EUROPEAN PARLIAMENT

Science and Technology Options Assessment

STOA

SYSTEMIC APPROACH TO ADAPTATION TO CLIMATE CHANGE AND RENEWABLE ENERGY HARNESSING (BIOMASS AND MINI-HYDRO)

FINAL REPORT

(IP/A/STOA/FWC/2008-096/LOT3/C1/SC2)

PE 471.580

EUROPEAN PARLIAMENT

DIRECTORATE GENERAL FOR INTERNAL POLICIES
DIRECTORATE G: IMPACT ASSESSMENT
SCIENCE AND TECHNOLOGY OPTIONS ASSESSMENT

SYSTEMIC APPROACH TO ADAPTATION TO CLIMATE CHANGE AND RENEWABLE ENERGY HARNESSING (BIOMASS AND MINI-HYDRO)

FINAL REPORT

Abstract

Pyrolysis technology has been assessed in this report based on an examination of the costs, the benefits, the barriers to market uptake, and the potential for EU funding to contribute to innovation and/or technology deployment. Given the benefits associated with the application of biochar to soils, here we consider how it can be utilised in the context of on-farm mitigation options. Looking at application of the technology from this perspective helps underline the importance of local context and soil properties. In carrying out cost-benefit analysis however, it has been challenging to calculate the cost of biochar given the lack of available information. For this reason, we have had to consider the cost of the entire pyrolysis lifecycle by looking at the cost of a number of other products such as pyrolysis oil. We maintain that the added benefit of biochar in terms of its ability to address adaptation, improves its overall cost-effectiveness. We also conclude that, although there is significant potential to implement mini-hydro for mitigation purposes, investment in the technology with the dual purpose of addressing both policy agenda items is not likely to improve its overall cost effectiveness given the limitations associated with implementation.

IP/A/STOA/FWC/2008-096/LOT3/C1/SC2 JANUARY 2012
PE 471.580 EN

This project has been carried out by Institute for European Environmental Policy.

AUTHORS

Jane Desbarats, IEEP
Bettina Kretschmer, IEEP
Robbie Watt, IEEP
Keith Whiriskey, IEEP

RESPONSIBLE ADMINISTRATOR

Peter Ide-Kostic
Science and Technology Options Assessment
Directorate G: Impact Assessment
DG Internal Policies
European Parliament
Rue Wiertz 60 - RMD 00J016
B-1047 Brussels
E-mail: peter.idekostic@europarl.europa.eu

LINGUISTIC VERSIONS

Original: EN

ABOUT THE EDITOR

To contact STOA or to subscribe to its newsletter please write to:
stoa@europarl.europa.eu

Manuscript completed in January 2012

DISCLAIMER

Table of Contents

FIGURES

TABLES

EXECUTIVE SUMMARY

Climate change will have serious impacts on the entire European territory, which will require the implementation of adaptation measures at the local level. Securing adequate public funding to respond to the impacts of climate change has been complicated by a number of events including the financial crisis of 2008/09. Looking at longer-term solutions, the increasing scarcity of financial resources to address climate change may necessitate more creative solutions in terms of addressing both mitigation and adaptation. This report illustrates the extent to which technologies such as pyrolysis and mini-hydro can address both environmental agendas.

Our research indicates that the ability of these two types of technologies to address both adaptation and mitigation is limited to specific applications. For pyrolysis, it is only biochar, a product of the pyrolysis process that has the potential to act as a response measure for the impacts of climate change on soil. Biochar serves to offset both erosion and water saturation associated with increased precipitation. We maintain that the ability of the pyrolysis process to generate renewable energy while still generating a product that addresses adaptation represents a "win-win" scenario in terms of investment in the technology. From a cost-effectiveness perspective, this is where the biggest gains will be made in terms of addressing both adaptation and mitigation simultaneously.

It is difficult to evaluate the synergies between adaptation and mitigation in instances where both issues do not interact within a defined project boundary. If you consider the application of biochar from pyrolysis to soil, it serves to reverse soil erosion while enhancing carbon sequestration simultaneously. For mini-hydro, the ability of the technology to respond to both issues will depend on a range of contextual factors. Determining the improved cost-effectiveness of bioenergy technologies such as pyrolysis and biochar products, while considering adaptation and mitigation synergies, is more straightforward given the ability to confine its implementation to a given project boundary. It is for this reason that the report in question focusses more on biomass and pyrolysis.

Pyrolysis technology has been assessed in this report based on an examination of the costs, the benefits, the barriers to market uptake, and the potential for EU funding to contribute to innovation and/or technology deployment. Given the benefits associated with the application of biochar to soils, here we consider how it can be utiliSed in the context of on-farm mitigation options. Looking at application of the technology from this perspective helps underline the importance of local context and soil properties. In carrying out cost-benefit analysis, however, it has been challenging to calculate the cost of biochar given the lack of available information. For this reason, we have had to consider the cost of the entire pyrolysis lifecycle by looking at the cost of a number of other products such as pyrolysis oil. We maintain that the added benefit of biochar in terms of its ability to address adaptation, improves its overall cost-effectiveness.

In Chapter four, we argue that the cost of pyrolysis oil is competitive with fossil fuels given future fossil fuel prices, project scale, feedstock cost, and shipping efficiency. Overall lifecycle analysis of pyrolysis indicates that biochar has the potential to further enhance the cost-effectiveness of the technology, although the cost of biochar will depend on the use of different feedstock and the cost of the pyrolysis process (including capital costs). When dedicated energy crops are used for pyrolysis, there is the danger of considerable environmental costs associated with greenhouse gas emissions from direct or indirect land use change.

In the light of the information available in the Wood Energy Outlook from 2010, uptake of pyrolysis could be problematic if wood waste were to become a key feedstock given the anticipated competition for wood waste products. This reality is further supported by the PRIMES cost projections, which indicate that the cost of pyrolysis will increase by 2030 given competition for feedstock.

With respect to environmental benefits, the production of biochar from pyrolysis is carbon negative. The Fourth Assessment Report from the Intergovernmental Panel on Climate Change indicates that emissions from soil are an important contributor to emissions from the sector as a whole suggesting that biochar could have an important role to play in mitigating emissions from agriculture by sequestering carbon in soil.However, unlike pyrolysis oil, biochar is not being produced on a commercial scale. Given the vast environmental benefits of the biochar product, implementation of the appropriate policy framework will be crucial in order to leverage investment in to pyrolysis technology and its products. From an international perspective, the development of biochar within the European Union could be further enhanced by its replication in the developing world as part of technology transfer.

1. INTRODUCTION

1.1 Project Background

Climate change will have serious impacts on the entire European territory. The nature of these impacts will vary throughout Europe given ambient geomorphologic and climatic factors. Broadly speaking, they will range from prolonged periods of drought associated with increased temperature and reduced precipitation in the southern parts of Europe, to the flooding associated with increased temperature in northern and central Europe (European Parliament, 2010). What is certain is that these impacts will require the implementation of adaptation measures at the local level.

Securing adequate public funding to respond to the impacts of climate change has been hampered by a number of factors, including volatile oil prices and the financial crisis of 2008/09. Looking at longer term solutions, the increasing scarcity of financial resources to address climate change may necessitate more creative solutions in terms of addressing both mitigation and adaptation. Furthermore the economic crisis has highlighted the negative effect high energy prices can have on economic growth, reinforcing the need to implement systemic solutions to climate change. Given the need to counter the impacts of climate change, recoverable energy resources may provide a solution by simultaneously switching away from fossil fuels (mitigation) and addressing the impacts of climate change (adaptation). In light of increasing fiscal constraints, cost-effectiveness may be increased by addressing both adaptation and mitigation objectives using one renewable energy technology.

On the synergies between mitigation and adaptation, the Intergovernmental Panel on Climate Change (IPCC) states that:

> "Intricacies of the inter-relationships between adaptation and mitigation become apparent at the more detailed analytical and implementation levels. These intricacies, including the fact that specific adaptation and mitigation options operate on different spatial, temporal and institutional scales and involve different actors with different interests, beliefs, value systems and property rights, present a challenge to designing and implementing decisions based on economic trade-offs beyond the local scale" (Klein et. al.,2007, p.747).

The IPCC further claims that adaptation and mitigation are not mutually reinforcing and that "there is no consensus as to whether or not exploiting inter-relationships between adaptation and mitigation is possible, much less desirable" (Klein et. al., 2007, p.749). Despite the misgivings of the IPCC, considering the continuing economic constraints, and the potential benefits (or 'win-wins') that may occur as a result of mitigation–adaptation synergies, such opportunities do merit further investigation.

Using the bioenergy sector (focussing on the pyrolysis product biochar) and small-scale hydro (or "mini-hydro") as examples, this report explores the potential of certain renewable energy technologies to address both environmental agendas. The study considers the trade-offs between the implementation of both pyrolysis and small-scale hydro in terms of countering the impacts of climate change, while also harnessing sources of renewable energy, and determines how meeting both adaptation and mitigation objectives will improve technology cost-effectiveness overall.

1.2 The Relative Importance of Biomass and Hydropower

Biomass and hydropower are both important technologies in the context of the EU's renewable energy targets, and the Renewable Energy Directive (RED) (2009/28/EC) in particular. The RED sets out binding targets aimed at the promotion of renewable energy. The overall target requires the delivery of an EU-wide 20 per cent share of renewable energy in gross final energy consumption by 2020, with the level of effort differentiated across Member States as specified in Annex A of the Directive. Targets can also be met using solar energy, wind power, tidal and wave power, and geothermal.

Having undertaken an analysis of 23 National Renewable Energy Action Plans (NREAPs) in 2010, IEEP determined that the cumulative renewable energy share in gross final consumption will be between 20.2 per cent and 22.4 per cent by 2020, and the 20 per cent target is expected to be met both by the European Union as a whole and by each Member State (Atanasiu, 2010). Bioenergy (biomass, bioliquids and biofuels) accounts for almost 54.5 per cent of the 2020 renewable energy target in the NREAPs examined, with a significant increase in absolute values anticipated. Solid biomass and forestry biomass in particular will continue to be the major source for bioenergy, and is estimated to represent 36 per cent (83Mtoe) of the EU renewable energy target by 2020. Overall, the bioenergy contribution to final energy consumption is expected to more than double, from 5.4 per cent in 2005 to almost 12 per cent (124Mtoe) in 2020. The contribution of hydropower to renewable targets in 2020 however (including large and small scale) is expected to be fewer than 3 per cent.[1]

From an adaptation perspective, the relative importance of biomass and hydropower is also a function of project boundary and contextual implementation issues. As illustrated in the IPCC quote on page six, local context is a key consideration in the analysis of adaptation and mitigation synergies.

1.2.1 Hydropower

Our research indicates that the ability of the two types of technologies to address both adaptation and mitigation may be limited to specific applications. For biomass, it is only biochar, a product of the pyrolysis process, which may help address the impacts of climate change on soil. Biochar serves to offset both erosion and water saturation associated with increased precipitation. We maintain that the ability of the pyrolysis process to create renewable energy while still generating a product that addresses adaptation represents a "win-win" scenario in terms of investment in the technology. Determining the improved cost-effectiveness of biomass technologies such as pyrolysis and biochar products, while considering adaptation and mitigation synergies, is more straightforward given the ability to confine its implementation to a given project boundary. If you consider the application of biochar from pyrolysis to soil, it serves to reverse soil erosion while enhancing carbon sequestration simultaneously.

---

[1]. See: www.erec.org

For hydro, the ability of the technology to address both issues will also vary depending on the scale of installed generating capacity, and whether the technology utilises a run of the river approach or reservoirs. For reservoirs located upstream, the technology would be able to manage increased river flows from flood events that could impact downstream communities. In short, there are numerous local factors to consider in assessing the adaptation and mitigation benefits of hydro. The length of rivers, the standard flow volumes and applicable hydrological regimes, complicate cost-benefit analysis particularly with respect to adaptation benefits. Given the complexity of watershed management, investment in hydropower does not immediately result in adaptation benefits; its ability to respond to the impacts of climate change will depend on a number of other factors that fall outside the project boundary of either large- or small-scale generation.

Although we focus primarily on the costs and benefits of pyrolysis and biochar in this report, more background on the adaptation and mitigation potential of hydropower is provided in Chapter six.

1.2.2 Pyrolysis and biochar

Converting solid biomass such as wood to energy is typically undertaken with the use of boilers. When solid biomass is combusted in boilers it generates two recoverable products: heat and energy. The boiler combustion process (or gasification) itself, however, does not produce a recoverable material that can be used to address adaptation. If one was to consider the possibility of implementing measures that would have a range of adaptation and mitigation benefits, pyrolysis products such as biochar could have benefits in terms of both mitigating greenhouse gases (GHGs) and responding to the impacts of climate change. Biochar can be used as a soil additive to increase its resilience to flooding and associated soil erosion.

We must stress the fact that the ability of pyrolysis to address adaptation is limited to an application that produces biochar. If the process is being used to incinerate inorganic matter, then it does not produce a product that can be applied to soil. In addition, for the technology to help avoid the impacts associated with indirect land use change (ILUC), the inputs must also be limited to existing wood waste or agricultural products and should not utilise dedicated energy crops.

1.3 Biochar in an Agricultural Context

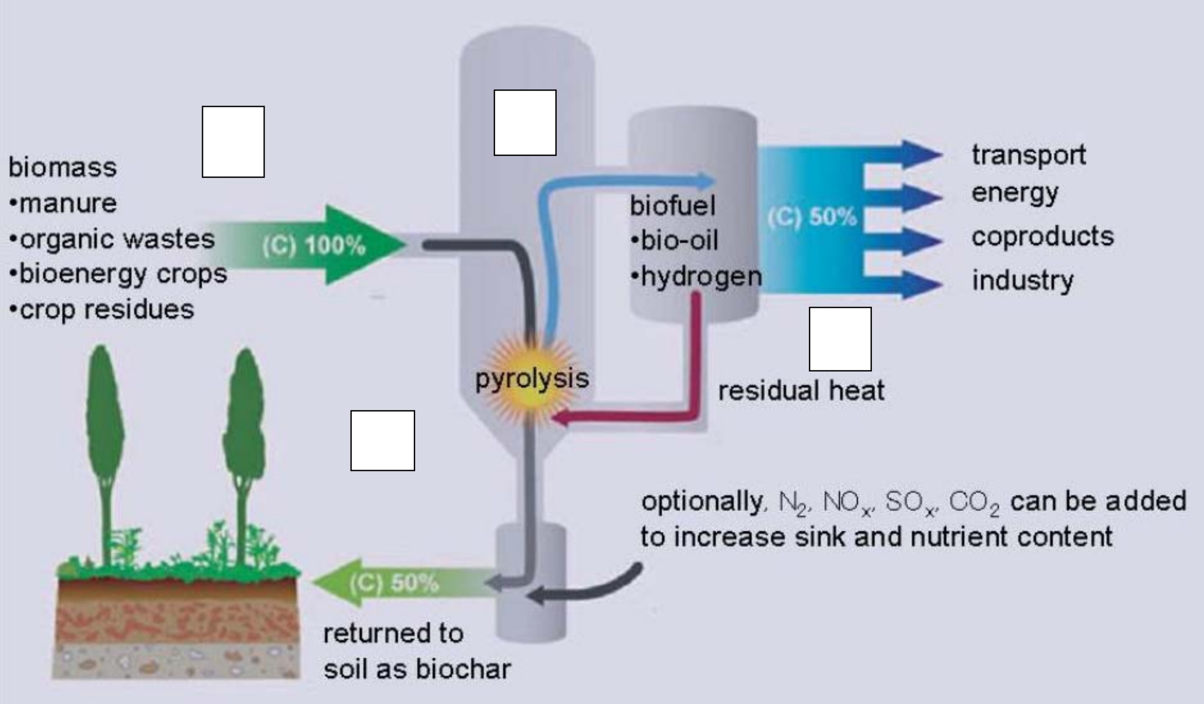
Pyrolysis technology will be assessed in this report based on an examination of the costs, benefits, barriers to market uptake, and the potential for EU funding to contribute to innovation and/or technology deployment. Given the benefits associated with the application of biochar to soils, here we consider how it can be utilised in the context of on-farm mitigation options. Looking at application of the technology from this perspective helps underline the importance of local context and soil properties.

