Bio-char and Biogas Research - applicability to developing countries

Research Report

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for

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INTRODUCTION

This report provides a view on the following two China – UK SAIN proposals in terms of where the proposals fit within the current discussions on innovative energy technology that may benefit developing countries and the potential costs/benefits including low carbon benefits:

- Integrating biogas into circular agriculture: tools, analysis and policy implications
- Life Cycle Assessment of Biochar Production Systems based on Pyrolysis and Gasification Technologies

The report reflects the authors' views and is based on experience as well as limited research in the time available for the response. It is hoped that the main areas of research and key issues with regard to the technology have been covered.

The report is divided in two parts, each addressing one proposal.

PART 1: INTEGRATING BIOGAS INTO CIRCULAR AGRICULTURE

DEFINITION OF BIOGAS TECHNOLOGY AND FIT WITH CURRENT DISCOURSE ON INNOVATIVE ENERGY TECHNOLOGY

Biogas is produced from the fermentation of organic waste by anaerobic (i.e., without oxygen) digestion. Organic matter breaks down by biological decomposition producing a gas that is 55-80% methane, depending on inputs (feedstock).

Waste is fed into a digester directly or following pre-treatment. Following digestion the biogas is collected and can be fed into a gas network or used directly on site. The applications of the gas thus produced include:

- Cooking and lighting
- Heating and hot water generation
- Electricity generation
- Vehicle fuel.

The residual slurry/digestate is removed from a separate outlet and can be used as fertiliser. Temperature affects the rate of biological reaction (i.e., the volume of gas produced per kg of feed per day) which means that in colder climates less gas is produced.

Biogas is a well established low carbon technology with widespread use and therefore the basic technology is not innovative. Although the basic technology is established, there are still many problems with the technology and in many cases the biogas plant does not operate at all, or for many years. Therefore, there is and has been scope for many innovations to improve the technology, the treatment of the waste, the efficiency, the scope and use of biogas and digestate. Moreover, in many developing countries, the technology would be considered innovative.

Biogas systems range from household systems (requiring approximately 1-2 cows, 5-8 pigs or 4 adults) providing gas for cooking and some lighting, to industrial scale systems producing MW of electricity.

KEY ISSUES WITH RESPECT TO BIOGAS AND ITS USE IN DEVELOPING COUNTRIES

Biogas is an appropriate technology and has a potentially significant role to play in developing countries since it uses locally available resources (household, agricultural, municipal and industrial organic wastes) to produce clean energy and organic fertilizer. It can protect local water resources by reducing local pollution and reduces pressures on landfill, green house gases and enhances energy availability.

The benefits of biogas plants include:

- Production of methane which can be used for cooking, heating, hot water, lighting and/or electricity.
- Reduced pollution from the treatment of raw waste streams that may have been dumped directly on land or in water sources. Treatment and use of organic waste is becoming more of a problem in both rural and urban areas in developing countries.

- The by-product (digestate) is a high nutrient organic fertiliser which can be used on local farmland; it can form a possible source of extra income for the biogas plant owner and potentially reduces the use of chemical fertilizer.
- Reduction in carbon dioxide equivalent emissions (greenhouse gases) due to the destruction of methane. In the absence of a biogas system some methane is produced from the raw waste material which is emitted directly to the air. With biogas the digestion process produces methane under controlled conditions which can then be destroyed.
- Possible additional income from CERs if the project is registered as a CDM project.
- Improved sanitation. The digestion process kills many of the pathogens and bacteria dangerous to human health, particularly useful when used for latrine waste.
- Access to electricity and improved services.
- Reduced quantities of woodfuel needed where gas used for cooking and heating (and therefore an associated reduction in woodfuel collection and time, reduced pressure on forests and a reduction in desertification).
- Improved air quality through offsetting the use of firewood for cooking and improvements in indoor air pollution.
- Improved lighting where electric or gas lighting replaces candles and/or kerosene.
- Job creation for new business.

Biogas can be used in developing countries at a small scale level for households, boarding schools and houses, prisons and farms. In addition biogas has potential to be used at a larger scale for larger animal farms, using municipal and food processing waste, waste water, organic industrial waste as well as for other agricultural wastes, for example straw or sugar cane as used in the Philippines and Brazil. The efficiency of the biogas system improves if there is a mixture of feedstock.

However biogas cannot be used everywhere since there are some minimum requirements for a sustainable successful biogas system which determine whether it is appropriate for a specific site or application. These include:

- Sufficient and appropriate feedstock over a whole year, and available in the long term. The list of potential feedstock is long and includes agricultural waste (animal manure, straw, grass, hay, sugar beet, potato, bananas), food processing waste (sugar, breweries, meat waste etc), municipal and household organic waste, sewage and waste water. However in each case it has to be possible to collect the waste, for example if the animals are not in barns it is difficult to collect the waste. Similarly only organic household waste can be used so means for separation must exist. In addition if a co-digestion plant is preferred it is important that the various feedstocks are compatible.
- There should be an economic rate of return on any project to succeed in the long term. Therefore there should be a market for the gas and/or electricity and fertilizer.
- Water supply. Although systems exist for dry anaerobic digestion systems and have been proven, systems have shown to be more successful with lower solid waste.
- Warm temperatures to ensure the digestion process continues year round or a provision for heating is required. This can be provided with a heat exchanger from an electricity generator in cooler climates.

