon Chair: Dr. Simon Shackley, UKBRC

2.00 – 3.30 pm – Break Out Groups

Facilitators: Saran Sohi, Stuart Haszeldine, David Manning, Ondřej Mašek, Jason Cook, Elisa Lopez-Capel, Simon Shackley

Scribes: to be appointed

3.35 – 4.00 pm – Coffee Break on the balcony

4.05 – 4.30 pm – Integrated Findings of the Break Out Groups

Discussion led by the Chair

4.35 – 5.00 pm – Wrap Up: How do we move forwards?

Discussion led by Stuart Haszledine

RECEPTION

5.15 to 6.45 pm: Reception Hosted by UKBRC or Researchers, Stakeholders and the Media - Atrium/Balcony

Guest Speaker: Professor Aubrey Manning OBE, FRSE, FIBiol

Brief Account of the Workshop

Prof. Stuart Haszeldine

Prof Haszeldine opened the day with an introduction. The UK Biochar Research Centre (UKBRC) is a parallel group to the Scottish Centre for Carbon Storage. Whilst the latter was set up to look at capturing carbon from power stations (CCS), the UKBRC extends the research into removal of carbon from the atmosphere. Biochar is a complex issue with many small players researching various aspects but there is a need for systematic research looking into questions such as the life-cycle of biochar carbon, soil impacts, and the value of pyrolysis-biochar in energy terms, soil improvement, climate and waste management. Of these four areas, there needs to be positive impacts in at least one or two of these areas, and ideally in all four. For a technology to be realised, it needs to move up the scale from academic research to 'readiness' (i.e. from theories to practical implementation). How can research shorten the lead-time from R&D to development and deployment. Some groups see themselves as ready for deployment, whereas others do not.

There is much contradictory evidence and regulators need robust and reliable information to develop and implement policy and rules governing the industry. The Centre has funding, mostly from the Engineering and Physical Sciences Research Council (EPSRC), of £2m over 5 years. Its mission is to weigh-up the evidence base - can Government and business make safe and secure decisions on biochar? To do this, there needs to be reliable manufacturing and categorisation and classification of different biochars, the process needs to be de-risked and monitored (e.g. in the CDM) and so on. The Centre lies between biochar's proponents (e.g. the International Biochar Initiative (IBI) and Jim Hansen) and those against it (e.g. BiofuelWatch and George Monbiot).

Dr John Gaunt

Dr Gaunt, an adjunct Associate Professor, College of Agriculture and Life Sciences, Cornell University and Carbon Consulting LLC delivered the keynote speech. He has a soil science background and believes that biochar research is driven by the need to reduce CO_2 concentrations in the atmosphere, which is predicted to rise to 650ppm and needs to be stabilised at 450ppm (requiring 35Gt CO_2 equivalent reduction per year by 2030 Vattenfall estimate).

Biochar offers an almost unique potential to drawn down CO_2 from the atmosphere, in contrast to strategies that reduce our rate of emissions. Annually, anthropogenic sources emit 7 - 9 Gt (Gigatonnes) carbon into the atmosphere, which is a small fraction of global carbon fluxes (soil, oceans etc). The flux of C through plants is 120 Gt of C annually, if we accept that when converted to biochar 20% of C captured through photosynthesis is stabilised against short term release back to the atmosphere the annual hypothetical potential for stabilisation is 24 Gt C (88 Gt CO_2e).

Understanding of biochar's behaviour in soil has been drawn from studies of ancient terra preta soils of the Amazon and other soils around the world. These provide evidence to increase confidence about its long-term carbon storage properties and of the benefits of biochar to soil fertility.

Pyrolysis of biomass for the production of biochar and bioenergy produces avoided emission from a number of sources. Where the biomass feedstock (e.g. green wastes) is diverted from management in a way that led to production of nitrous oxide or methane emissions, this represents avoided emissions. These avoided emissions are; energy produced during the pyrolysis process which replaces fossil fuel use, the C stabilised as biochar represent an avoided emission (as the C would otherwise have been released as CO_2 through burning or decomposition), and finally biochar application to agricultural soil which can reduce the need for fertilisers and reduce emissions of nitrous oxide and methane.

A paper by Gaunt & Cowie (2009)[1] contains figures for the potential GHG reductions based on green waste, cattle manure and wheat straw. Summary data indicated that a single unit which can process 2t dry matter per hour (the likely size of a small scale facility) would deliver approximately 14,000 – 58,000 t CO_{2e} avoided emissions annually. Application of this biochar to agricultural land would result in a further 700 – 1700 t CO_{2e} avoided emissions.

Therefore, from a carbon trading perspective for ease of management and to reduce risk, biochar might be better disposed of in landfill, down disused coal mines or as a construction material.

In contrast to the configuration described above sugarcane crop residues present an another example of a potential biochar feedstock. Sugarcane residues used to be burned in the field to enable manual harvesting of cane, and are now frequently left in the field are removed and turned into biochar without impairing soil fertility, together with bagasse (the residue left after cane processing). This would deliver in the order of 700,000 t CO_{2e} avoided emissions for a typical Brazilian sugarcane plantation.

If biochar is to deliver a major carbon offset option, it needs to be done at the Gt scale. There is an almost infinite number of technology configuration. In order to achieve a Gt offset quickly and effectively, whilst managing risk and uncertainty, it is desirable to identify configurations of feedstock, pyrolysis technology, bioenergy and biochar product that can deliver significant offset potential and to focus on these as scalable or repeatable opportunities .

There has been a huge surge in biochar R&D, with 160 papers published in just the last year or so. Commercial pyrolysis has existed for some time, however, and technology providers are looking at the opportunities that producing biochar may offer them. Whilst it is tempting to see a long term research opportunity, the immediacy of the climate problem means that we do not have this luxury. Linear technology development models are not appropriate. The attitude of many is that biochar is not a research challenge - we should just do it. There are some players who think they could be ready to produce biochar commercially in 6 - 12 months. This provides a unique challenge and opportunity for interdisciplinary research.

Q&A
What is the negative effect on the biosphere of removing rotting biomass carbon?
Biochar creates an environment conducive to biological activity. Even aggressively harvested cereal crops leave 45% of the organic matter in the ground (e.g. roots and exudates) so removal of surface residues is not seen as a problem. In the case of sugarcane, the bagasse was traditionally burned. Even repeated removal of waste does not reduce Soil Organic Matter (SOM) as this breaks down in a relatively short timescale in the soil anyway. Other land management techniques were suggested, which would help to reduce any potential negative effects, including low tillage, microbial inoculation, and adding trace minerals to the soil.

One of the slides showed a carbon offset benefit factor 30 times smaller than other offsets. Could biochar benefit be improved by designer biochar?
Yes, trading carbon via biochar is not a good bet unless the biochar products have increased value or use (e.g. for soil improvement). The gigatonne problem means that large amounts are needed for carbon trading.

Peter Read commented that carbon is not being removed and sterilised but is being used to improve soil condition and productivity.

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[1] Gaunt, J. and A. Cowie. 2009 Biochar, greenhouse gas accounting and emissions trading. In. Biochar for Environmental Management: science and technology. Eds. Lehmann J. and Joseph S. pp.317-336

Dr Ondrej Masek

Dr Ondrej Masek works for UKBRC as a lecturer in engineering systems, spoke on the engineering principles in biochar production. Biochar (or charcoal) has been produced for thousands of years (for cooking and smelting). It is made by pyrolysis (combustion usually without air) or gasification above 300^{o}C. The product is not pure carbon but has other impurities depending on the exact process. Pyrolysis is complex - above 300^{o}C, wood carbohydrate polymers (e.g. cellulose, hemicelluloses, lignin) cross-link and smaller molecules can interact. Temperature and pressure determine the primary, secondary and tertiary processes and end products (e.g. soot, tars, polycyclic aromatic hydrocarbons (PAHs) and char) as does the feedstock used.

Slow pyrolysis (i.e. a slow heating rate, and a lower temperature) gives a high yield of biochar (solids) while fast pyrolysis, with a higher heating rate, maximises liquid products (i.e. fuels). Biomass pyrolysis is endothermic (i.e. you need to supply energy) but between 280 and 350^{o}C it becomes exothermic (giving out more energy than went into the reaction). Slow pyrolysis and temperatures below 400^{o}C increase biochar production and the process can be altered to maximise solid or liquid products.

