Biochar Commercialisation in Mexico

Setting the Context for a Multidisciplinary Research Programme

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List of abbreviations and acronyms:

CH_4	methane
CO_2e	carbon dioxide equivalent
GHG	greenhouse gas
GtC	gigatons of carbon
K	potassium
LCA	life cycle analysis
MACC	marginal abatement cost curve
MRT	mean residence time
MtCO_2e/yr	megatons of carbon dioxide equivalent per year
N	nitrogen
N_2O	nitrous oxide
P	phosphorous
PBS	Pyrolysis-Biochar System process
RD&D	research, development and deployment

Executive summary

Climate change mitigation has been recognised by governments the world over as an important long-term policy initiative and many institutions have begun to invest in research and development initiatives focused on reduction of atmospheric emissions of carbon that show promise of widespread and large-scale application. Biochar has been identified as one option to reduce atmospheric emissions of carbon, both directly by long-term stabilisation of organic carbon and indirectly by displacing fossil fuel emissions.

Biochar is defined as the solid material that results when organic matter is heated in a low oxygen environment, by processes commonly referred to as pyrolysis and gasification. When processed under these conditions a high fraction of carbon remains stabilised in the char and is only emitted over hundreds or thousands of years. Evidence suggests that the charred solid is beneficial to soil fertility in many contexts and new research has considered alternative means of utilising it for alternative investments. Finally, gasification and pyrolysis technologies also produce liquids and gases that may be used to supply heat and electricity. Biochar deployment thereby has the potential to provide a number of environmental, economic and social co-benefits.

This report asks what steps would need to be taken to begin to make biochar commercial in Mexico and is the culmination of a short research project undertaken between December 2012 and May 2013.

The report is divided into the following sections:

- Section 1 provides a brief overview of the science behind biochar, technology options, infrastructure requirements, the benefits of use and research activities around the world.

- Section 2 develops the case for biochar commercialisation by considering the potential social and economic benefits in more detail.

- Section 3 explains how biochar fits within the institutional context of Mexico's government policies and regulations.

- Section 4 provides a case study of how biochar can be integrated into Mexican industrial activities and proposes additional areas where this may take place in the future.

- Section 5 lays out a roadmap of activities that will support biochar research, development and deployment in Mexico.

- Section 6 provides a short summary of recommendations.

It is still early days for biochar research and development activities and much uncertainty therefore remains around the magnitude of possible benefits. Biochar development does however draw a major advantage from the relative ease with which it can be scaled up economically under different scenarios. This places it in a the category of mitigation activities that should deserve more attention from governments interested in addressing several overlapping public policy aims simultaneously through a trial-and-error approach. We hope that this will be clear to the reader by the end of this report.

Contributors

This report was authored by Rodrigo Ibarrola and Benjamin Evar from the University of Edinburgh. Contributions on translation were made by Rodrigo Céspedes Sotomayor, also at the University of Edinburgh.

About the UKBRC

The University of Edinburgh is Scotland's leading research focused university and ranks in the top 20 of global research universities. In the most recent UK Research Assessment Exercise, the University's College of Science & Engineering continues to be a top performer – 96% of the research was rated 4*, meaning that it is world-leading in terms of originality, significance and rigour. The University is home to the UK Biochar Research Centre (UKBRC, www.bio-char.org.uk) currently the largest research centre in the UK dedicated to the study of biochar as a means of atmospheric carbon removal and long-term sequestration. In 2010 the UKBRC pioneered a comprehensive review of biochar for the UK Government (Defra and DECC), which included an assessment of biomass resources and the suitability of different technology options. The report is available from the UKBRC website. The UKBRC has informed policy and research initiatives at the highest levels with evidence submissions to the Scottish Government, the Royal Society, and the Royal Society of Edinburgh. Additionally, the UKBRC has its own dedicated biochar laboratory with a capacity to produce biochar from a range of materials at different scales. The UKBRC is committed to generating high calibre research on several issues related to biochar including soil science, pyrolysis technology and socio-economic assessments.

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- REMBIO – Mexican Bioenergy Network
- FCO – British Foreign and Commonwealth Office in Mexico
- SAGARPA - Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food
- INECC – National Institute of Ecology and Climate Change
- SEMARNAT – Ministry of Environment and Natural Resources
- INIFAP – National Research Institute for Forestry, Agriculture and Livestock
- The World Bank
- SOFAGRO – National Agricultural Finance Company
- IMCO – Institute for Competitiveness
- FIRCO – Shared Risk Trust
- IADB – Inter-American Development Bank
- World Bank

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1. A brief overview of biochar

What is biochar?

Biochar is a porous, carbonaceous, solid material produced by thermochemical conversion of organic materials in an oxygen depleted atmosphere, which has the physicochemical properties suitable for the safe and long-term storage of carbon in the natural environment and, potentially, the improvement of soil fertilities. Biochar is produced using pyrolysis technologies (similar to gasification) in a Pyrolysis-Biochar System process (PBS, see Figure 1). The PBS process combines pyrolysis technology, transport options, distribution and storage infrastructure, and the eventual application of biochar e.g. in soil improvement (Shackley and Sohi 2010).

Why does biochar matter?

Biochar stabilises carbon in the final charred material and thereby reduces direct carbon emissions to the atmosphere. Biochar can also function as a soil enhancer by retaining key nutrients in soils. In some contexts this has the potential to significantly increase the fertility of soils while reducing agricultural waste and producing renewable energy. In some biochar systems all four of these objectives can be met in a sustainable manner (see Figure 2), while in others a combination of two or more objectives can be obtained.

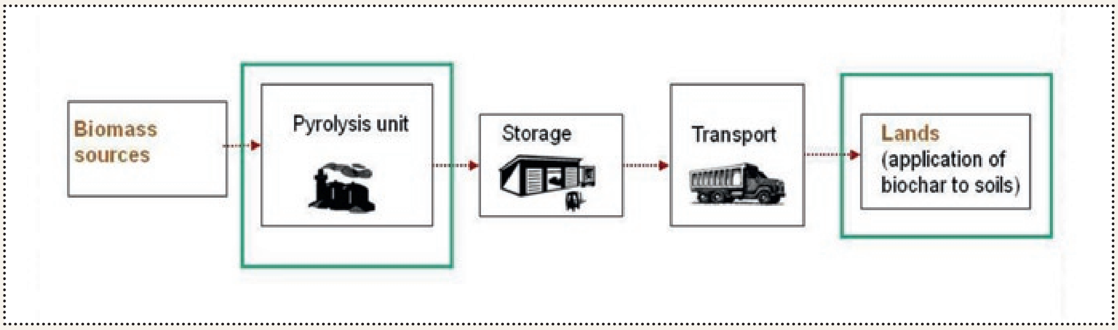

Figure 1. Example of a pyrolysis-biochar system (Shackley and Sohi 2010).

