

Potential for Biomass and Biofuel through Sustainable Intensification of Agriculture and Reduction of Food Losses and Waste

Jeffrey Skeer¹, Shunichi Nakada²

¹IRENA Innovation and Technology Centre, Bonn, Germany

²Japan International Research Center for Agricultural Science, Tokyo, Japan

Email: jskeer@irena.org, snakada@affrc.go.jp

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Abstract

Substantial potential exists to expand supplies of biomass for energy applications through more systematic collection of agricultural residues, more intensive cultivation of croplands, and reduced waste and losses in the food chain. This study aims to show how the potential can be calculated from public information sources, to put the potential in the context of global needs for liquid transport fuels, and to suggest some practical policy options for bringing part of the potential to market. It finds that if the theoretical potential is fully realized, enough liquid biofuel could be produced to displace the equivalent of all current global liquid fuel use for transport.

Keywords

Biomass, Biofuel, Sustainable, Yields, Food

1. Introduction

Substantial potential exists to expand both food and fuel supply in a sustainable fashion. While food and fuel production have often been seen as being in conflict, and while expanded biofuel production has been seen as leading to land use change that reduces global sequestration of carbon, there are actually several ways to boost food and fuel production simultaneously without using additional land. This study explores how much bioenergy could be produced in these ways, including through more systematic collection of agricultural residues, more intensive cultivation of croplands (with higher yields), and reduced waste and losses in the food chain.

As food production expands to meet the nutritional needs of growing populations, there is also increased production of agricultural residues. If sustainable shares of these residues were fully collected while allowing for

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residues that are fed to animals for meat and dairy production, substantial amounts would be left over. These could provide fuel for combined heat and power plants, process heat for first-generation biofuel production, or lignocellulosic feedstock for second-generation biofuel processes.

Accelerating yield growth through modern agricultural practices, it should also be possible to grow the same amount of food on less land. The freed up land could be planted with a mix of rapidly growing trees (short rotation coppice) for combined heat and power or second-generation biofuel, high-yielding conventional biofuel crops such as sugar cane, and grasses for lignocellulosic conversion.

Farmland needed for food production could be further reduced by managing the food chain more efficiently and by modifying food consumption habits. Globally, over a third of all food is lost or wasted. If food losses and waste could be reduced or eliminated, obviating the need to grow this food, substantial further amounts of land could be made available for bioenergy and biofuel production.

2. Potential for Bioenergy from Sustainable Collection of Agricultural Residues

For every ton of crop produced, an amount of residues is available in the field after harvest, of which a fraction can be practically and sustainably collected, typically assumed to be between a quarter and a half¹ to ensure that enough is left to regenerate the soil [1]-[4]. In addition, a share of residues is attached to crops when they enter processing plants, most of which can also be collected.

Multiplying the tons of each crop in each country [5] by tons of harvest and processing residue per ton of crop [6], some 161 EJ of agricultural residue was generated worldwide in 2010. Taking 25% to 50% of harvest residue and 90% of processing residue, 55 to 90 EJ could have been used. With projected growth in food supply [7], assuming that the mix of crops is constant, available agricultural residue could reach 79 to 128 EJ by 2050².

However, much of this residue would likely be used for animal feed. Dividing the supply of meat between traditional grazing systems and higher-yield “mixed” systems in each country, and multiplying by the amount of residue used to produce each ton of meat, 19 EJ of residue is seen to have been used for feed in 2010. With projected growth in meat consumption [7], 33 EJ of residue could go to feed by 2050, leaving 46 to 95 EJ to use for biofuel³. At a 40% conversion efficiency in a lignocellulosic process, this residue would yield 18 to 38 EJ of biofuel. That is up to a third of all the liquid fuel that was used for transport in 2012, or nearly twice the amount of fuel used for marine shipping and aviation [8]⁴.

3. Potential for Bioenergy through Sustainable Intensification of Agriculture

Growth in yields per hectare is responsible for some 80% of the increase in food production and residue potential implicit in FAO projections. Another 10% is due to planting multiple crops on the same land each year; only 10% of projected increased food production comes from expanding arable land [7]. But yields could grow faster if greater efforts were made to expand extension services that let farmers in countries with lower crop yields adopt the practices that produce higher yields elsewhere. With higher yields per hectare, less land would be needed for food and more could be used for biofuel feedstock.

FAO projects that global average major crop yield (excluding fruits and vegetables) will rise from 4.2 t/ha in 2010 to 5.1 t/ha in 2050. But applying the regression trend in yield growth by crop from 1961 through 2013, the average could reach 6.6 t/ha in 2050 [5]. While 1079 M·ha would have to be planted in 2050 to meet world food needs at projected yields, just 839 M·ha would be needed at the higher yields, freeing 240 M·ha for biofuel crops.