One of the biggest advantages of pyrolysis technology is its ability to address greenhouse gas mitigation in a range of different sectors. Different sectors use different feedstock and different reactor types; this will depend on the type of product they are seeking to maximise. Power generators (for examples refer to Chapter 2) will be more interested in the bio-oil which can be obtained using inorganic waste while farmers could be interested in biochar which would be obtained using biomass only. The technology also has waste management applications and can be used to incinerate a range of organic and inorganic waste.

Again, given that we are looking at the potential of the technology to reduce greenhouse gas emissions on a net basis, or to be "carbon negative", we focus here on the potential to leverage uptake of the technology using biomass feedstock and the application of biochar to soil. Data is used to illustrate the cost of the technology for pyrolysis products to determine whether it can be cost-competitive with fossil fuels.

Our recommendations have been based on consideration of the various elements of the pyrolysis supply chain. Given the complexity of the technology, there are a number of issues to consider in evaluating the technology. These are described in relation to the numbers provided in the chart below:

Figure 1-1 Overview of Pyrolysis



Taken from Quade, p. 75

1) Feedstock: there are a number of feedstock that can be used as part of the pyrolysis process – including plastics and inorganic waste. This report demonstrates that the production of both pyrolysis oil and biochar is more sustainable and more cost-effective when lignocellulosic and organic waste products are used (such as 'arboricultural arisings' or green waste, animal waste, wood waste and straw) and not dedicated energy crops (such as miscanthus or short rotation coppice).

2) Pyrolysis reactors: there are a variety of different types of reactors used to heat biomass; these are outlined in greater detail in Chapter 2. Generally speaking, it is the lower temperature reactors which produce a greater amount of biochar and the higher temperature fast pyrolysis processes that yield primarily bio-oil (also referred to as pyrolysis oil).

3) Industrial applications of pyrolysis products and co-generation: there are several other applications for the products of the pyrolysis process. Bio-oil can be used for converted diesel engines and for small-scale combined heat and power applications. Syngas can be used to generate heat and power and can also be converted to hydrogen. More detail on the range of applications is provided in Chapter two.

4) Application of biochar in soil: biochar can be added to soil to increase rates of carbon sequestration while at the same time improving the productivity of soil. Research undertaken to date indicates that application of biochar in different soil types will result in different rates of carbon sequestration.

If you consider the application of the various products of the pyrolysis process, it is clear that biochar will be of interest to a limited number of sectors. For that reason, our assessment of biochar benefits focuses primarily on prospects for greenhouse gas mitigation with the agricultural sector and as a product capable of enhancing soil quality.

1.4 Research Gaps and Barriers to Market Uptake

We have investigated two distinct elements of technology finance that need to be considered in encouraging uptake of the technology: innovation and deployment. While some funding sources may help increase the rate of deployment, other funding sources may be required to help address a number of existing research gaps as part of the innovation chain. The potential for biochar to benefit the agricultural sector suggests that we may need to harness the capacity of rural communities and farms to implement the technology.

The ability of biochar to sequester carbon in combination with different soil types still requires investigation. In considering the adaptation benefits of biochar, it is also difficult to quantify costs and benefits without knowing more about the precise nature of local impacts, and the characteristics of the underlying morphology. Quantifying the impacts of climate change requires a detailed vulnerability assessment of the area. For adaptation, we maintain that the benefits are difficult to quantify and are more likely to be associated with overall improvements to societal welfare or to the natural environment. There are a number of on-going EU research administered under the 7th Framework Programme that aim to quantify the costs and benefits of potential adaptation measures.[2]

Our recommendations in Chapter seven are based on assessments of various costs and benefits, focussing on specific applications of the technology. While we have compiled information related to both the costs and benefits of the technology, we have not undertaken more detailed cost-benefit analysis *per se*. Information has been gathered based on available literature. Although there are a number of environmental benefits associated with the technology, it was not possible within the scope of this contract to investigate all of them. For this reason, the analysis completed in all chapters needs to consider the following data uncertainties:

- Although there is the potential to use hydrogen from pyrolysis in a number of different applications (fuel cells, combined cycle gas turbines, etc…), we would need to investigate the feasibility of developing the appropriate infrastructure for its distribution. For this reason we have not investigated the costs and benefits of syngas;

---

[2]. For more information, refer to: www.climatecost.eu.

- It is difficult to determine indicative costs and benefits given that implementation of the technology is highly dependent on feedstock, the type of pyrolysis reactor utilised, and the soil type in cases where biochar is a consideration. It is for this reason that we have proposed undertaking more localised research on the basis of regional pilot studies;
- It has been difficult to obtain appropriate cost data for feedstock and pyrolysis products. There is a lot of information available in relation to the cost of bio-oil, but we need to be clear that this cost pertains to a specific application of the technology and may not necessarily represent the cost of biomass based feedstock. Given that biochar related applications of the technology do not exist on a commercial scale in the EU, we have had to refer to cost data available for bio-oil applications in North America.

2. MITIGATION POTENTIAL OF PYROLYSIS AND BIOCHAR

As the description of the various pyrolysis products in Chapter 3 will demonstrate, there are numerous ways through which the technology can contribute to the reduction of greenhouse gases. Given the numerous applications of bio-oil in various sectors, it is difficult to comment on its precise mitigation potential. Given that we are focussing on biochar in this report, and the potential for its application as part of enhanced rural development, here we focus on the mitigation potential of biochar in an agricultural context.

The potential for the agricultural sector as a whole to contribute to greenhouse gas reductions has been discussed on the margins of the UNFCCC negotiations process. Reijnders (2009) has studied the relative merits of forests, landfilled biomass and biochar for offsetting greenhouse gas emissions. He concludes that while forests (due to uncertainty about permanence of and leakage effects caused by forestation projects) and landfilled biomass are not adequate offsetting methods, biochar may perform better in terms of permanently locking carbon in the ground.

Referring to data included as part of the IPCC Fourth Assessment Report, and the potential for agriculture to contribute to global mitigation efforts, carbon sequestration in soil and hence the potential for biochar is significant. As the table below indicates, the potential for cost-effective mitigation from agriculture in OECD countries is equivalent to that for industry, and greater than that for forestry and waste. Looking at the potential for mitigation in non-OECD countries (including the developing world) suggests that biochar could have significant technology transfer potential. Potential emissions reductions from the agricultural sector in non-OECD countries are greater than those for forestry, waste, and energy supply.

Table 2-1 Data from the IPCC and the Fourth Assessment Report

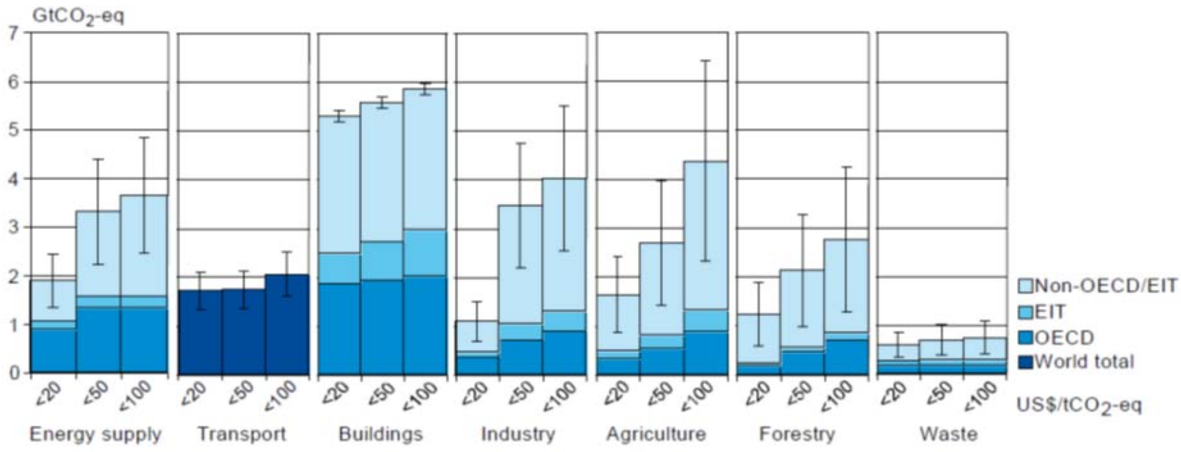


Figure 12 Global economic mitigation potential

As discussed throughout this report, the key benefit of pyrolysis is attributed to the product biochar. Biochar essentially helps reduce carbon losses by slowing decomposition and is most effective when applied to agricultural soils, degraded soils, or to halt the loss of carbon from cultivated peatlands. Despite biochar's mitigation potential, considerable uncertainties in terms of lifecycle emissions remain, including emissions from dedicated biomass cultivation, land use change emissions and reduced soil carbon when residues are the feedstock for biochar production. A number of key biochar experts and soil scientists freely admit the challenges to quantifying benefits; these are challenges typically associated with the quantification of emissions reductions from soil and with the measurement of improvements to soil quality (Bell and Worrall 2011).

Some scientists claim that the benefits of biochar can be attributed to an increase in net primary production from enhanced soil fertility.[3] For example, application of biochar in Europe has served to enhance the productivity of vineyards in Switzerland and Spain.[4] However, we must emphasis the fact that the ability of biochar to enhance soil productivity is largely a reflection of the soil type to which it is applied.

Sensitivity analysis indicates that the most sensitive parameters determining net carbon abatement are: the rate at which carbon from biochar remains in the soil, changes to soil organic carbon content from biochar application, greater electrical conversion efficiency as part of the pyrolysis process, heat uptake as part of the pyrolysis process, and biochar handling losses. (Interpretation of sensitivity and lifecycle analysis needs to consider the assumptions made regarding carbon properties and heat uptake as part of the pyrolysis process.[5])

Net carbon abatement is also a function of feedstock and reactor type. Roberts et al (2010) have studied the greenhouse gas emissions emitted by the slow pyrolysis-biochar lifecycle and the economic viability of biochar systems for a number of feedstock including arboricultural arisings and crops grown purposefully for energy use.[6] Regarding the GHG balance, the highest net reductions in GHGs can be achieved from an arboricultural arisings based pyrolysis system.[7]

---

[3]. See: http://www.biochar-International.org/sites/default/files/final%20carbon%20wpver2.0.pdf

[4]. See: http://www.ithaka-journal.net/druckversionen/biochar_in_vineyards.pdf; http://news.albetinoya.com/2011/04/biochar-new-treatment-for-our-vineyards.html

[5]. There are a number of uncertainties that need to be considered as part of standard lifecycle analysis completed for pyrolysis. Authors differ in terms of the assumptions in relation to an applied carbon stability factor, and in terms of accounting for heat uptake as part of the overall process. While Roberts et al base their analysis on a carbon stability factor for biochar of 80 per cent; Hammond et al (2011) use a factor of 68 per cent.

[6]. Defined in the supporting Information as a 'mixture of leaves, brush, and grass clippings, where the relative fraction of each (67, 25, and 8 wt. %, respectively) is estimated from typical yard waste collections in Suffolk County, NY' (pS5).

[7]. A few of their central underlying assumptions are summarised as follows: They apply a 'conservative estimate' of 80 per cent of the carbon in the biochar being stable and hence remaining sequestered in the soil; they do not assume any crop yield increases from biochar application as their case study focusses on high-yielding soils in the US corn belt that reduce the ability of biochar to increase yields further. They do assume increased fertiliser use efficiency, however, and hence better crop performance in the presence of reduced chemical fertiliser application. Linked to this is the assumption that soil N_2O emissions decrease by 50 per cent (p829).

The main reductions are from carbon contained in the biochar and sequestered in the soil on a long-term basis. Due to indirect land use change (ILUC) consequences from using dedicated energy crops as the pyrolysis feedstock, this approach could lead to net emissions depending on the scale of ILUC. Pyrolysis could therefore be less beneficial in cases where it is utilising purposefully grown energy crops as opposed to green waste products such as arboricultural arisings.

Authors come to a number of interesting conclusions with respect to pyrolysis technology and the ratio of energy production to the rate of greenhouse gas abatement. While slow pyrolysis delivers little electricity output, it outperforms standard biomass combustion, gasification and fast pyrolysis in terms of carbon abatement. The abatement benefits from slow pyrolysis become much more obvious when compared against the average carbon intensity of the 2030 electricity mix as Table 2-2 below demonstrates.

Table 2-2 Comparing Electricity Generation and Carbon Abatement

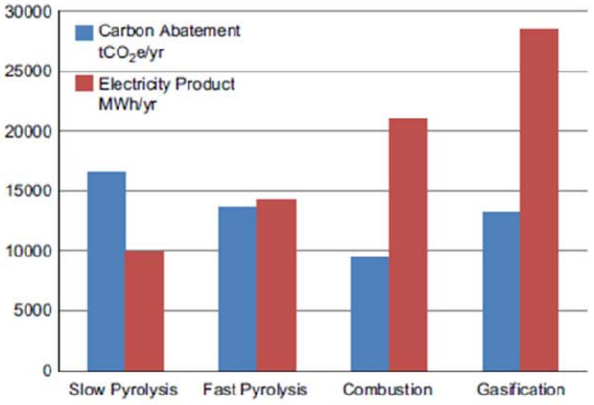


Fig. 8. Carbon abatement and electricity production for slow pyrolysis, fast pyrolysis, biomass combustion and gasification processing 20,000 odt/yr of short rotation coppice, offsetting the average grid carbon intensity for 2008.

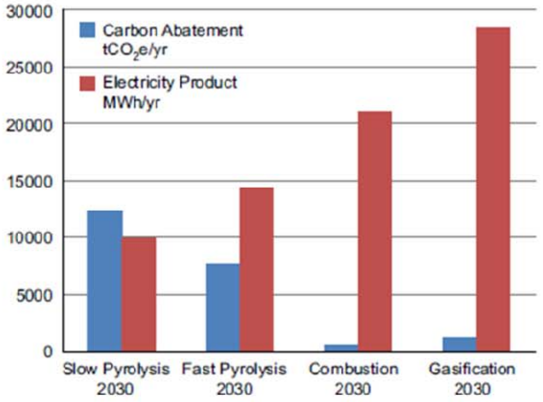


Fig. 9. Carbon abatement and electricity production for slow pyrolysis, fast pyrolysis, biomass combustion and gasification processing 20,000 odt/yr short rotation coppice, offsetting predicted average grid intensity in 2030.

