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POTENTIAL ENERGY GENERATION AND CARBON SAVINGS FROM WASTE BIOMASS PYROLYSIS IN ISRAEL

E. R. Graber[1*] and E. Hadas[2]

[1] Institute of Soil, Water and Environmental Sciences, The Volcani Center, Agricultural Research Organization, POB 6, Bet Dagan 50250 Israel
[2] Investment Financing Department, Ministry of Agriculture and Rural Development, Bet Dagan 50250 Israel

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ABSTRACT

The purpose of this paper is to evaluate the potential for energy production and reductions in greenhouse gas (GHG) emissions in Israel via the pyrolysis of waste biomass and application of the biochar co-product to the soil. Data were compiled documenting the scope of waste biomass production in the agricultural and urban sectors of Israel (3.9 million tonnes of dry wastes per year), and, using literature sources, estimates were made of the yields of pyrolysis co-products that could be obtained from the different wastes. These estimates were converted to fossil fuel and carbon emissions offsets in order to evaluate to what extent adopting pyrolysis/biochar soil application could help in Israel's attempts to reduce its reliance on non-renewable energy sources and reduce its GHG emissions. It was calculated that pyrolysis energy products could reduce annual use of fossil fuels by approximately 7.3%, and the combined carbon credit for fossil fuel displacement and permanent carbon sequestration would represent 7.5% of Israel's annual CO_2-C emissions. Approximately another 0.5% C reduction is anticipated to accrue as a result of avoided emissions from composting and other land applications of the wastes, and reductions in N_2O emissions from agricultural soil. If we consider only those wastes which are currently readily accessible, the fossil fuel use savings would be 3.2% annually and the CO_2-C savings would be 3.3% annually.

Keywords: biochar, greenhouse gas emissions, pyrolysis, Israel, biomass wastes

[*]Corresponding author: e-mail <ergraber@volcani.agri.gov.il>, Phone: 972-3-968-3307, Fax: 972-3-960-4017

1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), the earth's temperature rose 0.6°C during the 20th century, and is projected to continue to rise between 1.5 to 4.5°C by the year 2100 [1]. Man-made, anthropogenic greenhouse gas (GHG) emissions are widely believed to be the dominant causal factor for these increasing temperatures, which lead to other related changes in climate. As a result of growing concern over global climate change, there is a world-wide drive to develop different strategies for reducing net emissions. One of the major strategies is to shift from a 'petroeconomy' fueled by fossil carbon to a 'bioeconomy' fueled by biomass [2]. The bioeconomy is conventionally thought to be carbon neutral, whereby the carbon emitted through biomass use replaces the carbon absorbed during crop growth [2]. However, many argue that much first-generation biofuel production (i.e., ethanol from corn, primary crop production for biodiesel, etc.) is almost entirely carbon positive due to heavy inputs of fossil fuels and fertilizers for agricultural production [3-5]. Therefore, there is a strong impetus to develop 'second-generation biofuels' that rely on production of biofuels from waste feedstocks. Pyrolysis, the direct thermal decomposition of biomass in the absence of oxygen to an array of solid (biochar), liquid (bio-oil) and gas (syngas) bioenergy products [6,7] is one such technology.

Pyrolysis can be optimized to produce syngas, bio-oil or biochar co-products. Being an exothermic process, pyrolysis of biomass produces more energy than is invested [8,9]. When the solid biochar co-product is applied to soil, it has been reported to improve soil tilth and crop production [10-18]. Importantly, the biochar remains in the soil in an essentially permanent form, with a half-life estimated to range from 100s to several 1000s of years [9,19-21]. Consequently, energy production from biomass via pyrolysis with subsequent application of the biochar product to the soil is a carbon-negative process [21]. Furthermore, modest additions of biochar to soil have been reported to reduce emissions of greenhouse gases from cultivated soils [22]. While

some fresh organic matter is needed by agricultural soil to maintain its productivity, much agricultural waste (and other kinds of organic waste streams) can be turned directly into biochar for application to the soil and for creation of biofuels. For example, biochar production can utilize much urban, agricultural or forestry biomass residues, including and not limited to wood chips, corn stover, rice or peanut hulls, tree bark, paper mill sludge, animal manure, olive mill waste, municipal solid waste, municipal sludge, and recycled organics [7].