Various biochar production methods have been developed, including microwave heating. Some are easier to scale-up than others. Simple ‘earth pit’ technologies only produce about 10% biochar while novel methods can achieve up to 50%. Simpler (batch) methods are cheaper and more widely available but are less efficient with limited scope for heat recovery. The industry would tend towards continuous (rather than batch) biochar production which is more efficient, can be flexible in the feedstocks type and can integrate heat use. It is however more complex and expensive. Novel processes include flash carbonisation (under pressure) which is quick while microwave pyrolysis minimises secondary products and the char has a better structure. Gas and liquid products of pyrolysis can be used for heat and/or electricity generation in a number of ways.

Q&A
What is the difference between charcoal and biochar?
They are essentially the same but charcoal usually refers to batch systems. The term ‘biochar’ was coined by Peter Read some 5 years ago as a more ‘friendly’ term.

How do biochar systems cope with mixed feedstock, such as municipal solid waste (MSW)?
MSW is potentially problematic, in part because of the concentration of heavy metals.

Does biochar produced by different methods have different properties in soil?
The char structure will differ depending on the process used to produce it, and on the feedstock but the impacts of these types of biochar on soil are not well enough understood as yet.

Dr. Saran P Sohi

Dr. Saran P Sohi works for UKBRC and is a lecturer in Soil Science for Biochar. His talk looked at the key biochar research needs. UKBRC recently received a DEFRA contract to assess biochar. What are the motivations behind biochar - is it really ‘win-win’? Motivations include climate change, bioenergy, enhanced food production and commercial gain.

Biochar has soil benefits which can potentially mitigate some of the pressure from intensive agricultural methods (e.g. reducing chemical run-off). However once it has been added to the soil, it is irremovable, and biochar is not inert and its properties vary over time (e.g. nutrient benefit will decrease with time), so it is therefore vitally important to understand these properties.

Scale is also important - what quantity of biochar do we need and what is the land availability? There is also the timescale to consider - when compared to the IPCC scenarios, actual industrial CO_2e world emissions appear to be at the top end of the modelled range. Waiting for comprehensive functional understanding can slow things down. The feedstock type can also be a limitation as you can’t just switch from one to another if they are too different. If we have viable pyrolysis systems now, would their priority be to produce bioenergy or deal with waste?

Some risks and limits include the fact that biochar carbon in soil could exceed organic carbon within 15 - 150 years if its application is not regulated; biochar cannot be retrieved from the soil once applied; there needs to be a global adoption of best practice; NGOs need to be involved; and seepage (direct loss) and leakage (indirect loss) both need to be understood. A portion of biochar is highly labile and this varies depending on the process used, and other abiotic and biotic factors.

Much research has been done into terra preta soils but we have no way of knowing what ancient people applied to the soil, only what we see now. Archaeologists have found charcoal kilns dating from the 1800s in the Appalachian Mountains, and these are another potentially important research site. Likewise historical and archeological charcoals of UK and EU.

Biochar application impacts soil chemistry, including that it raises soil pH (liming effect) while its nutrient content depends on the feedstock used. Physical impacts include water retention (including solutes) and bulking of the soil, although lab experiments show that bulking is transient. The albedo of the soil will also be altered; dark soils absorb more heat and in Japan charcoal is applied to the land surface to melt snow in advance of planting. There are many inconsistencies and uncertainties in our knowledge. For example, David Wardle reported that fire-derived charcoal caused a loss of forest humus[2], but there are alternative explanations for this priming effect[3]; other evidence suggests that biochar incorporation can increase soil organic matter. Reported increases in crop yields are not likely to be a direct result of the char application but due to indirect effects and we need to understand these (e.g. changes in pH or microbial ecology, the original soil type etc). Much soil research has been lab-based and results are not understood (e.g. impacts on soil based emissions of N_2O emissions).

There was no time for Q&A

Breakout Groups:

Seven breakout groups were organised which looked at motivations, risks & barriers, and research requirements for biochar. Simon Shackley reported back the top 3 for each topic and audience members added to this. More detailed notes on some of the breakout group discussions are provided in the Annexes.

Motivations
Climate benefits/CO_2 stabilisation
Soil benefits
Economics (carbon markets, increased crop yield, decreasing waste)
Sustainable development - opportunities for poor countries to gain economically
Energy production - replacing fossil fuels

Risks & Barriers
In UK - Acceptability to market and regulators
    Regulatory strangulation
    Public perceptions
    Unknown processes in soils, including contamination by organic compounds
    Cost - need for subsidies if energy is excluded
    Sustainability of feedstocks

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[2] Wardle, D. A., Nilsson, M. C., & Zackrisson, O. (2008). Fire-derived charcoal causes loss of forest humus. Science, 320(5876), 629-629.

[3] Lehmann, J. and Sohi, S. (2008), Comment on “Fire-Derived Charcoal Causes Loss of Forest Humus”, Science, 321: 1295c

Overseas - Corruption
Lack of regulation
Leakage onto other types of land uses (competition or conversion of land)
Lack of knowledge and/or appropriate technology

Research needs

- One group argued that some uncertainties should not hold up biochar from being deployed
- Large scale reproducibility using sugar cane, rice paddy and landfill (these can be prioritised because they are relatively homogenous land types - if you test one, another is likely to have similar properties – and between them could constitute a major part of the one gigatonne carbon storage challenge).
- Life cycle of carbon and nitrogen
- Chemical and biological impacts on soils
- Feedstocks, processes and soils standardisation procedures (for reliable scientific results)
- Net climate forcing of carbon (including albedo)
- Dissemination of information as key points for policy makers (i.e. not just in academic papers)
- Temperate vs tropical research (most in audience who were working on biochar were looking at temperate, but the greatest potential is in tropical countries)
- Soil capacity for biochar (what's the maximum load, what's the frequency of application? etc.)
- Understanding of when use of feedstocks for energy is more valuable than use of biochar as soil improvers.

There was concern noted over the 'we know enough, we can get on with it' attitude given the problems we've had over the application of 'green compost' to land for food production in the UK, and warnings that the furore in the marketplace over sewage sludge on cereal land manures on lettuces could be repeated and should not be under-estimated. John Gaunt responded by saying that we know enough about producing biochar and its offset potential but we should use low-risk routes for disposal (e.g. landfill, old coal mines) until we understand the soil science better. David Wayne wanted to add that the cost of research to answer the many question is small, at least in relation to the sums of money liable to be invested relevant projects. There was discussion about the parallels that might be drawn between various biofuel "debacles" and the biochar proposal. There was a call for a "comprehensive full accounting" to be undertaken for PBS, that allowed included all foreseeable feedback effects such as modification of the planet's albedo. It was commented that if biochar is seen to 'work', that it might be difficult to control technological quality of PBS pyrolysis, with the risk of enhanced trace gas emission, not least from stimulating the expansion of traditional charcoal manufacture. Nonetheless, it was important that standards were laid down very soon, to guide those wishing to comply with best practice.

Workshop conclusion

The final session wrapped up by asking how we (UKBRC and those present) should move forward. Stuart Haszeldine (SH) started off with mechanisms for information exchange within the gathered community - annual meetings & an up-to-date website are easier to do than more frequent meetings and quarterly newsletters. Should UKBRC join the IBI? How to collaborate?
Q - Can UKBRC speak for all and renew its mandate at an annual meeting? SH - academics have independence and don't tend to get involved in lobbying and advocacy.
Q - Agree that independence is vital for reporting negative findings and problems as well as positive findings. Knowing the pitfalls is important especially given the timescale.
Q - There should be a body which represents more than one university - we need a multi-disciplinary forum
Q - Academic societies such as the British Society of Soil Science require topics for annual meetings - biochar should be put forward for this so as to facilitate more detailed and focused discussion as well
Q - A forum should have a central place where meeting minutes are available for those unable to attend and provide a platform focused reviews on different biochar topics should be produced to distil academic papers for a wider readership
Q - A forum should have NGO input given that public perception is a potential barrier. SH - maybe politicians too?
Q - Is there an overlap between academia and advocacy? Do we need a UK Biochar Initiative?