Taken from Hammond *et al*, 2011, p. 2653 and 2654

If we were to consider a scenario where biochar was being sold to power generators to replace the use of coal, its mitigation potential is further enhanced. Using regional emissions baseline as a comparator, for the area in which biochar is being created, the combustion of biochar in an integrated gasification combined cycle (IGCC) plants combined with applications to soil, results in greenhouse gas emissions savings that are 29 per cent lower than in the case of biochar application to soils only (Roberts et al, 2010). The superiority of a ‘biomass-to-biochar-to-soil’ system is also demonstrated in comparison to the direct combustion of biomass, the former yielding higher emission savings and immediate sequestration benefits from reducing atmospheric CO_2.

If one considers the contribution of transport as part of the supply chain, research undertaken by Rogers et al (2009), indicates that emissions associated with transport of the feedstock are minimised in instances where it is confined to the biomass growth area. This emphasises the possibility that the costs and harmful impacts of pyrolysis could be minimised in cases where its uptake is confined to a specific boundary to encourage more sustainable rural development particularly in an agricultural context.

While authors differ on some topics, Roberts et al and Hammond et al found that the rate of greenhouse gas reductions could be attributed to specific types of biomass on a mass balance basis. Also similar to Roberts et al, Hammond et al found that considering the pyrolysis supply chain as a whole, that the greatest abatement benefits can be attributed to actual soil sequestration from biochar.

For medium- and large-scale plants, the electricity generated is the next important contributor to GHG reductions, whereas ‘agricultural impacts’ (improvements in net primary productivity, increased levels of soil organic carbon and reduced need for fertiliser) are more significant for small-scale plants. In short, authors conclude that the greatest potential for net abatement lies with large-scale pyrolysis plants.

Roberts et al came to a number of other important conclusions. In relation to feedstock, all were viable in terms of ‘delivering net carbon abatement and electricity production’. The ultimate choice of feedstock depends on local conditions and environmental indicators beyond net abatement as well as better future knowledge about the relative merits of different biochar types. Feedstock production is the greatest source of emissions from non-residue products, while transport was only a very minor contributor.

Nonetheless, the results of all the research completed to date would be further enhanced by a better understanding of the interaction of biochar with a range of different soil types. In the EU, it will be difficult to justify investment in biochar without knowing more about how biochar will interact with regional soil properties. Bell and Worrall (2011) conclude that the relative benefits of biochar application are likely to vary according to soil type, and point out the limitations of their work calling for further research before large-scale adoption is considered. In particular, Bell and Worrall were not able to make use of biochar derived from pyrolytic processes and hence used lump-wood charcoal as a substitute. While the authors do not believe that different charcoal sources and production methods would alter their qualitative conclusions about the carbon sink potential, performance on other environmental factors (such as nitrate leaching) and soil productivity could make charcoal application undesirable. From a cost perspective however, the benefits of pyrolysis technology are only likely to outweigh actual costs if biochar is applied to agricultural soils as a result of on-farm pyrolysis, where a number of different feedstock (including a range of different farm waste) are used (Bell and Worrall, 2011).

3. OVERVIEW OF PYROLYSIS TECHNOLOGY

Biomass is still the main source of renewable energy around the world, with almost 10 per cent of total energy consumption in 2006 deriving from biomass.[8] Much of this is traditional biomass use for cooking and heating in less developed countries. In the EU biomass is the most important form of renewable energy for power and heat production as well as transport energy and will play an important role in meeting Europe's "20-20-20" targets by the year 2020, and in meeting targets under the Renewable Energy Directive.[9] For that to take place a number of uncertainties and misperceptions in the debate regarding biomass energy need to be addressed, for instance regarding its sustainability, cost-competitiveness, logistical viability, availability, and its potential impact on food and feed production. In this chapter we focus on existing availability of the technology, and its more common applications.

The pyrolysis process has been utilised for the production of charcoals throughout history; and in the mid nineteenth century used to liquefy coals for the production of kerosene for heating and light. At the end of the 1980s, pyrolysis was used as part of small-scale rural applications with the product being used as feedstock for the chemical industry (Faaij, 2004). The process involves the thermochemical decomposition of organic material due to heating in the absence of free oxygen, generally at a temperature above 430^0C. The process is applied in the chemical industry, bio-fuel production, plastic waste disposal, coke and carbon fibre manufacturing. In cases where the feedstock comprises inorganic waste, the pyrolysis process releases volatile materials producing three major yields: a liquid, a gas and a solid. Thick bio-oil liquid is produced containing hydrocarbons, water and heavy tars. The oil generally has approximately half the heating value of conventional fuel oil. A syngas is also generated, containing a mix or carbon monoxide, hydrogen, carbon dioxide and other gasses. Finally a solid residual product is produced, a charcoal, carbon or biochar.

Pyrolysis is a term used to describe the thermal cracking (or decomposition) of biomass at temperatures ranging from 400-600°C in the absence of air. It involves quickly heating the biomass (by using hot sand), followed by the rapid condensation of the vapours produced. Fast pyrolysis yields 70 per cent bio-oil and the process takes only seconds.

---

[8]. Background report to the position paper of IEA RETD and IEA, bio-energy, Delft/Darmstadt, July 2010.

[9]. According to analyses of the Member States' National Renewable Energy Action Plans (NREAPs), biomass will make up 19 per cent of total renewable electricity in the year 2020, 78 per cent of total renewable heating and cooling in 2020 and 89 per cent of total renewable energy in transport. Altogether, bioenergy is expected to contribute over 50 per cent of total renewable energy use. (http://www.ecn.nl/docs/library/report/2010/e10069_summary.pdf and Atanasiu, 2010).

The following illustration provides a more simplified overview of the process:

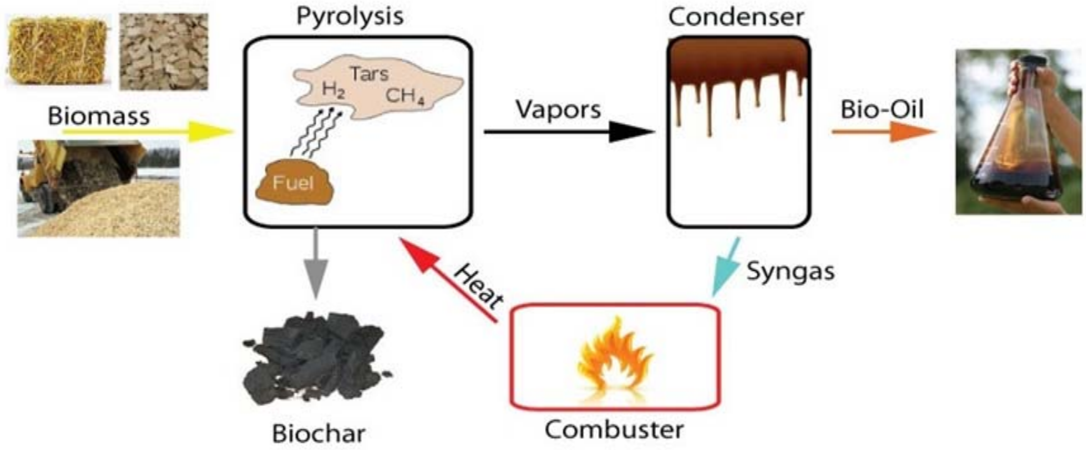


Figure 3-1 Overview of Pyrolysis Process, IEEP, 2011

Heating the biomass is undertaken using a number of different reactor technologies. Each reactor type has different advantages and disadvantages summarised in the table below.

Table 3-1 Comparison of Reactor Types

Reactor Technology	**Process**	**Pros**	**Cons**	**Research and Development**	**Scale of Operation**
Fluidised Bed	Mixing of biomass particles with heated sand particles	• Sand to Biomass heat transfer is excellent • Mature technology	• Difficulties in bio-oil cleaning – biochar found in bio-oil reducing potential applications • Added expense of bio-oil cleaning • Inert gasses reduce thermal efficacy	Dynamotive operate two commercial plants of this type in Canada.	Commercial scale
Rotating Cone	Biomass particles are fed into the bottom of a rotating cone with inert heat carriers	• Rapid heating • Simplified Bio-oil cleaning • Absence of diluting gases in bio-oil • Low residence time (< 0.5s)	• Lower tolerance for variable biomass • Increased pre-treatment of biomass • Current systems combust biochar for process energy	BTG operate a fully functional pilot plant in Malaysia (92t/d). Current EU demonstration plant under construction in Holland	Pilot scale, soon to be at commercial scale
Ablative Reactor	*Biomass is pressed onto a hot rotating surface (600^oC)*	• *High Bio-Oil yield* • *Utilises larger biomass particles*	• *Limited heat transfer* • *Restriction in feedstock shape, size & density*		*Still in research phase*

Compiled by IEEP, 2011

Refer to Annex II for diagrams and illustrations of these three reactor types.

The relative ratio of syngas, bio-oil and char produced by pyrolysis is dependent on the optimisation of the process chosen and the feedstock available. During fast pyrolysis, finely ground material is rapidly heated to moderate temperatures under pressure generating a higher yield of bio-oils, reducing the production of non-condensable gasses and solid biochar. Slow pyrolysis is optimised for the production of syngas and material is heated to higher temperatures and for longer residence times (Mohan, Pittman and Steele 2006).

The energy requirements of the pyrolysis process will generally cannibalise approximately 10 - 20 per cent of the energy produced, however this is again dependent on the feed stock and the scale and efficiency of plant used. Looking at outputs in terms of biochar, we can say that temperature and residency of feedstock in the reactor is a key determinant of the type of output. In short, slow pyrolysis yields more biochar and fast pyrolysis yields more bio-oil. (Yoder et al, 2011)

Fast pyrolysis may involve a range of different processes and reactors, including fluidised bed, rotating cone, vacuum and ablative reactors. As table 2-1 above indicates, all reactor variants have advantages and disadvantages regarding biomass feed preparation, bio-oil yield & quality, process cost, scalability, reliability and efficacy. Pre-feed drying is a uniform step in all processes, and reducing water content is crucial to increase process efficacy and prevent excess water content in produced oils. Due to the poor thermal conductivity of biomass and the rapid heating required to generate high yields of bio-oil, milling of biomass is necessary to provide small reactive particles (≤5mm). (Venderbosch & Prins, 2009)

All reactors variants are an attempt to increase the efficiency of rapidly heating biomass and accurately controlling the particle residence time (≥1s). Longer residence times are not desirable as excess heating will produce secondary reactions and cracking, reducing the quality and quantity of bio-oil produced. Effective biochar removal from bio-oil is also desirable as it can reduce industrial applications of the oil while increased char content contributes to secondary cracking of the oil, further reducing quality. (Bridgwater & Peacoke, 2000) All energy required by the reactors is provided by products generated in the production of bio-oil. Depending on the reactor configuration, produced syngas and/or biochar may be combusted to provide process heat.

Table 3-2 Typical product yields (dry wood basis)

Process	**Conditions**	**liquid** wt%	**gas** wt%	**biochar** wt%
fast pyrolysis	short residence time, mod temp	≈75	≈13	≈12
slow pyrolysis (Completed with vacuum type reactors)	very long residence time temp	≈30	≈35	≈30

Taken from Mohan, Pittman and Steele, 2006

In parallel to conventional thermal pyrolysis, advanced microwave heating pyrolysis techniques are under development. Microwaves allow greater control of the pyrolysis process, selectively activating biomass components, while rapidly and uniformly heating the whole biomass volume. This can produce a more efficient pyrolysis reactor, while making plants more compact and flexible; allowing optimisation for liquid fuels, syngas or biochar (Bio-refinery Microwave Demonstrator, 2010). Bio-oils produced with microwave-assisted pyrolysis often contain less hazardous compounds than oil produced by conventional pyrolysis (Fernandez, Arenillas and Menendez, 2011). Microwave-assisted pyrolysis has yet to be operated at a commercial scale, but has been demonstrated at a scale in excess of 100kg/hr. (Robinson and Snape, 2010)

There is a greater amount of commercial interest in fast pyrolysis than there is for slow pyrolysis at the current time, although our research indicates that slow pyrolysis has been used to demonstrate the feasibility of biochar yields from the process. Although slow pyrolysis results in higher yields of biochar it may be less economical although this will depend on its application, and the market position of the operator. In other words, while a power generator will have more interest in the profitability of bio-oil to fund plant operations, and possibly further investment in other renewable technologies, a farmer for example may be more interested in slow pyrolysis given its ability to generate more biochar. A farmer's interest in slow vs. fast pyrolysis will depend on-farm economics and the extent to which they benefit from the sale of other pyrolysis products such as bio-oil.

3.1 Existing Technology Uptake

In 2007 Dynamotive (a biofuels company) commissioned a large commercial pyrolysis plant in Ontario, Canada consuming 200 tonnes of waste wood material per day. The plant is optimised for the production of bio-oil and produces 22_{wt} per cent biochar as a by-product. The plant may also produce a product marketed as bio-oil plus, where separated biochar is finely ground to approximately 8 microns in size and added to bio-oil. The plant produces an energy output equivalent of 130,000 barrels of oil per year (Sims, 2007). In 2003, Dynamotive received cd$ 4.5m from Technology Partnerships Canada to support technology R&D and facility development (Bnet, 2003).

North America has seen rapid development of the implementation of large commercial pyrolysis plants. In 2010 the technology firm Ensyn received the planning approval to construct and integrate a large 400t/d pyrolysis plant with a sawmill operation in Alberta, Canada. Utilising waste wood from the mill makes the reactor the biggest in the world, producing 85 million litters of bio-oil annually. In 2010, with federal government support, Ensyn also began testing bio-oil to supply an Albertan paper mill's energy needs. A commercial scale fast reactor is planned for Arkansas U.S.A, consuming waste sawdust from approximately 25 sawmills. The plant may be eligible for state and federal grants (US$ 2 – 5 million) (Dynamotive, 2009). The paper company crane has proposed co-locating a pyrolysis plant with a paper mill in Massachusetts.

The first commercial scale pyrolysis plant in the EU is set to come online in 2012 at Hengelo, the Netherlands, and is to be operated by the Biomass Technology Group (BTG) (Yeh, 2011). The plant is again optimised for the production of bio-oils and will consume 120 tonnes/day of local wood residue. The 25MWth (megawatt thermal) plant is considered poly-generation as the fuels produced will be used onsite in existing boilers to generate electricity. The facility has received €4.95 million from the Seventh Framework Programme (FP7, 2010).

In 2010 a 7.5MW pyrolysis and gasification plant was granted planning permission in Bristol in the UK. The plant, however, will consume various non-organic waste products such as plastics and glass; thus, due to the gasification process, it will not produce biochar. A €30 million, 200 ton/day pyrolysis plant was granted planning permission in Ireland in 2011. The plant will consume both biomass and municipal waste; producing bio-oil and syngas to generate electricity (6MW). Current plans require that any biochar produced has to be combusted on site to increase thermal efficiency (Glanpower, 2011). The project has also been submitted for funding as part of the NER300 (SEAI, 2011).

