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Title

Biowaste conversion technology for household food and energy security in the Philippines: appropriate on-site small-scale rice husk waste carbonisation.

Biographical notes

Ricardo F. Orge is a Supervising Science Research Specialist of the Philippine Rice Research Institute (PhilRice) based in Munoz Science City, Nueva Ecija, Philippines. Ricardo holds a Ph.D. degree in Energy Engineering and currently doing research works related to the utilization of rice by-products (rice hull and rice straw) for co-generation of biochar and energy. His other interests include farm mechanization and rice seed storage management.

Mark P McHenry researches various new technology developments in the School of Engineering and Energy within Murdoch University's Faculty of Minerals and Energy. Mark has published several peer-reviewed journal articles, book chapters, and reports on renewable energy resources and technologies, carbon biosequestration, power systems, bioenergy conversion technologies, soil organic carbon and biochar developments, energy policy, and agricultural mitigation and adaptation to climate change.

Abstract

Successful long-term domestic rice research to feed the rapidly increasing population in the Philippines facilitated increased production of the nation's staple from 11.786 MT in 1999 to 16.258 MT in 2008. The additional rice production has correspondingly increased the annual milled rice husk waste resource to around 3.4 MT – currently a disposal problem for millers who often dump the waste in open fields to slowly decompose. The waste represents approximately 42 million GJ of energy, equivalent to 7 million barrels of oil. This paper discusses the local development of an inexpensive, simple, fast, safe, and versatile continuous rice husk carboniser which overcomes many limitations of existing batch carbonisers, including unacceptable operator emission exposures. The small-scale, portable, motor-less carboniser was designed to allow retrofitting of heat recovery components for alternative applications, including crop drying, and steam-driven systems, such as water pumps, as co-products to biochar used locally as a fertiliser.

Keywords

Food security; energy security; biowaste; biomass; biosequestration; rice; rice husk; renewable energy; biochar; carboniser; carbonisation.

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1 Introduction

The incidence of poverty in the Philippines in 2006 was 32.9%, as defined by the lack of income needed to purchase basic nutritional requirements and other non-food needs. In 2008, around 26% of Philippine children were both malnourished and underweight (United Nations, 2010). Increasing the incidence of poverty since 2006 was the 2008 “shock” in the international food and fossil fuel prices resulted in a substantial increase in the Philippine retail price of rice, and also general food inflation which has not returned to pre-shock levels. Impacts on the poorest (rural) levels of society in the Philippines during the 2008 food and fuel crisis lead to lower employment, although the inflationary pressures also lead to a notable decline in real wages for the wealthier classes (United Nations, 2010; van der Meulen Rodgers and Menon, 2010). The negative impact was unlikely assisted by the Philippines currently importing the vast majority of their biofuels from major international producers (predominantly Brazil) to meet their biofuel blending targets set by the Biofuel Act (2006) (ISSAAS 2007; Corpuz 2009; Borines et al 2011). In terms of the food price increase impact on rural areas, the simple assumption that rice price increases benefit all rural rice producers in the Philippines is erroneous (Reyes et al., 2009). Around one quarter of subsistence rice producing households (around 3 million people, and increasing) are net losers from price increases, as they are unable to produce sufficient rice to supply their own rice demands for the year (Reyes et al., 2009; United Nations, 2010). In contrast to energy, the Philippines as a nation is close to self-sufficient in terms of rice production. Yet, most households are not rice (or other food) producers, and any benefit from price increases will be distributed unevenly. Inflationary food pressures will disproportionately fall on the substantial population that do not produce food. Therefore, with the increasing price of energy and food, the efficient and safe use of biowaste residues such as rice husks as an alternative source of bioenergy in poorer households is becoming necessary.