This concept has come to be known as the 'Charcoal Vision', a "win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality" [19]. To achieve this vision, the development of integrated agricultural biomass and bioenergy systems is required. In [19] it was calculated that implementation of 'The Charcoal Vision' in the US using sustainably produced biomass from harvestable forest and crop lands could generate enough bio-oil to displace about 25% of U.S. annual oil consumption. The combined C credit for fossil fuel displacement and permanent sequestration of the co-produced biochar in the soil would make up about 10% of the average annual U.S. emissions of CO_2–C.

'The Charcoal Vision' has economic and infrastructure advantages over mega-biorefineries for the production of bioenergy [19], as pyrolyzers can be scaled from small to large to match locally distributed sources of biomass, thus minimizing transportation costs for bulky biomass. Pyrolyzers are robust and can process diverse sources of biomass as well as biomass contaminants (soil, stones, plastic etc.), such that cleanliness during harvesting, storage, and processing of biomass is not a major concern. Pyrolyzers are also relatively inexpensive. Pyrolysis of organic wastes and soil application of the resulting biochar also has some advantages over alternative uses for organic wastes (such as composting), including the destruction of plant pathogens, the production of energy, and the achievement of long-term carbon sequestration in the soil.

The purpose of this paper is to evaluate the potential for energy production and reductions in greenhouse gas emissions in Israel via the pyrolysis of waste biomass, particularly considering that biochar can help to develop sustainable food and fuel production in regions such as ours with severely depleted soils and inadequate water resources. We compiled data documenting the scope of waste biomass production in the agricultural and urban sectors in Israel and using literature sources, estimated the yields of pyrolysis co-products that could be obtained from the different wastes. These estimates were converted to fossil fuel and carbon emissions offsets in order to evaluate to what extent adopting the "The Charcoal Vision" could help in Israel's attempts to reduce its reliance on non-renewable energy sources and to reduce its GHG emissions.

The Kyoto Protocol required Annex I countries to reduce their GHG emissions by 5% compared with 1990 levels. While Israel was not designated as an Annex I nation in the Kyoto protocol, Israel will be required to reduce emissions under the new Copenhagen protocol being developed to replace the Kyoto protocol in 2012. To date, at least 20 countries, as well as the United Nations Convention to Combat Desertification (UNCCD) Secretariat, have made agenda submissions to the United Nations Framework Convention on Climate Change (UNF-CCC) seeking to include biochar as a high-potential climate change mitigation and adaptation tool being negotiated at Copenhagen (http://www.biochar-international.org/-policy/international).

2. ISRAEL – SALIENT FACTS

2.1. Population and Agriculture

Israel, home to 7.3 million citizens as of December 2008, is located in the Middle East, bounded to the west by the Mediterranean Sea, to the north by Lebanon and Syria, to the east by the Jordan and the West Bank, and to the South by Egypt (Figure 1). More than 85% of Israel's population is concentrated in the highly urbanized coastal plain region, where population density in 2007 reached as much as 7073 inhabitants per km^2 in the Tel Aviv district. Its total land area is approximately 22,000 km^2, of which about 440,000 ha is arable. Currently, about 355,000 ha are under agricultural cultivation, approximately equally divided between irrigated and non-irrigated agriculture. The major arable soils are not very fertile, and consist variably of sandy, clayey, or silty clay loams with little structure and low in organic matter content. Though small in land area, 4 climatic zones are represented in Israel, including Mediterranean, sub-tropical, semi-arid and arid. Accordingly, rainfall amounts vary from less than 30 mm per year in the southern part of Israel to close to 1000 mm per year in the northern-most reaches. Almost all yearly rainfall occurs in 3-4 winter months, with rainfall being poorly distributed and highly variable spatially and

temporally. The country is subject to frequent droughts, and water scarcity is a major challenge.

