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Economics of pyrolysis-based energy production and biochar utilization: A case study in Taiwan

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HIGHLIGHTS

- Profitability varies due to sales revenue from electricity generation.
- Neither fast pyrolysis nor slow pyrolysis is profitable under current electricity price.
- Both systems offset about 1.4 t to 1.57 t of CO_2 equivalent per ton of raw material.

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ABSTRACT

Pyrolysis is an alternative form of renewable energy production and a potential source of greenhouse gas emissions mitigation. This study examines how poplar-based biochar can be applied in Taiwan for electricity generation and for soil improvement and to what extent it brings economic and environmental benefits. It is a preliminary study and focuses on the balances of different economic and environmental items. This paper reports on a case study examination of the economic and greenhouse gas implications of pyrolysis plus biochar utilization. The case study involves using poplar grown on set-aside land in Taiwan with the biochar applied to rice fields. We examine both fast and slow forms of pyrolysis and find how the profitability varies under different price structures. The results show that fast pyrolysis is more profitable than slow pyrolysis under current electricity price, GHG price and crop yield as the slow pyrolysis generates relatively less electricity but lower value product—biochar. We also find that fast pyrolysis and slow pyrolysis offset about 1.4 t and 1.57 t of CO_2 equivalent per ton of raw material, respectively.

1. Introduction

Taiwan imports more than 99% of its fossil fuel use and low energy security is her major concern. Greenhouse gas (GHG hereafter) emissions are also an issue with the preponderance of emissions arising from energy use. Thus there is a desire for the development of alternative energy forms that can be produced domestically and have lower GHG emission profiles. Consequently the Taiwanese government is considering ways of producing renewable energy. To date the main means considered for producing renewable energy have largely been limited to those that produce ethanol with some limited consideration of electricity (CEBIO, 2007).

An alternative route involves the use of pyrolysis which through the heating of organic material at elevated temperatures in the absence of oxygen generates products commonly called bio-oil, biogas and biochar (Mohan et al., 2006). All of these products can be used in forms of energy production and all of which involve recycling of carbon rather than net emission of stored fossil carbon. Although some studies indicate that some forms of bioenergy (such as bioethanol) may not be able to reduce net GHG emissions, bioelectricity and biochar have evidence to reduce net GHG emission through life-cycle analysis. However, the amount of GHG emissions can be offset depends on the feedstock used and other factors, which will be examined carefully in this study.

Furthermore, biochar can be used as a soil additive that has been found to sequester carbon in a stable form, improve retention of nutrients and water, and enhance crop yields (Lehmann et al., 2003; Chan et al., 2007). Thus pyrolysis has desirable, beneficial properties. However, for it to be implemented on a large scale it

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must be economically attractive. This paper appraises the economics of pyrolysis use in a Taiwanese case study setting using poplar as the feedstock following a similar approach that used in McCarl et al. (2009). We also investigate how variations in key factors like energy prices, GHG offset prices, and crop yield enhancements affect the profitability of fast and slow pyrolysis. The results will not only provide information for Taiwanese government for possible future pyrolysis-based electricity development and associated GHG offsets, but also indicate how pyrolysis-based electricity and GHG offsets can be affected by other factors such as fertilizer and irrigation, which is also useful for real application outside of Taiwan.

Specifically, we examine the following:

(a) The cost of feedstock harvest, hauling, storage and use.
(b) The costs of energy production/pyrolysis operation.
(c) The revenues gained from energy sale;
(d) The value of yield enhancements and input reductions from biochar application and associated application costs;
(e) A full GHG accounting including: offsets for displaced fossil fuels; increased fossil fuel usage in feedstock production, hauling and pyrolysis operation; sequestration enhancements and losses involved with removals of feedstock and biochar application; and fertilization related GHG alterations due to feedstock production and nutrient retention.

2. Pyrolysis and biochar

Pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen where

- Fast pyrolysis involves biomass being rapidly (on the order of 5 s to 10 s) heated to between 400 °C and 550 °C (Bridgwater, 2005).
- Slow pyrolysis involves slower heating to less than 400 °C (although other definitions have higher temperatures (Bridgwater, 2005)). The biomass is typically heated for at least 30 min and possibly several hours.