Q - If producing a newsletter, there needs to be news to report in it (e.g. members experimenting with their own small pyrolysis units)
Q - IBI has national chapters and a monthly newsletter. Easy to say but who funds it and who takes the lead? UKBRC could produce a newsletter without having an IBI sect in UK. All should feed news to UKBRC anyway, regardless of what structures or forums exist.
Q - In addition to NGOs and public perception, waste and incineration schemes are unpopular and often thwarted by small vocal groups opposing them due to unfounded claims. How to educate and discriminate biochar from charcoal, and at the same time disseminate objective and impartial information?
Q - Academics should urge Government to decide where biochar falls - currently dealt with by DECC and DEFRA.
Q - Research conducted in UK may not be deployed here. Could Edinburgh investigate different feedstocks with equipment installed here? Query importance of field trials (?)
Q - Would DfID fund tropical research?
Q - Access to biochar is a problem - need standard UK sources of char for testing. SH - such a proposal would need supporters - 20+ indications of academic support
Q - It might be difficult to import 'uncooked' biomass for biochar production but UK has a range of soils and feedstocks, and charcoal at least is currently imported at a rate of 65,000 t per annum
Q - Such a project would require co-funding
John Gaunt - this group should share results, which is important to show the value of research to others. There is land in the UK which needs to be restored, giving biochar an early entry potential. Also golf course and back yards may have potential. Don't assume there are no opportunities for biochar in UK or temperate countries even if on a relatively small scale in the global context
Q - A biomass pyrolysing facility is being built in Munich and should open next month; production at a scale of 10kg will be possible at University of Limerick by June this year
Q - Can we produce a delegate list with emails to enable contact? A show of hands indicated that everyone was happy for this. Delegates will be emailed and asked permission/opt-out.
Q - Presentations will be available on UKBRC website
Q - Lay foundations for PR improvements - biochar is still relatively unknown even among carbon reduction circles.

Acknowledgements

Thanks to the following for preparing these notes: Mandy Meikle, Kimberley Pratt, Elisa Lopez-Capel, Saran Sohi, Simon Shackley, Stuart Haszeldine, John Gaunt, Ondřej Mašek, David Manning and Sarah Carter.

Annexes: Breakout Group Discussions

Whilst seven break-out groups were held, not all the groups chose to write-up a report on the discussions held. The information below is therefore not necessarily representative of the discussions in all groups.

Group 1: Moderator - Simon Shackley (University of Edinburgh, UKBRC)

Attendees: Matthew Brander (Ecometrica), Mairi Black (Imperial College London, Porter Alliance), Kimberley Pratt (Scottish Agricultural College), Phillipa Ascough (Scottish Universities Environmental Research Centre), Roger Unwin (Consultant), Emmanuel Duga (University of Reading, Soil Science Department), Dan Gaze (Centre for Alternative Technology), John Kearney (Centre for Alternative Technology), Ulrike Schwarz (J&K Trainer Brownrigg Farm) and Ulrich Loening (Centre for Human Ecology/Lothian Trees and Timber).

Motivations for Biochar:

- Carbon fixation
- Stabilisation of contaminants
- Conflicts between research and policy → risk. Where are the riskiest unknowns? We can't afford 10 years of research.
- Soil improver for agriculture – re-carbonisation, health impacts on plants, reduced runoff, carbon store, fertility, water retention etc.
- Better waste management
- Climate change mitigation
- Carbon market
- Other green house gases emissions
- Farm scale recycling and closing the loop
- Risk of loosing Nitrogen from use of manure
- Human (and others) health

What is Biochar?

There was discussion about the term biochar and whether a definition which separated it from charcoal could be found. It was suggested that charcoal was any solid material produced from biomass which was pyrolyised and biochar was, therefore, a subset of charcoal. However, other members of the group felt that charcoal was a subset of biochar. The eventual definition may focus on the function of the product rather than the physical properties of the char. There also needs to be stronger definitions of where biochar falls under UK regulations for waste management. Since it is made from biomass some people doubted whether biochar should fall under waste management at all.

Key Variables:

- Feedstock
- Production
- Soil Types/climate

Risk Management:

- Is biochar a waste or part of an agricultural process? How does this fit with current UK regulations? When is biochar a waste? It depends on the inputs and purpose of process. Nature has no waste.
- Farm assurance schemes
- Big risk: once it is in the soil, it is impossible to get biochar back
- Mobile pyrolysis units could be used to reduce transport risks
- What will DEFRA be concerned about? N cycle, regulation and definitions. What are the priorities and key policy drivers, and how does biochar impact on these priorities?
- Hyper-regulation – over regulation can stifle a new industry

- Time and money – research questions could take years to answer but climate change demands action now
- Defining the size of the system is required – if biochar is implemented at the local level then this could reduce the risks.
- Trade-off between risks
- CDM Vs VCS
- Lack of incentives
- Public perception and the track record of biofuels

Research Questions:

- What is the difference between biochar and soil carbon/ stabilised organic matter? How do we measure biochar? Look at the baseline before biochar is added and compare to experimental data.
- How should carbon credit methodologies be implemented? Research base for the baseline data needs to be defined and quantified.
- What are the differences between tropical and temperate (UK) biochar datasets?
- Should a UK/international body be set up to respond to criticism of biochar?

Top Three:

Motivations:

1. Carbon fixation/ climate benefit
2. Soil Improvement
3. Economic benefits

Risks (UK):

1. Acceptability to the market
2. Strangulation by regulation
3. Uncertainty associated with new agricultural practices

Risks (BRICS):

1. Leakage/ Land use
2. Complexity for verification – so many unknown variables
3. Under-planning

Research Questions:

1. Carbon and Nitrogen life cycles
2. Impacts on soil: physical, chemical and biological
3. Agronomy

Group 2: Moderator - Elisa Lopez-Capel (Newcastle University and UKBRC)

Key Motivations

Categories

-Climate change: adaptation, carbon sequestration, positive benefits (increase yields), indirect benefits (stop leakage), more efficient land management (reclaimed land, set-aside, avoid de-forestation)

-Mitigation with no change in lifestyle

Full list of categories

1. Carbon credits (poverty alleviation) →1 vote
2. Carbon capture
3. Adaptation
4. Energy for poor people
5. Waste management →1 vote
6. Health benefits
7. Cleaner energy
8. Landfill diversion
9. Climate change (reduce emissions) →8 votes
10. Sustainable cycle (land use, yields, energy) →1 vote
11. Flexibility (food-energy balance)
12. Security (Energy)
13. Economics (viable)
14. Land productivity
15. Public awareness/politicians

Reporting back (shortlist and reason)

Carbon credits (poverty alleviation) →1 vote because of poverty alleviation

Sustainable cycle (land use, yields, energy) →1 vote because of food security

Climate change (reduce emissions) →8 votes because of C capture and adaptation

Risks and barriers (UK)

Categories

Some defined below

Full list of categories

1. Energy pays more than C credits
2. Sustainability (nutrient dynamics, labile SOM depletion if increase amount of biochar?)
3. Change is soil chemistry (needs to be fully understood, CEC, pH, mineral…)
4. Which carbon can I get carbon credits for? Validation problem. Credits for reduce use of fertilizer, soil C content, more for recalcitrant than labile C?
5. Production of GHG. Whole process level information (feedstock-transport-power plant..), trap C but what about NOX? →1 vote
6. Positive benefits not guarantee→1 vote
7. Uncertainty of impact of stability of soil carbon (C/N ratio and C pools)
8. Lack of knowledge: need more research, method and technique limitations (lab experiments may not be relevant in field situation, adequate monitoring, economics, wrong methods?) →4 vote
9. Competing industries (waste management incineration, AD/solar/wind/…)
10. Timescale: lack of datasets collected at the right scale (representative of long term) →1 vote
11. Public acceptability: No back up from regulators, politicians, general public. →2 vote

Reporting back (shortlist and reason)

Lack of knowledge (scientific etc) → therefore there is a lack of support from regulators, research councils, politicians, public

Production of GHG→ from feedstock production, thermal process, soil application

Public acceptability→ social acceptance is low

Risks and barriers (BRIC/DC's)

Categories

Full list of categories

1. Previous ones described for UK
2. Corrupt governments/agencies→2 vote
3. Monitoring by corrupt governments/agencies→1 vote
4. Lack of infrastructure/capital→2 vote
5. Food security/ poverty
6. The go ahead without knowledge/understanding/lack of regulation→2 vote

Reporting back (shortlist and reason)

1. Corrupt governments/agencies
2. Lack of infrastructure/capital→ not economically viable at large scale (so that it can make a noticeable impact)
3. The go ahead without knowledge/understanding/lack of regulation→ lack of planning and regulations. This could cause an economical, environmental and health risk, and have a negative impact of the success of biochar implementation.