The over-arching aim of the project detailed in this paper was to develop technology that reduces the vulnerability of rice producers to increasing energy and fertiliser input costs, resulting in a contraction of food inflation risks which undermine increased production achievements. Maintenance of access to affordable and nutritious food is a fundamental necessity alongside economic and environmental factors of food production and development (PMSEIC, 2010a). The parallel challenge of “clean development” is hampered by the high costs of secured renewable energy supplies, particularly in low-income countries (UNDP, 2010). The redirection of agricultural food outputs for bioenergy applications alongside increased food demand from expanding global populations has lead to concerns about the ability of low-income regions to absorb higher food commodity prices (Shapouri and Rosen, 2007; United Nations-Energy, 2007). This work explores one simple example of an appropriate small-scale, low-cost bioenergy conversion technology designed to improve both food and renewable energy security in low-income rural rice regions, in the context of the Philippines.

The continuous pressure of increasing rice production to feed the growing population in the Philippines, coupled with the introduction of higher yielding varieties, and other technologies, has resulted in a growing rice husk bioenergy resource. The average annual rice production increase was almost 558 kt between 1999 to 2008 (see Figure 1). Rice husk (or hull) is the outer covering of the rice grain which is removed during the process of milling. It constitutes 20 to 25% of the total rice grain harvested from the field (Jenkins, 1989), and is locally known as *palay*. The milled rice husk waste is one of the most abundant national agricultural residues, and is also one of the most underutilised biowastes in the Philippines. While no formal data exists on the utilisation level, the Biomass Resource Survey Project of the Philippines Department of Energy, as cited by Elauria (2009), estimated a domestic rice husk utilisation of only 10-20%, as compared to 60-70% for bagasse and 40-50% for coconut wastes. Unutilised rice husks are becoming a growing problem as manifested by common sight of large piles of rice husks, newly dumped and decaying in vacant lots and road sides (Luh, 1991). The common occurrence of igniting the husk waste is a widespread cause of air pollution in rice growing regions, and also leads to significant nutrient loss (particularly nitrogen) from farms in the combustion products (Haefele et al., 2009). Furthermore, if the rice husk wastes remain unburnt, the decomposing piles give off dusts high in silica which can cause respiratory problems, and also skin conditions through irritation. As rice husk residues exhibit heating values of around 14 GJ t^{-1} (Jenkins, 1989; Natarajan et al., 1998), there is around 42 million GJ of energy, equivalent to 7 million barrels of oil literally wasted, and there is a need to capture this significant national resource using suitable bioenergy technologies.

[Insert Figure 1 approximately here]

2 The place of bioenergy in transitional economy agricultural systems.

The ability for people to utilise the energy in available agricultural biowaste residues is dependent on the affordability of suitable bioenergy conversion technologies, and the relative cost of competing technologies, including other renewable technologies (United Nations-Energy, 2007). There are often relatively low levels of mechanisation and high labour components in agricultural production in transitional economies. Lower wages received by farm labourers in low income regions may not reduce agricultural production below that of comparable countries using higher levels of mechanisation, which is the case in the Philippines (Dawe et al., 2006). However, global energy prices influence the local cost of transitioning to more productive mechanised agricultural production and delivery (including fuels, fertiliser, downstream processing, and transport) (PMSEIC, 2010a). For example, batch rice dryers with a 5 t capacity typically consume around 80 L of kerosene over 8 hours (Haefele et al., 2009), and are a relatively expensive option compared to the common practice of drying rice on vehicle roads, despite the obvious quality and hygiene benefits of mechanical dryers. Therefore, the conversion of biowaste residues for bioenergy (and also biochar production) has several co-benefits of localised commercial opportunities, increased employment, additional energy production, greenhouse gas mitigation, and agricultural productivity benefits through greater yield and mechanisation (United Nations-Energy, 2007; PMSEIC, 2010b).

A greater focus on development of suitable agricultural biowaste conversion technologies that enhance agricultural productivity can insulate higher energy prices without trading food security for energy security by reducing primary agricultural food output to meet bioenergy targets (United Nations-Energy, 2007). A combined focus on the local development towards non-food/feed residue conversion for energy, and the potential for biochar for soil biosequestration can reduce the current renewable bioenergy policy problems, including the increased net indirect emissions from additional fertiliser requirements (United Nations-Energy, 2007; PMSEIC, 2010b). If during the conversion of the husk residues to biochar some useful energy can be extracted, these "ecologically sustainable" agricultural systems can, in theory, be carbon neutral or even negative (McKendry, 2002; Lehmann, 2007).