During pyrolysis, biomass is converted into three products:

1. a liquid product called bio-oil, pyrolysis oil or bio-crude;
2. a solid charcoal product that can be used in a range of applications, including use as a soil additive (and in that use is commonly called ‘biochar’) or as a source of energy in the conversion process;
3. a non-condensable gas product containing carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4) and higher hydrocarbons, which is called ‘biogas’, ‘syngas’ or ‘pyrolysis gas’.

Slow pyrolysis yields relatively more biochar, but less bio-oil. Wright et al. (2008) indicate that fast pyrolysis yields about 15% biochar, 70% bio-oil and 13% syngas. Ringer et al. (2006) indicate that under slow pyrolysis, about 35% of the feedstock ends up as biochar, 30% as bio-oil and 35% as syngas. In both cases, the bio-oil can then be cleaned and further processed to produce higher-quality fuels (Czernik and Bridgwater, 2004, used to produce electricity, or it can be refined to produce chemical feedstocks such as resins and slow-release fertilizers. Each of these is a potential source of value. Some studies (Diebold et al., 1999; Ruth, 2003; EIA, 2004) point out that per ton of raw bio-oil (that is, directly produced from pyrolysis operation) has less energy content than refined bio-oil because water, alkali, sulfur and other chemical components must be removed to upgrade the bio-oil. However, we are able to clean and upgrade bio-oil to meet the specification for certain petroleum-based distillate and residual fuels (Scahill and Amos, 2003). While biochar was initially viewed as a source of energy and can be burned to supply process energy, it can be used for water purification, gas cleaning, or for charcoal in home cooking. In addition, it is a potential source of several valuable environmental and agronomic benefits (see discussion in Lehmann and Joseph (2009)). Potentially, the energy products and the biochar as a soil additive have GHG implications, displacing both fossil fuel use and nitrogen fertilizer with their associated emissions, plus sequestering carbon. The carbon sequestration benefit is mainly due to the application of biochar, which can last in the soil for thousands of years and store carbon in a more stable form.

3. Examination of a biomass to pyrolysis feedstock prospect

Economic and GHG value plus offsetting cost arises in a number of ways from the pyrolysis/biochar process. Below we consider benefits and costs, first, and then examine implications from changes in the GHG balance.

3.1. Costs and benefits

The economic costs and benefits components we consider are:

- feedstock production and collection;
- feedstock hauling;
- feedstock storage and pre-processing;
- feedstock processing;
- pyrolysis operation;
- energy sales;
- biochar hauling and application; and
- biochar-induced cropping system gains.

3.1.1. Feedstock production and collection

Biomass incurs costs in production, assembly, harvesting, collection and compaction (Caputo et al., 2005). Because Taiwan does not produce poplar, we assume that the poplar yield is 7.6 t per year per hectare, based on Aylott et al. (2009). In addition, we assume that the inputs used to produce poplar do not change significantly. However, since we cannot assure this assumption, we increase and decrease the production costs by 20% to reflect their possible variability. Data comes from the Forest and Agricultural Sectors Optimization Model (FASOM) that developed by Dr. Bruce McCarl and Taiwan Agricultural Sector Model (TASM) that developed by Dr. Chi-Chung Chen. The estimated results (in 2007 US dollars) are shown in Table 1.

Moreover, we assume that the poplar is produced on set-aside land with an opportunity cost of zero. The reason that we assume that the opportunity cost is zero is because currently every hectare of set-aside land receives $3000 subsidy from government for not cultivating. If the set-aside land produces anything other than

Table 1
Costs from feedstock production.

Poplar production costs	Unit	Production cost	20% more	20% less
Establishment cost	US$/ha	156	187.2	124.8
Fertilization	US$/ha	29.1	34.9	23.3
Machine plus labor	US$/ha	285.4	342.5	228.3
Energy	US$/ha	14.67	17.6	11.7
Poplar production cost	$ per ton	63.8	76.6	51.1