Figure 1 Location map of Israel.

Agriculture has always been the major consumer of water in Israel, consuming an average of 1208 million cubic meters (MCM) per year since 1975 (Figure 2). However, agriculture's proportion of total water use has been declining over those same years due to steady increases in domestic and public consumption (Figure 2). In 2007, agriculture consumed 1185 MCM, as compared with 768 MCM by the domestic and public sector and 119 MCM by the industrial sector. Agriculture utilizes an ever-increasing share of marginal waters, mainly treated sewage wastewater, saline waters, and collected floodwaters, and a declining proportion of fresh water (Figure 3).

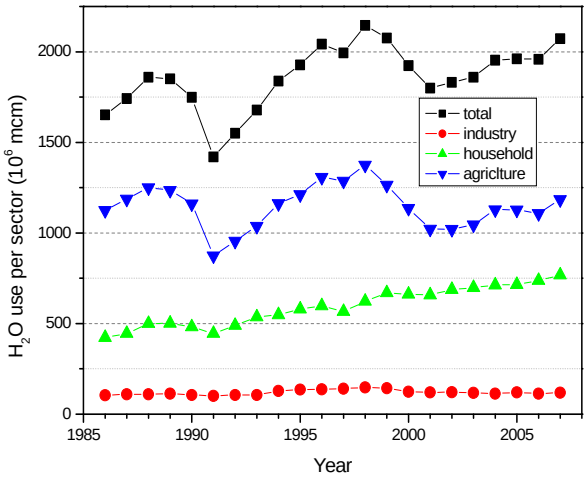

Figure 2 Temporal trends in water use in Israel according to sector. Data from the Israel Central Bureau of Statistics.

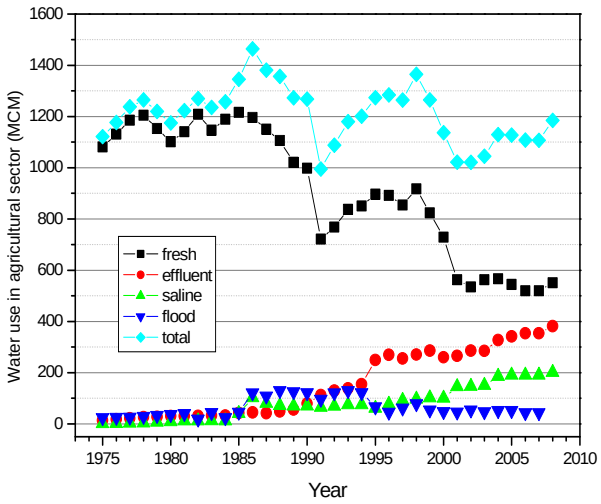

Figure 3 Temporal trends in water use in the agricultural sector according to water type. Data from the Israel Central Bureau of Statistics.

2.2. Energy Consumption

Israel's energy consumption has risen from little more than 8 million tonnes of oil equivalents (TOEs) in 1980 to about 20 million TOEs in 2006 (Figure 4).

Over the same time period, the population increased from 3.8 million to 6.9 million, meaning there was an increase in per capita fossil fuel consumption (Figure 4). Today, transportation is the major consumer of energy (32%), followed by industry (24%), residential (17%), commercial and public services (8%), agriculture (1%), and non-energy uses and other consumption (18%) (Figure 5).