Table 3-3 Examples of Existing Installations

Country	Company	Units built	Capacity kg waste/h
Canada	Dynamotive	4	8,000
Canada	Ensyn	8	4,000
Canada	Pyrovac	1	3,500
Canada	Abritech	4	2,083
Netherlands	BTG	4	2,000

Compiled by IEEP, 2011

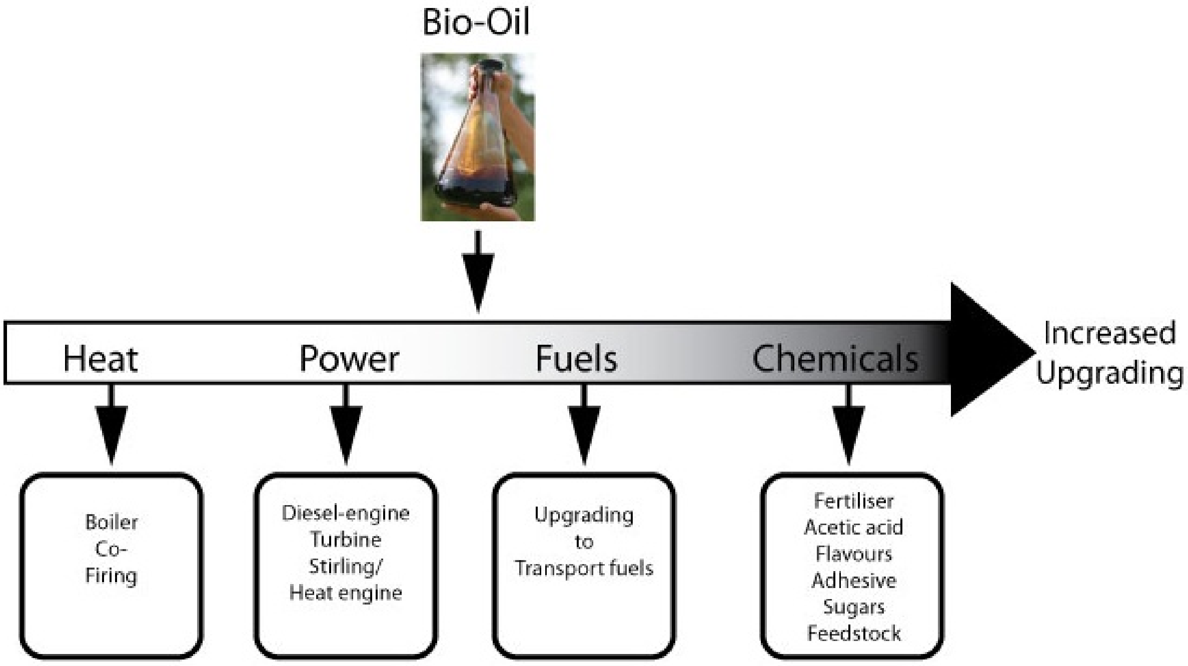
For more implementation examples of the technology refer to Annex I.

3.2 Applications of Pyrolysis Products

Due to pyrolysis technologies' long history and varied industrial application, the process now appears at many different scales and complexities. Many large pyrolysis plants have been proposed over the previous decade, however there are few large full scale plants currently operating exclusively on biomass. These plants have been limited in the past, often due to poor economic incentives and lack of sufficient biomass availability for consumption. However, the economics of pyrolysis plants have improved with higher conventional oil prices and the increasing maturity of government supported research development and demonstration projects. Global investment in commercial fast pyrolysis plant for the production of bio-oils has increased markedly in recent years.

There are a number of different applications for pyrolysis products. Bio-oil may be utilised in heating, power generation and as a feedstock for the chemical industry. Bio-oils contain large water content and are highly acidic, making them corrosive; so upgrading of the fuels is often desirable particularly for use in modified diesel engines and smaller scale combined heat and power systems (Brown and Stevens, 2011). Syngas may be converted to hydrogen for use in electricity generation and heating. Although upgraded fuel can be used in Combined Heat and Power and modified diesel engines, it cannot be mixed with fossil fuels or other biofuels. More specifically in relation to engines, they can only be used as part of a separate ("dual") injection system (Van de Beld et al, 2011).

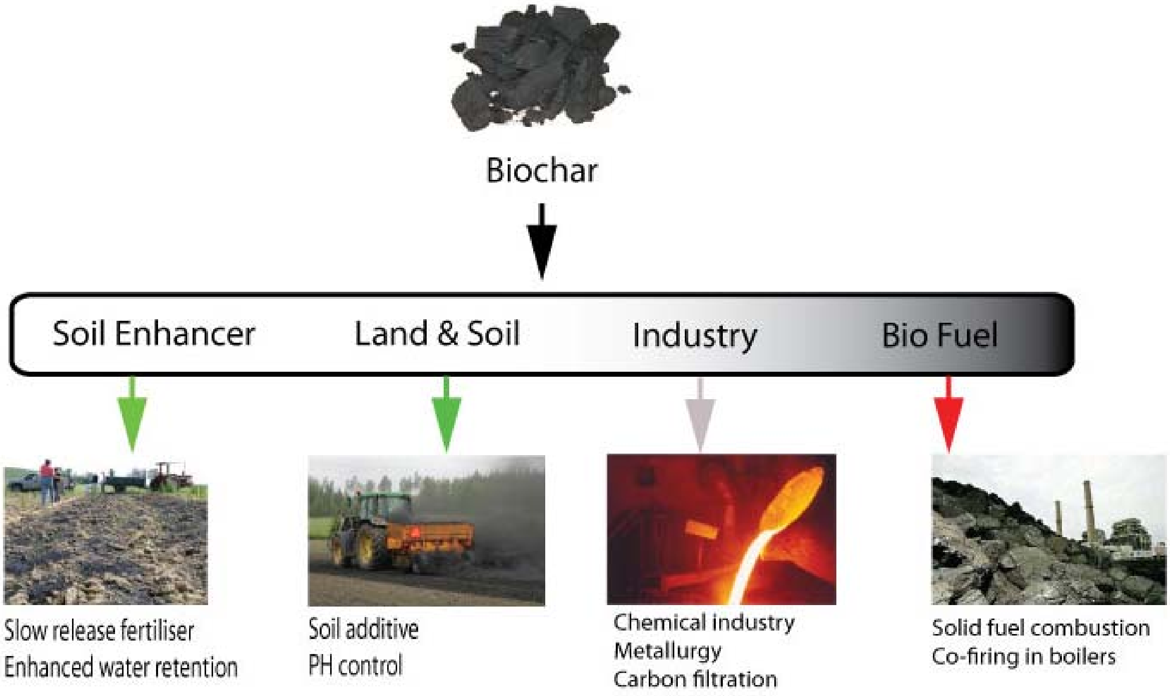
Figure 3-2 Applications of Bio-oil



IEEP, 2011

Co-generation of bio-oils or syngas at conventional large combustion plants has long been proposed as an attractive proposition to supplement power generation and utilise local waste products. Bio-oils and syngas may be used to co-fire plant boiler units, reducing the consumption of fossil fuels and utilising formerly discarded waste. If there is the potential to utilise the produced bio-oil for electricity, then a given pyrolysis plant may be fitted with a bio-oil engine generator, a boiler or be co-located with an existing power plant. On a farm it may be more desirable to store it in a tank and use it for residential heating purposes.

Figure 3-3 Applications of biochar



IEEP, 2011

Small industrial, mobile and semi-mobile pyrolysis units are currently under development for use in the agricultural sector. These units may be attractive due to lower capital costs for the consumption of on-farm waste material such as plant husks, animal waste and manure; producing saleable bio-oils, syngas, CHP and biochar as a soil conditioner (Fransham and Badger 2006; Coleman, et al. 2010). The Canadian engineering company Agri-Therm has developed a mobile fast pyrolysis system allowing the reactor unit to travel to farms, utilising seasonal stockpiles of low density organic waste (Agri-Therm, 2011).

Figure 3-4 Agri-Therm portable fast pyrolysis unit (Agri-Therm, 2011)

Mobile pyrolysis technology is of particular interest in developing countries, with high agricultural organic waste and poorly developed infrastructure increasing the cost of transporting wastes to centralised processing plants (Brick, 2010). In the developed world, a mobile pyrolysis unit would be beneficial given that transport costs can be minimised by locating pyrolysis units close to feedstock. (Refer to discussion below in Section 4.2.)

Companies such as Abri Rech, Re:char and Big have all developed similar technologies that process input ranging from half a tonne per day to 100 tonnes per day. The technology is in the process of commercialisation and is marketed in some western markets now (Big, 2011) (T R Miles, 2010).

4. COST OF PYROLYSIS

There are a number of costs and benefits associated with pyrolysis. Based on the initial research question outlined in the specification, this report outlines the costs and benefits associated with biochar. Our presentation of costs considers two distinct perspectives: the cost of the pyrolysis products in the context of the energy market, and the cost of the entire process including biochar. We consider the possibility that pyrolysis products could be competitive with fossil fuels in the short term, referring to data available for the sale of bio-oil. Longer term, our discussion of a PRIMES model run indicates that the cost of the technology could increase given the increased demand for biomass feedstock.

Bioenergy has been increasingly scrutinised in terms of its overall impacts on the environment. If you consider the start of the supply chain for pyrolysis, there is the risk of emissions from indirect land use change and the cultivation of feedstock, and the possibility that the demand for certain feedstock will compete with arable land used to grow food crops primarily for first generation biofuels (Bowyer, 2010). Emissions from ILUC as far as pyrolysis is concerned may be an issue for all feedstock including wood waste and first generation energy crops. While it is important for pyrolysis products to be cost-competitive, the production of them must be sustainable.

We must emphasise the fact that it is difficult to monetise a number of the benefits associated with implementation of the technology, particularly in relation to adaptation. It is easier to monetise the economic benefits associated with either the sale of bio-oil, given the development of bio-oil on a commercial scale in North America for example, and the fact that emissions reductions can be calculated based on standard mass balance calculations. The feasibility of using the price of carbon to quantify either costs or benefits will of course depend on the state of the carbon market.

Nonetheless, there is an inherent challenge in monetising some of the more indirect costs and benefits related to pyrolysis technology particularly with respect to the uncertainty related to the application of biochar to agricultural soil. Although it is possible to provide a rough estimate of the value of sequestration on the basis of a market price for carbon, establishing a net present value for key parameters as part of the baseline is problematic (Defra, 2011, p. 89). The uncertainty associated with permanence of the reduction necessitates assessment of the issue on the basis of scenarios and hypothetical examples. As the section on benefits below indicates, determining an applicable range of uncertainty for carbon sequestered in soil will only be possible if the appropriate monitoring and verification protocols are implemented.

4.1 Pyrolysis Technology Cost

Determining the costs and benefits for pyrolysis, given the benefits to the environment and society, does not consider the lost opportunity costs associated with uptake of the technology. We do not consider how investment in pyrolysis and biochar results in lost revenue for conventional fuel and energy suppliers. Given the numerous applications of the technology and its products, this analysis considers the benefits associated with soil resilience and improved agricultural practices. In theory, it would be possible to calculate all the potential costs within this supply chain (in producing, transporting and applying biochar to soil) to determine the break-even selling point (BESP) per tonne of biochar; his total cost would then be compared against all financial, environmental and social benefits (Defra, 2011, p. 90). As stated herein, obtaining all applicable cost data has been challenging. It has not been possible within the scope of this contract to quantify costs and benefits given the lack of available data.

Determining cost also varies considerably based on the particular application of pyrolysis technology; cost is dependent on the type of feedstock used, and the scale of the plant. Smaller plants are proportionally more expensive, given that the operations and maintenance costs associated with a plant constitute a significant percentage of the total cost (Defra, 2011, p. 92). Based on industry research completed in 1999, the cost of producing pyrolysis oils was in the range of 75-300€ per tonne of oil (or 4 to 18 € per GJ) for feedstock costs ranging from 0 to 100€ per tonne (or 0 to 1.9 € per GJ).[10] However, results from the PRIMES biomass model indicate that based on maturity of the technology in 2035, the standard total production costs for pyrolysis oil will be €53/GJ/year. The model runs provided by PRIMES assume an increased demand for biomass feedstock, hence accounting for the higher cost. Refer to Annex III for a breakdown of the results of the PRIMES Biomass data; model runs were obtained from the E3MLab in June of 2011.

4.1.1 Pyrolysis Oil as an Alternative Fuel: Price Comparison

There is growing recognition of the fact that the production cost of pyrolysis oil could be competitive with that for standard fossil fuels.[11] The competitiveness of pyrolysis oil will improve in cases where it is able to substitute for fuel in diesel engines, particularly given the recent increase in diesel prices.[12] Diesel prices (without tax) have reached levels of up to 10 €/GJ in recent months.[13]

---

[10]. See: http://www.btgworld.com/index.php?id= 22&rid=8&r=rd

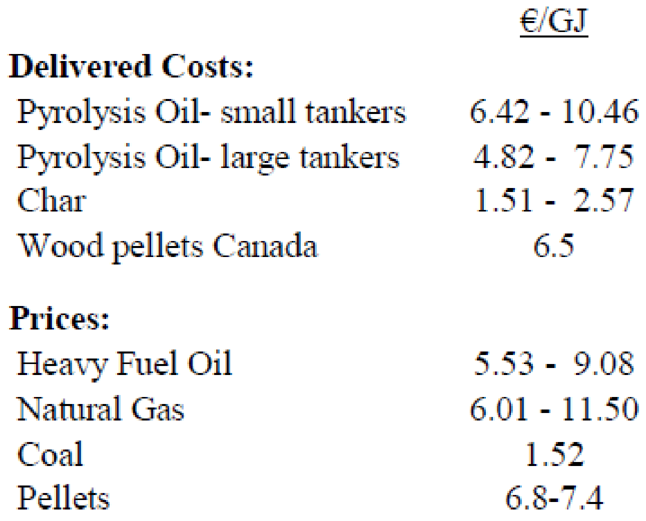
[11]. See: www.biofuelsdigest.com/blog2/2009/08/28/anellotech-launches-latest-fast-pyrolysis-venture-expands-growing-field-of-biocrude-pyrolysis-companies/. University of Massachusetts based company that wants to produce biofuel from pyrolysis at a price that is at parity with fossil fuels by 2019.

[12]. We have not considered the emissions associated with the fuel upgrading process as part of our analysis. This may warrant further investigation in order to determine whether the technology is carbon negative.

[13]. See, www.btg.com, accessed July 2011.

Canadian experts on pyrolysis have studied the costs of producing pyrolysis oils in different potential source countries with a view to exporting these to meet renewable energy targets in the EU (Bradley, 2006). Figure 4-2 summarises the main results. The labels 'small tankers' and 'large tankers' refer to the different modes of transport used to ship the pyrolysis oil to the EU. For confidentiality reasons, actual manufacturing costs are not displayed and 'all costs are lumped together including labour, utilities, maintenance, royalties, debt repayment and equity returns' (Bradley 2006, p32). Here we need to stress the fact that these numbers do not consider the cost or benefits of biochar. The description of market uptake for the technology in Canada for example, is based on the commercial viability of pyrolysis oil which has been produced using both organic and inorganic feedstock.