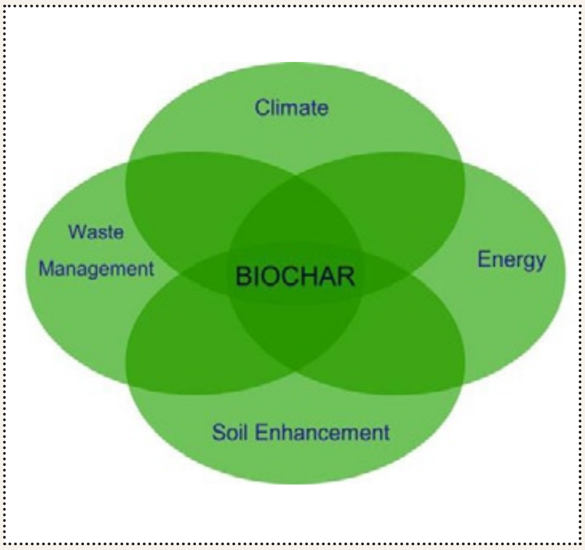

Figure 2. Main objectives of a sustainable biochar system (Shackley S., Saran Sohi, 2010).

Biochar production options

Biochar is produced through a process of carbonisation in which organic materials such as feedstocks are converted into biochar through thermal processing. Different carbonisation processes are possible and vary as a function of the time, heat and pressure exposure available across a range of equipment and feedstocks. Virgin biomass resources are derived from whole plants and trees such as agricultural or forestry residues, while non-virgin biomass resources include bio-materials that have undergone physical or chemical processing. These include wood waste, food waste and sewage sludge. Table 1 lists a range of examples of biomass resources according to these two categories.

Virgin biomass	Non-virgin biomass
Straw	Sewage sludge
Wood chips or pellets	Digestates
Manure	Paper sludge
Residues from energy crops	Draff (remains from whisky production)
Arboricultural arisings	Wood waste from construction industry
Miscanthus	Food waste
Residues from agricultural sector (rice husks, corn stover, coffee husks, etc.)	Bagasse from sugar production

Table 1. Examples of biomass resources for biochar production.

Technology overview

The most common processes for biochar production are pyrolysis and gasification, but other options are available such as torrefaction. Each option produces a different mix of solid, liquid and gaseous end products and advantages therefore differ according to the application aims. Energy products may be recoverable for use elsewhere such as in district heating or electricity turbines or may simply be burned and emitted as heat. Biochar system configurations may therefore involve additional technologies that produce recoverable energy in addition to the solid char on a range of scales from small household units, to larger kilns or retorts, and industrial sized bioenergy power plants (see Figure 3 right).

Pyrolysis systems generally require specialised equipment to contain the baking biomass while excluding oxygen from the process. The reaction chamber is vented to allow gas to escape, which is often referred to as "syngas". Alternatively, part of the syngas may be redirected to sustain the energy required to fuel the combustion chamber, thereby significantly reducing the addition of energy required to run the process (IBI 2013).

Table 2 (page 8) lists some details for three of the more common types of thermochemical conversion systems in use today: slow pyrolysis, fast pyrolysis and gasification. The amount of biochar and co-products (syngas, oils) produced by these systems will differ according to the exposure factors mentioned above.
In general, fast pyrolysis tends to produce more liquids while slow pyrolysis produces more syngas and biochar. Finally, gasification systems produce smaller quantities of biochar and higher quantities of syngas.

Figure 3. Different scales of technologies to produce biochar (Hines Farm Blog 2013; climatetoday.org; Ondrej Masek, UKBRC 2010).

	Temperature and duration	Solid (Biochar)	Liquid	Gas
			Bio oil	Syngas
Slow pyrolysis	~500 °C, Days	35%	30%	35%
Fast pyrolysis	~500 °C, Sec.	12%	75%	13%
Gasification	>800 °C, Hours	10%	5%	85%

Table 2. Average product yields from different technology processes. Exact quantities will vary depending on scale, input material and other factors (Shackley and Sohi 2010).

Stability of carbon in biochar

Large amounts of agricultural residues, biodegradable waste and forestry biomass are currently incinerated or left to decompose in several places around the world. These practices release carbon and methane emissions back into the atmosphere. Biochar production and utilisation systems differ from these practices and most biomass energy systems because the technology involved directly reduces the release of emissions, by storing them in the form of stable soil carbon and thereby functions as a carbon "sink", or a carbon-negative technology system. The carbon in biochar is stored mainly in a highly recalcitrant chemical form. Although little research has been published on its long-term stability, studies suggest a mean residence time (MRT) for biochar in soil of *at least* 100 years, compared to 50 years for bulk soil organic matter (Shackley and Sohi 2010) or 2 to 5 years in fresh biomass or manure (Riegelhaupt, 2013). The MRT of carbon stability is also highly dependent on wider social and environmental factors as the influence of both feedstock availability and production conditions affect the physicochemical properties of both the biochar and the receiving soil (Lehmann *et al.* 2009).

A recent study (Cross and Sohi 2013) that developed a tool for assessing the long-term carbon sequestration potential of biochar identified that the stability of carbon in several biochar samples ranged between 42-76%. Other studies have suggested that stability may reach 90% under some conditions (Shackley *et al.* 2011a). It is primarily this relatively high fraction of long-term stable carbon that makes biochar an option for global climate change mitigation.

Mitigation potential of pyrolysis-biochar systems

Recent life cycle analyses (LCA) have been carried out for small, medium and large scale PBS based on different types of biomass feedstocks technologies to assess the potential for carbon mitigation and electricity production (Hammond *et al.* 2011; Ibarrola *et al.* 2012). These studies have shown that PBS may achieve greater carbon mitigation than other bioenergy systems. The largest contribution to carbon mitigation comes from the stabilised carbon (40-50%). Additional mitigation is achieved from the less certain effects of increased soil organic carbon levels and decreases in nitrogen, phosphorous and potassium fertiliser requirements (25-40%). Finally, the displacement of high-carbon energy generation technologies will indirectly contribute to additional mitigation.

These assessments show that even when the less certain effects on soil organic carbon levels are not accounted for, PBS could mitigate approximately 0.5 tCO_2e/yr (carbon dioxide equivalent emissions per year) from the increased stability of carbon in biochar stored in soils. Scenarios based on these assumptions about direct and indirect mitigation suggest that use of PBS in Scotland could mitigate 0.4-2.0 $MtCO_2e$/yr, increasing to 1.5-4.8 $MtCO_2e$/yr by 2050 (Ahmed *et al.* 2011). Figure 4 below summarises the input options, outputs, direct and indirect mitigation potentials, and impacts involved with PBS.