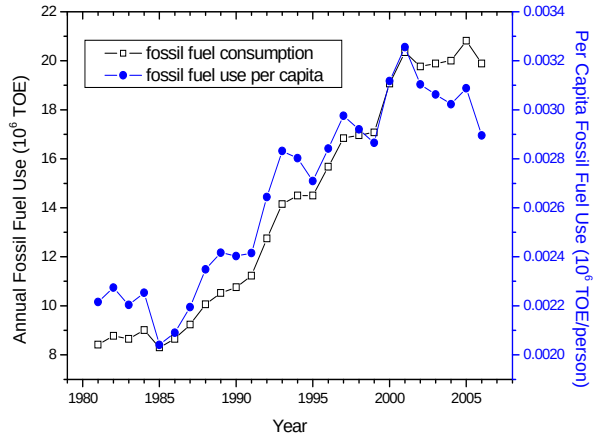

Figure 4 Temporal trends in fossil fuel consumption and per capita consumption in tonnes of oil equivalents (TOE). Data from U.S. government Energy Information Administration; http://tonto.eia.doe.gov/country/country_energy_data.cfm?fips=IS

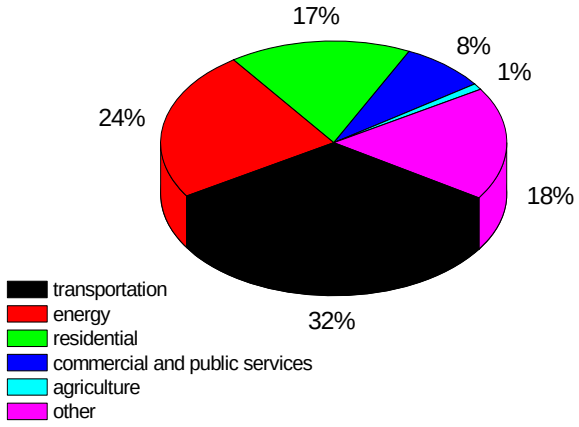

Figure 5 Energy consumption by sectors in 1999. Data from the Israel Central Bureau of Statistics.

2.3. Greenhouse Gas Emissions

The energy industry accounted for 57% of Israel's greenhouse emissions in 2007, followed by 20% by the transportation sector, and 15% by the manufacturing and construction industries sector (Figure 6). Together, these three sectors accounted for fully 92% of Israel's greenhouse emissions in 2007, with the remaining 8% being made up mainly by methane emissions from the waste management sector. In the nationwide inventory of GHG emissions for 1996, total emissions were reported to be 62,700 x10^3 tonnes CO_2e.

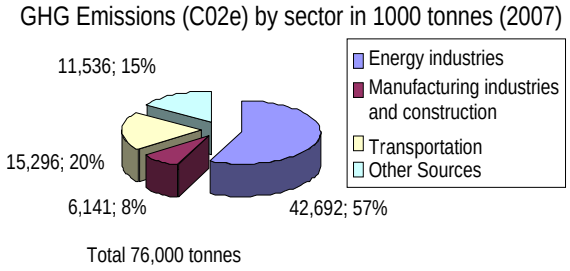

Figure 6 Israel's GHG emissions in 2007 as a function of sector. Data from the Israel Central Bureau of Statistics.

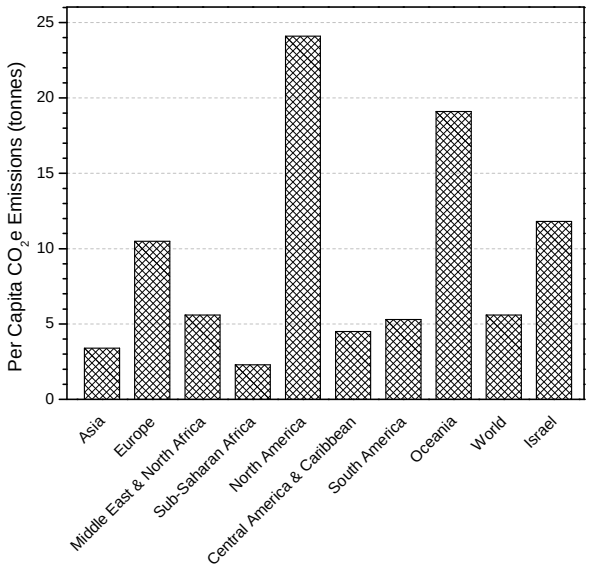

Figure 7 Per capita CO_2 equivalents emissions in tonnes, in different regions around the world for the year 2000. From data compiled by the World Resources Institute (http://cait.wri.org/).