At present, the conversion of rice husk into biochar is becoming a popular practice among Philippino farmers, particularly those practicing the *Palayamanan*® system of farming. *Palayamanan*® is a locally-developed system of farming which focuses on the integration of various farming components such as rice and other crops, livestock, fish, and recycling to minimise biowastes, where all materials are viewed as a resource. For example, rice husk biochar is used as bedding material to facilitate urine and manure collection in poultry, swine, and other animal husbandry systems, and once the biochar is saturated, it is used as an organic fertiliser (see Figure 2). The system aims to ensure food availability, increases farm productivity, profitability, and economic stability of farm families (PhilRice, 2005). It is also being considered as a rice research and development strategy (Sebastian et al., 2004). However, at present there is little scientific data available on the efficacy of rice husk biochar in rice producing regions. Initial research in south-eastern China by Zhang et al. (2010) found rice yield increases between 8.8% and 14% when rice husk biochar was applied at rates between 10 to 40 t ha^{-1}, respectively. Yet, significant additional research is required to determine the utility of rice husk biochar in other regions in the Asia-Pacific.

[Insert Figure 2 approximately here]

In recent years several peer-reviewed science and institutional publications have examined the potential uses of various biochars in agricultural systems in addition to carbon biosequestration. These generally include increased soil nutrient retention and cation exchange capacity, decreased soil acidity, decreased soil toxin uptake; enhanced physical soil structure; increased plant nutrient-use-efficiency, changes in CH_4 and N_2O soil emissions, increased beneficial soil microbe populations (including arbuscular mycorrhizal fungi), fungal pathogen resistance, etc. (PhilRice, 2003; Bridle, 2004; Rondon et al., 2005; Renner, 2007; Warnock et al., 2007; Wilson, 2007; CSIRO, 2009; Thies and Rillig, 2009). Nonetheless, more data is required to transfer general findings into suitable methods for specific agricultural and biosequestration applications utilities under various climates, soil types, rice cultivars, and rice production systems. In particular, fundamental data regarding rice crop yield differences at various rice husk biochar applications, the magnitude of displacement of specific fertiliser types, soil carbon biochar recalcitrance, and production, transport, and handling safety is required (Blackwell et al., 2009; PMSEIC, 2010b). Furthermore, the permanence of biochar in soils (and resultant benefits) are dependent on numerous variables, including the primary biomass characteristics, the production conditions, and the unique soil and soil management conditions which result in various biochar oxidation and decomposition rates (Graetz and Skjemstad, 2003; Lehmann et al., 2006; Lehmann 2007; Lehmann et al., 2009). Therefore, these uncertainties must be narrowed to enable farmers to capture the greatest benefits of biochar applications in rice production systems at minimum cost.