Going further, FAO has assessed the gap between current and potential crop yields, assuming the current mix

¹Reference [1] reports 75 kg/ha of nitrogen fertilizer allows at least 25% of residues to be sustainably collected on half of Australian croplands, reaching 50% of residues in southeast Australia and 75% in southwest Australia. Reference [2] reports that removing 50% or 90% of residue with no-till planting reduces soil carbon and nitrogen by only 6% to 7%. Reference [3] suggests 2.25 t/ha of residue can be removed for each crop under 2011 land management practices or 25% of 9.17 t/ha in total residue (weighting residue t/ha for each crop in table 5 by crop shares in table 7); table 6 shows no-till practices raise sustainable collection by 43%, *i.e.* to 35%, by 2030. Reference [4] asserts that 50% of residue can be sustainably collected.

²Projected yearly growth in food supply is globally 1.3% through 2030 (ranging from 0.8% in developed countries to 2.4% in Sub-Saharan Africa) and 0.7% from 2030 through 2050 (ranging from 0.3% to 1.9%).

³Projected annual growth in meat consumption is globally 1.4% through 2030 (from 0.6% in developed countries to 2.7% in Sub-Saharan Africa) and 0.9% from 2030 to 2050 (from 0.2% to 2.6%).

⁴Data in [8] for 2012 indicate 2.17 EJ for domestic navigation, 7.91 EJ for marine bunkers, 4.12 EJ for domestic aviation, and 6.75 EJ for aviation bunkers, or a total of 21.95 EJ for marine and aviation use.

of irrigated and “rain-fed” land. Globally, the average gap is 62.1 t/ha for sugars, 3.9 t/ha for cereals, 12.7 t/ha for root crops, and 0.6 t/ha for oil crops [5]. **Figure 1** illustrates the gap for maize, a leading cereal crop for biofuel production, in countries where it is grown; note that actual yield is less than 25% of potential yield for this crop in most of Africa and India and less than 40% in most of Latin America and Former Soviet Union.

For each country, taking the land to meet food demand with current yields for each crop type and dividing by the ratio of actual to potential yield, we calculated the land that would be required to meet food needs if the yield gap were closed. To close the gap would entail raising average global crop yield to 10.4 t/ha in 2050 so that only 527 M·ha would be needed for food, rather than the 1079 M·ha projected by FAO, leaving 552 M·ha for biofuel crops. If this land were planted with perennial grasses yielding 150 GJ/ha, it could produce 83 EJ of biomass. Converted at 40% efficiency, this would yield 33 EJ of biofuel, nearly a third of current transport fuel use.

4. Potential for Bioenergy on Land Freed by Reducing Food Chain Waste and Losses

Large amounts of food are lost in production and distribution, or wasted at the point of consumption. The FAO has found that one-third of food produced for human consumption is lost or wasted globally, amounting to 1.3 billion tons per year. Production and distribution losses have similar proportions in developed and developing countries, amounting to 31% - 33% in Europe and North America (280 - 300 kg out of 900 kg of food produced per capita per year) and 26% - 37% in sub-Saharan Africa and South/Southeast Asia (120 - 170 kg out of 460 kg of food produced per capita per year). But consumer food waste is much higher in developed countries (11% - 13%) than developing ones (1% - 2%) [9].

For each major region and food group, FAO data show percentage losses in agricultural production, post-harvest handling and storage, processing and packaging, retail distribution, and consumption [10]. From these, we calculated the total percentage and tonnage lost or wasted for each food group. **Table 1** and **Table 2** illustrate these for Europe and Sub-Saharan Africa, which are broadly representative of the pattern in developed and developing countries.

For crops directly consumed, we divided the tons lost or wasted by the average yield in tons per ha to calculate the number of ha that could be liberated by eliminating the losses and waste. For meat and dairy products, we first calculated the amounts of different kinds of feed to produce each, then the area used to produce the feed, and finally (multiplying this area by share of product lost) the land spared.

By this calculus, 442 M·ha of land could be freed up in 2050 by eliminating losses and waste for crops directly consumed as food, and another 340 M·ha could be freed up by eliminating losses and waste of meat and dairy products. With 782 M·ha liberated in all, biofuel crops yielding 150 MJ/ha would provide 117 EJ of biomass, converting at 40% efficiency to 47 EJ of advanced biofuel. If the yield gap were closed, land freed by eliminating waste and losses would decline to 619 M·ha, biomass potential to 93 EJ and biofuel potential to 37 EJ, still enough to displace a third of current liquid fuel use in transport. **Table 3** shows the overall land that could theoretically be freed in this case by eliminating losses and waste at each stage, for each region and globally.