- Training will be required to ensure that there are the skills to design, construct and operate and maintain the biogas systems. Many systems worldwide have failed due to a lack of skills in one or all of these areas.
- Biogas plants can be relatively expensive to set up and therefore the costs act as a barrier to widespread deployment.

There is already considerable experience of biogas in some developing countries, namely in China, India, Nepal, Vietnam, the Philippines, Thailand and Brazil. However in sub-Saharan Africa there are few examples certainly scope for more. A recent research paper[1] states that although the technology to produce biogas for farms and households has been in use in Africa for three decades, smaller plants for households or schools can be of "poor technical quality", are "not reliable and have poor performance in most cases". These smaller plants, found in many countries including Burkina Faso, Ghana, Lesotho, Morocco, Nigeria, Senegal, Tunisia, Uganda and Zambia, were often installed by nongovernmental organisations. The authors of the paper recommend investment in large-scale fermentation plants with 100m^3 digesters, as found in Botswana, Cote d'Ivoire, Egypt, Ethiopia, Malawi, Rwanda, South Africa, Tanzania and Zimbabwe. For example, a pilot project running since July 2006 in Tanzania's Korogwe district generates 150 kW of electricity from sisal waste, enough to provide power to a rural community. In Rwanda, the Kigali Institute of Science, Technology and Management (KIST) has successfully installed and operated biogas systems in at least 6 prisons with multiple systems of at least 50 to 100m^3.

However much of the existing experience, particularly in China and Africa, has not been successful for a number of reasons including insufficient project preparation, inappropriate design, low quality construction, lack of knowledge on the management and operation of the biogas system, lack of ownership of the technology, lack of incomes related to the biogas system and therefore a failure to operate sustainably.

KEY AREAS OF RESEARCH ADDRESSED BY THE PROPOSAL

As mentioned above much of the experience of biogas in China has been unsuccessful. The Ministry of Agriculture spends millions of RMB a year on biogas plants, many of which do not then operate. The background to the proposal identifies the key areas of under-performance of the Chinese biogas sector. IT Power would agree with these two areas which are:

- Unstable biogas production due to poor management, poor quality, poor control and design. Although there are already clear and good technical design and operation standards for biogas in China the majority of feasibility and design reports do not refer to these standards. There is certainly scope to improve the operation of the systems and also to introduce co-digestion and centralised plants to improve the operation of the plants.
- The digestate is wasted in many areas creating local pollution problems and therefore further work is required to increase the use of the digestate and to contribute to the Government's objective of a 'circular economy'.

The authorities at every level of government in China advocate the circular economy and think highly of biogas, but most biogas projects have been supported by national finance which does not create a sustainable development model. Therefore policy implications on

[1] Included as Annex 2

the development of biogas and relevant product markets will be the focus of further international cooperation projects to help achieve sustainability.

One of the key barriers to biogas in China is high up-front costs and a lack of sustainable incomes over the lifetime of the plant.

In addition there are other related areas for research including the pre-treatment of waste and associated measures such as the organisational structures for centralised systems and grid connection to help make biogas plants become more economic. Since there are low, or zero, charges for polluting there is little incentive to treat the waste using biogas unless there is a reliable income from the plant from electricity, gas and fertilizer.

The proposal aims to address some of these failures/issues with Chinese biogas systems and the use of the digestate. The main activities are very wide in their scope and are not clear in what they will provide. The analytical tools, framework and manuals will be useful but it is not clear who will use them in the future unless they become part of an established training package for biogas design institutes and agricultural specialists. Integration with activities on manure management would be an important part of the project. The proposed project will provide a number of papers; however these are not guaranteed to provide input into policy unless the Ministry of Agriculture is actively involved in the project. Unless funding is available there will be no follow-up demonstration projects.

SIMILAR WORK ONGOING ELSEWHERE

There are numerous waste treatment and biogas research projects being undertaken in China. The key agencies providing funding are the Ministry of Agriculture (MoA) and the Ministry of Science and Technology (MOST). These projects tend to be of technical research category. There are also several similar cooperation projects between European countries and Chinese counterparts which focus on the recycling of organic residues and aim to introduce advanced biogas experiences to China. As the basis of these cooperation projects, technical barriers have been assessed under each project. Therefore there does seem to be some overlap between some of these projects and the current proposal, both in terms of biogas operation research and on the use of the digestate. However there is generally scope to take some research further and none of the projects cover exactly the same scope, particularly with respect to the use of digestate. It is unclear if the tools and manuals to be produced will be different from those being developed elsewhere. Within the timeframe it is not possible to review all the Chinese funded biogas research projects.