Figure 4-1 Overview of Fuel Costs

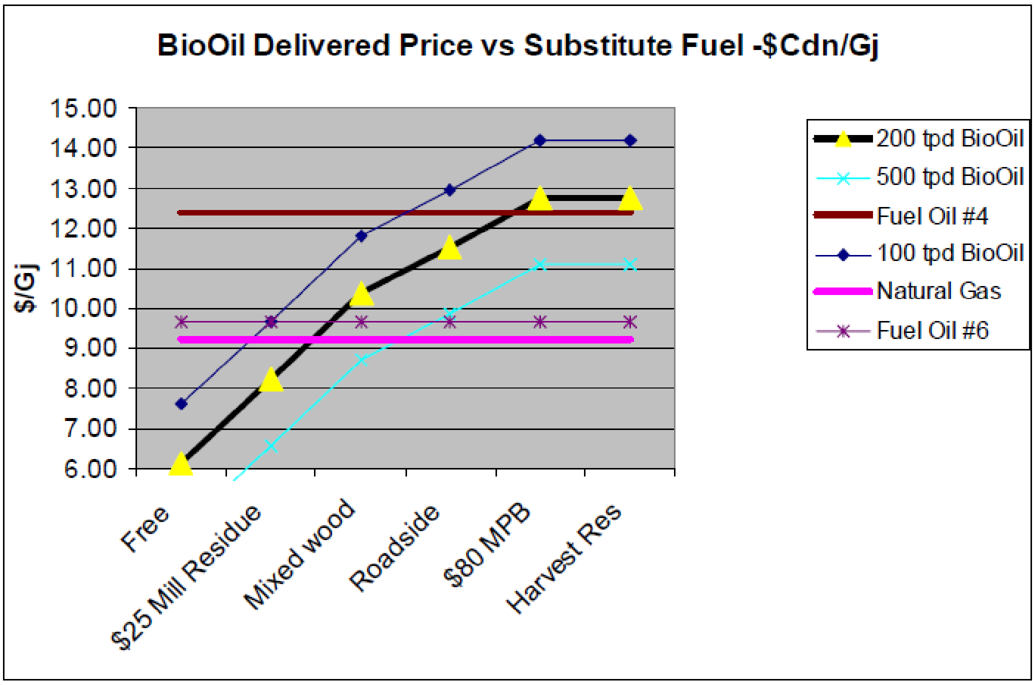


	€/GJ
Delivered Costs:	
Pyrolysis Oil- small tankers	6.42 - 10.46
Pyrolysis Oil- large tankers	4.82 - 7.75
Char	1.51 - 2.57
Wood pellets Canada	6.5
Prices:	
Heavy Fuel Oil	5.53 - 9.08
Natural Gas	6.01 - 11.50
Coal	1.52
Pellets	6.8-7.4

Taken from Bradley, 2006, p. 4.

If one assumes that the manufacturing costs are similar for all forms of pyrolysis, the main differences in 'delivered costs to the EU' stem from the type of feedstock used, the size of the pyrolysis plant and applied reactor type, and the efficiency of shipping. If we were to consider a scenario were the international transport costs were minimised, cost estimates for EU based pyrolysis products would look very different. Utilising EU based feedstock as part of the pyrolysis supply would not need to reflect the cost of shipping. Nonetheless, Canadian expertise and research is able to help determine the importance of feedstock costs and plant sizes as part of the overall net cost of the technology. In table 4-1 below, the effect on prices from using different feedstock in different plant sizes is illustrated and compared to fossil fuel sources, natural gas, fuel oil #6 and fuel oil #4 (both forms of heavy fuel oil). The work completed by Bradley also shows that the use of roadside waste as a feedstock, in other words one of the higher cost alternatives, is only competitive with the most expensive fossil alternative fuel oil #4 in the two larger pyrolysis plant types (Bradley, 2006, p. 17).

Table 4-1 Cost of Fuels Based on Volume and Feedstock Type



Taken from Bradley, 2006, p. 17.

4.1.2 Cost of Biochar and Lifecycle Analysis

Given that biochar is likely to be of greatest interest to individual farmers, our analysis focuses on the cost of biochar from an on-farm perspective. The overall cost of pyrolysis and its products may be even more competitive under a scenario where the benefits of biochar are included. These benefits will, however, need to be weighed against the additional costs associated with biochar itself. Given the fact that the biochar product results in carbon savings when it is applied on soil, we need to consider both the costs and benefits associated with competing soil additives such as compost. This is a crucial consideration given that the feedstock used for compost would be a prospective feedstock for on-farm pyrolysis.

The lost opportunity cost associated with competing soil enhancement products would be a consideration in examining the economic feasibility of biochar for individual farmers. The lost revenue associated with compost is considered based on the use of on-farm inputs only (commonly referred to as "arboricultural arisings") and the costs faced by them as part of the waste management process. Roberts et al (2011) summarise these costs and benefits in table 4-2.

Table 4-2 Additional Costs and Cost Savings for Biochar

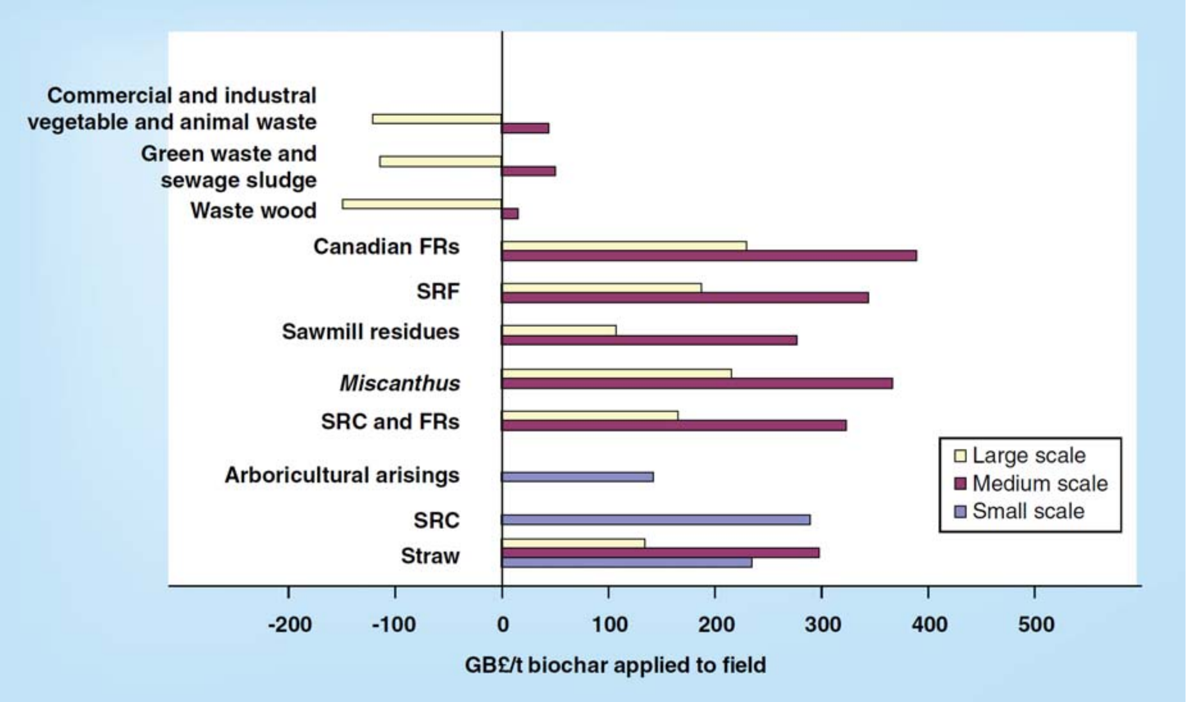
Costs	Revenues and Cost Savings
• Feedstock costs; • Pyrolysis; • Feedstock transport; • Biochar transport; • Biochar application; • Lost compost revenue (green waste or arboricultural arisings).	• Biochar increases amounts of phosphorous and potassium, leading to higher quantity and quality crop yields; • Improved fertiliser efficiency from biochar application (reduced fertiliser cost); • GHG emission reduction; • Energy produced; • Avoided gate fee (arboricultural arisings); • Avoided compost cost.

Taken from Roberts *et al*, 2010, p. 829

Roberts *et al* have undertaken a more elaborate economic assessment that distinguishes between a high and low revenue scenario to illustrate the revenue generating potential of carbon offsets based on a price per tonne of CO_2 equivalent of 80 $US and 20 $US, respectively. As seen for other pyrolysis products, the overall cost is impacted by the cost of feedstock and the type of pyrolysis reactor used (as well as lost compost revenue in the case of on-farm waste). In cases where it is possible to utilise syngas for heat and power, there can be additional revenues. For both the high and low revenue scenarios, it is the uptake of on-farm feedstock that renders pyrolysis technology economically viable. The switchgrass scenario, which is assumed to have a more significant ILUC effect, remains unprofitable in both scenarios. For swtichgrass, pyrolysis is only economically viable in cases where the price of carbon is significantly higher. Sensitivity analysis shows that while transport distances have a minor impact on the GHG profile, they constitute the most important determinant for the profitability of the different processes.

Shackley *et al* (2011) have developed costs for UK pyrolysis-biochar systems for small, medium and large plant sizes and eleven feedstock categories including purposefully grown crops, coppice and forestry and waste sources. (The term “waste sources” is used to refer to biomass waste sources and does not refer to inorganic matter.) They present a framework of costs and benefits of pyrolysis (2011, p.341) similar to Roberts *et al* (2010) without undertaking a full cost-benefit analysis due to a lack of data and poor understanding of the potential agricultural benefits associated with biochar application such as increases in yields and soil organic carbon and reductions in fertiliser requirements and nitrous oxide emissions. This more cautious approach questions the assumptions of others, among them Roberts *et al* (2010), on crop yield increases from biochar application for example. Instead of a full-fledged CBA, Shackley *et al* present their results as a ‘break-even selling point’ (BESP) or a net production cost. Any additional benefits not captured in their analysis would have to add up to this net production cost in order to make sure biochar use is economically viable.

Figure 4-2 Net Cost of Biochar Produced with Small, Medium and Large-scale Pyrolysis



Taken from Shackley *et al* (2011, p348).

**Note: FR: Forestry residue; SRC: Short rotation coppice; SRF: Short rotation forestry.

This graph indicates that the greatest cost savings are achieved when secondary waste products are used as feedstock in large-scale plants.

Similar to previous studies, Shackley *et al* find that the most important components of costs and benefits are pyrolysis operation, capital costs and feedstock costs (they compare biomass feedstock only). The sale of electricity and incentives from renewable energy policy (UK Renewables Obligation), where energy is created using organic feedstock (biomass waste that is not sent to landfill), provide financial benefits given the avoided cost of gate fees. (This applies more to medium and large plants.) The transport costs for both waste and non-waste products are similar, so few additional costs accrue in a non-waste feedstock scenario.

Shackley *et al* (2011) highlight that pyrolysis-biochar systems are at a disadvantage due to their low yield of renewable energy (which would provide them an income from financial incentives part of renewable energy policy) and a lack of corresponding value for the carbon content. The most promising commercially viable element of the technology is biochar production from waste streams including inorganic matter. However, applying biochar derived from waste to agricultural land could pose environmental risks and hence faces regulatory issues. There is therefore the need to study these risks and associated mitigation strategies more thoroughly. A potential 'niche development' for biochar is the production from 'arboricultural, green waste and wood waste arising from urban centres' (Shackley et al, 2011, p. 353). Authors stress that uptake of biochar could be accomplished through the establishment of better measurement standards under the carbon market, and the inclusion of biochar within environmental stewardship schemes under the Common Agricultural Policy of the EU' (Shackley et al., 2011, p. 353).

Lifecycle analysis completed for pyrolysis by a number of authors indicates that transport of feedstock is not a prime contributor to overall emissions. This is particularly true in cases where biomass is being transported within the biomass growth area. Given that biomass needs to be transported wet (the weight of wet feedstock results in lower fuel efficiency for road transport), it is more cost-effective to locate biomass near pyrolysis units. It may be better for this reason, to have pyrolysis plants located remotely in rural areas (Rogers et al, 2009).

4.1.3 Summary of Cost Discussion

The data obtained from project developers indicates that in the short term, based on current prices for diesel, pyrolysis could be cost-competitive. Output from the PRIMES Biomass model however, indicates that with increasing demand for biomass feedstock, the cost of the technology may increase. We need to emphasise the fact that the data used to estimate the current costs of pyrolysis may not reflect longer term biomass feedstock prices and are based on an unknown mix of feedstock. On the other hand, the longer term cost estimates produced by PRIMES also do not consider the potential marketability of biochar, and a number of other environmental benefits that are difficult to quantify.

5. PYROLYSIS, BIOCHAR AND ADAPTATION

As stated in the introduction, the synergy between adaptation and mitigation is maximised at the local scale. Based on this reality, and the need to consider a specific project boundary as specified in the terms of reference for this contract, we have compared the cost of biochar with other soil management options designed to address the impacts of climate change in the agricultural sector. These costs reflect the ability to reduce greenhouse gases, address biodiversity, and counter the impacts of climate change on soil simultaneously. (Hart et al, 2011)

5.1 Improved Soil Resilience and Adaptation

There is potentially a strong link between biochar, water retention, and increased soil resilience. Given that applying biochar to soil could improve its ability to retain water, and hence improve its resilience, it could be a possible adaptation measure in terms of flood prevention. However, while biochar is generally thought to be porous and to improve water retention, the confidence in the evidence base required to come to this conclusion remains low (Defra, 2011, p. 14). The general effect of biochar on water holding capacity, especially biochar produced from non-woody feedstock, has yet to be quantitatively established. (Defra, 2011, p. 23).

Nonetheless, there is a wealth of research indicating how biochar has helped to improve water retention of soil in relation to specific soil types. Fieldwork completed by Karhu et. al (2010) found that biochar was able to improve methane uptake and increase soil water holding capacity by 11 per cent. The conclusion calls for further research into how this might apply to different kinds of soils. Water retention properties should be of critical importance in climate change adaptation, where mitigating drought, nutrient loss and erosion are critical (Sohi et al, 2009).

There is mounting evidence that modern land use practices have enhanced surface runoff and increased the risk of local flooding. Increased runoff is due to many land management factors including loss of hedgerows and runoff from bare soil, drains and ditches. Peak discharge and particular overland flow is also sensitive to soil characteristics. Highly compacted intensively farmed soils have poor infiltration rates, with the upper few centimetres quickly becoming saturated and impermeable. This reduces the soil’s ability to absorb, store and transmit moisture to the subsurface and in times of increased precipitation this generates surface flow and runoff. In cases this may exceed local channel network capacity, leading to increased flows, over silting, inundation and flooding (Gonzalez-Sosa et al, 2010).

Conditioning soil to increase its ability to absorb and retain water may help to alleviate the problem of “muddy floods” leading to slower and less rapid drainage of water to the channel system. Some soil scientists claim that biochar’s high inner surface areas and generally high porosity expands soil’s ability to store water (Verheijen, et al. 2009). Biochar has also been shown to effectively increase storm water retention, especially in areas with extended dry periods (Beck, Johnson, and Spolek 2011).

However, depending on the original soil type, biochar can also decrease water retention. Adding biochar to heavy clay soils may decrease water availability, while sandy soils my benefit from higher water availability. It is also possible for biochar to cement and clog soils, creating barriers to moisture flow, increasing runoff and lowering infiltration rates (Verheijen et al, 2009). Again, in order to determine how biochar will contribute to soil resilience, assessment needs to be undertaken for a number of different soil types. As the graph below illustrates, the ability of soil to retain water decreases (even with added biochar) as soil becomes more and more compacted.