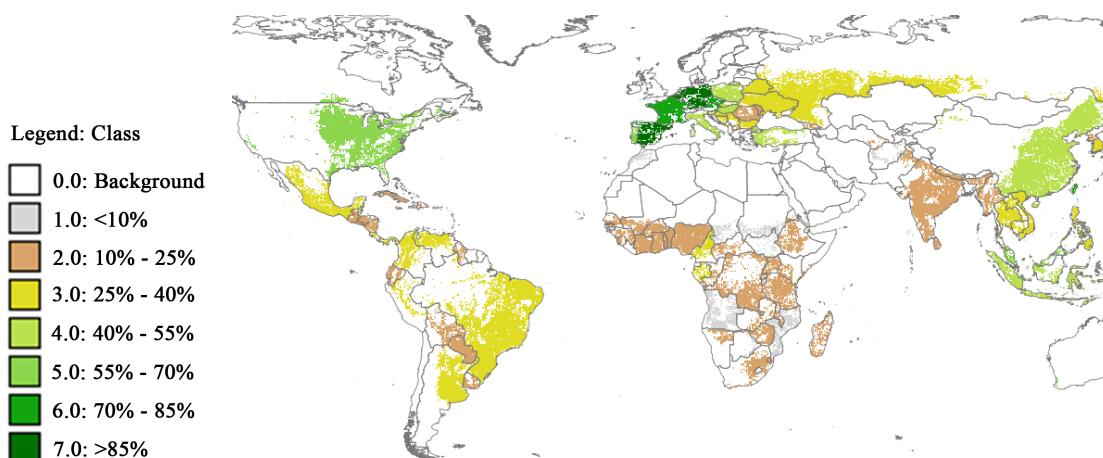


Figure 1. Ratio of actual to potential yield for Maize (Year 2000) [9].

Table 1. Shares of food production lost at different stages of the food chain in 2007 in Europe [10].

Food Group	Total Loss All Combined	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Cereals	39%	2%	4%	10%	2%	21%
Roots & Tubers	65%	25%	9%	14%	5%	12%
Oilseeds, Pulses	22%	11%	1%	5%	1%	4%
Fruit & Vegetables	57%	25%	5%	2%	9%	16%
Meat	23%	3%	1%	5%	4%	10%
Fish & Seafood	35%	10%	1%	6%	8%	9%
Milk	13%	4%	1%	1%	0%	7%

Table 2. Shares of food production lost at different stages of the food chain in 2007 in Sub-Saharan Africa [10].

Food Group	Total Loss All Stages Combined	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Cereals	20%	6%	8%	3%	2%	1%
Roots & Tubers	51%	16%	18%	12%	3%	1%
Oilseeds & Pulses	32%	14%	8%	7%	2%	1%
Fruit & Vegetables	57%	11%	9%	23%	12%	3%
Meat	32%	18%	1%	5%	7%	2%
Fish & Seafood	35%	6%	6%	8%	13%	1%
Milk	26%	6%	11%	0%	9%	0%

Table 3. Land freed by eliminating losses at different stages of the food chain by region (Million hectares).

Region	All Stages Combined	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Europe	84	14	5	18	10	37
Africa	81	32	12	18	14	6
Asia	247	53	37	55	46	57
OECD Pacific	24	4	1	6	4	10
North America	74	14	3	16	8	33
South America	108	29	9	26	20	23
World	619	146	68	140	102	165

5. Energy Security Implications and Possible Policy Options

The analysis indicates a potential for up to 270 EJ of primary biomass from residues (95 EJ), land freed by closing the yield gap (82 EJ), and land freed by eliminating waste and losses in the food chain (93 EJ). This could provide up to 216 EJ of useable bioenergy in a first generation biofuel conversion process or a conventional process for heat and electricity generation, or up to 108 EJ of useable bioenergy in a second-generation conversion process to produce drop-in diesel fuel for jets, ships and trucks—roughly equivalent to the total amount of current liquid fuel use for transport worldwide in 2012. In view of the large potential, it is useful to consider what portion might practically be realized and what policies and measures would hold the most promise for developing the potential and bringing it to market.

Several courses of action could help to raise agricultural yields, which is key to raising supplies of residues

and to freeing land for bioenergy crops. Capacity building and extension services could be expanded to spread modern farming techniques in developing countries. Best practices on logistical approaches for cost-effective harvesting of farm and forest residues could be compiled and disseminated. Agroforestry strategies for investing in cultivation of a mix of high-yielding food and fuel crops could be developed from successful experiences with stakeholders in different developing regions. Secure land tenure and effective land governance, in countries that do not have them, are essential to providing the financial incentives for long-term investment in intensive, sustainable land management.

A variety of policies and measures could also help to reduce food losses and waste. In developing countries, improved harvesting techniques, storage and cooling facilities and better packaging can reduce food spoilage, while expanded transportation infrastructure can bring more food to market while it remains fresh and saleable. Extension services and capacity building could help improve harvesting techniques, local health regulations could require better packaging, and development assistance could help build better infrastructure. In developed countries, waste can be reduced by differentiating prices to encourage sale of food items that are not perfect in shape or appearance, modifying labels so that “best-before” dates do not encourage consumers to discard food prematurely, and raising awareness of possible uses for safe food that is thrown away. Regulations to allow the sale of lower quality food items that meet health guidelines, engagement by food distributors and retailers to make food labels more informative and advertising to change consumers’ attitudes can all play helpful roles [10].

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