Potential benefits in soils

Apart from its function in long-term carbon retention, biochar addition to tropical soils has been shown to improve crop yields, in some cases dramatically. In more fertile soils, or in soils that receive high levels of inputs and are not liable to water-stress, the corresponding impact of biochar on agronomic performance has yet to be demonstrated. Emerging evidence from field trials using biochar in the UK and other temperate countries indicates a modest benefit from the limited trials performed so far. The most important research findings that entail potential benefits to soils are as follows:

a) pH, mineral nutrient retention and labile carbon – the typically alkaline pH and mineral constituents of biochar (ash content, including N, P, K and trace elements) may provide important agronomic benefits in many soils, at least in the short to medium term, during which time all labile fractions of organic carbon may also be important.

b) Water retention – the addition of biochar to poorer-quality sandy or silty soils has been demonstrated to enhance crop yields. This results, in part, from the enhanced water retention of relatively porous materials.

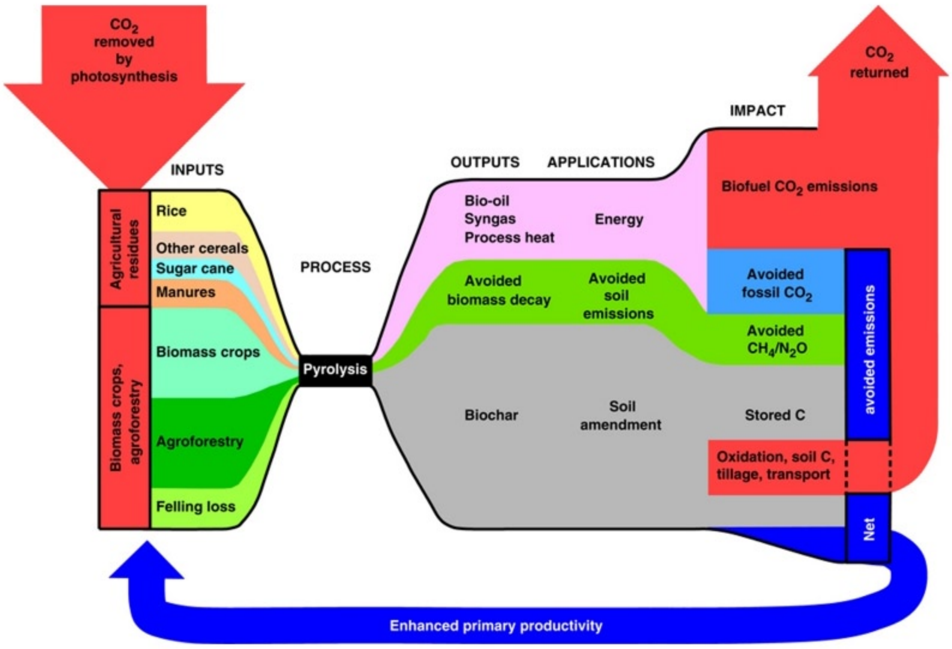

Figure 4. Overview of the pyrolysis-biochar system life cycle. CO_2 is removed from the atmosphere by photosynthesis. Organic wastes such as residues from timber production, forestry, agriculture and even sewage sludge are processed through pyrolysis to produce biochar, oils, syngas and process heat. Biochar is sequestered in soils ensuring long-term decay of carbon rather than immediate emissions to the atmosphere and may function as a soil amendment. The process likewise reduces emissions of other GHGs such as CH_4 and N_2O from soils and from use of fertilisers. Bioenergy generation may displace fossil fuel reliance resulting in part of the fixed carbon being emitted to the atmosphere in the short term (Woolf et al. *2010).*

c) Long term impacts in soil ecology – a combination of physical and chemical properties may be sufficiently and fundamentally altered such that a sustained change in microbial communities results with potentially more efficient patterns of carbon utilisation and nutrient cycling (Shackley *et al.* 2011a).

Biochar research, development and deployment around the world

Biochar RD&D is rapidly increasing and generating interest around the world (see Figure 5 below) and is increasingly perceived as a sustainable integrated resource management strategy, with which to address environmental, social and economic policy objectives. Owing to the context specific nature of such benefits, findings are highly sensitive to the climate, soil quality, social factors and economic drivers. This makes it problematic to generalise findings from one part of the world to another.

At the moment there are no research and development initiatives explicitly focused on biochar in Mexico. The rest of this report analyses the potential benefits of biochar deployment in Mexico by considering the economic, political and social context. The resource potential impacts of introducing biochar are also assessed. Finally, section 5 presents a roadmap for future research and development activities that will provide more detailed assessments of the potential benefits from commercialisation.

Figure 5. Biochar initiatives around the world (IBI 2013).

2. The case for biochar commercialisation

Mitigation potential in a commercial context

Biochar produced from pyrolysis and sequestered in soils has the potential to significantly contribute to global climate change mitigation by altering practices related to land use, forestry and agriculture. It has been estimated that changing agricultural practices from slash-and-burn to slash-and-char techniques could offset 12% of anthropogenic carbon emissions from this sector globally. To this may be added mitigation from various pyrolised organic green and processed residues.

Finally, if biofuels were to be produced using pyrolysis co-products to displace fossil fuels, total theoretical mitigation globally has been estimated to reach 5.5-9.5 GtC/yr by 2100 (Lehmann *et al.* 2006). These large numbers have however provoked controversy (Paul *et al.* 2009) partly because of the significant levels of land use change that they imply will have to take place (Berndes *et al.* 2003). Such changes would inevitably involve a major impact on social systems and it has therefore been suggested that a more realistic maximum global estimate would be in the range of 1 GtC/yr by 2050 (Woolf *et al.* 2010). This implies that, properly deployed, biochar has the potential to function as a mitigation 'wedge' alongside other technologies and social changes to meet carbon stabilisation aims for the middle of the century (Pacala and Socolow 2004).

GHG emissions from land use change, agriculture and forestry together amount to nearly 19% of Mexico's total. While this is less than emissions from its energy industry (at nearly 22%) the emissions are spread over a large number of activities (SEMARNAT and INECC 2012) owing to the large portion of the population employed in smaller agricultural based activities. The distribution of many smaller land use activities, and the comparatively low barriers to entry involved with simple PBS, make Mexico a prime location to consider biochar as a mitigation option.

Wider development of commercial or near-commercial renewable technologies globally over the last forty years owes much to government support mechanisms that have subsidised electricity production, mandated increased usage (through renewable obligations and fuel mixing), and the development of grid infrastructures to accommodate increasing decentralised generation. Such efforts have also been used to promote biomass based electricity, heat and fuel products and may very well be required for biochar in the longer term.

However, a biochar economy involves several outputs that may already be brought to market commercially in many situations. Biochar may be used as an addition to fertilisers to increase yields (see section 1) or added to animal feeds; oils may be processed for use as fuel; and depending on the location and needs of users, heat may be harvested to dry green waste (Hammond and Rödger 2012).