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Emissions increased to 75,666 x10^3 tonnes CO_2e in the inventory for 2007. Per capita emissions were essentially steady over this time interval, at about 10.8 tonnes per person annually. Although Israel was classified as a developing country under the Kyoto Climate Change Convention of 1992, a comparison of per capita GHG emissions between Israel and other countries shows that Israel's emissions are on par with those of many of the developed countries listed in Annex I, particularly those in Europe (Figure 7).

In 2001, the government of Israel established an inter-ministerial committee on climate change and resolved to undertake voluntary activities to restrict or reduce emissions of GHGs according to targets to be set by the committee. The committee is currently drafting those targets, taking into account economic development needs, economic feasibility, population growth and impacts on Israel's international status. The proposed plans for reducing GHG emissions include technological measures as well as regulatory and economic mechanisms. Israel's climate change activities also include preparing national inventories on anthropogenic emissions and removals of greenhouse gases, ratification of the Kyoto Protocol in March 2004, and establishment of a Designated National Authority for the Clean Development Mechanism. Under the protocol currently being developed in Copenhagen to replace the Kyoto Protocol in 2012, Israel will be required to reduce its GHG emissions.

Unfortunately, in contrast to many developed countries whose greenhouse gas emissions are decreasing, Israel's emissions are predicted to continue to increase under a "business as usual" scenario. Clearly, the challenge lies in stabilizing emissions and reversing the trend. The waste management and energy sectors are considered to be major candidates for emissions reductions. This is because the waste management sector, while recording significant improvements over the last decade, remains the main contributor of methane emissions, and has great potential for emissions reduction. Similarly, since the largest anthropogenic source of GHG emissions is oxidation of carbon when fossil fuels are burned to produce energy, changes and improvements in the electricity production system and use of renewable energy have significant potential to reduce GHG emissions. Pyrolysis of biomass waste and application of the biochar co-product to the soil can play a productive role in both emissions reductions and production of energy from renewable resources.

3. AVAILABLE WASTE BIOMASS

To evaluate the potential for energy production and reductions in GHG emissions in Israel via the pyrolysis of waste biomass, we analyzed the quantities of agricultural, municipal and forestry wastes produced on an annual basis. Agricultural and forestry wastes in tonnes dry weight for 2008 are broken down by type in Table 1. Dry weight quantities of municipal wastes and sewage sludge from 2008 are also tabulated in Table 1. There it can be seen that Israel generated close to 3.9 million tonnes of agricultural and domestic wastes in the year 2008. Of these wastes, nearly 48% was urban yard waste, 22% from livestock (including cows, sheep and poultry), 12.4% from municipal solid wastes, and almost 11% from total crop production. Forestry wastes make up only 3.4% of dry waste biomass.

Table 1 Agricultural, municipal and forestry wastes for the year 2008.

Waste	Total tonnes dry matter	Tonnes of readily accessible dry matter*
Orchard wastes	227,881	49,364
Greenhouse wastes	17,159	11,439
Open pasture wastes	164,313	36,502
Animal wastes	861,212	643,791
Sewage sludge	120,153	18,205
Municipal wastes	480,423	47,314
Forestry wastes	133,531	
Roadside wastes	8,225	65,155
Yard waste	1,851,327	800,705
Greenhouse plastic wastes	10,150	10,150
Total wastes	3,874,374	1,682,624

*These values represent the amounts of the different materials that are readily accessible today for use in composting, according to [25].

4. CALCULATIONS

In order to calculate fossil fuel savings and carbon sequestration potential, it is necessary to estimate the amounts of pyrolysis co-products (syngas, bio-oil, biochar) that can be obtained from the different wastes. For the lignocellulosic wastes, this was

estimated using published data of pyrolysis co-product yields for a variety of lignocellulosic feedstocks over a range of temperatures [6] (Figure 8). From the data, plots of feedstock lignin content versus co-product yield at a given representative temperature (477°C) were constructed (Figure 9) and used to compute regression equations giving the relationship between lignin content and co-product yield.