Examples of current international cooperation projects of which IT Power is aware are:

- ADB's USD 80m agricultural sector loan project aims to develop a market environment for medium and large scale biogas plants whilst ensuring an integrated approach to ecological farming practices (the use of the digestate). The project has already carried out a gap analysis on biogas plants and provided guidelines to improve the technical specifications. As part of the project operational manuals and maintenance handbooks will be prepared to improve the operation of the biogas systems and the use of on-farm practices with digestate to reduce pollution and increase carbon storage in the soil. In cooperation with this there is a GEF USD 9.2 m grant specifically to demonstrate and prepare manuals for centralised and co-digestion plants. The Chinese partner is the Ministry of Agriculture.
- World Bank has a couple of eco-farming projects which are looking at both the operation of biogas as well as the use of digestate.

- GTZ's USD 6m project objective is to improve the technical standards and the operational performance of medium and large scale biogas plants by supporting four plants as Sino German best practice demonstration projects including co-digestion. The project includes help to implement a sector policy to ensure availability and continuous high performance in plant operation. The partner is Ministry of Agriculture.
- Sino-German project: recycling of organic residues of agricultural and municipal origin in China. The project is to develop viable solutions for establishing a new system towards the recycling of organic residues in China for the improvement of environmental quality, the generation of renewable energy, the reduction of greenhouse gas emissions and the enhancement of regional added-value, and to optimize the processes on an existing pilot plant in a pilot region in order to achieve optimized flows of water, energy, carbon, nutrients and pollutants as well as to present strategies and implement innovative technologies towards an environmentally sound intensive animal production in Chinese peri-urban areas. The Chinese partner is Ministry of Science & Technology.

PROPOSAL POTENTIAL TO PROVIDE A BROADER GLOBAL PUBLIC GOOD RESEARCH PROJECT BEYOND THE UK AND CHINA

There is some scope to use the experiences of China and UK as lessons learned for other countries. These general issues will also be relevant in other developing countries but some of the issues are quite China specific and it would be difficult to transfer the results directly to other countries. Although many biogas plants do not work well in China it is an advanced biogas market, compared to most developing countries.

Research of this type will be most effective in/with a target country. Although the options for co-digestion and centralised plants are possible in most countries the type of locally available feedstock will tend to vary, along with the local soil and agricultural practices and therefore generic lessons could be transferred but it is unlikely that specific ones could be transferred.

The tools and manuals developed could be transferable to other countries if designed with widespread dissemination in mind.

Interestingly there is also a Chinese funded development project focused on biogas development in Tanzania. Anecdotal evidence suggests that the plants being built are having the same problems as those in China, for the same reasons.

AMENDEDMENTS TO PROPOSAL TO INCREASE ITS POTENTIAL GLOBAL PUBLIC GOOD BENEFIT AND RELEVANCE TO INNOVATIVE LOW CARBON ENERGY TECHNOLOGY IN DEVELOPING COUNTRIES

To increase the applicability of the proposal beyond China an option would be to include another developing country partner so that any tools/manuals etc are sure to be applicable in another situation. Attached as Annex 2 to this document is a paper written regarding biogas research in Africa which outlines what research is being undertaken there. It may be worthwhile to include one of these research organisations within the proposal.

If the project would like to have a more positive policy related output then the relevant government agencies should be engaged in the project or it is possible that the results will not be used beyond the project. There are existing technical guidelines and they are not followed.

The content of activities could be made clearer, particularly activities 4 and 5.

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5. Biogas technology research in selected sub-Saharan African countries – A review, Anthony Manoni Mshandete and Wilson Parawira. (Annex 2)
6. Biogas plants providing sanitation and cooking fuel in Rwanda, The Kigali Institute of Science, Technology and Management (KIST), Ashden Awards, 2005

ANNEX 1 - OVERVIEW OF CURRENT STATUS OF BIOGAS PLANT TECHNOLOGY IN CHINA

Biogas projects in China have been achieving great development so far, and have developed a variety of anaerobic reactors. At present, up-flow solid reactors (USR) and up-flow anaerobic sludge blankets (UASB) have been regularly applied in the area of animal waste as resource utilisation in the animal industry. Continuous Stirred-Tank Reactors (CSTR) and HCF anaerobic process are also applied now. These technologies have been used to build the medium to large scale biogas projects.

In general, the utilisation of organic waste and livestock manure to produce biogas has become an international trend. Europe applies the highest standard worldwide on biogas technology. In China biogas projects are currently developed and built by breeding farms themselves. To date standard models were not established and the technology is limited to a certain plant size and slurry density. Although the anaerobic fermentation technology may follow international standards, the basic equipment, process control systems as well as energy efficiency needs to be further promoted.