Research Barriers. How can researchers address these challenges?

Barriers

1. Funding support to address the lack of knowledge
2. Limitations of methods and techniques available. Some techniques are very expensive and not suitable for large number of samples. There is a need for rapid screening techniques
3. Only short term answer achievable
4. Need to prioritise: carbon capture in developed countries versus agricultural benefit in developing countries.
5. Timescales

How can researchers address these challenges? And by when?

When → IPCC dictates the deadlines 2012? 2050?

How:

- Obtain information from existing operating pyrolysis plants
- Use information available form 4 year studies and try to extrapolate
- Carbon capture can be done. The technology is available, even if simply burying biochar.
- Waste management
- We can help with (although not fully address) the Gt scale

Group 3: Moderator – Ondrej Masek (University of Edinburgh, UKBRC)

Motivations

1. Reduce emissions
2. Financial incentives → identified as major incentive
3. Easiest option for CCS → identified as major incentive
4. Soil conditioner → identified as major incentive
5. Waste disposal
6. Distributed energy
7. Avoided land claim
8. Local ownership / flexibility

Risks

- Soil fertility effect may be absent →identified as major risk
- Stability
- Contamination
- Irreversibility
- Insufficient regulations and misdirected incentives →identified as major risk
- Threat to wildlife
- Non-sustainable feedstocks →identified as major risk
- Impact on food quality
- Nutrient loss
- Forest / soil fire
- For ground-stored biochar – lifetime?

Barriers

- Risk assessment strategies
- Public perception
- Over regulation

Research questions / objectives

- Basic characterisation and standardisation of resources and processes
- Learn from biofuels – sustainability, Life Cycle Assessment
- Develop framework for regulation development
- Dissemination of findings to policy makers

Group 4: Moderator – Stuart Haszeldine (University of Edinburgh, UKBRC)

Motivations for biochar

1. Profits from the system
2. Carbon markets
3. Sustainable development (including scalar / land area issues)
4. Fertility (also can aid germination and establishment of seeds in the soil).
5. Nutrient retention
6. Greenhouse gas reduction → identified as major incentive
7. Health benefits risk
8. Landfill offset
9. Is biochar enough? (it's a question worth answering in the changing climate)
10. Alternatives are not abundant for CO_2 draw down / CCS technology

The economics

Biochar by itself is not economic; the value is derived from an integrated approach. 50% of cellulose can produce useful and valuable chemicals. Carbon trading also is important as it may enable otherwise un-economic schemes to be feasible; however the extent is unknown, particularly in the current economic crisis.

Risks and barriers

- Demonstrable technology → Primary barrier
- Regulations → Secondary barrier
- Profit → Secondary barrier
- Public perception
- Health (risk to humans)
- Mobility (cheap batch production is available however)
- Land availability
- Feedstock competition (anaerobic digestion, mass burn in cultivation, burning)
- Business models
- Costs (including capital costs, the risk is that the technology may not operate at an economic scale).

Research challenges & How to move forward

- Prove technology – pilot demonstrations to remove / reduce the risk
- Increase understanding of revenue and ongoing income streams available
- Work with regulations / policy drivers
- Verification
- Time is imperative
- Large scale field trials in most important areas first (Brazil, Africa)
- Focus on sugarcane and rice husks
- Development and manufacture of feedstocks
- Donors need incentives to provide funding – direct: Government funding, indirect: Shell etc.
- Systematic global programme
- Involve engineers
- Identify early opportunities and classifications

Group 5: Moderator – Saran Sohi (University of Edinburgh and UKBRC)

Motivations for Biochar

These are in an approximate order of importance for the group.

- Human [Humanity's] future – as an ethical [-moral] issue
- Maintenance of total stock of carbon in soil (as distinct from increasing it)
- Energy and fuel (especially in context of energy security)
- Climate change mitigation ([by offsetting CO2 emissions elsewhere] and lower net emission of other greenhouse gases)
- Increasing crop yields [via soil fertility]
- Food supply (as distinct from crop yield on area basis)
- Nutrient management [in agriculture] and fertiliser 'replacement'
- Agricultural sustainability [maintaining yield, harmony of farming and environment]
- Flood management, [efficiency of] water use … [water management generally]
- Water pollution [control of…] – environmental angle
- Biomass burning [minimisation of…] – air pollution (human health angle)

- Waste management (whole supply chain)
- Poverty alleviation
- Profit [and various things around this]
- Reduced pressure on [rain]forest (specifically)
- Erosion control

Risks and Barriers – UK

- Biochar may [comprehensively] “not work” – RN: [self explanatory]
- Plastic waste may be used (a benefit?)
- Wind-blown biochar (health)
- Application of biochar to natural systems where not suited, and/or leading to loss of [pre-existing] soil carbon
- “Non-carbon” benefits will not be recognised
- Loss of counterbalancing “global dimming” effect from smoke will be lost
- Earth’s albedo could be modified – RN: complex and unexpected feedbacks need to be identified and evaluated
- Impact on diversity on soil (may be changed, may be decreased, balance may be changed) – RN: carefully evaluate impacts on below-ground biodiversity
- Efficacy of agrichemicals reduced
- Store up (or beneficially neutralise?) soil contaminants
- Impacts on plant pests (beneficial?)
- Regulation (..might stifle the opportunity)
- Technology innovation [not understood]
- Under-estimation of benefits [by markets or scientifically] – RN: to fully evaluate nature and reliability of all possible benefits
- Capacity [for pyrolysis–biochar systems is ultimately and fundamentally] limited

Risks and Barriers - BRICS

Key reasons for selecting BRICS over “developing countries” for debate –

- Scale of production and NPP within a single national boundary very high
- Scale of [many individual] farms – and plantations – very large
- Scale of pyrolysis plant and ease of monitoring [biochar application] large
- Extent of rice based cropping (as a key global source of methane)
- Scale of carbon emission from other sectors within same countries are escalating [so clear choices for GHG management within, rather than trans, boundary]

Risks:

- [Knock on effects on] land-use – possible accelerated loss of forest … and associated biodiversity
- Does not deliver [promised net GHG benefit]
- Weak regulatory frameworks [but noted that these combined with flexibility and entrepreneurial culture could assist in realising the opportunities…]
- Emissions quota is larger so reducing incentive to support PBS [?]

UK BIOCHAR WORKSHOP – 1ST APRIL 2009

List of delegates: Alphabetical by Surname

Dr Paul	**Alexander**	Royal Horticultural Society
Mr Richard	**Allen**	Centre for Alternative Technology (CAT)
Dr Phillipa	**Ascough**	Scottish Universities Environmental Research Centre (SUERC)
Dr Francisco	**Ascui**	University of Edinburgh, Business School
Miss Madeleine	**Bell**	Durham University
Dr Mairi	**Black**	Imperial College London, Porter Alliance
Prof Stefano	**Brandani**	University of Edinburgh
Mr Matthew	**Brander**	Ecometria, Edinburgh
Dr David	**Brignall**	Wardell Armstrong LLP
Miss Laura	**Brown**	Durham University
Mr Matthew	**Brown**	Askham Bryan College
Dr Peter	**Brownsort**	University of Edinburgh, School of GeoSciences
Mr Chris	**Budleigh**	Psi-ense Ltd.
Ms Yasmin	**Bushby**	University of Edinburgh
Miss Sarah	**Carter**	University of Edinburgh
Dr Joanna	**Cloy**	University of Edinburgh
Mr Gary	**Connelly**	Ethos Energy Ltd
Mr Jason	**Cook**	University of Edinburgh, UKBRC
Dr Julia	**Cooper**	Newcastle University
Dr Rocio	**Diaz-Chavez**	Imperial College, Centre for Environmental Policy
Colin	**Cunningham**	Scottish Environmental Technology Network
Dr Karen	**Dobbie**	Scottish Environment Protection Agency (SEPA)
Mr Emmanuel	**Duga**	University of Reading, Soil Science Department
Dr Rachel	**Dunk**	Crichton Carbon Centre
Dr Mark	**Durenkamp**	Rothamsted Research