3 Results and discussion

The carboniser prototype was developed with the primary functions of reducing the rice husk waste disposal problem, increasing on-farm nutrient turnover, increasing carbon biosequestration in soils, and enabling co-production of useful heat and organic fertiliser for locally sustained and secure rice production systems. In contrast, conventional open batch rice husk carbonisers are able to convert around 1.6 m^3 of rice husk into biochar in four to five hours, at a temperature range of between 520°C to 560°C, and have no heat recovery capability (PhilRice, 2005). Figure 3 shows the low-cost continuous carboniser prototype developed by the primary author which is able to convert around 40 kg of rice husk each hour with a biochar yield of approximately 40% (by weight). Table 1 shows a list of construction materials and their respective costs, and Table 2 shows a summary of performance test results. The continuous rice husk carboniser is able to be filled with rice hull for ignition and started in less than three minutes with 300 mL of kerosene. The carboniser requires no electricity to operate, and rice farmers can produce biochar on-farm in the field where it is needed (see Figure 4 for the final biochar product). The carboniser can also provide useful heat from the exothermic process (see Figure 5 for a microboiler attachment steam output). Suitable complementary heat recovery technologies (such as microboilers, heat exchangers, etc.) enable options such as crop drying, soil sterilisation, or pumping water required for rice production. The continuous operation enables an uninterrupted renewable energy source for these activities, reducing the incidence of idle capital, and excessive operation and monitoring intensities. Only periodic agitation of the husks around the opening between the top and bottom hoppers is required to reduce inconsistencies in conversion and to maintain stable high temperatures. Material and heat balance results for the carboniser were calculated to assess the flow and fate of the rice husk constituents and the ambient air inputs (see Figure 6, Table 3 and Table 4 for modelling results, assumptions, and model inputs). The developed continuous carboniser prototype efficiently removed biomass carbon fractions from the carbon cycle into biochar soil amendments, and also has the capacity to displace some farm energy demands currently supplied by fossil-derived fuels.

[Insert Figure 3, 4, 5, and 6 approximately here]

[Insert Table 1, 2, 3, and 4 approximately here]

While this low-cost continuous carboniser (and many others developed or in development around the world) are a promising start, much additional research is required to determine the net potential benefits (economic, human health, environmental, agronomic benefits, useful energy, etc.) of small-scale suitable rice husk carbonisation technologies in rice growing regions in transitional economies. The authors offer some suggested areas of further research:

- Continued advancement and testing of continuous carbonisers to characterise performance (including chromatography) to determine effective operating parameters aimed towards high gasifier performance, usability, safety, with a focus on affordability in terms of purchase and maintenance;
- The development of small-scale heat recovery systems retrofitted into carbonisers to produce heat or steam. Heat exchangers designed for use in small-scale rice drying systems can utilise small boilers coupled to a steam driven pump for use in ricefields, or other uses and;
- The development of household rice husk-fuelled cooking stoves operating with clean emissions (smokeless, and low CO) which also generates biochar as by product. (Biochar has greater uses than ash as a household garden potting medium or soil conditioner), and;

- Basic agronomic effects of rice husk biochar in rice systems, recalcitrance over time, (etc.) of biochar produced under various conditions.

4 Conclusion

Maintaining food production productivity and capacity is essential to ensuring food security to a vulnerable population, and there are growing concerns over transitional economies decreasing resilience to food and fuel market volatility (United Nations 2010). Unless agricultural wastes are used to meet biofuel targets, countries in the Asia-Pacific risk exacerbating domestic food and fuel price inflation (Dawe et al., 2006; Reyes et al., 2009; van der Meulen Rodgers and Menon 2010). The often oversimplified “food vs fuel debate” (United Nations-Energy 2007) is clearly not isolated to the Philippines, or the Asia-Pacific in general. However, commonsense policies in the region can avoid the predictable outcome of increased international food/feed price inflation when using food/feed to meet bioenergy policy targets (PMSEIC, 2010b).

The development of the carboniser prototype satisfied the project aim to develop a technology that reduces the vulnerability of rice producers to increasing energy and fertiliser input costs that also bolster agricultural food productivity. The relatively simple and affordable rice husk carboniser technology operates continuously and is able to achieve high temperatures for alternative applications while producing good biochar yields by weight of high quality. The ability for rice farmers to process around 40 kg of rice husk into biochar in one hour, at around 40% biochar yield, with a purity of approximately 99%, enables them to avoid both dumping or setting fire to waste rice husks, and have a cleaner, safer, and faster alternative than all other comparable locally available on-site rice husk removal (Orge et al. 2013). The downstream potential of applying rice husk biochar to soils may also have agroecosystem-wide benefits, yet this require detailed analysis to refine local crop, biological, and chemical uncertainties, in addition to the economics and safety of transporting, handling, and applying the biochar (Joseph et al. 2009; McHenry 2011, 2012). Furthermore, the additional option of retrofitting heat capture technology (such as heat exchanges and microboilers to utilise the heat produced on-site from the carboniser is a much needed source of clean and affordable energy in region, with the potential for use in crop drying and cooking, and even steam-driven systems such as water pumps, soil sterilisation, or water pumping (Orge et al. 2013).