Such potential benefits and the scalability of systems place biochar in an advantageous position as a GHG mitigation option compared with higher cost emerging technologies. Limited efforts have already been made to reap the commercial benefits of biochar in Mexico as described in section 4. However, the range of potentially commercial options from integrating biochar with existing practices has barely been assessed yet.

Economic costs and benefits

In the UK, the carbon abatement (or mitigation) costs of biochar have been estimated for a number of scenarios. Figure 6 below is a marginal abatement cost curve (MACC) for biochar applied in the UK. A MACC plots potential emissions reductions (in tCO_2e) from different mitigation options against the cost (here in £) of implementation. Cheaper options here involve a *net negative cost* to the economy, in other words a *net benefit*. Included in the net abatement assessment is the stable carbon in the biochar as well as the offset carbon emissions arising from bioelectricity generation. The MACC is therefore highly specific to the UK energy grid, the type of organic material and the pyrolysis or gasification method used. In the scenario below, 6 $MtCO_2e$ can be abated at a relatively low cost (less than £20/tCO_2e, or US\$30/tCO_2e). Reliance on alternative technologies and inputs thereafter leads to a steep increase in the cost of processing and production. The principle of introducing lower-cost options first should be kept in mind when deciding how to optimally integrate biochar production in any economy and is contingent on a detailed assessment of specific (national and regional) circumstances.

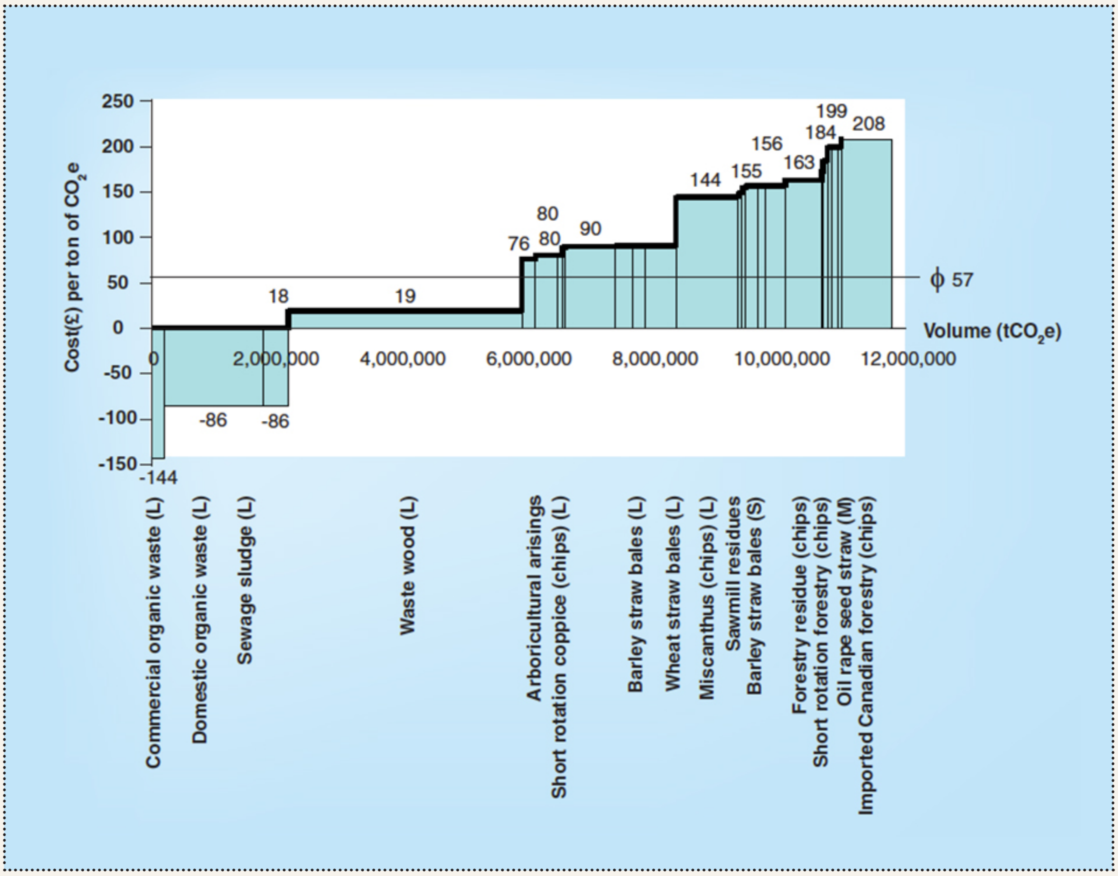

Figure 6. Biochar marginal abatement cost (£/tCO_2e) for feedstock supply scenario in the UK. Note that values do not include indirect effects of biochar in soils on net CO_2e abatement, such as reduced reliance on chemical fertilisers.

L: Large scale; M: Medium scale; S: Small scale. The average cost of £57 has been indicated in this scenario to show the availability of relatively affordable options from large scale production (Shackley et al. *2011b).*

A study conducted in the UK context (Shackley *et al.* 2011b) concluded that the break-even selling point of biochar may lie between £-148 to 389 (US$ -222 to 584) per ton of biochar produced, delivered and spread on fields. As in figure 6 above, negative costs indicate a profit-making activity. Under the assumed conditions the most profitable source of biochar was from wastes (wood waste, food waste, sewage sludge and green waste), despite such materials likely facing complex regulatory issues such as standards and testing. Another source (BBF 2012) indicates that when traditional charcoal kilns are used the cost of production can vary from £20 to £300 per ton of biochar. With such large ranges in the estimates it is implied that costs would be reduced as biochar production increases and production technologies improve. This will also occur as co-products will more easily be brought to market and economies of scale thus underlie current assessments of future cost reductions.

Detailed information of biochar costs do not exist for the Mexican context, but an estimate is provided in section 4 for specific sectors and technologies.

3. Institutional context in Mexico

The General Law of Climate Change

Analysis by SEMARNAT shows that national GHG emissions will grow 70% by 2050 relative to 2000 (UNCTAD 2012). In response to this challenge the new General Law of Climate Change passed in 2012, to make Mexico one of only two national jurisdictions, along with the UK, to mandate the reduction of GHGs. A principal objective of the Law is to "promote the transition to a competitive, sustainable and low carbon emission economy." The Law thereby aims to ensure that Mexico's economic growth is not unduly hampered by regulations and the statement may be interpreted as a provision that prioritises R&D projects with the potential to support economic output in the long run while mitigating GHGs.

The Law includes detailed measures to promote this transition in the coming decades. GHG emissions are to be reduced 30% by 2020 and 50% by 2050 (relative to the year 2000). It aims to make clean energy sources 35% of all electricity generation by 2024. It mandates emissions reporting from a number of sectors under a public emissions registry that will cover power generation and use, transport, agriculture, stockbreeding, forestry and other land uses, solid waste and industrial processes. The Law also provides the government with the authority to establish a voluntary emissions trading system that may be linked with the international carbon market in later years (de Mauleón Medina and Saito 2012).