The definition of medium and large scale biogas (MLBGP) according to the National Standard NY/T 667-2003: Classification of scale for biogas engineering in China is shown in Table 1.

Table 1: Definition of small-, middle- and large scale biogas plants in China National Standard NY/T 667-2003

BGP size	Individual Fermenter size (m^3)	Total Fermenter size (m^3)	Biogas Production (m^3/d)*
Large	≧ 300	≧ 1,000	≧300
Middle	≧50 - 300	≧100 – 1,000	≧50
Small	≧20 - 5	50 – 100	≧20
* Daily lowest biogas yield at ≧25°C fermenter temperature			

Basically all plants must have and (i) feedstock input and plant output measuring system, (ii) feedstock pre-treatment, (iii) slurry use or processing and (iv) biogas storage, purification and utilisation.

In the following, characteristics, advantages and disadvantages of the most popular AD technologies used in China will be briefly described.

Conventional anaerobic digester

Conventional anaerobic digesters are simple unstirred systems, applied as underground or tank reactors which can be easily applied to treat waste with different dry matter content. The features are large reactor volumes (determining the investment costs) with a high hydraulic retention time (HRT), not heated, with low biogas yields, which are no longer used in China because of low efficiency.

USR anaerobic process

The USR anaerobic process is relatively simple and the technology can be easily applied to treat waste with high dry matter content. The anaerobic material settles down at the bottom of the reactor and is digested rapidly when it comes into contact with the activated sludge. Undigested biomass solid particles and the anaerobic product are retained in the reactor by natural settlement. Since the overflowing sludge discharges from the upper part of the reactor, it goes through a much higher solid retention period (SRT) and microbial retention period (MRT) than hydraulic retention period, thus enhancing the rate of decomposition of organic solids and the reactor's efficiency. In the USR anaerobic process the feed dry matter concentration (DM %) is usually between 4% and 6%. Raw material should be pre-treated in order to remove grass stalks and other larger solids that may cause plugging of pumps and pipes.

Upflow Anaerobic Sludge Blanket

An Upflow Anaerobic Sludge Blanket (UASB) digester is a continuously fed anaerobic digester. This system uses an anaerobic process to form a blanket of granular sludge which is suspended in a tank. Waste flows upwards through this blanket and is process by anaerobic microorganisms present in the blanket. The blanket remains suspended due the combined action of the upward flow, and gravity, the use of flocculants aids this process.

The anaerobic degradation due to the waste coming in contact with the microorganism present in the sludge blanket produces biogas. The upwards motion of the released bubbles cause hydraulic turbulence that provides mixing without any mechanical parts. At the top of the reactor a gas-liquid-solid three-phase separator is present. The biogas is collected using a gas caps, and the treated liquid effluent is pumped away. Solid sludge particles will settle down to the surface of the sludge blanket. In comparison to other systems UASB has a higher efficiency, requires lower investment and needs less floor space, but is not suitable for treating feedstock with an high amount of suspended solids and therefore the feedstock materials need solid-liquid separation, which reduces the biogas yield accordingly.

UASB digesters are more suited to the treatment of more liquid waste with 3% total suspend solids larger than 75mm. At present UASB reactors are employed in the livestock industry in several areas of China.

Continuous Stirred Tank Reactor

Continuous stirred tank reactor (CSTR) technology involves the installation of mixing devices in the conventional anaerobic digester. Since the raw materials and microorganisms are in a completely mixed state, efficiency is markedly improved in comparison to conventional anaerobic reactors. The digester is suitable for the treatment of raw materials that contain large quantities of dry matter. In the digester the newly added raw materials will be mixed with the digester contents quickly due to the mixing devices, so the concentration of new feedstock is maintained on a low level all over the digester. This type of digester is widely used in developed countries particularly in Denmark and the United Kingdom (UK).

HCF anaerobic process

The High Concentration Flow (HCF) reactor contains a mechanical mixing device that supports the anaerobic decay of the feedstock. One side of the HCF anaerobic reactor contains an input pipe with a grid, at the other end of the reactor slurry is discharged by overflow (liquid phase) and sedimentation (solids). Total solid raw materials can reach 8% in a HCF reactor.

Red- sludge plastic cover anaerobic fermentation

Red-sludge plastic cover anaerobic fermentation devices are divided into a front side and rear side fermentation pool. The front fermentation area adopts the principle of an internal circulation (IC) reactor, while the bottom is an inclined shaft structure, which can achieve single-level and multi-level sludge mixing. The rear fermentation area uses anaerobic filter (AF) and anaerobic activated sludge. The covering material of the fermentation device uses 'red-sludge' plastic. 'Red-sludge' plastic has good endothermic character, corrosion-resistant, anti-UV, anti-aging features and it can absorb solar energy. In direct sunshine, the temperature in the red-sludge plastic reaches 35~55 degrees which supports the anaerobic fermentation process, raises biogas productivity, and improves sewage degradation. The device is suitable for southern regions of China, but requires a relatively large area of land.