Dr Paul	**Eke**	University of Edinburgh, Scottish Centre for Carbon Storage
Dr Chris	**Ennis**	Clean Environment Management Centre
Corinne	**Evans**	
Ms Mariska	**Evelein**	Carbon Consulting LLC
Dr Jean	**Fitzgerald**	East Malling Research
Mr Alfred	**Gathorne-Hardy**	Imperial College, Centre for Environmental Policy
Dr John	**Gaunt**	Cornell University, College of Agriculture & Life Sciences
Mr Dan	**Gaze**	Centre for Alternative Technology (CAT)
Dr Nigel	**Goddard**	University of Edinburgh
Mr Brendan	**Hamill**	University of Edinburgh
Mr Jim	**Hammond**	University of Edinburgh
Dr Jerry	**Harrison**	VenEarth Group
Mr Rob	**Harley**	Bioclimate Research & Development
Prof Michael	**Hayes**	Carbolea, University of Limerick
Prof Stuart	**Haszeldine**	University of Edinburgh, School of GeoSciences & UKBRC
Ms Kathleen	**Hewlett**	Soil Association
Dr Neil	**Hipps**	East Malling Research
Archie	**Hunter**	
Colin	**Hunter**	
Dr David	**Hutchinson**	Charcoal Foundation
Mr Richard	**Illiffe**	Centre for Alternative Technology (CAT)
Mr Gerry	**Jones**	Centre for Alternative Technology (CAT)
Dr John	**Kearney**	Centre for Alternative Technology (CAT)
Dr Andy	**Kerr**	University of Edinburgh, SAGES
Dr Russell	**Layberry**	Oxford University
Mr Arthur	**Llewellyn**	Carbon Gold, London
Dr Ulrich	**Loening**	Centre for Human Ecology / Lothian Trees & Timber
Dr Elisa	**Lopez-Capel**	Newcastle University, SWAN Institute & UKBRC
Dr James	**Mair**	Heriot Watt University
Dr Phillip	**Mann**	Oxford University
Dr Pete	**Manning**	Imperial College

Prof Aubrey	**Manning**	University of Edinburgh
Prof David	**Manning**	Newcastle University, IRES & UKBRC
Dr Ondrej	**Masek**	University of Edinburgh, UKBRC
Mr Michael	**McCreath**	TC McCreath & Co
Dr Niall	**McNamara**	Centre for Ecology & Hydrology (CEH), Lancaster
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Ms Alexa	**Morrison**	Plan Vivo Foundation, Edinburgh
Ms Janet	**Moxley**	Scottish Environment Protection Agency (SEPA)
Dr Mark	**Naylor**	University of Edinburgh
Dr Peter	**Olsen**	Scottish Environment Protection Agency (SEPA)
Ms Kimberley	**Pratt**	Scottish Agricultural College (SAC)
Cahyo	**Prayogo**	Warwick University
Ms Anna	**Presswell**	Mercy Corps UK
Dr Colin	**Pritchard**	University of Edinburgh
Ms Deborah	**Proctor**	Joint Nature Conservation Committee (JNCC)
Dr Barry	**Rawlins**	British Geological Survey (BGS)
Prof Peter	**Read**	Massey University, New Zealand
Dr Bob	**Rees**	Scottish Agricultural College (SAC)
Dr Frances	**Rayns**	Garden Organic HDRA
Dr David	**Reay**	University of Edinburgh
Dr Steven	**Robinson**	University of Reading, Department of Soil Science
Dr Alison	**Rollett**	ADAS
Mr Grant	**Rooney**	Alba Building Sciences Ltd
Mr Andy	**Rutherford**	University of Edinburgh, School of GeoSciences
Dr Ruben	**Sakrabani**	Cranfield University
Dr Ulrike	**Schwarz**	J&K Trainer Brownrigg Farm
Mr Graham	**Scott**	Sustainable Oban
Dr Simon	**Shackley**	University of Edinburgh, UKBRC
Dr Helen	**Sneath**	University of Surrey

Dr Saran	**Sohi**	University of Edinburgh, UKBRC
Ms Angela	**Smith**	University of Edinburgh, School of GeoSciences & UKBRC
Dr F Alayne	**Street-Perrott**	Swansea Bichar Research, Swansea University
Mrs Chue Po	**Tan**	University of Edinburgh
Mr Roger	**Unwin**	Consultant
Ms Naomi	**Vaughan**	University of East Anglia, School of Environmental Sciences
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Mr Christopher	**Willans**	Newcastle University
Evan	**Williams**	Consultant
Dr Roger	**Williams**	Royal Horticultural Society
Dr Jeremy	**Wingate**	Forest Research
Chris	**Winslow**	Consultant
Mr Ben	**Witchells**	BioRegional
Dr Phillip	**Woodhouse**	University of Manchester, School of Environment & Development
Mr Dominic	**Woolf**	Swansea University

UKBRC

www.biochar.org.uk

UKBRC

Biochar, reducing and removing CO2 while improving soils: A significant and sustainable response to climate change

Evidence submitted to the Royal Society Geo-engineering Climate Enquiry in December 2008 and April 2009

Simon Shackley, Saran Sohi, Stuart Haszeldine, David Manning and Ondřej Mašek

May 2009

UKBRC Working Paper 2:

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Summary

1. The focus of this response is evaluation of a single option – that of biochar for carbon storage in soils.
2. Biochar is primarily a response to climate change. Carbon savings come from carbon sequestered for the long-term (100's to 1000's years) in biochar, and from avoided emissions (from substituting fossil fuels and fertiliser; and through suppression of methane and nitrous oxide emissions).
3. A conservative estimate is that 1 gigatonne of carbon per year can be stored in biochar by 2050, and probably by 2030, mostly produced from agricultural residues and organic wastes. More ambitious proposals, which progressively use dedicated biomass stocks, could increase this to 5 – 9 gigatonnes C per year by 2100, and probably much earlier, though careful evaluation of the environmental and socio-political implications of such a scenario is necessary (e.g. to ensure that it does not simply lead to a massive expansion of unsustainable agri- and silvicultural plantations).
4. Whilst biochar is readily produced from a wide range of organic feedstocks and wastes, the efficient 'closed-system' slow pyrolysis technology is still at a relatively early stage of development and is consequently still relatively expensive. As experience grows, several dominant designs should emerge and unit costs and maintenance & operation costs should come down.
5. Biochar has been shown to improve productivity of crop growth in many different soil and agronomic conditions, though there is a lack of scientific understanding of what explains this effect. Biochar has also been reported to suppress CH_4 and N_2O emissions from soil and to improve water retention.
6. The UK's universities and research institutes are ideally placed to take biochar RD&D forward. A coordinated approach by the Research Councils will, however, be necessary.

Question 1: What do you consider to be the current state of knowledge regarding the feasibility, efficacy and predicted impacts of biochar schemes?

What is biochar? Biochar is a black carbon material produced from the decomposition of plant-derived organic matter (biomass) in a low- or zero-oxygen environment (i.e. pyrolysis or gasification) to release energy-rich gases which are then used for producing liquid fuels or directly for power generation. The carbon atoms in biochar molecules are strongly bound to one another, and this makes biochar resistant to attack and decomposition by micro-organisms. By contrast, the carbon in most organic matter is rapidly (between 1 and 5 years) returned to the atmosphere as CO_2 through respiration. Consequently, biochar is a potentially highly valuable way of stabilising carbon and storing it in soils and is one of very ways of removing CO_2 from the atmosphere. There are a very wide range of potential biochar feedstocks: e.g. wood waste, timber, agricultural wastes, manure, leaves, food wastes, straw, paper sludge, green waste, distillers grain, bagasse and many others.

The main technologies for producing biochar are fast, moderate and slow pyrolysis and gasification. Pyrolysis produces between 12 and 35% biochar (dry basis), with slow pyrolysis (at about 500^{o}c and with a very long vapour residence time of between 5 and 30 minutes) giving the best biochar yields. Gasification occurs at a higher temperature of at least 750^{o}c with a moderate vapour residence time of 10 to 20 seconds (Brown, 2009) and generates approximately 10% biochar (dry basis). Biochar has a unique porous structure and chemical composition which enhances soil fertility and allows for a more sustainable use of some soils. Biochar is first and foremost, however, a response to the problem of climate change. This is through the long-term storage of carbon in soils in a stable form as biochar, with additional carbon offsetting arising from the avoided emissions from fossil fuel combustion, fertiliser application and field operations.