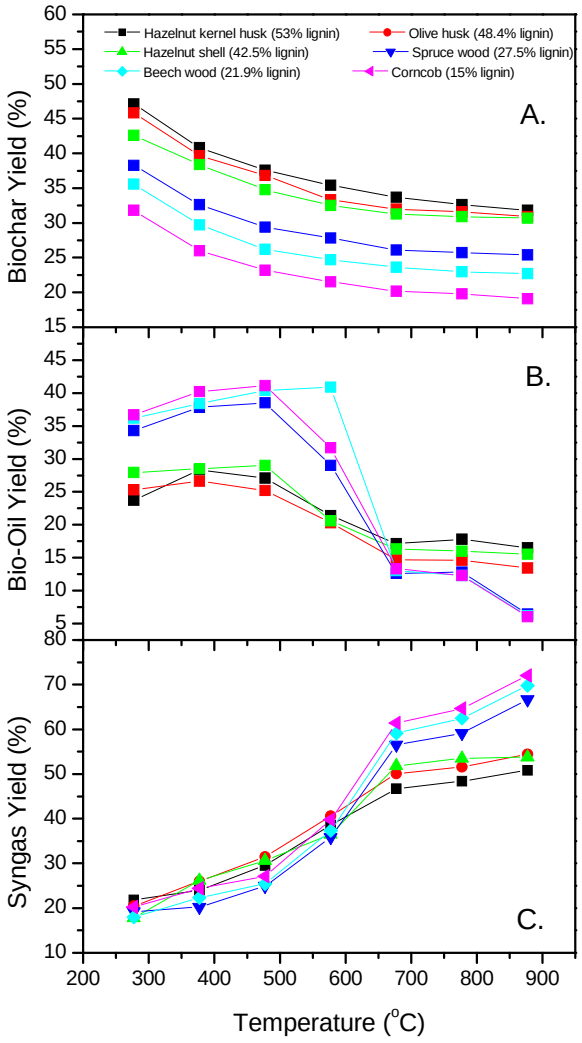

Figure 8 Pyrolysis co-product yields for different feedstock as a function of pyrolysis temperature. Data from [6].

Lignin contents for the different lignocellulosic feedstocks common in Israel were obtained from the literature, and then co-product yield for the feedstocks was computed using the regressions shown in Figure 9 (Table 2). For animal wastes, sewage sludge and municipal solid wastes, data for pyrolysis co-product production at 500°C was obtained from [23], and for plastic wastes under the same conditions from [24].

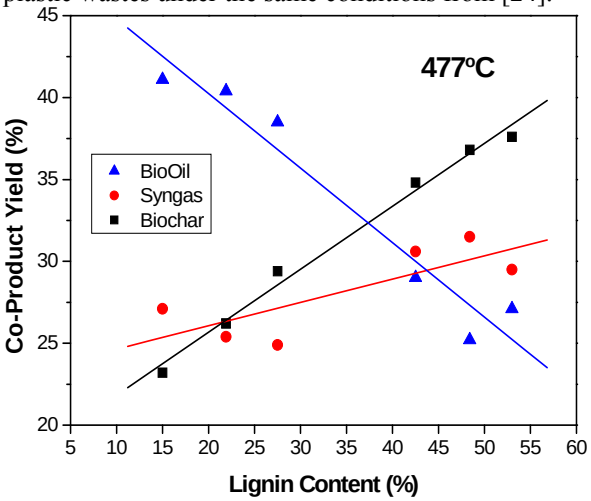

Figure 9 Co-product yield versus feedstock lignin content at 477°C. Data from [6].

Table 2 Co-product relative production (%) as function of the waste feedstock, using data as discussed in text.