Benefits of technology

A comparative analysis of the options described above highlights that each process has its advantages and disadvantages. As a mature technology that has been more widely applied in China, USR processes are preferred, especially when applied to treatment of pig manure and biogas projects with central gas supply in the central and southern parts of China. HCF processes are suitable for various types of small biogas projects that treat waste. Since UASB processes are only applicable for the treatment of pig farm waste, the use of this method is limited. CSTR processes are suitable for the treatment of raw materials that contain large quantities of dry matter of high concentrations. Red-sludge plastic anaerobic fermentation devices can make use of solar warming in areas with a warm climate and long sunshine hours, but all other anaerobic digestion processes require the installation of heating and heat exchange devices.

Table 2: Comparison of technology and cost-effectiveness of anaerobic treatment technologies

Categories	Ordinary digester	CSTR	UASB	HCF	USR
organic load g/l	<3.0	5.0～10.0	8.0～15.0	5.0～10.0	5.0～10.0
allowed content of influent organic SS	Up to 50g/l	50～120g/l	<4g/l	50～120g/l	50～120g/l
COD removal %	Lower	Medium	Higher	Medium	Medium
HRT (d)	Longer	Medium	Shorter	Medium	Medium
Power consumption	More	More	Little	Less	Less
Production control	More easily	More easily	More difficult	More easily	More easily
Investment	Larger	Medium	Less	Medium	Medium
Area	Larger	Medium	Smaller	Medium	Medium
Operation experience	Little	More	More	Less	More
Operating cost	Low	Lower	Lower	Lower	Lower
Reactor volume (m^3)	Medium	Bigger	Bigger	Smaller	Bigger
Main waste types	Cow, pig, poultry manure	Cow, pig, poultry manure	Waster water	Cow, pig manure	Cow, pig, poultry manure

A large and medium-sized biogas project, whose raw materials come from 10,000 pig's dung, could produce 600 cubic metres of biogas. The biogas can be used for household heating and cooking, heat maintenance of pig sheds, Boiler heating and other uses. If it is supplied through centralised distribution networks, it can meet the gas demands of 500-600 farmers' daily life. Technology of biogas power generation is already mature. The produced electricity can meet the needs of farms themselves and villagers nearby. At the same time, the waste heat of generators can be recycled for increasing the temperature of biogas production material.

Development problems and proposed strategies for biogas in China

At present, one of the key barriers to biogas is that although there are significant environmental and energy benefits there are not sufficient economic benefits to encourage farmers to invest in biogas. The solution is establishing demonstration projects supported by finance special funds and financial support policies of the bank. Cultivating and regulating the biogas market, developing a specialised biogas operating company to decrease the investment and operation cost and ensure efficient operation. Perfecting the biogas technology and product's criterion, supervising and service system, choosing feasible technology and disposal mode according to the local environment, introducing and developing correlative equipment and key technology. And Biogas project construction can be assured to be developed well by the integrated utilisation of resources and the efficient conversion of energy.

While as for the policy implication, the Chinese policy environment and the market aspects assessment should also be included as an important content. Technical barrier such as low efficiency is only part of the existing problems which can be solved relatively easily. Research institutions in China have been working on diverse issues for the biogas technologies and made achievements. As a rule, economic benefits will be the best drive of industry development. On the other hand incentives are not strong enough to encourage the commercial development of manure management and biogas utilization, which is the key problem to be solved. Economic benefits will have bigger effects on biogas development which will naturally have good policy implications.

ANNEX 2 - ANTHONY MANONI MSHANDETE AND WILSON PARAWIRA. BIOGAS TECHNOLOGY RESEARCH IN SELECTED SUB-SAHARAN AFRICAN COUNTRIES – A REVIEW. *AFRICAN JOURNAL OF BIOTECHNOLOGY* VOL. 8 (2), PP. 116-125, 19 JANUARY, 2009.

PART 2: LIFE CYCLE ASSESSMENT OF BIOCHAR PRODUCTION SYSTEMS BASED ON PYROLYSIS AND GASIFICATION TECHNOLOGIES

1 DEFINITION OF BIOCHAR, PRODUCTION METHODS AND FIT WITH CURRENT DISCOURSE ON INNOVATIVE ENERGY TECHNOLOGY

Biochar is the product of pyrolysis (or gasification) of biomass which is the chemical decomposition of organic material when submitted to high temperatures (>300 °C) under a limited supply of oxygen. Essentially, biochar is charcoal - a solid with a high content of carbon and slow decomposition rate. Biochar is distinguished from charcoal by the purpose of its production, not by its chemical properties.