Longevity of Biochar Carbon Storage: Biochar from forest fires has existed in some soils for 10,000 years, whilst radiocarbon dating of the *terra preta* soils of Amazonia show that the carbon can persist in the soil for between 500 and 7000 years before present (Lehmann et al., 2009). One conservative estimate is that the Mean Residence Time (MRT – the average time that biochar remains in the soil) is between 1000 and 2000 years for dryland conditions of northern Australia. A recent study confirmed that the MRT for black carbon in two Australian savannah regions was between 1,300 and 2,600 years (Lehmann et al., 2008). The half-life of biochar found in coastal temperate forests in western Vancouver has been calculated as 6623 years (Lehmann et al., 2009). There are, however, some other studies which show a much faster turn-over time for biochar. A study of fires in the Russian steppe concluded that the turn-over time of biochar was only 293 years. Meanwhile, biochar stocks formed after savannah burning in Zimbabwe had a MRT of only a few decades. Lehmann et al. (2009) suggest that these much lower residence times might be explained by processes other than mineralization alone (such as leaching or erosion).

The longevity of biochar in soils should not be overestimated: an unknown but large-scale mechanism for removing black carbon appears to exist. We know that more black carbon is produced than is found in possible long-term sinks (e.g. ocean sediments and the soil organic carbon pool) (Woolf 2008). Over-accumulation of black carbon in soils is also inconsistent with empirically-validated models of the response of carbon in soils. One of the critical research needs is better understanding of such processes on different timescales. In summary, whilst there are major scientific questions to be addressed regarding longevity, there is good evidence that biochar, if managed correctly, will remain in soils for at least 1000 years and possibly much longer. These timescales look sufficient for biochar to qualify as a viable option for atmospheric CO_2 reduction (since, to be effective in tackling anthropogenic climate change, the carbon must be removed from the atmosphere for hundreds to a thousand years) (Shackley and Gough 2006).

How Much Carbon Can Biochar in Soils Store? The amount of biochar that can be stored in soils is a function of the concentration of the material in the soil and the depth to which it is incorporated. To date, we have the evidence of the *terra preta* soils of Amazonia, which contain approximately 50 tonnes of black carbon per hectare to a one meter depth (Glaser et al., 2001). Applications of up to 140 tonnes of biochar per hectare on weathered soils in the tropics resulted in crop yields, and without reaching a point at which yield increases ceased (Lehmann et al. 2006). Several trials with particular crops have shown a threshold effect, and Lehmann concludes that: “crops respond positively to bio-char additions up to 50MgC ha^{-1} and may show growth reductions only at very high applications.” Biochar is a variable substance whose properties are determined by feedstocks, conversion processes and the soils into which it is applied. Exactly how much biochar can be applied in different agricultural and land-use contexts, and on what timescales, is not well understood at present.

Lehmann et al. (2006) estimate that current global *potential* production of biochar is 0.6 ± 0.1 gigatonnes per year (10^9 tonne or $PgCyr^{-1}$). They estimate that by 2100 production of biochar could reach between 5.5 and 9.5 gigatonnes per year. There are very large uncertainties attached to these numbers, however, arising from competition for land-use, competition for use of biofuels and agricultural wastes and a huge divergence (of nearly 1000%) in different expert estimates of the potential future global supply of biomass for bioenergy purposes. Woolf (2008) estimates that if all existing agricultural crop residues were used to produce biochar, this would constitute 1 gigatonne of carbon storage. A reasonably conservative assumption would be that biochar has the potential to offset global atmospheric carbon emissions at the gigatonne per year scale by 2050 (and probably by 2030 if a concerted effort were made) - one of the climate ‘wedges’ in Pacala and Socolow’s (2004) schematic, hence comparable to other major mitigation activities (CO_2 Capture and Geological Storage (CCS), renewables, efficient vehicles, etc.).

Positive Impacts of Biochar Upon Soils: Studies of biochar-rich *terra preta* and *terra mulata* soils in Amazonia have stimulated interest in the agricultural benefits of incorporating biochar into soils. Crop fertility appears to improve in many situations where biochar has been incorporated, whilst such soils appear to retain water more effectively, as well as possibly reducing run-off of agricultural inputs and, in some circumstances, limiting nitrous oxide and methane emissions. In tropical environments, biochar has sometimes increased crop yields 2- or 3-fold, although at the moment the impact is not predictable. Biochar can also reduce the number and intensity of field operations, thereby reducing diesel use. And biochar addition appears to stimulate the net primary productivity of many agri- and ecosystems, thereby resulting in a net uptake of carbon.

Reviews of the agronomic impacts of biochar have been undertaken by Woolf (2008) and Blackwell et al. (2009). The reason why soil productivity is improved appears to be related to the following factors: reduction in soil acidity, improvement in the cation exchange capacity, an improved habitat for soil microorganisms and better water holding capacity. The pore size allows beneficial microorganisms to find suitable shelter from predatory soil fauna. Meanwhile, water retention in biochar occurs because water molecules collect in the voids, though chars can be hydrophobic so there is some uncertainty on whether water retention will be a universal property of biochar (Woolf, 2008). Whilst most greenhouse- and field-trials generally show the beneficial impacts of biochar upon agronomic performance, there is a high degree of variability in the response - hardly surprising considering the diverse sources of biochar and the highly variable soils and agronomic systems into which biochars have been introduced.

The Efficacy of Biochar as a Form of Carbon Storage: Evaluating the efficacy of biochar requires consideration of the energy and carbon balance of the full life-cycle. What is the energy yield (i.e. energy inputs compared to the energy outputs) for pyrolysis biochar systems (PBS)? What is the net carbon benefit (i.e. avoided greenhouse gas emissions plus carbon that is sequestered in the long-term) of PBS and how does this compare to other ways of using biomass for sustainable energy (such as combustion for electricity or heat, Combined Heat and Power, anaerobic digestion, fermentation, etc.). Is it better in carbon terms to use biochar as an energy source rather than applying it to soils as a long-term carbon store?

Fowles (2007) found that in terms of carbon balance, it is better to use biomass for PBS than for straight combustion if the reference case (i.e. what is being replaced) is natural gas or the national grid mixture. On the other hand, if coal combustion is being replaced, then more carbon emissions are avoided by using the biomass for conventional electricity generation than to use PBS. Fowles assumed that 30% of the material is converted to, and permanently stored as, carbon as well as a 33% efficiency for biomass combustion. Furthermore, if biomass combustion is utilised with a Combined Heat and Power system (which typically reaches 80% efficiency), then use of biomass in such a way is preferable to PBS, except when the reference case is natural gas at 80% efficiency. Fowles did not include the avoided CO_2 emissions arising from the use of pyrolysis syngas or bio-oils, or suppression of non-CO_2 GHGs, so his estimate of the carbon value of biochar is almost certainly an underestimate.

As yet, very few Life Cycle Assessments (LCA) of pyrolysis + biochar have been undertaken so we cannot currently answer several key questions. Gaunt and Lehmann (2008) compared growing winter wheat with the production of bioenergy crops (BECs) (Miscanthus, switch grass and corn) and also explored the use of crop wastes (winter wheat straw and corn stover) to produce biochar. Their findings can be summarised in the key points below:

- The energy output is greater than the energy input by 2 to 7 times in the case where slow pyrolysis is optimised for biochar rather than for energy production (with a consequent 30% reduction in energy output). This energy balance compares favourably with comparable technologies such as ethanol from corn (which yields 0.7–2.2 MJ MJ^{-1}).
- The CO_2 emissions arising from pyrolysis are in the range 91 to 360 kg CO_2 per MWh (with no account taken of carbon sequestered in char, or other impacts of char on GHG emissions when applied to soils). This compares with emissions of 390 to 880 kg CO_2 per MWh for gas and coal respectively (in the UK).
- Including all the carbon avoided and sequestered, PBS accounts for 4 to 8 tonnes carbon avoided per hectare per year when PBS is optimised for energy generation; and between 12 and 19 tonnes avoided per ha per year when PBS is optimised for biochar production. Hence, optimising for biochar production rather than bioenergy avoids between 3 and 5 times more carbon. The carbon stored in biochar accounts for 41 to 64% of the overall carbon avoided, whilst avoided fossil fuel emissions, reduced fertiliser use and reduced non-CO_2 GHG emissions account for the remainder.