Waste	Lignin Content (%)	Biochar (%)	Bio-oil (%)	Syngas (%)
Orchard wastes	19	25	41	26
Greenhouse wastes	14	23	43	25
Open pasture wastes	14	23	43	25
Animal wastes	…	60	35	7
Sewage sludge	…	60	35	7
Municipal wastes	…	60	35	7
Forestry wastes	30	30	36	27
Roadside wastes	28	29	37	27
Yard waste	15	24	43	25
Greenhouse plastic wastes	0	0	65	32

Ash makes up the remainder to 100%.

5. DISCUSSION

The estimated relative amounts of bio-oil, syngas and biochar that can be generated from the wastes during slow pyrolysis at a temperature of about 500°C are

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shown in Table 2. By multiplying the data in Table 1 with that in Table 2, we generated estimates for the total potential production of the different pyrolysis co-products from the various available feedstocks in a given representative year (2008). This is given in Table 3. Total potential biochar production is 1.46 million tonnes, bio-oil 1.53 million tonnes, and syngas, 0.72 million tonnes. Also shown are the amounts that could be produced from those materials which are readily accessible today for use in composting, according to [25]. The "readily accessible" amounts are 45%, 43%, and 41% of the total potential amounts, for biochar, bio-oil and syngas, respectively.

If we consider that the energetic value of bio-oil is approximately 40% that of fossil fuel oil [19], we calculate that the 1.46 million tonnes of bio-oil can replace 610,000 tonnes of fossil fuel oil. This amount represents approximately 7.3% of the annual fossil fuel oil use in Israel, which stood at 8,315,000 tonnes in 2006. In the current calculation, we assume that the co-produced syngas goes entirely to support the thermal conversion process, which includes drying, grinding and pyrolyzing the feedstock. Since much drying occurs naturally during in Israel's semi-arid to arid climate, it can be anticipated that generated syngas will be in excess of that needed to support the process. As a result, fossil fuel savings may be higher.

The replaced fossil fuel oil would offset 524,000 tonnes of C each year, following the conversion factor given in [19]. In addition, application of the generated 1.46 million tonnes of biochar to the soil would sequester 919,000 tonnes of C (assuming an average C content of 63%, [19]). Together, carbon savings would reach 1.44 million tonnes C annually. Given that in 2006, Israel's C emissions stood at 19.3 million tonnes, we calculate that a total of 7.5% annual reduction in carbon emissions can be achieved. According to data presented in [26], approximately another 0.5% C reduction can be anticipated as a result of avoided emissions from composting and other land applications of the wastes, and reductions in N_2O emissions. If we consider only those wastes which are currently easily and readily accessible for use in composting, the fossil fuel use savings would be 3.2% annually and C-savings 3.3% annually.

Pyrolysis of wastes and soil application of the biochar product have far greater GHG sequestration potential and energy production potential than alternative uses for the wastes like composting [26]. For Israel, where about 50% of available wastes are yard wastes which are mainly composted, this may be an important consideration.

Table 3 Estimated production potential of the different co-products from all feedstocks, and from the readily available feedstocks.

Waste	Biochar (tonne)	Bio-oil (tonne)	Syngas (tonne)	Biochar (tonne) readily accessible	Bio-oil (tonne) readily accessible	Syngas (tonne) readily accessible
Orchard wastes	57,205	93,250	58,929	12,392	20,200	12,765
Greenhouse wastes	4,010	7,374	4,327	2,673	4,916	2,885
Open pasture wastes	38,397	70,610	41,435	8,530	15,686	9,205
Animal wastes	516,727	301,424	60,285	386,274	225,327	45,065
Sewage sludge	72,092	42,054	8,411	10,923	6,372	1,274
Municipal wastes	288,254	168,148	33,630	28,389	16,560	3,312
Forestry wastes	39,418	47,665	36,713	0	0	0
Roadside wastes	2,365	3,011	2,238	18,733	23,850	17,728
Yard waste	439,736	787,147	469,487	190,187	340,444	203,055
Greenhouse plastic wastes	0	6,598	3,248	0	6,598	3,248
Total production	1,458,204	1,527,280	718,702	658,101	659,952	298,537

Other advantages to pyrolysis compared with composting include pathogen destruction, reduction in odor nuisances, and longer term influence on soil properties. However, finding markets for bio-oil remains a major challenge because as an acidic emulsion with ~20% water, options for its use are limited [7]. Bio-oil can be burned directly in some (modified) industrial boilers to produce heat/steam. However, research is needed to find efficient ways of producing liquid transportation fuels from bio-oil.