Figure 5-1 Soil Water Retention Properties Relative to Soil Density

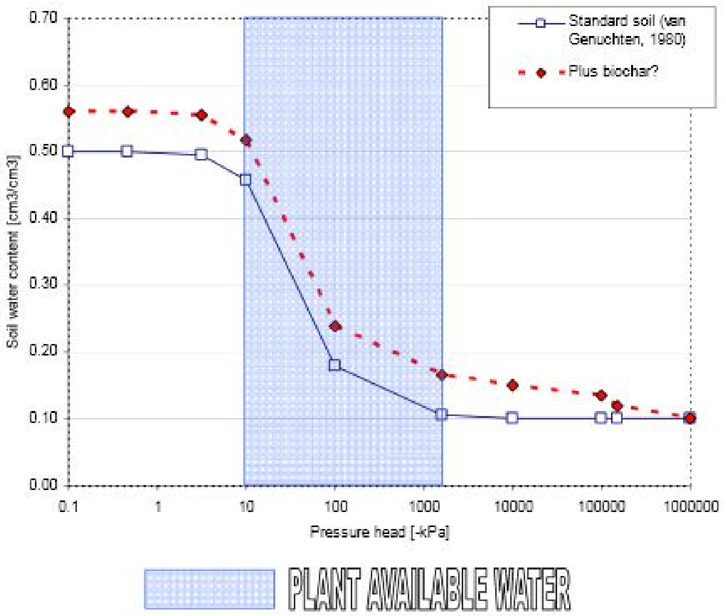


Figure 3.1 Typical representation of the soil water retention curve as provided by van Genuchten (1980) and the hypothesized effect of the addition of biochar to this soil

5.2 Cost of Biochar in Comparative Perspective

There are a number of different soil management practices that could be used to address the impacts of climate change on soil. Based on a case study completed for the environmental benefits of soil management in the Murcia region of Spain, the following costs were calculated for a range of different agricultural practices. (Hart et al, 2011, p. 76) Biochar is categorised as the "addition of exogenous organic matter" (EOM) and is highlighted in yellow.

Table 5-1 Total Costs of Practices to Address Soil Erosion and Organic Matter Content Issues

	A	B	C	D	E	
Practice	Area to be managed (ha)	Unitary one-off costs (€/ha)	Unitary annual costs (€/ha)	Total one-off costs (€)	Total annual costs (€)	Comments
Contour tillage	515,793	0	20	0	10,315,860	
Reduced/conservation tillage	516,243	0	0	0	0	
Soil conservation structures	79,041	2,500	125	49,400,579	9,880,116	Build in 25 per cent of area; maintain in 100 per cent
Natural vegetation on edges of fields and rural tracks and water banks	516,243	0	50	0	25,812,136	Hedgerows not considered.
Keeping overwinter stubbles	142,856	0	28	0	3,999,958	Cost of crop rotation not included
Green manure	111,316	0	44	0	4,897,899	
Change crop rotations/Increase fallow index in crop rotations	143,305	0	32	0	4,585,772	
Vegetation strips	515,793	Calculated crop by crop		83,262,015	50,554,646	
Mulching using crop residues	261,622	0	136	0	23,838,963	Calculated for 2 applications every 3 years
Non-harvested fringes on annual rain fed crops	142,827	0	0	0	0	Vegetation fringes considered instead
Addition of exogenous organic matter	397,525	0	400	0	52,473,255	1 application every 3 years
Forestation of agricultural lands	2,618	1,800	500	4,712,491	1,309,025	
			TOTAL	**137,375,085**	**187,667,630**	

Taken from Hart et al, 2011, p. 106.

Referring to the example provided for EOM, Column A refers to the entire area to be impacted by the addition of biochar to soil. Column B refers to an initial start-up cost, while Column C refers to annual maintenance and operations cost. The annual operations cost for all hectares (A x C) is provided as a total cost in Column E. The cost as determined for this table is based on "income foregone" as a result of applying biochar. It could include additional costs associated with both the purchase of the product and as part of its application. However, while it may be a more expensive soil management option for an individual farmer, the cost may not reflect the value of other pyrolysis products. Depending on the type of technology used to produce the biochar, it could be produced on farm using a mobile pyrolysis unit that also produces bio-oil.

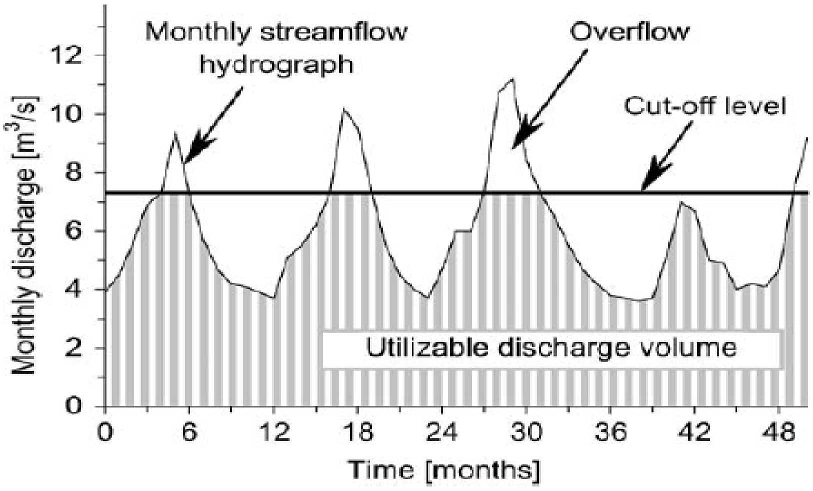
6. HYDROPOWER: ADAPTATION AND MITIGATION SYNERGIES

As stated in the introduction, hydropower is not a suitable technology in terms of leveraging synergistic benefits for both the adaptation and mitigation agendas. There are a number of environmental impacts to consider, in addition to the uncertainty associated with actual precipitation and hydrological regimes. Hydropower can be generated utilising a number of different types of design, and magnitudes, with widely different impacts on and benefits for natural and social environments (Egré & Milewski, 2002). In order to determine the actual benefits of the technology given its numerous applications, meaningful analysis must consider the specific type of hydropower technology in question. Furthermore, social and environmental impact assessments of hydropower schemes only make good sense in reference to complex local scenarios of water basins.

There are two general types of hydropower: run of the river, and hydropower utilising dams and reservoirs. Medium and large hydropower for reservoir based hydro is classified by the International Energy Agency (2010) as 100-300 MW and > 300 MW respectively, and, given the construction involved, is a practice which has become increasingly unpopular in Europe because of the substantial environmental impacts entailed. Nevertheless, reservoirs offer the benefits of flood protection (which may be increasingly relevant under the intensified hydrological cycles of a warmer world) and the ability to follow rapid changes in electricity demand to ensure security of supply (which is increasingly important with an expanding but intermittent renewable energy sector), possibly using pumped-storage (World Energy Council, 2004, p. 201-3).

These advantages of flood protection and security of supply are not offered by small 'run-of-river' hydro schemes, typically less than 10 MW in size (IEA 2010). Power generation stations are unable to harness high water discharge levels associated with intense rainfall events and high levels of precipitation that might be experienced in regions of Europe in the future. This is because they are usually not able to take advantage of overflow volumes that exceed the cut-off maximum productivity level (see Figure 6-1).

Figure 6-1 Applied Concept of Utilisable Discharge for Power Generation at Run-of-river Stations



Taken from Lehner et al, 2005, p. 852.

Run-of-river schemes, despite these limitations, are typically viewed as having fewer environmental impacts than large hydropower and therefore tend to be more politically acceptable. However, small hydro also has environmental impacts associated with fisheries habitats and stress on riverbeds. If you consider the aggregate environmental impacts per unit of electricity production, the advantage of small-scale hydropower appears to disappear given that a large number of individual small run-of-river hydropower projects might well have a greater cumulative impact than one very large reservoir project (Egré & Milewski, 2002).

Water management, of which hydropower is just one element, is best undertaken with an ecosystems approach that integrates the uses of land, water and resources to promote sustainability within natural hydrological boundaries of water basins. This is advocated in the European Water Framework Directive and also the European Flood Risk Management Directive, for example, promoting the principle of integrating objectives in management schemes that encompass the area of land drained by a river and its tributaries (Biesbroek et. al., 2009, p.235). Thus, assessment of the benefits of different types of hydropower ought to be undertaken with an eye on the likely impacts not just on climate change mitigation and adaptation but also on a wide range of other policy objectives, within the context of an entire water basin. Assessments must take account of the broad scope of economic and social issues in complex water and human systems, many of which are particular to local situations of conflicts of interest over water resources (Varela-Ortega et. al., 2011).

The complexity of watershed management is complicated by the uncertainty associated with future hydrological scenarios. Severe alterations in hydrological regimes are to be expected in the future, leading to unstable trends in hydropower potentials because of climate change and changing precipitation levels, and also growing social and economic pressures on water use. General Circulation Model runs continue to present contradictory results for water availability in several regions of Europe, with some areas showing opposite results or different orders of magnitude change (e.g. Lehner et. al., 2005, p. 853). This seriously complicates the challenge of planning adaptation in light of unknown climate-induced changes to the hydrological cycle.

7. CONCLUSIONS: INCREASING UPTAKE OF PYROLYSIS TECHNOLOGY

7.1 Summary of Costs and Benefits

In Chapters 4 and 5 we outlined both the costs and benefits of pyrolysis technology focussing on products such as biochar and bio-oil. This analysis has been undertaken to demonstrate whether the product is both cost-effective and carbon negative, and how the technology needs to be implemented in order to maximise the mitigation and adaptation benefits. Based on this assessment, we have outlined a number of recommendations in relation to further research and development and to a number of financing options to help increase uptake of the technology.

With respect to costs, our research has indicated the following key points:

- That the cost of pyrolysis oil is competitive with fossil fuels given future fossil fuel prices, project scale, feedstock cost, and shipping efficiency.
- The overall lifecycle analysis of pyrolysis indicates that biochar has the potential to further enhance the cost-effectiveness of the technology.
- The cost of biochar will primarily depend on the use of different feedstock and the cost of the pyrolysis process (including capital costs).
- When dedicated energy crops are used for pyrolysis, there is the danger of considerable environmental costs associated with greenhouse gas emissions from direct or indirect land use change. The use of otherwise unutilised waste resources mitigates these costs.

With respect to benefits, we have been able to determine the following:

- Based on the literature reviewed for this report, the production of biochar from pyrolysis is carbon negative in theory although issues of project scale and feedstock type need to be considered in its application.
- Based on data presented by the Intergovernmental Panel on Climate Change, emissions from the agricultural sector comprise a significant percentage of global emissions. The Fourth Assessment Report indicates that emissions from soil in particular are an important contributor to emissions from the sector itself. Biochar could have an important role to play in mitigating emissions from agriculture. From an international perspective, the development of biochar within the European Union could have the potential for replication in the developing world as part of technology transfer.
- The overview of the technology in Chapter 3 reveals that there are numerous applications of pyrolysis. Apart from biochar, other products would have the potential to help leverage greenhouse gas emissions as part of power generation and as part of transport. The technology is attractive in the sense that it would be flexible enough to respond to emissions reductions needs in a number of different sectors.
- The literature reviewed for this report indicates that there are instances where biochar has been able to enhance the productivity of soil and improve crop yields. It has also resulted in increased potential for water retention.
- The cost-competitiveness of the products is attractive. The commercial viability of pyrolysis oil may make it easier to co-finance further development of biochar although this will depend on the percentage weight ratio of products and the applied reactor type. This will ultimately depend on a high price for fossil fuels.

- The use of mobile pyrolysis units could increase farm productivity by providing energy outputs and biochar as a potential soil improver, thereby contributing to rural development.
- There is the potential to use wood waste from forest management practices in the pyrolysis process.

The ideal application of pyrolysis technology could be envisaged as follows:

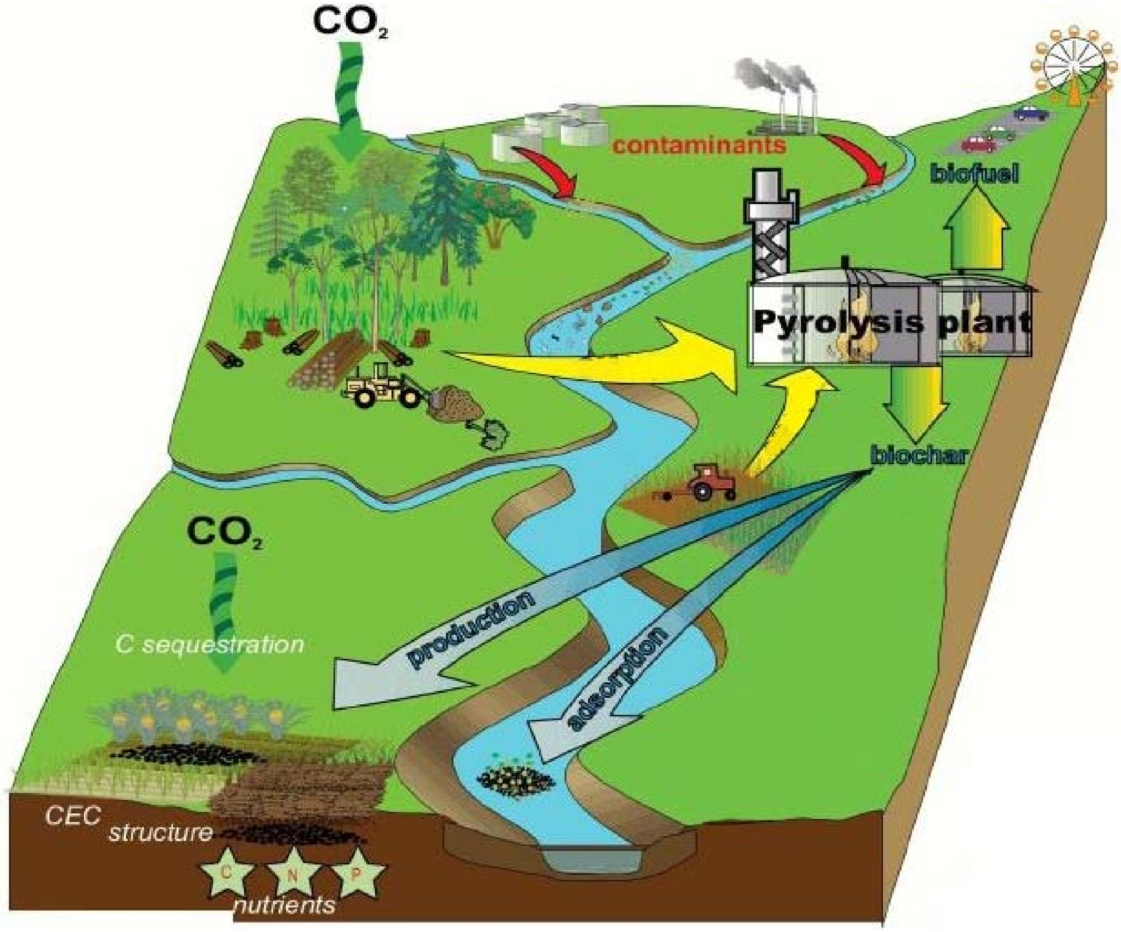


Figure 7-1 Spatial Illustration of Biochar Benefits

Dynamotive, edited by IEEP, 2011.

Another indirect benefit of pyrolysis would be the possibility that it could contribute to forest management in cases where excess biomass, or "free residues", from forests is utilised. The Wood Energy Outlook indicates that there is industry support for the sustainable use of "free residues" (arboricultural arisings or green waste) as a bioenergy feedstock and that this could encourage rural development. However, the Wood Energy Outlook (2010, p.4) also indicates that the competition for biomass residues is likely to increase particularly given the economic downturn and the slowdown in resource outputs on the part of the pulp and paper sector. Nevertheless, if one considers potential adaptation measures for the forestry sector, wood waste could be made available through the forest thinning practises required to counter the spread of forest fires caused by extreme heat.