2. How do you think research into biochar should be taken forward, and by whom?

UK universities and research institutes are very well positioned to take forward RD&D on biochar. There are core competencies in the life sciences, soil and other geosciences, sustainable energy engineering, and systems analysis. The UK Biochar Research Centre will endeavour to play a coordinating and facilitating role to UK research activities, in addition to undertaking leading-edge research.

3. What factors need to be considered before deploying any biochar schemes? Who should be responsible for any deployment?

To our knowledge, there are no evident negative impacts arising from applying biochar to soils. According to Gaunt and Lehmann (2008), use of slow pyrolysis avoids the production of dioxins and polyaromatic hydrocarbons, which can be persistent organic pollutants. If biochar is deemed to be a by-product that is being disposed-of, then it is classified as a waste and the pyrolysis process and disposal of the biochar is subject to the onerous requirements of the Waste Directive. There are also regulations controlling what is put on to agricultural land in the UK and it is clear that a detailed environmental impact assessment will be necessary prior to any deployment of biochar, to ensure that there are no adverse impacts. Biochar projects in developing countries that are aiming to secure carbon credits, will be subject to evaluation under the Clean Development Mechanism. It is important that appropriate environmental impact assessment methodologies are developed and adopted internationally and the UK Government could play an important role here.

4. What do you consider to be the most important political, social, legal or ethical issues raised by biochar?

The use of PBS need to be carefully evaluated to ensure that there are no adverse impacts on land-use, potential conflict with food production or biodiversity protection. As is the case for biomass for bioenergy in general, if biochar becomes one of the principal carbon reduction 'wedges', there are inevitable implications for land-use change globally on a large-scale. Such land-use change raises important questions at a number of levels: environmental impacts from (potentially) intensive land-use; carbon emissions from forest clearing which may take years to 'pay back'; land ownership and equity issues regarding who benefits and who loses out from large-scale plantations; ethical issues regarding whether large-scale, intensive biomass cultivation is consistent with moves to a more sutainable zero-carbon society (e.g. see Ernsting and Rughani (2008) for a critical NGO perspective on biochar). If PBS is to contribute constructively to a sustainable response to carbon reduction, it is vital that the lessons of the past regarding the adverse environmental and socio-economic and political impacts of intensive plantations are learnt and acted upon.

5. What do you see as the main barriers to, and opportunities afforded by, biochar?

Biochar provides an opportunity for involving farmers and landowners as participants in carbon markets; this is important to rural livelihoods and diversification in all countries, and lends itself particularly well to poverty alleviation in developing countries. Creative approaches to certification and verification of biochar under the Clean Development Mechanism (CDM) could permit a much-needed step-change in the engagement of small farmers from developing countries in the CDM. There is, furthermore, an opportunity for biochar to contribute to low-carbon food chains, i.e. if the carbon stored in biochar (derived from crop residues) can be accounted for in the carbon footprint of foods. PBS may also provide important low- or negative-carbon alternatives to existing and emerging waste technologies.

A key barrier at present is the lack of reliable off-the-shelf pyrolysis technologies at a suitable price. Technology development is proceeding rapidly but there is, as yet, no 'dominant design' in the market, and it is likely that a variety of competing designs will be available to developers over the next few years before the market settles on a few preferred designs. At this stage of the technology cycle, costs per unit are likely to remain high and performance, reliability and operability parameters are still being formalised. Partly as a consequence of technological uncertainties, economic analyses of biochar are at present in their infancy. Gaunt and Lehmann (2008) found that the cost of reducing a tonne of CO_2 in the PBS they examined was between \$9 and \$16 (relative to maximising the plant for energy production). This is considerably less than the average cost of a tonne of CO_2 under the EU ETS over the past several years. The authors do not, however, provide a full economic costing of their PBS, so the abatement cost is not comparable with commonly quoted values for other technologies. McCarl et al. (2009) have undertaken a full economic costing of biochar for US conditions and find that the use of maize residue using fast or slow pyrolysis is not profitable. They do find, however, that the economic value of carbon storage in biochar is slightly greater than its value as an energy source, especially at the summer 2008 carbon price on the EU ETS (\$40 tCO_2^{-1}). For slow pyrolysis to be economic, however, would require the carbon price to double to \$79 tCO_2^{-1}.

6. Where do you feel that biochar fits in the greater scheme of climate research and action to mitigate and adapt to climate change?

PBS has a relatively low-capital intensity and a short lead-time. This means that, once good technology designs are available in the market at the right price, deployment could take place rapidly at the global scale. Herein lies an important advantage of biochar compared to low-carbon energy projects which are capital-intensive and have a long lead-time - such as CCS and nuclear power. More research is needed to explore the interactions between deploying biochar on a gigatonne scale and other elements of a c. 10 GtC reduction strategy to 2050. For example, is it consistent with other bioenergy and biofuels policies and ambitions? What would be the implications of an aggressive biochar strategy for land-use, food production and rural livelihoods? Biochar may also help in adapting to climate change through its role in water management, mitigation of erosion and creating a more resilient agricultural system.

7. Are there any other issues related to biochar that you consider to be important

Deploying PBS is complex because of the range of sectors and policy domains which are affected: energy & climate, soils, waste, agriculture & food, water, rural development, and so on. PBS is vulnerable to price fluctuations in products and services in a number of these different markets. Hence, PBS deployment would require recognition of multiple benefits and appropriately designed policies.

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To Bury or to Burn? Optimal use of Biochar for Cost-Effective Carbon Abatement

Supplementary evidence to the Royal Society Geo-engineering Climate Enquiry

1. Introduction

Charcoal and similar pyrolysed materials are potential fuels with an economic value. Furthermore, their use as a source of energy could offset carbon emissions arising from combustion of fossil fuels. Therefore, a critical question is whether it is better to burn biomass or char as a fuel, or to bury biochar in soils as a carbon store, with the additional indirect benefits arising from its impacts upon other greenhouse gas fluxes, crop and net primary productivity, and so on.

2. Definitions

Biochar: We refer to char as biochar where it is deliberately applied to land for carbon abatement and/or agricultural reasons; we refer to it simply as char where it is used as a fuel.

Bury: We use the term ‘bury’ to mean incorporation of biochar into soils, or into landfill or the sub-surface (disused mines, etc.), for carbon storage and/or for agronomic reasons.

Carbon abatement is defined here as the net effect of changes in greenhouse gas fluxes resulting from the production and application of biochar. This can include any or all of the following: carbon stored directly in the biochar; CO_2 released during pyrolysis; offset CO_2 emissions arising from avoided fossil fuel combustion; offset carbon emissions from reduced chemical inputs to agriculture; suppression of nitrous oxide and/or methane through biochar addition to soils; offset carbon emissions from reduced operations in the field. Which of these components is included will be specified in the text.

Carbon abatement efficiency is defined as the net carbon equivalent abatement delivered during the processing of a unit of feedstock.

3. Utilisation of Biomass for Energy or for Producing Biochar

We considered whether biomass feedstocks themselves are better utilised for a pyrolysis-biochar system (PBS) or for combustion in the evidence which we submitted in December 2008 (on page 3). It was noted that, in general, there is reasonably good evidence that PBS has a better carbon abatement efficiency than bioenergy alone, though this is dependent on the comparison reference case. Since we submitted the evidence in December 2008, we have undertaken our own analysis of the issue and have produced similar findings to Fowles (2007) and Gaunt & Lehmann (2008). Our simple calculations, focusing just on the thermal conversion processes, indicate that if the syngas and/or oil from pyrolysis can be effectively utilised, then the carbon balance from PBS (but not accounting for the indirect benefits of biochar to greenhouse gas fluxes) is slightly better than that of combustion. Any additional benefits arising from the indirect effects of biochar (reduced fertiliser, suppression of N_2O emissions, etc.) would increase the carbon abatement efficiency advantage of producing biochar over using biomass for combustion.