Principal objectives and legal provisions in the Law are specifically relevant to considering the role of biochar R&D. This is firstly supported by the legal mandate to reduce GHG emissions, which clearly supports mitigation activities that work by directly reducing emissions through sequestration, rather than indirectly by aiming to displace high-carbon energy generation technologies with low-carbon renewable options. Secondly, the Law includes an objective to promote research, development, dissemination and transfer of technologies and innovations that may help to reduce GHG emissions. Biochar is one technology option for which knowledge, largely established in other countries, could be transferred to Mexico and support existing biomass expertise. Thirdly, the Law includes an objective to reduce the vulnerability of human and natural systems to the effects of climate change. This objective could be met where there is evidence that biochar addition to soils increases crop resilience by retaining nutrients in exhausted soils or vulnerable climates.

Additional project activities established under the Law likewise support using biochar as a mitigation option. Article 49 establishes several working groups with different mitigation areas and *Working Group VI for Projects that Reduce Emissions and Capture Greenhouse Gases* would be a relevant forum in which to assess future regulations related to biochar. Another project activity charges the National Forestry Commission with designing strategies and policies to achieve a 0% rate of loss of carbon in original ecosystems, using sustainable development and community forest management practices – a goal that may be supported with the selective use of biochar alongside other practices. The Law establishes a National Policy on Mitigation that sets out a two-phased framework for the introduction of mitigation policies that are thought to involve a cost to society. This firstly establishes voluntary actions for sectors regulated by the law, and secondly specific emission reduction targets. It has been suggested that this framework would be suitable for REDD initiatives and it could likewise be a framework to support biochar R&D. Finally, the Climate Change Fund established by the Law may provide early financial support for some of these initiatives.

Related policy initiatives

Biochar RD&D may be suited to a number of overlapping policy initiatives. This section discusses policy activities related to climate change mitigation, bioenergy production, and agricultural development as a starting point for envisioning future activities and introducing specific governance initiatives.

The General Law of Climate Change has followed more fundamental legislation in promoting GHG mitigation. In 2007 Mexico introduced the National Strategy for Climate Change (ENACC). Following this the first stage of the Special Programme on Climate Change (PECC) was developed for the period 2009-2012. The PECC gave rise to 105 objectives, and 294 specific mitigation and adaptation activities were developed across several sectors. By the middle of 2012 the PECC was estimated to have reached 95% of its goals across these initiatives and led to the mitigation of over 48 $MtCO_2e$ annually for the period (OECD 2013). This success has formed the foundation for further aims to mitigate 261 $MtCO_2e$ annually by 2020. In order to accomplish this goal, over 150 activities were identified by 2012 that were thought to have a total mitigation potential of 130 $MtCO_2e$ annually by 2020, half of the goal for that year. A range of projects will still need to be developed and biochar could represent one effort in the land use and agriculture sector, which has been identified as the area with the largest mitigation potential (SEMARNAT and INECC 2012).

Other policy support may be found in the Biofuels Promotion and Development Law enacted in 2008, which envisions around 15 $MtCO_2e$ in potential annual mitigation by 2030. Biofuels are preferably to be produced from non-edible residues from agriculture to reduce conflicts with food production. In Mexico such resources are not fully utilised at the moment and could be used to develop distributed energy production systems. Some assessments of the potential biofuel production from residues are already in place and research by the UN has concluded that:

- *bioelectricity* could produce 10.5% of annual electricity consumption;
- *bioethanol* could replace 6.3% of gasoline demand;
- *biodiesel* could replace 23.2% of national diesel demand; *and*
- *biomethane* could meet up to 14% of natural gas demand.

The promotion of biofuels in Mexico thus has the potential to support the creation of new energy focused jobs, displace hydrocarbons from electricity production, deliver transport fuels, and reduce GHG emissions. To facilitate this development an inter-ministerial working group has been established with a remit to consider options in support of biofuels. This will firstly need to focus on residue collection and processing options, considerations that could include a pyrolysis processing component. Two types of incentive areas have been identified that would support policy objectives related to biofuels. The first of these includes existing programmes that support rural development and fisheries, in other words integrating bioenergy development as a component in existing activities. Secondly, targeted funds could be used to support risk sharing through a cooperative financing route (UNCTAD 2012).

Incentives such as these that focus on the incremental introduction of activities within existing policy areas, may also prove to be highly effective at locating niches for emerging options such as biochar where existing legislation supports a number of related activities. Mexico has the largest population in rural areas in the OECD. 22% live in rural areas where there are 8 million farmers (UNCTAD 2012). 63% of agricultural employment is attached to farms of less than 5 hectares (Fox and Haight 2010) and 61% of the rural

population lives in poverty (UNCTAD 2012). Resources for capital investments of any kind are therefore extremely limited in smallholder farming communities and it may be vital that aims to introduce biochar into rural settings are connected with existing support mechanisms.

The Law for Sustainable Rural Development was enacted in 2001 to help increase the quality of life in farming communities while recognising these financial limitations. This paved the way for the creation of a rural development programme in 2007. The programme focuses both on social policies and productivity support e.g. through measures that enhance the economic and environmental life cycle performance of crops (UNCTAD 2012). With targeted support such measures may also support climate change mitigation. The agricultural and forestry sector is a significant contributor to GHG emissions in Mexico and generated around 135 MtCO_2e in 2002 (PECC 2009), 21% of total emissions. A number of measures may be introduced as part of the rural development programme to support the livelihood of farming communities while mitigating emissions.

The World Bank's (Johnson *et al.* 2010) low-carbon MEDEC model suggests several low-cost mitigation measures for the Mexican rural context. One of these is the displacement of 70-100% of traditional charcoal production in favour of more efficient kilns by 2030. The measure is estimated to be cost-effective for the economy and adds a net gain of US\$20/tCO_2e mitigated. However, there are no government programmes in place at the moment specifically to introduce these kilns, and a range of national and international sources of funding will therefore likely play a role. Analysis for the PECC has suggested that such kilns could be introduced by organising cooperatives around collective use (IMCO 2011) to share costs and risks, similar to other rural development activities. These efforts could be integrated with biochar production by putting part of the char produced aside for permanent burial in soils where crop yields are thought to benefit. Existing institutional frameworks may thereby promote another type of rural development activity that could reduce emissions and stabilise yields while increasing chances of loan repayment.