Biochar has been used in agriculture due to its capacity to improve the properties of some types of soils, allowing increased crop production yields. The use of biochar as a soil amendment can reduce or even eliminate the usage of fertilizers and irrigation requirements. This is of special importance for developing countries with reduced access to synthetic fertilizers and with low/poor quality soils.

Recently, biochar has been attracting scientific research not just because of its soil amendment characteristics, but principally because of its carbon sequestration properties. All types of biomass are suitable to be transformed in biochar and added to soils where they will stay for considerable longer periods of time than if the biomass is left to decay. Researchers have found biomass residues (biochar) from forest fires more than 10,000 years old; however, there is still uncertainty about its permanence in soils.

Currently, there are three broad techniques to produce biochar: carbonisation, pyrolysis and microwave. Traditional techniques to produce charcoal are based on the carbonisation of biomass. They usually involve the use of batch kilns which are energy inefficient and polluting. However, batch kilns are still the primarily technique employed to produce charcoal in developing countries. Consequently, many projects in developing countries that encourage farmers to use biochar to increase their agricultural yields are using batch kilns.

There are basically four pyrolysis[2] modes, each one with different product yields as shown in the table below. These pyrolysis techniques have been developed to maximize the process energy efficiency and also to achieve more flexibility on the energy output usage (gases and liquids produced can be stored for later use) relative to the direct combustion[3] of biomass. Optimising energy production in all the pyrolysis methods leads to minimal quantities of biochar production. Therefore, if pyrolysis is adjusted to produce more biochar, less energy either thermal, oil or gas will be obtained.

Table 1: Typical product yield (dry basis) for different modes of pyrolysis

Pyrolysis modes	Time	Temperature (°C)	Liquid (%)	Char (%)	Gas (%)
Fast	1-10 sec	400 - 550	75	12	13
Moderate	10-20 sec	~500	50	20	30
Slow	>30 min	<400	30	35	35
Gasification	10-20 sec	>750	5	10	85

[2] Although gasification is generally treated separately from the other pyrolysis methods, one of its chemical reactions is pyrolysis. Therefore, throughout this report pyrolysis covers gasification and pyrolysis except where gasification is explicitly stated.

[3] The process of direct combustion has low (<5%) production of biochar, often insignificant (<1%)

Consequently, during commercial operation, pyrolysis systems usually face more issues compared to the systems which use direct combustion. Although pyrolysis is usually considered the most cost efficient method to extract energy from biomass, its commercial usage is often avoided due to the complexities pointed out above which can lead to frequent operational interruptions. The dependence on a specific type of biomass can even adversely affect the project economic viability when competition for the feedstock appears, as replacing it with another type of biomass can be a complex and costly operation.

Commercial utilisation of pyrolysis faces a large number of constraints, as pointed out above, which causes the developers of biomass plants to avoid the usage of these technologies. Current applications of pyrolysis are usually supported by governments which can to some extent assist in securing finance and the operational logistics. Therefore, although the usage of pyrolysis to extract energy from biomass is well recognised its commercial use can still be considered innovative particularly in developing countries where there is usually a lack of capacity and skills.

Fast pyrolysis can be considered a pioneering technology as there is practically no commercial experience of its use with biomass as feedstock. Gasification can also be considered an innovative technology due to its almost insignificant use in developed and developing countries. However, if biochar becomes a recognised tool as a soil amendment and a carbon sequestration instrument, these two technologies should have to become mainstream due to their potential to produce biochar and use energy efficiently.

Biochar production using microwaves is proposed by only one company – Carbonscape – which claims efficiency of approximately 50% in the yields of biochar production using their technology. However no relevant scientific research has been done in this particular technology.

2 BENEFITS OF BIOCHAR

The application of biochar to the soil is usually regarded as having the three following benefits:

- Higher crop yields in agriculture while using less fertilizers and irrigation
- Restoration of degraded or poor quality soils
- Carbon sequestration

Higher crop yields due to the application of biochar appear to come from a combination of reduction of soil acidity, improvements to soil cation exchange capacity, increase in water holding capacity and improved habitat for beneficial soil organisms. Research on the influence of biochar on crop productivities is limited to field trials in tropical and savannah climates. Additionally, the increased productivity rates do not follow any pattern on quantities of biochar and/or fertilizers applied and, sometimes, the improvements are just marginal.

While crop production rates generally increase with the application of biochar, there is practically no research on the economic viability of the technique. The costs of using biochar will depend on its price or production and also on the cost of its application in the fields. Therefore, the economics of applying biochar might not be offset by the higher crop yields.

Natural decaying biomass from plants is the principal element of the soil substrate and the biggest source of the necessary nutrients for plant growth. Frequently, degraded soils become less productive due to the usage of inappropriate farming techniques which cause severe reductions in their organic content. This leads to the break of the cycle from the source of nutrients in the soil. The application of biochar to degraded or poor quality soils will improve the soil properties as pointed out above but, most importantly it will provide the necessary substrate for plant growth allowing the soil nutrients to be re-established.