Research undertaken by IEEP in relation to forest fires within the EU indicates that one of its leading causes has been the "lack of appropriate fire-preventive forest management" which "makes fire control extremely difficult under adverse weather conditions" (IEEP, 2008). Our research indicates that locating pyrolysis units in close proximity to this type of biomass feedstock could ensure that the process remains carbon negative while also allowing it to contribute to the adaptation agenda.

7.2 Barriers to Technology Penetration

In addition to the lack of finance, the key barrier to the penetration of pyrolysis is the availability of biomass, particularly if the technology is to produce biochar. Drawing on the information provided in Chapter 3, one of the largest pyrolysis plants in the world (implemented by Ensyn in Alberta, Canada) combusts 400 tonnes of wood waste per day. If each country in the EU were to implement a large-scale commercial pyrolysis plant using wood waste feedstock, roughly 4 million tonnes of wood waste would be combusted annually although other biomass feedstock could also be combusted. In light of the information available in the Wood Energy Outlook from 2010, this could be problematic given that the competition for waste feedstock is likely to be as great as for energy crops. This scenario is further supported by the PRIMES cost projections, which indicate that the cost of pyrolysis will increase by 2030 given competition for feedstock (PRIMES model run, 2011).

Analysis of 23 NREAPs, however, provides a different picture (Atanasiu, 2011). In terms of primary energy, the NREAPs estimate a 100 per cent increase in the EU-wide domestic feedstock potential between 2006 and 2020 (figure 6). The greatest anticipated increases are in Portugal (with an over 3000 per cent estimated increase in local feedstock exploitation), the Netherlands (1379 per cent), Ireland (636 per cent), Italy (389 per cent) and Slovenia (201 per cent). The direct wood supply from forest and wooded lands and the indirect supply of wood biomass for energy generation together are expected to increase by 25 per cent at the EU level, with an important estimated growth in Italy (354 per cent), and Ireland (111 per cent).

A significant EU-wide increase is forecast for agricultural crops and fishery products directly used for energy generation, from 19.6 per cent in 2006 to 31 per cent by 2020 (Atanasiu, 2011). The use of agricultural and fishery by-products for energy generation is expected to more than triple in all 27 Member States. Portugal (4557 per cent), Ireland (1078 per cent), Czech Republic (1018 per cent) and Italy (530 per cent) have the most optimistic forecasts, while Sweden estimated a 33 per cent decrease in the use of domestic agricultural resources for energy purposes. With regard to biodegradable municipal and industrial waste and sewage sludge, Ireland (5337 per cent) and Italy (230 per cent) plan the greatest increases.[14]

---

[14]. The biodegradable municipal and industrial waste and sewage sludge are usually converted into biogas by the anaerobic digestion process. Anaerobic digestion is a well proven renewable energy and waste management technology. It produces biogas from organic materials such as manure and slurry, food waste and sewage sludge.

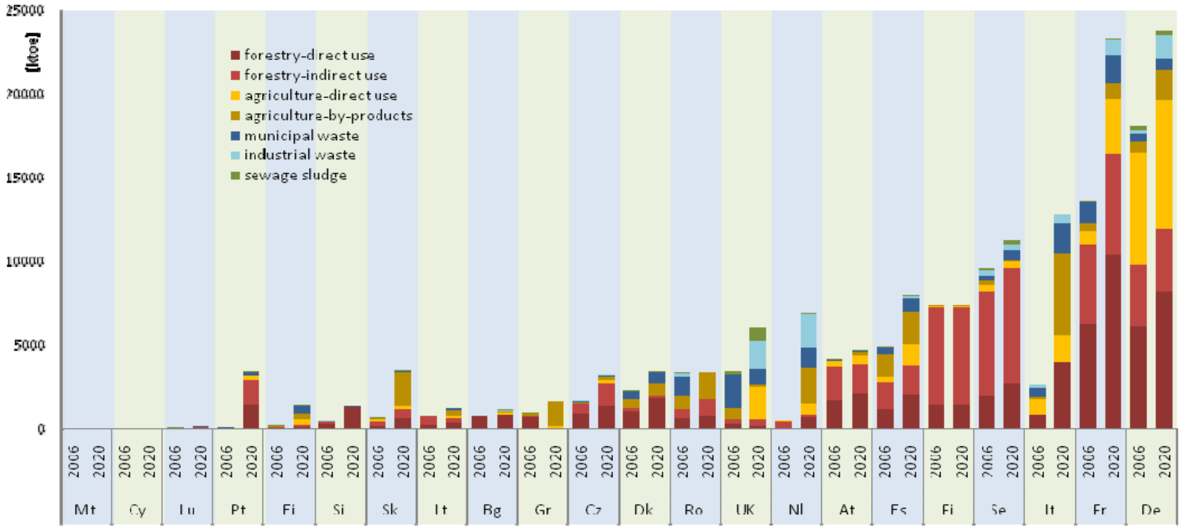


Figure 7-2 Biomass Feedstock in 2006 and the NREAPs Estimations for 2020

Taken from Atanasiu, 2011, p. 12.

The availability of organic feedstock notwithstanding, a number of additional issues need to be considered with regard to the market penetration of pyrolysis:

- Our research indicates that the costs and benefits of pyrolysis are maximised for larger-scale applications. We need to consider whether there will be enough biomass to meet the anticipated demand for large-scale pyrolysis in order to keep the cost of the technology down.
- We also need to consider whether there will be enough demand for biochar for it to become a self-financing technology.
- What will be the potential to trade offsets from carbon sequestered in soil? At present carbon sequestration in soil is not a common source of carbon offsets on the carbon market either as part of the EU-ETS or as part of the Clean Development Mechanism (CDM). If offsets from soil are included as part of the CDM, there could be an increased demand for technologies that reduce greenhouse gas emissions from soil in developing countries. [15]
- If there is a demand for biochar, given that pyrolysis is most cost-effective on a larger scale, the ability of slow pyrolysis reactors to supply the required amount would need to be considered. Given that fast pyrolysis produces less biochar, it is not clear whether the supply of biochar would be sufficient. Most of the research undertaken to date does not consider how the demand for the product could be met by either fast or slow pyrolysis.

---

[15]. The biodegradable municipal and industrial waste and sewage sludge are usually converted into biogas by the anaerobic digestion process. Anaerobic digestion is a well proven renewable energy and waste management technology. It produces biogas from organic materials such as manure and slurry, food waste and sewage sludge.

- The success of biochar will depend on three key factors: its ability to sequester carbon in soil, its ability to improve soil productivity, and its ability to retain water. While researchers are not all able to agree on the soil enhancing properties of the product, they acknowledge that its future success hinges on its interaction with a wide range of soil types. More localised research is required to determine how the product will react with certain soil types. This is crucial in order to determine which areas of Europe would be suitable for its demonstration.
- While the technology is cost-competitive, its ability to compete with fossil fuels will ultimately depend on the price of oil. Biomass-based pyrolysis may only be competitive in instances where there is the appropriate policy environment encouraging the uptake of alternative fuels. Cost will also be minimised through an economy of scale. If it is only cost-competitive under a scenario where a significant amount of biomass feedstock is required, then the technology may have more ILUC impacts.
- There may be a number of technical issues that warrant further investigation. Although pyrolysis oil can be upgraded for use as a transport fuel, the energy intensity of the upgrading process would need to be compared against the overall mitigation potential of the fuel to ensure that it is carbon negative.
- More investigation into the biodiversity impacts of the technology is required, particularly in cases where wood waste from forestry thinning practices is utilised for adaptation purposes.

Having reviewed the advantages and disadvantages of the technology, and some of the challenges to achieving a more successful rate of market penetration, this section will consider how certain EU funds or other policies could be utilised to increase the uptake of pyrolysis. Here we review the role of the Common Agricultural Policy, the carbon market, the potential for technology transfer, the role of research and development funding, and the role of cohesion funds.

7.3 Innovation and the Role of Research and Development Funding

There are a number of risks and uncertainties related to the development of biochar pyrolysis. While pyrolysis oil is already being produced on a commercial scale, improving the profitability of the system to include biochar will require undertaking a number of demonstration projects throughout Europe to demonstrate its longer-term sequestration potential, and to determine how it reacts with different soil types. More localised research will also be required to demonstrate if biochar has the potential to address the impacts of climate change such as flooding. Public funding through the EU 7th Research Framework Programme could have an obvious role to play in terms of funding additional pilot projects that would help determine the impacts of local soil properties on biochar potential.

A call for expressions of interest was issued by the European Industrial Bioenergy Initiative (EIBI) on 15 July 2011 to help fund "demonstration and flagship projects in line with the EIBI specifications." On 20 July, an FP7 Energy Call was launched for a range of bioenergy technologies including pyrolysis.[16] However, while both calls make funding available for demonstration projects, the motivating factor is the production of second generation biofuels such as pyrolysis oil, but not biochar. The FP7 Energy, Environment and Agriculture Work Programmes for 2012 do not mention funding additional research related to the development of biochar.

More comprehensive analysis of the cost-effectiveness and competitiveness of biochar need to be undertaken based on consultation with project developers, and with modellers responsible for PRIMES cost outputs. The cost of biochar as an adaptation measure could be reviewed using the results of the ClimateCost project and the derivation of adaptation damage cost functions.

7.4 The Role of the Common Agricultural Policy

The Rural Development Pillar of the Common Agricultural Policy (Pillar 2) contains measures that Member States can use to provide support for capital investments for on-farm renewable energy generation or as part of local renewable energy initiatives. This could be a way of supporting the instalment of equipment needed for on-farm pyrolysis systems yielding energy output and biochar. Examples of such systems are the small mobile pyrolysis units introduced in Section 2.2. Relevant measures are:

- Measure 124 on 'cooperation for development of new products, processes and technologies in the agriculture and food sector and the forestry sector', used in many Rural Development Programmes for renewable energy production;
- Measure 125 on 'Infrastructure related to the development and adaptation of agriculture and forestry', including investments in renewable energy infrastructure for on-farm use;
- Measure 311 'Diversification into non-agricultural activities' / Measure 312 'Business Creation and Development' / Measure 321 'Basic services for the economy and rural population': three measures that can be used to support investments in rural areas to improve the production of renewable energy in rural areas/local communities.

Shackley *et al* (2011) suggest using agri-environment schemes, part of Pillar 2 of the CAP, to support biochar application on EU farms. While this might be a sensible conclusion reached on the basis of research he undertook in the UK, more localised research is needed to test the effect of biochar on different soil types throughout Europe. Promoting biochar application as part of agri-environment schemes would only be justified if it is able to deliver clear beneficial environmental outcomes given the local conditions.

---

[16]. The biodegradable municipal and industrial waste and sewage sludge are usually converted into biogas by the anaerobic digestion process. Anaerobic digestion is a well proven renewable energy and waste management technology. It produces biogas from organic materials such as manure and slurry, food waste and sewage sludge.

However, should agri-environment schemes become a viable option for funding biochar and pyrolysis, this would limit the potential to leverage carbon finance in cases where the Common Agricultural Policy applies to privately held land. Public subsidies would undermine the legitimacy of a trading scheme that sought to create market competition for greenhouse gas offsets from soil.

7.4.1 The Role of the Cohesion Funds

There are a number of funds administered under the Cohesion Policy framework. These include the Structural Funds which are used to finance projects as part of regional and urban development. Rural development is supported by the European Regional Development Fund, which comprises a small share of the funds' overall allocations. Rural development was also previously funded under Cohesion Policy as part of the European Agricultural Fund for Rural Development (EAFRD), but this is now administered by DG AGRI and is linked to the CAP.

While a number of rural development objectives could be funded under Pillar 2 of the CAP as part of the Less Favoured Area measure, there is a growing recognition as part of discussions related to the EU budget post 2013 that Cohesion Policy could be used to target rural development objectives given that its overall aim is to reduce disparities between levels of social and economic development (IEEP, CAP2020 briefing, 2011). Funding rural development as part of Cohesion Policy would allow Pillar 2 to focus potentially on sustainable land management. Given this reality, Cohesion Policy funding would have a limited role in terms of increasing the uptake of pyrolysis at the farm level.

7.5 The Carbon Market and Technology Transfer

The agricultural sector has played a limited role in terms of contributing to greenhouse gas emissions reductions under the carbon market. Under the Marrakesh Accords, there are a number of technologies that qualify for reductions under the Clean Development Mechanism (CDM), including enteric fermentation, anaerobic digestion and composting. Farming practices that reduce emissions from soil, such as no-till farming, do not count towards reductions under the CDM. While they are viable offsets in some developed countries, there are relatively few examples of successful projects that have sequestered carbon in soil outside North America and Australia. As the literature reviewed for this report has revealed, a monitoring and verification protocol would need to be developed for soil-based reductions to be traded on the carbon market.

In the EU, the role of the carbon market in incentivising emissions reductions from afforestation and reforestation has been non-existent to date. The EU-ETS does not recognise credits generated by LULUCF projects under the CDM, although it is likely that, with the move to avoided deforestation under the Protocol and the success of the Cancun agreement in terms of establishing the appropriate reporting requirements for forestry, they may be accepted within the EU-ETS in future trading periods. If there is a move to recognise avoided deforestation, then perhaps the Commission will move on to consider offsets from improved soil management practices.

Until a decision is made to include carbon sequestered in soil within the EU (either from domestic or international projects), it is unclear whether biochar will be funded through the carbon market. Similarly, until a decision is made to include carbon sequestration in soil under the CDM, the potential for the international carbon market to leverage technology transfer remains limited. Projects that utilise biochar in developing countries could be funded by standard development banks, or could possibly qualify as an adaptation measure under the proposed UNFCCC Green Climate Fund.

While the market cannot be used to leverage reductions on an *ex post* basis, pyrolysis technology is currently being funded through additional credits available as part of the New Entrants Reserve. Pyrolysis technology has been targeted as part of the call for proposals; the Irish project described in Chapter 3 has submitted a proposal for funding under the NER300 programme. This funding, however, focuses on the potential for the technology to fund bio-oil and not biochar.

7.6 Final Conclusions

A review of potential funding options at the EU level indicates that there may currently be limited potential to finance research for biochar. In order for deployment of the technology to increase, however, it will be crucial to determine which soil types are compatible with biochar application. This research is fundamental in order to determine the overall marketability of the product throughout the EU, and to determine the appropriate economy of scale. This research needs to be undertaken in order to determine the overall financing need for funding under the CAP, and as part of potential offsets under the carbon market.

The current status of carbon sequestered in soil in the EU-ETS and in the international carbon market means that opportunities to leverage technology implementation or replication in other markets are limited. Nevertheless, a number of factors need to be considered in terms of prioritising some funding options over others. Should biochar become a viable measure for funding under Pillar 2 of the CAP, reductions obtained as a result of this funding will rule out the potential for carbon finance given that reductions cannot typically be co-funded with the use of public funding.

Nevertheless, there are very few examples of projects that sequester carbon in soil that involve private landowners. Farmers would be required to report emissions data in order for the EU-ETS to accurately track reductions from farms. It therefore appears that, given the uncertainty associated with permanence of carbon sequestration in soil and the current status of the carbon market, funding the application of biochar may be more feasible if one were to consider its potential to improve soil productivity and water retention. Even in developing countries, it may be more straightforward to fund biochar on the basis of its environmental benefits and the possibility that it is able to increase soil resilience thus minimising flooding and the impacts of climate change. However, until the cost of adaptation measures can be accurately determined, it will be difficult to argue that biochar will improve the competitiveness of pyrolysis.

REFERENCES

Agri-therm, http://www.agri-therm.com/index.htm, (accessed July 22, 2011).