Biochar has found pending support in limited legislative initiatives around the world, notably under the now defunct American Power Act introduced in the US in 2010. The Act included research grants, recognition of biochar as an immediate mitigation activity and support for its inclusion in a domestic carbon offset programme (Biochar-international.org 2010). Australia has opened the door to accepting biochar as an eligible mitigation activity under its National Carbon Offset Standard. However, trading of carbon offsets from biochar initiatives will not commence until a methodology is in place – similar to the obstacle faced under voluntary and mandatory carbon trading standards elsewhere in the world (Cowie 2012).

Such emerging initiatives and Mexico's existing legal and policy context indicate that biochar commercialisation at first may need to be supported as a niche R&D activity. Several aims that follow from existing policies are already able to lend support to biochar activities where climate change mitigation, soil yield stability and increases, as well as distributed energy generation are in focus. However, following assessments of renewable energy technology commercialisation worldwide, targeted government support programmes (Neuhoff 2007) or other incubation schemes (Jacobsson and Lauber 2006) may be needed for early R&D efforts until costs are reduced. More specifically, experiences with the introduction of bio-based energy sources around the world strongly suggest the need for such specific government support. The Brazilian sugarcane industry received substantial targeted government support during early years of its biofuel program (Hira and Oliveira 2009), support that was subsequently phased out as costs decreased with larger scales of production (Goldemberg *et al.* 2008). The Swedish biofuel strategy introduced tax-breaks to promote ethanol sales as well as grants for consumers willing to purchase flex-fuel vehicles (Pacini and Silveira 2010).

The adequacy of similar support mechanisms in the Mexican context will depend on the scale of pyrolysis technologies introduced. Some options are already cost-effective and wider adoption is held back by scientific uncertainty and limited experience rather than cost. Some of these parameters are assessed in the following section, which considers how biochar could help to reduce emissions in Mexico given the specific resource availabilities.

4. Integrating biochar into the Mexican context

Mexican biomass sector overview

Mexico has a huge potential for biomass resources to produce biochar, biogas, liquid and solid biofuels (table 3). Estimates indicate that the energy potential of predominant sources of bioenergy amounts to 3,569 PJ/yr, or 42% of primary energy consumption in 2008. However, only 5% (432 PJ/yr) of primary energy is currently being supplied through bioenergy. A breakdown of the sources of biomass fuels shows that wood is mainly used along with sugarcane bagasse and charcoal, but there is also experience in the area of bio-digesters, methane capture and electricity generation in landfills, as well as highly efficient wood stoves for cooking in rural areas (REMBIO 2011).

Furthermore, there have been a number of emerging initiatives based on liquid biofuels, particularly biodiesel, through initiatives focused on both first- and second-generation fuels.

Costs in the Mexican context

Production costs of biochar in the Mexican context may vary greatly depending on factors such as the availability of workers, the type of biomass used, and the type of gasification/pyrolysis technology. In some areas, like the sugar industry, existing technologies could be adapted with minor modifications. The case study in Box 1 estimates a cost range between US$5-60 per ton of biochar depending on the production capacity of mills and the technology used to separate and collect biochar.

Box 1: Sugarcane case study

Bagasse and molasses (or cane syrup) are usually obtained as by-products of sugar production. During the process of cane juice clarification, a solid residue called cachaça is generated.

In Mexico, sugar mills or *ingenios* use the bagasse obtained as fuel to generate most of their energy consumption in the sugar production process, through co-generation of electricity and process heat schemes. As a result, combustion gases and ash are produced and the organic carbon in bagasse is released as CO_2.

A recent study conducted by the National Institute of Ecology and Climate Change (INECC) and the Inter-American Development Bank (IADB) explored a potential scheme to mitigate emissions in the sugar agro-industry. The proposed solution involves capturing part of the carbon contained in the bagasse and cane leaves in the form of biochar and adding it into the sugarcane cultivated soil, along with the *cachaça* that is commonly used as an organic fertiliser. This has two goals: to create new, stable, soil-based carbon storage and to increase the soil's capacity to retain water and nutrients (Riegelhaupt, 2013).

According to the study, creating biochar through this process would not require significant investment in technology and could instead be accomplished by making relatively minor modifications to the sugar mill boilers. Adjusting some factors in the operation can increase the percentage of solid particles resulting from incomplete combustion of bagasse in boilers, and by adding cyclone precipitators or scrubbers it is possible to separate these solids to mix them with cachaça.

Type and origin	Units	Units	PJ/year	Percentage
Wood from native forests	Mt (odt)/year	101	1,515	42%
Wood from Eucalyptus plantations	Mt (odt)/year	26	345	10%
Industrial residues from dedicated crops (e.g. bagasse from sugar mills)	Mt (odt)/year	29	431	12%
Agricultural residues	Mt/year	13	227	6%
Cattle feed residues	Mt (odt)/year	15	114	3%
Agricultural residues from dedicated crops (e.g. sugarcane for ethanol)	Mt (odt)/year	8	86	2%
Industrial residues from forestry activities	Mt (odt)/year	3	63	2%
Sugarcane for ethanol	Mt/year	206	338	9%
Sorghum grains for ethanol production	Mt/year	----	202	6%
Palm oil for biodiesel	Mt/year	13	121	3%
Jatropha curcas for biodiesel	Mt/year	4	57	2%
Cattle Manure	Mt/year	35	35	1%
Organic waste	Mt/year	----	35	1%
Total			3,569	100%

Table 3. Predominant types of biomass available in Mexico and estimated quantities for each (REMBIO 2011).

In contexts where a more significant investment in production technology would be required, costs will vary more depending on the production system. For simple, small-scale biochar production systems (+/- 100 tons per year), such as Adam Retort-type furnaces, costs could be less than US$10 per ton of biochar produced. More advanced systems with larger production capacities (+/- 400 tons per year), could increase cost up to US$100 per ton.

It is important to point out that these factors are based on generic technical and economic assumptions that do not apply specifically to Mexico. To better understand and define production costs here, cost-benefit analyses specific to the country and individual regions will be required for a range of implementation settings (industrial, agricultural, etc.).

Biochar mitigation potential in Mexico

According to the study mentioned above, the mitigation potential from the production and use of biochar from sugar production is 0.572 $MtCO_2e$/yr by 2020, increasing to 1.196 $MtCO_2e$/yr by 2030. To arrive at these figures it was assumed that 10% of the carbon content from boiler-burned biomass would be processed into biochar in 2020, increasing to 20% by 2030.

The mitigation potential of biochar increases far beyond these figures when the total biomass noted in table 3 is used to guide scenarios. Progressing from the assumption of a 10% conversion rate of biomass into biochar and a 30% rate of availability of biochar from treated biomass, it is estimated that over 10 $MtCO_2e$/yr could be mitigated up to 2020. This potential represents about 5% of the goal in the PECC[1].

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[1] The PECC aims to mitigate 261 $MtCO_2e$/yr until 2020.