Whilst energy use by the rural poor in the Philippines is relatively small in total and in terms of the percentage of income (United Nations-Energy, 2007; Reyes et al., 2009; United Nations, 2010), the additional energy resources for pumping, cooking etc. will no doubt be useful to many lower-income rural households. However, it is the primary agricultural yield benefits of the nutrient recycling and soil conditioning properties of the biochar additions which may have the greatest value to low-income rice producing regions, yet presently exhibits the greatest uncertainty. Further research into agronomic efficacy of the rice husk biochar will be of immediate importance to both underpin further rice production, and rich husk carbonisers, to enable the reduction of the impacts from cost inflation for imported fertilisers, food, and energy.

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Figures and Figure captions:

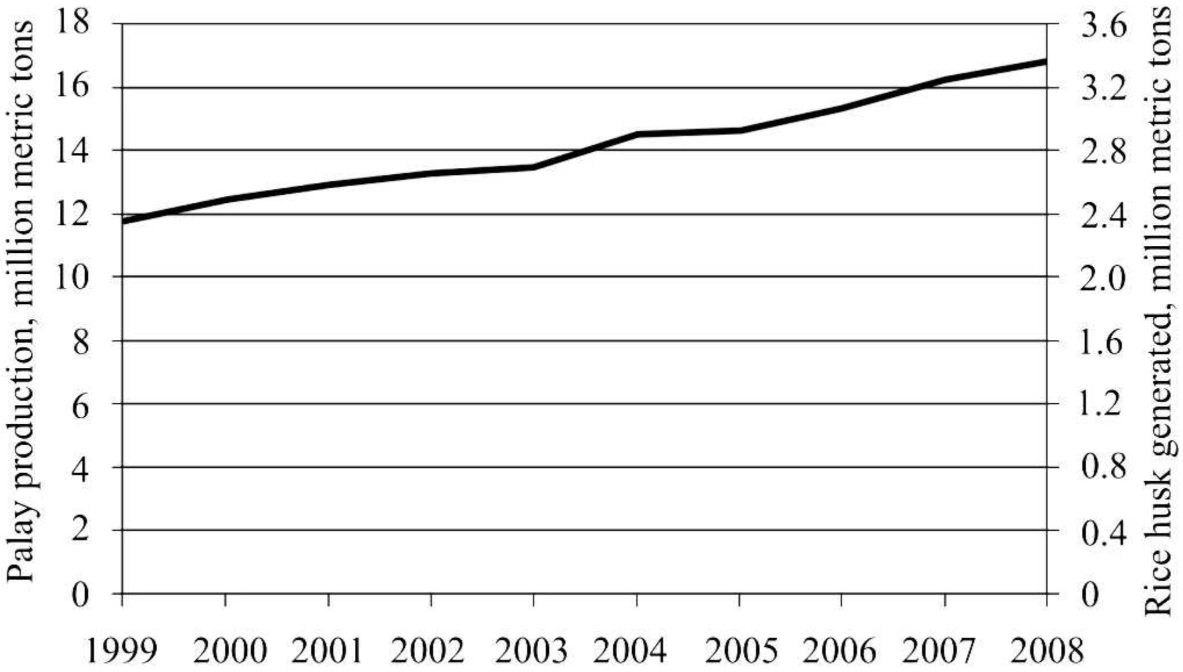

Figure 1 *Palay* production and estimated amount of rice husks over 1999-2008. Source:

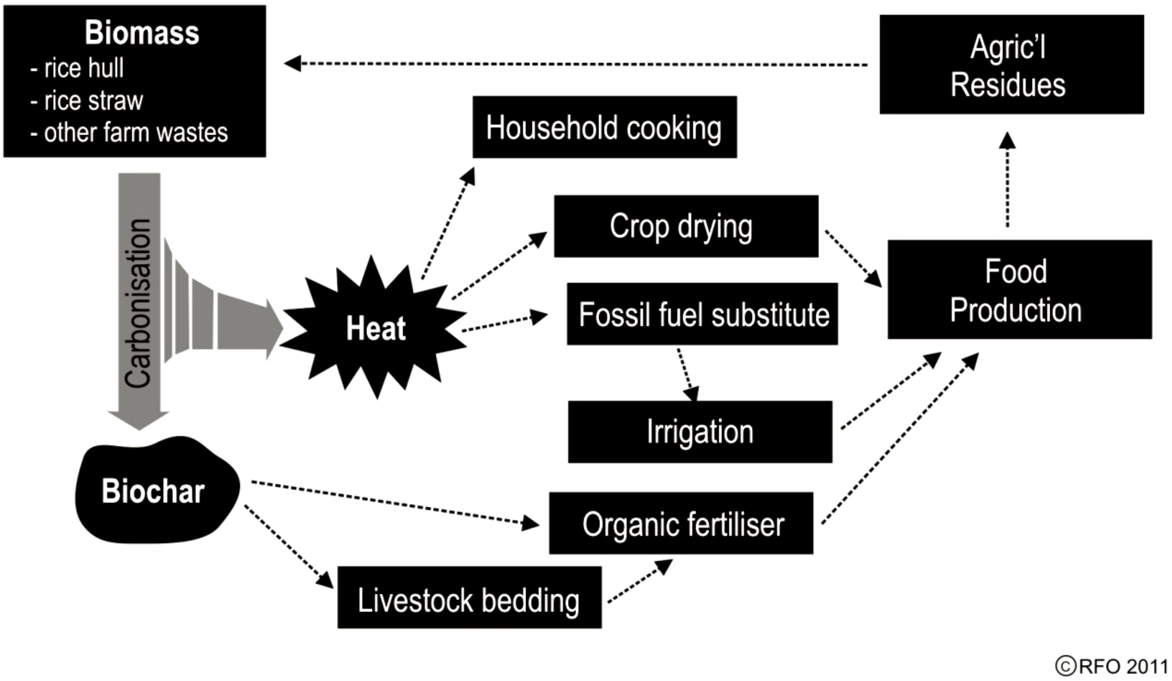

Figure 2 On-farm options for biochar and waste hear recovery from carbonisers.