Naturally or through conventional management, biomass eventually decays or is burnt producing either methane or CO_2. The stability of the biochar can avoid, at least during a long period of time, the return of the carbon to the atmosphere. Therefore, if the process of producing biochar does not emit more GHGs than it is fixing, biochar can become a climate change mitigation instrument. And, in this case, the method of biochar production will be particularly important since it determines the quantity of carbon being sequestered in the biochar and, eventually, in the soils.

3 KEY ISSUES WITH RESPECT TO TECHNOLOGY AND ITS USE IN DEVELOPING COUNTRIES

The use of gasification and pyrolysis technologies for energy production is restricted to developing countries with political incentives to promote them. This is the reason why China, India and Brazil have a substantial number of biomass gasification projects operating with agricultural residues and have become exporters of these technologies.

However, despite the considerable experience and maturity in gasification technologies in these 3 countries, their usage remains marginal in the context of biomass utilisation. This is due to the reasons described earlier in this report.

Biomass in least developed countries generally accounts for approximately 50% of their primary energy resource for non-electricity applications. However, due to a combination of lack of governmental bioenergy policies, financial resources and skills the application of these technologies still remain in their infancy.

There is limited experience of pyrolysis and gasification in most other developing countries. Pyrolysis and gasification are complex technologies that frequently encounter problems even when operating in developed countries and their use in developing countries would, therefore need significant increases in skill levels. Kilns are appropriate in developing countries but are very inefficient as they cannot make use of the thermal, gas and liquid energy that are produced as by-products. However, their biochar production efficiency can be quite high as well designed kilns can achieve efficiencies of more than 30%.

Developing countries are the ideal candidates for the roll out of biochar mainly because of the effects it can have on crop yields. Agricultural farms in developing countries tend to be of small or family scale, often without resources for applying modern agricultural techniques and/or chemical fertilizers. Agricultural productivity is, consequentially, lower compared with developed countries.

Field studies in least developed countries are using traditional methods to produce biochar and applying it to the soils. Their results show an increase in crop productivity while reducing or even eliminating the need to use fertilizers or irrigation. Therefore, biochar has the potential to increase crop production and mitigate the consequences of low water availability in these countries.

Furthermore, some soils in these areas become degraded due to inappropriate agricultural procedures or through more extreme natural events caused by climate change or otherwise. Biochar can be used to rehabilitate these soils providing more agricultural land for the local communities.

If carbon sequestration becomes an internationally recognised climate change mitigation instrument, capable of generating finance and resulting in avoided carbon emissions, biochar could also bring financial revenues to developing countries.

However, before incentives are made to increase biochar usage in developing countries the following issues will require further research:

- Deforestation – large scale development of biochar could result in increased deforestation due to uncontrolled biochar production using biomass from forests
- Soil improvement – careful studies should be made prior to the application of biochar in the soils in order to ensure that it will not lower its productivity and to understand the quantities that maximize crop productivity
- Soil degradation – the removal of biomass from lands needs to be carefully conducted in order to avoid soil degradation. Minimal quantities of biomass should be left to decay in the land to become nutrients for the vegetation
- Costs – the costs of biochar production and application may not be offset by the increase in crop productivity
- Pollution – batch kilns should be avoided for biochar production due its inefficiency
- Competing with food crops – if biochar becomes valuable, there is a substantial risk that biochar production will compete with food crops
- Less energy output – the processes of every available method to produce biochar can be adjusted to maximize biochar production, however, doing this makes them less energy efficient
- Competition with other biomass uses – biomass waste can already be used for other purposes (e.g. animal food, energy production). Biochar production could bring imbalances to local economies that rely on biomass sources

KEY AREAS OF RESEARCH ADDRESSED BY THE PROPOSAL

Research on biochar has been limited to soil amendment potential of the biochar and restricted to certain climates and soil types. Practically no work has been carried out to develop methodologies capable of quantifying the net carbon sequestration of biochar nor on the analysis of biochar production from pyrolysis and gasification.

The proposal addresses key issues related to the production of biochar as a carbon sequestration instrument using gasification and fast pyrolysis. This project could enormously facilitate similar future works with other technologies and/or to develop baseline methodologies capable of quantifying the total carbon sequestration from biochar production and application. These methodologies will be necessary if biochar becomes an eligible instrument for climate change mitigation – becoming a source of finance.

SIMILAR WORK ONGOING ELSEWHERE

The list below gives a snapshot of research being undertaken elsewhere. It is also worth mentioning the work being carried by the UK Biomass Research Centre which is a partnership between University of Edinburgh, Rothamsted Research and Newcastle University. They are developing strategic research on the capacity of biochar for climate change and soil productivity improvement. It has not been possible to provide the details of these research projects being carried out, due to resource constraints.