5. A roadmap towards commercialisation in Mexico

Biochar is a complex, multi-functional material that draws on a diverse knowledgebase to assess production, properties, impacts, interactions, costs and ultimately a range of benefits. In the absence of this diversity of perspectives applied in a specific geographical, social and economic context it is difficult to accurately assess the magnitude of such benefits. We therefore propose that Mexico should establish an integrated research programme, similar to the one proposed by Shackley and Sohi (2010), to focus on the issues detailed below.

Pilot production research facilities

A range of technologies can be used that produce biochar as a product – not only slow and fast pyrolysis, but also microwave-induced pyrolysis, hydrothermal carbonisation, torrefaction and gasification. A strategic approach to producing, testing and comparing biochar samples from these different technologies, under specific reproducible conditions, would improve the evidence basis associated with the properties of biochar produced under various conditions. It would also serve as a first step in assessing the characteristics of different biochar samples under specific soil conditions.

Key research topics to address include:

- Recipes for producing biochar with specific properties and functions;
- Acquisition of technological know-how to produce biochar with defined properties (e.g. pH, N, K, P, moisture content and water retention) for the Mexican context following analysis of production conditions;
- Understanding of the carbon and energy balance of alternative biochar production technologies;
- Better understanding of the labile and stabilised components of biochar and what influences the stability of carbon in the material.

Assessing the impacts of biochar in soils

If biochar is to become a widespread commercial proposition in Mexico, it will be necessary to establish reliable predictive knowledge of impacts in particular soil and agronomic contexts, just as is the case for chemical fertilisers and pesticides. Only when potential users are confident of the positive and cost-effective benefits of application will a biochar market emerge. If however biochar is solely introduced as a climate change mitigation mechanism the key issue will be the long-term stability of carbon.

Key research topics to address include:

- Short- and long-term effects of biochar in soils specific to the Mexican context;
- Development of modifications to existing agricultural equipment to achieve effective and efficient ways of storing and deploying biochar in realistic farm-based scenarios;
- Field experiments and trials that encompass diverse rotations and systems (arable, horticulture and grassland), including feedstocks derived from different types of biomass (including wastes);
- Comparison of likely values of biochar based soil management against returns established for active uses of other organic resources in soil management; *and*
- Evaluation of biochar as a vehicle of beneficial microorganisms in order to establish the effects on soil ecology.

Wider issues in biochar sustainability

The research topics outlined above should be understood as key elements in an agenda to assess the impacts of biochar as a social and economic system. The scalability of technical systems, the possibility of a range of economic products to be deployed, and the many different spatial-temporal and socio-economic contexts available all amount to thinking of biochar development not only as a technical solution, but as a *socio-technical system*. This raises multiple research topics that focus on different aspects of sustainable development.

Key research topics to address include:

- LCAs of pyrolysis-biochar systems to collect data across the whole supply-chain (from feedstock to field) in order to understand the mitigation potential of biochar in Mexico;
- Techno-economic cost modelling with a representation of key processes and stages, including production, distribution, storage and deployment;
- Comparisons with best-available data of the most effective way of using and managing limited biomass resources for biochar production and their availability from different industries e.g. bio-energy generation, waste management, agri-food systems, industry, etc.;
- Assessment of land-use implications of biochar deployment – how biochar might influence the competitive advantage of different crops and the knock-on effects on land-use decisions, supply and demand; *and*
- Elaboration of strategies for the sustainable use of biomass for biochar production based on national and international biomass sustainability standards.

Future steps

Figure 7 on page 23 depicts past activities undertaken in this research project and potential future steps to establish a research and development programme that will support wider commercial deployment of biochar options in Mexico. These activities will support wider integration into Mexican society by addressing the key topics outlined above. The aim is to form a knowledgebase that can be harnessed in promoting wider economic, social and environmental benefits associated with biochar.

Note that a primary aim of this project has been to establish a knowledge transfer network on biochar between the UK and Mexico. From hereon the University of Edinburgh, in conjunction with the British Biochar Foundation, will seek to establish research activities together with Mexican partner organisations. These activities will include a wide number of issues as outlined in the key topics above. Ultimately, these activities will create detailed analytical support for the commercial development of biochar under a range of settings and assumptions.

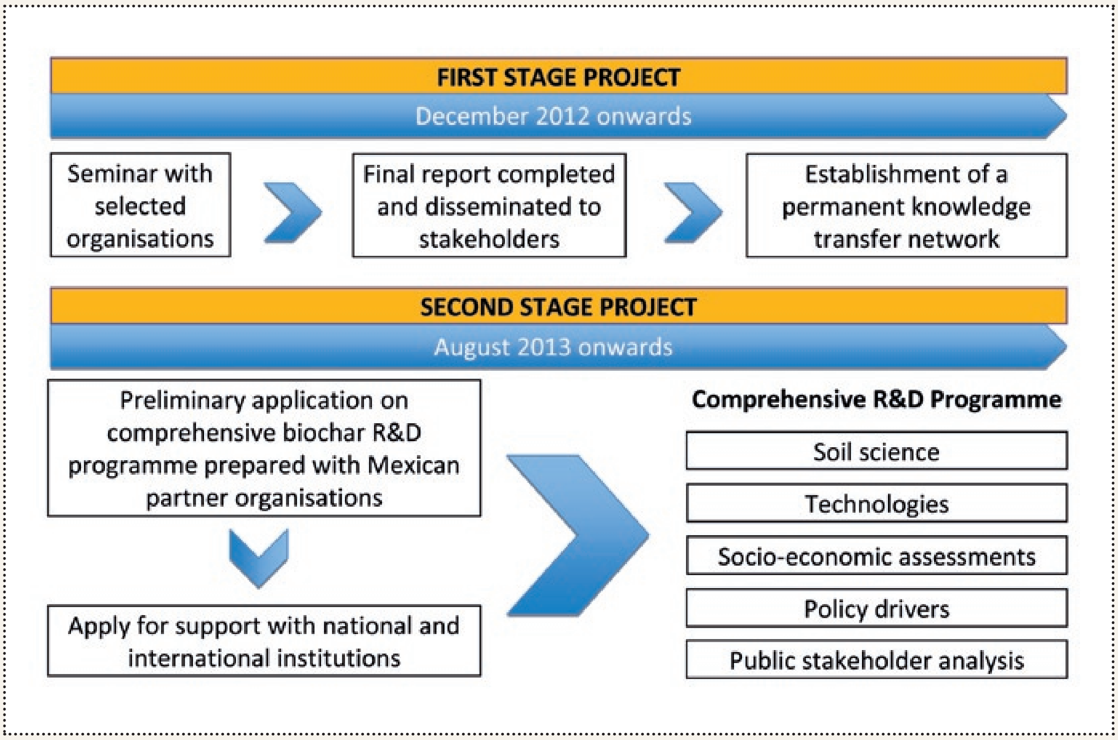

Figure 7. Past research project activities and potential scenario for future activities that would support development of a research and development programme for biochar in Mexico.