The McCarl et al. chapter (2009) takes a full Life Cycle approach to exploring fast and slow pyrolysis of maize stover, and subsequent biochar deployment, in mid-West USA conditions. For slow pyrolysis, 1.1 tonnes of CO_2 (equivalent) are abated per tonne of feedstock, whilst the value is 0.8 tCO_2e in the case of fast pyrolysis. We calculate that the offset CO_2 emissions from combustion of the maize stover would be approximately 0.4 tCO_2 per tonne feedstock (relative to coal, the reference case used by McCarl et al.). Hence, 2 – 3 times more carbon is abated by PBS than by biomass combustion; this is some what less than the numbers reported in Gaunt & Lehmann, probably because McCarl et al. make less optimistic assumptions. (Approximately half of the carbon abatement arising from use of biochar arises from the indirect impacts of biochar in the soil – these impacts are all currently subject to moderate to high uncertainty).

Having reviewed the available literature, and having done some analysis ourselves, it is clear that there are currently technical uncertainties in accounting for the energy outputs of the pyrolysis process. In the absence of a 'dominant design', there are a range of different technologies (different designs, scales, materials, costs, etc.) which are being explored for PBS. A further problem is that information on the technologies is frequently commercially confidential; hence not all the relevant information has been published in the literature. These factors currently limit our ability to provide a reliable and definitive carbon and energy balance for the pyrolysis process. The results of a comparison of PBS with biomass combustion also depends to some extent upon creating useful markets for the energy outputs of both, especially for the heat. More research is therefore needed to understand and properly model the thermal conversion that occurs during pyrolysis, at relevant scales and costs, etc.

The subsequent focus in this supplementary evidence is limited to the alternative uses of biochar once it is produced or to alternative versions of pyrolysis (fast and slow).

4. Literature Review

Two published studies have investigated this issue.

1. Gaunt and Lehmann (2008). Their Tables 3 and 4 compare total avoided emissions (kg CO_2 equivalent per hectare per year) from use of bioenergy crops (switchgrass, miscanthus, forage corn) and from use of crop residues (winter wheat straw and corn stover). The slow pyrolysis process either optimises energy generation, hence gasifies all the char to produce syngas that is used as an energy source, or alternatively produces as much biochar as possible. The results are summarised below in Table 1 for the case of off-setting natural gas. A greater carbon abatement efficiency is achieved by the addition of biochar to soils rather than using char for energy generation (200 to 400% increase in C abatement). Gaunt and Lehmann also calculate the costs of using biochar in soils rather than as a source of energy. The energy penalty from using biochar in soils is \$47 per tonne of biochar. Assuming that 85% of the biochar is stabilised carbon, the energy penalty (i.e. production cost) of a tonne of CO_2 equivalent abatement is \$55/3.67 = \$15.

This can be compared to the market value of CO_2 which has, in recent years and in different markets, varied from \$4 to \$40 tCO_2. Some analysts have argued that the true cost of a tonne of CO_2 emissions is higher: the UK government uses a shadow price of carbon of between £10 and £38 tCO_2 (\$15 to \$57 t tCO_2). (http://www.defra.gov.uk/environment/climatechange/research/carboncost/scc.htm). A reasonable argument can therefore be made that, where a reasonably high carbon price occurs, biochar production for soils (rather than use of char as a source of energy) makes good economic sense.

Table 1: Comparison of Slow Pyrolysis for Syngas Production versus Biochar Production for Different Bioenergy Crops and Agricultural Residues (expressed in kg CO_2 avoided per ha per year) (Off-setting Natural Gas)

Avoided emissions (kg CO_2 per ha per year)	Switchgrass	Miscanthus	Foragecorn	Winter wheat	Corn stover
Slow pyrolysis for syngas production	4234	4992	4083	2002	2173
Slow pyrolysis for biochar production	12551	15358	16912	9575	10688
Difference (biochar minus energy optimisation)	8317	10366	12829	7573	8515
Percentage increase in avoided emissions (biochar minus energy)	196	208	314	378	392

Source: Tables 3 & 4: Gaunt and Lehmann (2008)

2. McCarl, Peacocke, Chrisman, Kung & Sands (2009). A detailed life-cycle assessment model is developed for the case of maize residues arising from cultivation in the US Mid-West. The model is the most detailed analysis to date of the biochar production and application life-cycle. The pyrolysis plant envisaged is medium-scale (70,000 tonnes feedstock per year) and a fast and slow version of pyrolysis are compared. Because the biochar yield from fast pyrolysis is 4.5% compared to 35% from slow pyrolysis, this comparison allows the issue of whether biochar production is preferable to energy production from char to be examined. In the specific context of the US Mid-West, the net value of fast pyrolysis is -$45 per tonne of feedstock, whilst it is -$70 per tonne of feedstock for slow pyrolysis. Note, however, that this calculation assumes a very low value of carbon abatement of $4 t$CO_2$.

According to McCarl et al., the value of char as a fuel is $55 per tonne. Meanwhile, they estimate that the agronomic value of biochar applied to land is $33 per tonne. These numbers are sensitive to the price of coal, however. If the coal price as of December 2007 were used (rather than that at August 2008), the value of char as a fuel would drop to $18 per tonne, in which case biochar would have a higher value as a soil additive than as a fuel.

The calculations in the paragraph above do not include the value of offsetting carbon emissions from fossil fuel combustion, the value of the carbon stored, and the other changes in greenhouse gas fluxes. We can simply add the value of the stored carbon in a tonne of biochar to the agronomic value. Assuming 85% of the biochar consists of stabilised carbon, and a carbon abatement value of $40 per t$CO_2$e, then the carbon storage value of a tonne of biochar is: 0.85 x 40 = $34. Adding this to the agronomic value gives $67 per tonne biochar, which is greater than the value of char as a fuel.

Using a similar method to Gaunt & Lehmann, McCarl et al.'s data can also be used to derive an energy penalty for producing biochar for soils rather than biofuels of $40 per tonne of CO_2. This is considerably more than Gaunt & Lehman's estimate of $15 per tonne CO_2, though similar to other estimates in the literature (e.g. Lehmann, 2007).

Accounting for all changes in greenhouse gas fluxes over the lifecycle, McCarl et al. find that fast pyrolysis results in a net carbon abatement of -0.82 tonnes of CO_2 equivalent per tonne feedstock; whilst slow pyrolysis has a net carbon abatement of -1.11 tonnes of CO_2 equivalent per tonne feedstock. If we applied a carbon abatement value of $40 per t$CO_2$e, then the net present value of fast pyrolysis is -$15 per tonne feedstock, and that of slow pyrolysis is -$30 per t feedstock. With these assumptions, fast pyrolysis still appears to be more favourable than slow pyrolysis in terms of net present value.

McCarl et al. themselves conclude that: "… under current [August 2008] European levels of GHG offset prices, biochar use as a soil amendment in agriculture already exceeds its combustion value" (2009: 356). However, it is necessary to introduce a carbon price at the high end of recent historical experience ($40 per tCO_2) in order to get this result. Furthermore, their study still appears to favour fast pyrolysis, with a much lower char yield, over slow pyrolysis. McCarl et al.'s study is, inevitably, laced through with many assumptions: change in many of these can produce a quite different result.

5. Conclusions

The carbon abatement efficiency of PBS is higher than that for biomass combustion in most, though not all, cases. More research is required on the carbon and energy balance of pyrolysis utilising different feedstocks, conversion technologies, scales of operation, etc.

The two studies that have examined the issue of whether char from pyrolysis is best applied to fields as a biochar soil amendment, or utilised as a fuel for energy generation, come to somewhat different conclusions. This in itself is not that surprising, given that both studies are rather detailed case-studies that are highly context-specific: e.g. with respect to technology choice and performance, agricultural systems, costs, and so on. For example, Gaunt & Lehmann are comparing two versions of slow pyrolysis, whilst McCarl et al. are comparing slow and fast pyrolysis. Both studies exhibit a high degree of uncertainty due to the inevitable use of hard-to-validate assumptions.

Nonetheless, both studies indicate that in carbon abatement efficiency terms, biochar production is a better route to go down than char for energy generation / syngas production (the difference being far more marked in Gaunt & Lehmann than in McCarl et al.). More contentious is whether, in economic terms, it is more efficient to maximise biochar production rather than using char solely for energy production.

The Gaunt & Lehmann study is more UK-focused than McCarl et al.'s study, which is based upon the US Mid-West agricultural context. We intend to undertake several case-studies in the UK context in order to try and address this question further and will be happy to report back to the Royal Society with our results in due course.

References

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