- Institution: **UK Biochar Research Centre**

  Researchers: Dr. Simon Shackley

  Scope of work: Life Cycle Assessment (LCA) of biochar production using a variety of pyrolysis methods. Requirements of biochar carbon to be used in the Clean Development Mechanism

- Institution: **University of Copenhagen, Denmark**

  Researchers: Dr. Sander Bruun

  Scope of work: use life cycle assessment to compare the environmental impact of pyrolysis and biochar production with incineration of wheat straw in Denmark.

- Institution: **University of New South Wales, Australia**

  Researchers: Dr. G. Kelli Roberts

  Scope of work: Life Cycle Assessment of Biochar production from crops and crop waste to estimate their energetic, economic, and Climate Change potential.

- Institution: **National Agricultural & Food Research Institute, Japan**

  Researchers: Dr. Yoshiyuki SHINOGI , Dr. Koji Kameyama, Dr. Chen Yan

  Scope of work: Life Cycle Assessment of the environmental impacts of using pyrolysis to produce biochar from sewage, sludge, crop residues and cattle waste.

- Institution: **Universtity of Georgia, USA**

  Researchers: Dr. Keshav Das

  Scope of work: Thermochemical conversion of biomass into biofuels and bioproducts focusing in biochar pyrolysis processes and refinement.

- Institution: **Virginia Tech University, USA**

  Researchers: Dr. Foster A. Agblevor

  Scope of work: Testing of a transportable pyrolysis unit to convert poultry litter into bio-oil and biochar.

- Institution: **Rocky Mountain Research Station & University of Idaho, USA**

  Researchers: Dr. Deborah Page-Dumroese and Dr. Mark Coleman

  Scope of work: Fast pyrolysis of forest biomass to reduce availability on biomass in forest, increase soil productivity and sequester carbon.

- Institution: **Black is Green, Australia**

  Researchers: Dr James Joyce

  Scope of work: Commercial operation of a mobile pyrolysis unit to produce biochar

4 POTENTIAL OF THE PROPOSAL TO PROVIDE A BROADER GLOBAL PUBLIC GOOD RESEARCH PROJECT BEYOND THE UK AND CHINA

Understanding the optimum conditions that allow economic and sustainable bioenergy generation whilst also producing biochar, will be an important step for future planning of bioenergy plants in any country. It could help to determine the type of bioenergy plants that are proposed in certain situations.

Fast pyrolysis and gasification are technologies that still have a substantial number of issues to overcome in order to become mainstream technologies in both developing and developed countries. Government support through policies that encourage bioenergy utilisation has been shown to be essential in this regard.

Research at all levels of biochar production and usage is crucial to assess its viability as a soil improvement agent and/or a carbon sequestration instrument. National governments and most importantly international support for bioenergy could dramatically shift if biochar becomes a recognised instrument to fight the climate change. The proposed research on biochar production technologies appears to be a step on the way to assess relevance of biochar as a low carbon technology.

Developing countries especially the least developed countries where the application of biochar is likely to be crucial to rehabilitate low quality soils and increase their crop productivity have limited access to the technologies considered in the proposal (fast pyrolysis and gasification) and to the technical skills required for its operation. Significant capacity building and technology transfer would be required for these technologies, technology transfer is likely in the medium term rather than the short term. However there is progress and a South African company is developing pyrolysis plants and many others, in China and India, are already exporting gasification plants.

Several countries in Latin America (LA) are investing in biomass gasification plants where the results and findings of this project could possibly be transferred. Biochar application in LA could range from improving soil productivity to the restoration of degraded deforested tropical lands.

Countries with low quality soils and lack of financial resources to invest in modern agricultural processes and/or to rely on extensive usage of fertilizers are prime targets for biochar application. If well applied, biochar can contribute to increasing their agricultural yields.

5 AMENDEDMENTS TO PROPOSAL TO INCREASE ITS POTENTIAL GLOBAL PUBLIC GOOD BENEFIT AND RELEVANCE TO INNOVATIVE LOW CARBON ENERGY TECHNOLOGY IN DEVELOPING COUNTRIES

The proposal should provide more details and focus on assessing the LCA on a wide range of biomass feedstocks. Research could focus on biomass types that can become significant sources for biochar production, particularly in developing countries. Examples of possible biomass can be:

- Crop waste – rice husk, corn stalks, wheat straw
- City waste – urban municipal waste, food waste
- Wood residues – woodchips, leaves, branches
- Dedicated plantations – fast growth and native trees, energy crops, short rotation coppice

It would be useful to include an assessment of a baseline for the production of biochar. Both processes (gasification and fast pyrolysis) can be adjusted to maximise either energy or biochar production.

There should be greater details on how the project can benefit direct beneficiaries and how it can feed future developments on climate change instruments.

Other concerns are considered outside the scope of this proposal. These concerns include environmental concerns about the potential contamination of soils with heavy metals contained in biochar.

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