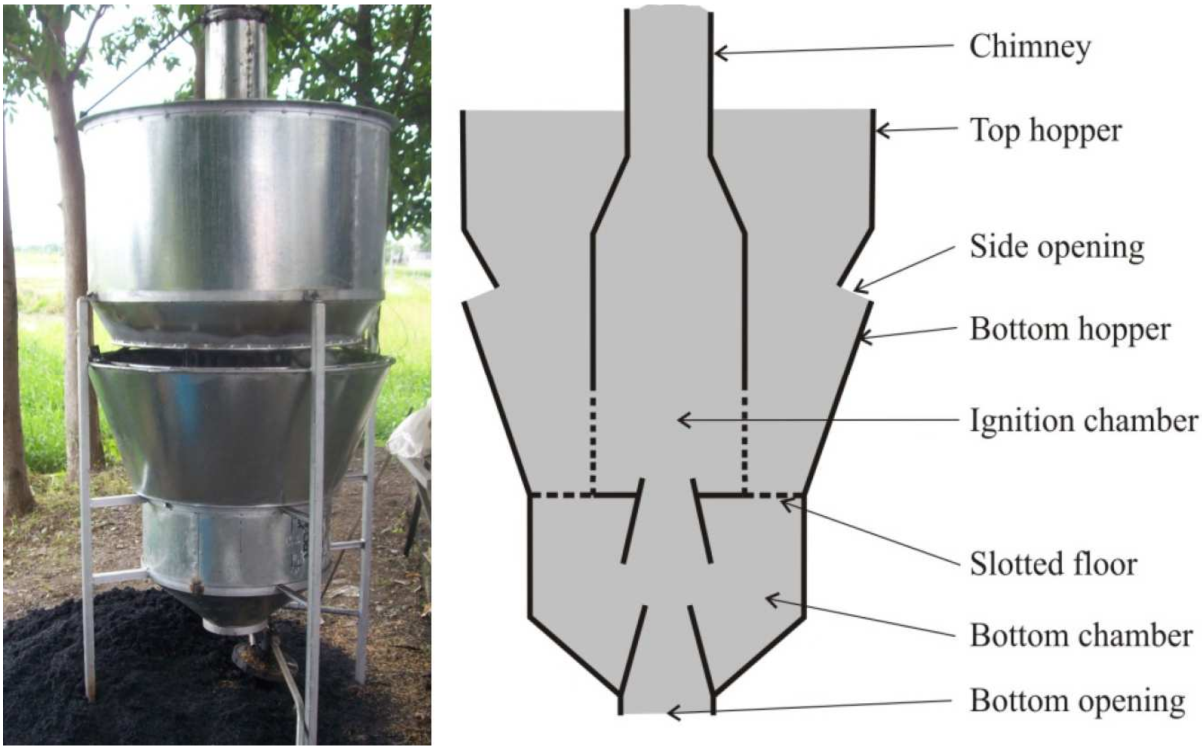

Figure 3 The prototype carboniser.

Figure 4 The bagged output biochar produced at PhilRice using the prototype carboniser, bagged ready for use in further experiments and organic fertiliser production.

Figure 5 The carboniser retrofitted with an operational microboiler.

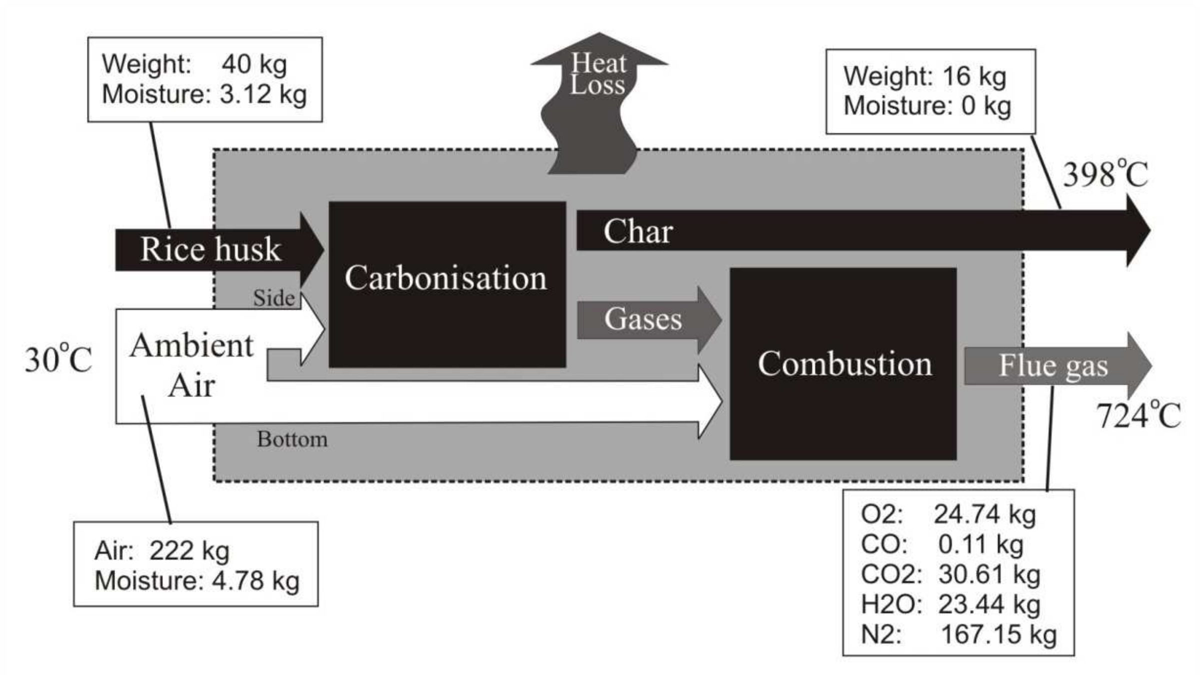

Figure 6 Modelled parameters used in the heat balance analysis.