"An Assessment of the Benefits and Issues Associated with the Application of Biochar to Soil", A report commissioned by the United Kingdom, Department for Environment, Food and Rural Affairs, and Department of Energy and Climate Change, Simon Shackley and Saran Sohi (editors), UK Biochar Research Centre, February 2011.

Atanasiu (2010), The role of bioenergy in the National Renewable Energy Action Plans: a first identification of issues and uncertainties, (http://www.biomassfutures.eu/work_packages/WP8%20Dissemination/D8.4%20bioenergy_in_NREAPs-final_08_12_2010.pdf.

Background report to the position paper of IEA RETD and IEA, bio-energy, Delft/Darmstadt, July 2010.

Beck, Johnson, "Amending Greenroof Soil with Biochar to Affect Runoff Water Quantity and Quality", *Environmental Pollution*, 2011: 2111-2118.

Bell MJ (2011), Optimising carbon storage by land-management. Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/740/.

Bell, MJ and Worrall, F (2011), Charcoal additions to soils in NE England: A carbon sink with environmental co-benefits? *Science of the Total Environment* 409, 1704-1714.

Biesbroek, G. Robbert, Swart, Rob J. & van der Knaap, Wim G. M., 2009, 'The mitigation-adaptation dichotomy and the role of spatial planning', *Habitat International*, Vol. 33, Issue 3, p.230-237.

BIG, *Black is Green (BiG).* 2011. http://www.bigchar.com.au/ (accessed July 18, 2011).

Bnet, *Findarticles.com*, 4 Sep 2003. http://findarticles.com/p/articles/mi_m0ein/is_2003_sept_4/ai_107253035/ (Accessed July 25, 2011).

Bowyer, C (2010), The Indirect Land Use Change Impact of the Use of Biofuels in the EU, Updated version (March 2011): http://www.ieep.eu/assets/786/Analysis_of_ILUC_Based_on_the_National_Renewable_Energy_Action_Plans.pdf.

Bradley, Douglas, European Market Study for BioOil, 2006, Climate Change Solutions. National Team Leader- IEA Bioenergy Task 40- Bio-trade

Brick, Stephen. *Biochar: Assessing the Promise and Risks to Guide U.S. Policy.* Madison: NRDC, 2010

Bridgwater, & Peacoke, (2000), Fast Pyrolysis Processes for Biomass, Renewable and Sustainable Energy Reviews, 1-73.

Brown, Robert, and Christian Stevens, Thermochemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, London: Wiley, 2011.

Coleman, et al., *Can portable pyrolysis units make biomass utilisation affordable while using biochar*, USDA forestry service proceedings, 2010.

Dynamotive, *Dynamotive U.S. Subsidiary Secures Biomass for Arkansas Plant*, 29 April 2009, http://www.euroinvestor.co.uk/news/story.aspx?id=10372976 (accessed July 25, 2011).

Egré, Dominique & Milewski, Joseph C., 2002, 'The diversity of hydropower projects', *Energy Policy*, Vol. 30, Issue 14, p.1225-1230.

European Forestry Commission, Thirty-Fifth Session, Lisbon, Portugal, 27-30 April 2010, Wood Energy for Europe: Status And Outlook / FAO. European Forestry Commission (EFC)

European Parliament Report on the Commission White Paper: 'Adapting to Climate Change: Towards a European Framework for Action' (2009/2152(ini)), Committee on the Environment, Public Health and Food Safety - a/-0057/2010

European Small Hydropower Association, www.esha.be, accessed July-August 2011.

FP7. *cordis.europa.eu/.* 21 Dec 2010. http://cordis.europa.eu/fetch?caller=fp7_proj_en&action=d&doc=2&cat=proj&query=012a60756427:85bc:5938d44d&rcn=94486 (Accessed July 25, 2011).

Fransham, and Badger. "Use of mobile fast pyrolysis plants to densify biomass and reduce biomass handling costs—A preliminary assessment." *Biomass and Bioenergy*, 2006: 321-325.

Glanpower, *Glanpower.com.* 2011, http://www.glanpower.com/pyrolysis/ (Accessed July 25, 2011).

Gonzalez-sosa et al., "Impact of Land Use on the Hydraulic Properties of the Topsoil in a Small French Catchment", *Hydro Process*, 2010.

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

Hart K, Baldock D, Tucker G, Allen B, Calatrava J, Black H, Newman S, Baulcomb C, McCracken D, Gantioler S (2011) Costing the Environmental Needs Related to Rural Land Management, Report Prepared for DG Environment, Contract No ENV.F.1/ETU/2010/0019r. Institute for European Environmental Policy, London.

Hydropower and the Environment: Technical and Operational Procedures to Better Integrate Small Hydropower Plants in the Environment; Sponsored by Intelligent Energy Europe and European Small Hydropower Association; Year of Publication not Stated, see: www.esha.be/fileadmin/esha_files/documents/SHAPES/Multipurpose%20schemes%20brochure%20SHAPES.pdf

Institute for European Environmental Policy, http://www.cap2020.ieep.eu/assets/2011/6/8/CAP2020_Policy_Briefing_May_2009__No_5__-_The_Future_of_Rural_Development_HM_KMB.pdf

Institute for European Environmental Policy, "Forest Fires: Causes and Contributing Factors in Europe", completed for the European Parliament, 2008.

International Energy Agency, 2010, 'Renewable Energy Essentials: Hydropower', http://www.iea.org/papers/2010/Hydropower_Essentials.pdf.

Karhu et al, Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – Results from a short-term pilot field study, Finnish Environment Institute, 2010.

Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, F.L. Toth, 2007: Inter-relationships between adaptation and mitigation. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 745-777.

"Launch of the European Advanced Biofuels Flightpath", see: http://ec.europa.eu/energy/technology/initiatives/biofuels_flight_path_en.htm

Lehner, Bernhard, Czisch, Gregor & Vassolo, Sara, 2005, 'The impact of global change on the hydropower potential of Europe: a model-based analysis', *Energy Policy*, Vol. 33, Issue 7, p.839-835.

Mohan, Pittman, and Steele, "Pyrolysis of Wood/biomass for Bio-oil: A Critical Review", *Energy Fuels*, 2006: 20 (3), 848–889.

O'connell, Enda, John Ewen, Greg O'donnell, and Paul Quinn, "Is There a Link Between Agricultural Land-use Management and Flooding?", *Hydrology & Earth Systems Sciences*, 2007.

Pratt, K. and Moran, D. (2010), Evaluating the Cost-effectiveness of Global Biochar Mitigation Potential, *Biomass and Bioenergy* 34(8), 1149-1158.

Primes Biomass Supply Model, description of version 3.1. E3Mlab – National Technical University of Athens: http://www.e3mlab.ntua.gr/e3mlab/primes%20manual/the_new_primes_biomass_model.pdf

Quade, Dorothee, "What are the Implications for Public Policy in New Zealand regarding Biochar as a Climate Change Mitigation Tool?", School of Geography, Environment and Earth Sciences, Victoria University of Wellington, June 2010.

Reijnders, L (2009). Are forestation, biochar and landfilled biomass adequate offsets for the climate effects of burning fossil fuels? *Energy Policy* 37, 2839–2841.

Roberts, KG, Gloy, BA, Joseph, S, Scott, NR and Lehmann, J (2010). Lifecycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential. *Environmental Science & Technology* 44(2), 827–833

Rogers, J.G., Brammer, J.G., Analysis of transport costs for energy crops for use in biomass pyrolysis plant networks, Biomass and Bioenergy 33, 2009.

Shackley, S, Hammond, J, Gaunt, J and Ibarrola, R (2011). The feasibility and costs of biochar deployment in the UK, *Carbon Management* 2(3), 335–356.

SEAI, *Sustainable Energy Authority of Ireland*, 2011. http://www.seai.ie/grants/ner300/ (Accessed July 24, 2011).

SHERPA project 'Small Hydro Energy Efficient Promotion Campaign Action' /Intelligent Energy for Europe Programme (IEE), (10/2005-09/2008), see: www.esha.be/fileadmin/esha_files/documents/SHERPA/Report_bassa.pdf

Sims, Bryan, *Biorefiningmagazine.com*, 2010 Oct 2007. http://biorefiningmagazine.com/articles/135/dynamotive-set-to-restart-guelph-ontario-bio-oil-plant- (accessed July 25, 2011).

Sohi et al, Biochar, climate change and soil: A review to guide future research, CSIRO (Australia) Land and Water Science Report 05/09, February 2009.

T R Miles, "Small-Scale Gasification and Pyrolysis", *Biofuels and Beyond*, Kennewick: T R Miles technical Consultants, 2010.

UBS (2010), Q-series®: Second-generation Biofuels, UBS investment research.

Varela-Ortega, Consuelo, Blanco-Gutiérrez, Irene, Swartz, Christopher H. & Downing, Thomas E., 2011, 'Balancing groundwater conservation and rural livelihoods under water and climate uncertainties: An integrated hydro-economic modelling framework', *Global Environmental Change*, Vol. 21, Issue 2, p.604-619.

Venderbosch & Prins (2009), Fast pyrolysis technology development, Wily InterScience.

Verheijen, Jeffery, Bastos, Van der Velde, and Diafas, *Biochar Application to Soils*, JRC, 2009.

World Energy Council, 2004, 'Chapter Seven: Hydropower', *Survey of Energy Resources*, p.199-232.

Yeh, Bryan, Independent Assessment of Technology Characterisations to Support the Biomass Program Annual State-of-technology Assessments, Oakland: NREL, 2011.

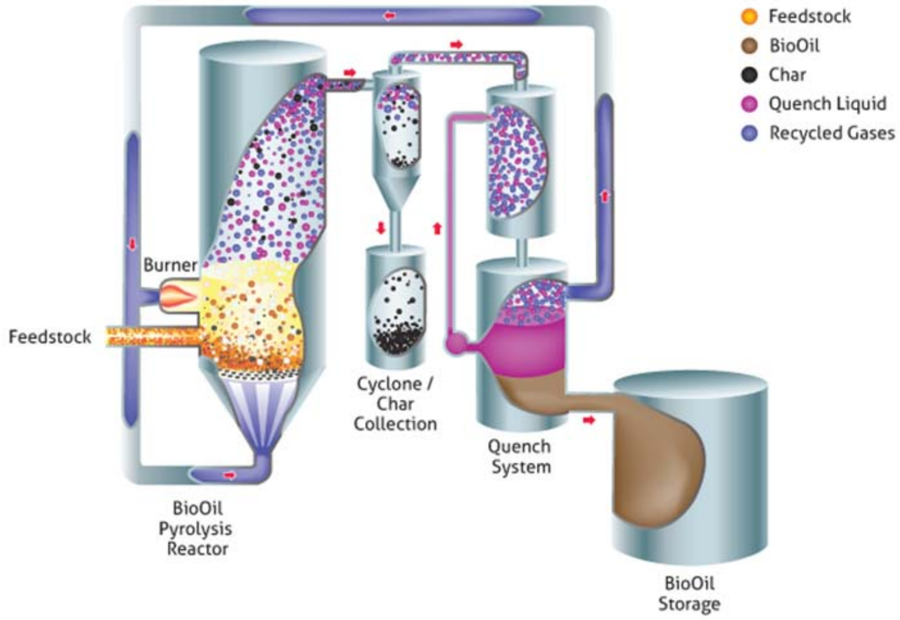
Yoder, J., Galinato, S., Granatstein, D. and Garcia-pérez, M. (2011), Economic Tradeoff Between Biochar and Bio-oil Production via Pyrolysis, *Biomass and Bioenergy* 35(5), 1851-1862.

ANNEX I: OTHER PYROLYSIS APPLICATIONS IN THE EU

Developer or Organisation	Country	Application	Scale and stage of development
BTG	Belgium	Rotating cone pyrolysis technology	Demonstrated for a variety of feedstock at 250kg/hr
FZK/LURGI; subsidiary of Air Liquide	Germany	Modifying flash cooker technologies	Anticipates that the technology will be able to process 10t/hr at initial commercial level
TNO	Austria	Use of cyclone technology at 500°c	Due to use of the cyclone technologies the end product is low in impurities.

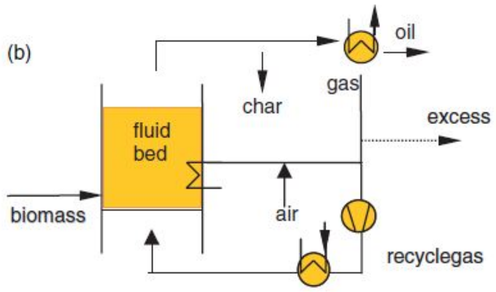
ANNEX II: PICTURES OF PYROLYSIS REACTORS

Fluidised Bed:

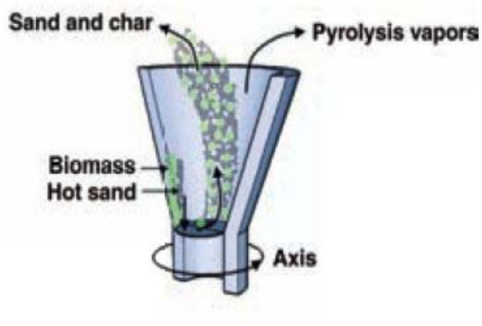


Source: http://www.dynamotive.com/technology/fast-pyrolysis/.

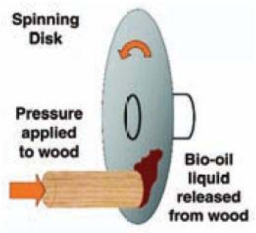
Or illustrated as follows:



Cone Reactor



Ablative Reactor



ANNEX III: PRIMES BIOMASS MODEL OUTPUT

Process Name: **Pyrolysis**

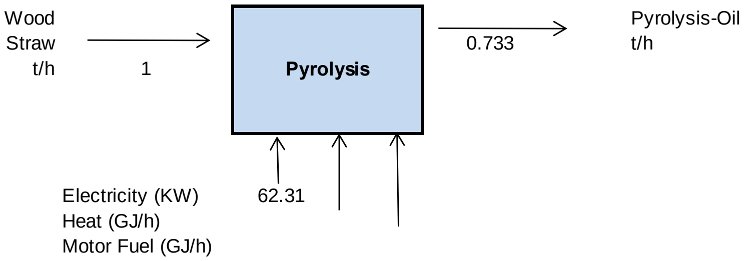
Input:	Straw	Wood
Blending Ratio	100%	100%
Output:	Pyrolysis-Oil	
Blending Ratio	100%	
By-products:	-	
Yield	-	

Technico-Economic Data	**Units**	**Now**	**Maturity**
Capital Cost	€/GJ/yr	35.54	33.00
Fixed Cost	€/GJ/yr	3.55	2.54
Variable Cost	€/GJ	13.9	7.78
Heatrate	%	1.65	1.57
Technical Lifetime	years	20	20
Load Factor	%	80%	80%
Consumption of Energy Products			
Motor Fuel	GJ en/GJ prod		
Electricity	GJ en/GJ prod	0.02	0.02
Heat	GJ en/GJ prod		

	GJ/t
LHV(feedstock)	**18.5**
LHV(output)	**15.3**

Overall Production Cost: 53.00

Estimated year of Maturity: 2035



Economic Data	**Per unit of Pyrolysis-Oil Output**	
Investment	4.6081	M€/t/h
Fixed O&M cost	0.4608	M€/t/h
Variable cost	257.150	€/t