The use of biochar in agricultural soils presents an opportunity to increase agricultural production efficiency, but a better understanding of physical/-chemical features that affect the agronomic benefits of biochar is required. To date, it has not been possible to translate the reported benefits of biochar use such as increased productivity, reduced water and fertilizer needs, and improved soil health, to "recommend-ations" to farmers. Lehmann [9] discussed impediments to the adoption of biochar use in agriculture, first and foremost among them being the great variability in biochar characteristics as a function of feedstock and production conditions (such as temperature). Biochar produced at temperatures below 400^{o}C may have a lower cation exchange capacity and surface area than biochar produced between 400-550^{o}C, which potentially may affect its suitability as a soil conditioner. Likewise, production conditions can have a dramatic effect on the stability of the char in the environment, affecting its utility as a long term carbon sink. The aging of biochar in soil tends to increase its CEC, but the factors involved in the development of CEC during aging are not well-defined. Understanding and optimizing these features requires an organized research effort.

Additional aspects of biochar use in soil that need to be considered include the possible occurrence of phytotoxic compounds or leachable metals in the biochar [27]. Levels of metal contaminants present in some feedstocks may limit the safe level of biochar application. For the most part, there is little information on contaminants present in different biochars, and more importantly, on their availability to plants and their potential for leaching to the environment. On the other hand, it should be borne in mind that carbon-based materials make excellent sorbents for many organic and inorganic pollutants, and the presence of biochar in a soil may help reduce pollutant leaching out of the soil zone.

A further challenge to the use of biochar in soil is the means of application [27], which will depend largely on the biochar physical properties and intended function. Tilling biochar into the soil can disturb soil structure and increase carbon turnover rates, as well as lead to dust and erosion problems. On the other hand, broadcasting the char on the soil surface may lead to runoff and erosion of the char, obviating its carbon sequestration potential.

For a country as small as Israel, one of the major limiting factors for the "Carbon Vision" may be the small agricultural land area. It is easy to calculate that at a typical application rate of 20 tonnes/ha, all the arable land would have been amended with char one time over the course of 13 years if 660,000 tonnes of biochar per year were produced according to the "readily available" scenario. Thus, sinks other than agricultural lands would be required for the biochar. These could include forests and urban gardens. On the positive side, the distributed nature of Israeli farming communities and municipalities makes the development of local pyrolysis solutions attractive, whereby wastes can be handled and pyrolysis products dispersed close to the site of generation. The potential water savings that could accrue from the improved water holding capacity of biochar-amended soils [13], is an additional attractive feature for this water-scarce region, as are improved soil tilth and soil fertility for the area's poor soils.

6. CONCLUSIONS

These general calculations demonstrate that pyrolysis of organic wastes for the generation of energy products to replace fossil fuels and biochar as a soil conditioner may play an important role in Israel's goals to reduce reliance on non-renewable fossil fuels and to reduce carbon emissions. It should be noted that the savings estimates are based on the use of slow pyrolysis, and that other techniques such as fast pyrolysis or gasification would yield different proportions of the co-products, changing the estimates accordingly. However, the results of the calculations are sufficiently promising to encourage follow-up economic analyses and detailed life cycle analysis for specific scenarios, including pyrolysis alternatives. This work is underway. In addition, the agricultural benefits of biochar for Israel's intensive agriculture need to be demonstrated through focused research activities, which are now in progress. Research needs include evaluating how the technology platform and quality of the biomass feedstock impact the response of soil-crop systems to biochar applications.

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