6. Summary and recommendations

This report has discussed the prospects and options for developing biochar as a commercial-scale option in Mexico by emphasising the many potentially beneficial impacts of use. To assess the potential for biochar as a carbon mitigation mechanism and achieve these related aims within a reasonable timeframe, a number of connected activities will have to be undertaken in the near future. These may be addressed through a comprehensive research programme to assess how biochar would function under a number of different assumptions and in different geographical and sectoral settings.

Based on this approach we recommend that the following activities are undertaken in the near future:

- *Life cycle assessments are critical to assess the potentially beneficial effects of biochar produced by different technologies, both as a mitigation option and as a soil enhancer in multiple soil types.*

- *Such effects should be considered in various social and resource environments – e.g. smallholder farming and large-scale industrial facilities. The range of parameters will be important to control in studies that aim to assess economic costs and benefits.*
- *Understanding the range of benefits and challenges to introducing and upscaling biochar in different settings will be dependent on detailed and comprehensive assessments of soil science, technology options and socio-economic factors simultaneously.*

- *A clearer agenda for supporting and regulating biochar should be developed under existing institutional frameworks such as the General Law of Climate Change and under bioenergy policies.*

- *Much of this work will be enabled by a dedicated biochar research programme, possibly introduced in successive stages. Assessing use in particular contexts is important to avoid recommendations that are based on over-generalised findings.*

References

Ahmed, S.J., Hammond J., Rodrigo I.E., Shackley S.J. and Haszeldine R.S. (2011). The potential role of biochar in combating climate change in Scotland: an analysis of feedstocks, life cycle assessment and spatial dimensions. *Journal of Environmental Planning and Management*,55(4).

BBF (2012). British Biochar Foundation. *Available at: http://www.britishbiocharfoundation.org.*

Berndes, G., M. Hoogwijk and R. van den Broek (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass & Bioenergy*,25: 1–28.

Cowie, Annette (2012). Bright Prospects for Biochar Offsets in Australia. International Biochar Initiative. *Available at: http://www.biochar-international.org/biochar_offsets_Australia.*

Cross and Sohi (2013). A method for screening the relative long-term stability of biochar. *GCB Bioenergy*,5: 215-220.

de Mauleón Medina, Claudia Cecile and Yolanda Saito (2012). A Legal Working Brief on the New General Law of Climate Change In Mexico. IDLO: Rome, Italy.

Fox, Jonathan and Libby Haight (2010). Subsidizing Inequality: Mexican Corn Policy Since NAFTA. In: *Fox, Jonathan and Libby Haight (Eds.). Mexican Agricultural Policy: Multiple Goals and Conflicting Interests. Woodrow Wilson International Centre for Scholars, University of California: Santa Cruz, CA.*

Goldemberg, J., Suani Teixeira Coelho and Patricia Guardabassi (2008). The sustainability of ethanol production from sugarcane. *Energy Policy*,36(6): 2086-2097.

Hammond, Jim and Jan-Markus Rödger (2012). Biochar: climate saving soils – Newsletter 1. Interreg IVB North Sea Region Programme.

Hammond, J., Shackley, S., Sohi, S., Brownsort, P. (2011). Prospective lifecycle carbon abatement for pyrolysis biochar systems in the UK. *Energy Policy*,39: 2646–2655.

Hines Farm Blog (2013). Flow Farm. *Available at: http://hines.blogspot.co.uk/2010/04/bio-char-flow-farm-bio-char.html.*

Hira, A. and De Oliveira, L. G. (2009). No substitute for oil? How Brazil developed its ethanol industry. *Energy Policy*, 37(6): 2450-2456.

Ibarrola, R., Shackley, S., Hammond,J (2012). Pyrolysis biochar systems for recovering biodegradable materials: A life cycle carbon assessment. *Waste management*, 32: 859-868.

IBI (International Biochar Initiative) (2013). International Biochar Initiative. *Available at: http://www.biochar-international.org.*

IBI (International Biochar Initiative) (2010). American Power Act Includes Support for Biochar. International Biochar Initiative. *Available at: http://www.biochar-international.org/policy/unitedstates#apa.*

Jacobsson, S., and Lauber, V. (2006). The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. *Energy policy*, 34(3): 256-276.

Johnson *et al.* (2010). Low Carbon Development for Mexico. The World Bank: Washington D.C.

Lehmann, Johannes, John Gaunt and Marco Rondon (2006). Bio-char sequestration in terrestrial ecosystems – a review. *Mitigation and Adaptation Strategies for Global Change*, 11: 403–427.

Neuhoff, K. (2007). Large-scale deployment of renewables. In: *Helm, D. (Ed.). The New Energy Paradigm (288-319). Oxford University Press: Oxford, UK.*

OECD (2012). OECD Environmental Performance Reviews: Mexico 2013. Chapter 4: Climate Change. Table 4.1 Special Climate Change Programme (PECC): Main mitigation measures to 2012 and achievements. *Available at: http://www.keepeek.com/Digital-Asset-Management/oecd/environment/oecd-environmental-performance-reviews-mexico-2013/special-climate-change-programme-pecc-main-mitigation-measures-to-2012-and-achievements_9789264180109-table19-en.*

Pacala, S. and R. Socolow (2004). Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science*, *305*(5686): 968-972.

Pacini, H. and Silveira, S. (2010). Ethanol or gasoline? Consumer choice in the face of different fuel pricing systems in Brazil and Sweden. *Biofuels*, 1(5): 685-695.

Paul, H., A. Ernsting, S. Semino, S. Gura, and A. Lorch (2009). Agriculture and Climate Change: Real Problems, False Solutions. *EcoNexus*: Oxford, UK.

REMBIO (2011). La bioenergia en Mexico, situacion actual y perspectivas.

Riegelhaupt (2013) personal communication.

SEMARNAT and INECC (2012). Mexico’s Fifth National Communication to the United Nations on Climate Change.

SEMARNAT (2009). Special Climate Change Program, 2009-2012 Mexico. Executive Summary.

Shackley, S., Carter, Sims, Sohi (2011a). Expert perceptions of biochar as a carbon abatement option. *Energy and Environment*, 22(3).

Shackley, Simon, Jim Hammond, John Gaunt and Rodrigo Ibarrola (2011b). The feasibility and costs of biochar deployment in the UK. *Carbon Management,* 2(3): 335–356.

Shackley S., Saran Sohi (2010). An assessment of the benefits and issues associated with the application of biochar to soil. HM Government: UK.

UNCTAD (2012). Mexico’s Agriculture Development: Perspectives and Outlook.

Woolf, D., J.E. Amonette, F.A. Street-Perrott, J. Lehmann and S. Joseph (2010). Sustainable biochar to mitigate global climate change. *Nature Communications,* 1: 56.

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