Tables and Table captions

Table 1 Input materials and costs of the prototype carboniser.

Quantity	Materials (local non-metric units)	PHP unit cost	PHP total cost
4 sheets	Galvanised Iron sheet G#18	1,250	5,000
4 units	Plain round bar, 3/8” diam. x 20 ft	160	640
4 units	Flat bar, ¼” thick x 1” x 20’	350	1,400
2 kg	Welding rod	90	180
1 can	Aluminium paint, 1/4L	45	45
2 bottles	Paint thinner	25	50
8 units	Machine bolt, 3/8” dia x 1”	0.50	4
	Total cost of materials, PHP (USD)		**7,319 (165)**

Table 2 Average prototype test performance data derived over several test runs. (The biochar quality was measured in terms of the fixed carbon content of the each 500 g sample taken for each test run, and was analysed by the Analytical Service Laboratory at PhilRice. Temperatures were determined by two (18 mm diameter, 0.5 m long) ceramic lined thermocouple probes installed at the top and bottom portion of the ignition chamber, and a Yokogawa Portable Multi-Thermometer (model 2423A) data recorder using type K thermocouple wires. Temperature readings were taken at five minute intervals, and the maximum temperature was an averages of the multiple test readings. The oxygen (O_2), carbon monoxide (CO), and carbon dioxide (CO_2) content of the exhaust gas were determined using an IMR® 1000 handheld gas analyser, and were also averages of the test runs.)

Performance Parameter	**Second prototype**
Approximate ignition time	~2.8 min
Input capacity	38.6 kg h^{-1}
biochar yield (by weight)	39.4 %
Maximum temperature	860.1 ^{o}C
Purity of biochar	98.8%
Emissions	
O_2	7.8%
CO	510 ppm
CO_2	6.8%

Table 3 Rice husk data used in the material and heat balance analysis. (MATLAB® was used to develop a material balance program to model the process, including input data from elemental and proximate analyses of the input rice husk, and actual operation of the carboniser during testing. The heat balances were calculated using the material balance conditions, with heat balance equations expressed as the enthalpies of the materials entering and leaving the carboniser.) For a detailed discussion of the program calculations see: (Orge et al 2013).

Parameter	**Value**
Proximate Analysis	
Moisture, %	7.8
Ash, %	18.1
Volatile, %	55.5
Fixed Carbon, %	18.6
Ultimate Analysis	
Carbon, %	38.2
Hydrogen, %	5.5
Oxygen, %	35.2
Nitrogen, %	0.9
Ash, %	20.2

Table 4 Properties of selected materials and compounds.

Material	**Property**	**Value**	**Reference**
Rice husk	Heating value	14,277 kJ kg^{-1} (3,410 kcal kg^{-1})	(International Rice Research Institute, 2009)
Rice husk	Specific heat capacity	1.76-1.84 kJ kg^{-1} ^{o}C^{-1} (0.42-0.44 kcal kg^{-1} ^{o}C^{-1})	(Belonio, 2005)
Rice husk biochar	Heating value	12,560 kJ kg^{-1} (3,000 kcal kg^{-1})	(Agriculture Business Week, 2009)
Charcoal	Specific heat capacity	1.0 kJ kg^{-1} ^{o}K^{-1}	(The Engineering Toolbox, 2010)
CO	Heating value	10,094 kJ kg^{-1} (2,411 kcal kg^{-1})	(The Engineering Toolbox, 2010)
Water	Heat of vaporisation	2256 kJ kg^{-1}	(The Engineering Toolbox, 2010)