GLOBAL ENERGY POTENTIAL OF AGRICULTURAL BIOMASS

SUMMARY

Consistent emissions of greenhouse gasses from the combustion of fossil fuels has led to long term effects threatening the health of our environment. As we turn to alternative sources of energy, biomass will become an increasingly important resource to draw from. Within the energy currently being produced from biomass, forestry is by far the largest contributor, generating approximately 87% of the bioenergy supply in 2012. [23] In addition to forestry, municipal waste and agriculture are potential sources of biomass. Due to the size of the agricultural industry worldwide and the diversity of its products, agricultural biomass is one of the greatest sources of renewable energy available today, and currently it is severely underutilized. There exists a variety of technologies available for converting agrobiomass into energy, including pyrolysis, combustion, anaerobic digestion, and ethanol production. This report analyzes the energy potential from biomass residues from sugar producing crops, cereals, oilseeds, cotton, tobacco, coffee, and cocoa. The product to residue ratio is used to estimate the amount of biomass available to be converted to energy. Yearly production data from the United States, India, China, Brazil, Russia, Europe (EU-27), Mexico, Japan, Turkey, Nigeria, and Côte d'Ivoire are included for an estimation of global energy output from agrobiomass.

INTRODUCTION

Climate change poses one of the greatest challenges to long-term human prosperity, and action in the near future will be required to mitigate its effect. It is widely acknowledged that human activities have exacerbated the climate effects of greenhouse gases in our atmosphere, particularly through our reliance on fossil fuels. Combustion of coal, oil, and natural gas releases carbon dioxide, along with other harmful emissions like sulfur oxides and nitrogen oxides, which when emitted into the atmosphere in quantity contribute to higher global average temperatures, ocean acidification, and other environmental effects that contribute to climate change. In addition to the direct harm fossil fuels do to climate, they are a finite resource, existing in limited deposits within the earth, and would be eventually depleted. Therefore a transition to renewable energy is necessary.

In projections that forecast various pathways for humanity's transition to renewable energy, green energy sources such as wind and solar do not have the capacity to provide for global demand, or at least would require a period of time before the infrastructure is in place to produce energy on a large scale. Bioenergy provides a promising alternative that will decrease our reliance on fossil fuels and supplement our energy supply during the transition to renewables. According to the IEA's projection for net zero carbon emissions by the year 2050, biomass would account for approximately 100 exajoules of energy production, just under 20% of the estimated 550 exajoules of global energy consumption. [24] The 1.5°C scenario as outline by IRENA places even more importance on bioenergy, as it estimates energy production from biomass would have to increase threefold to 150 exajoules. [25]

The methods for utilizing agrobiomass as a fuel source discussed in this report do not involve allocating land for so-called "energy crops," wherein resources would be diverted away from food crops. Rather, agrobiomass for bioenergy can be harvested in tandem with food crops, thus not impacting food supply. Currently, much agricultural waste is used inefficiently, either left in the fields or used as animal feed. While some agricultural matter left in the fields is good to protect soil quality, only a portion is needed to gain this effect. The IEA's plan for net zero emissions by 2050 necessitates the reduction of traditional uses of biomass in favor of more efficient modern methods. Excess amounts of scattered agricultural waste can additionally pose a fire risk, and also contribute to the spread of rot. Agricultural waste is often disposed off by stubble burning, which contributes to emissions of greenhouse gasses while not harnessing the energy within the waste.

This report analyzes the crop outputs of major agricultural nations around the world; the United States, India, China, Brazil, Russia, Europe (EU-27), Mexico, Japan, Turkey, Nigeria, and Côte d'Ivoire; with a focus on crops with the best known potential and technology to produce bioenergy in order to estimate current potential global energy output of agrobiomass.

TYPES OF BIOFUEL AGROBIOMASS

Generally, biofuels can be characterized as solid, liquid, or gaseous. Solid biofuels are combusted heat, typically used in the form of wood pellets or solid plant residues. Liquid biofuels include ethanol, biodiesel, and other plant oils that can be used as fuel. Gaseous biofuels are produced through controlled decomposition to create methane. The crops that are ideal for harvesting agricultural biomass are those that are produced on a wide scale with a sufficient amount of residues, for which there are a variety of conversion processes to produce bioenergy.

Sugars

Sugar cane and sugar beets can both be used to produce ethanol, as well as a combustive fuel source.
The byproducts of sugar cane harvesting include the tops and leaves left in the field, as well as bagasse from sugar cane milling. Bagasse is a fibrous residue that is able to be burned as well as processed into ethanol. The tops and leaves of sugar beets and sugar cane can either be burned directly or decomposed via anaerobic digestion to produce gaseous biofuels. Sweet sorghum stems can also be either used in ethanol production or burned directly.

Figure 1: Farmers in Punjab, India, burning rice residues in order to clear space for the upcoming wheat season. *International Center for Tropical Agriculture*. Neil Palmer. 2011.

Cereals

Cereals are often staple crops and can therefore be found in abundance around the world, including rice, wheat, corn/maize, rye, and barley. Straw from all of these cereals contains cellulose and hemicellulose which can be processed into ethanol, or can alternatively be dried and burned to produce heat. The cobs and stalks from corn, called corn stover, can be more efficiently converted to energy if left to dry for a period of time before burning in a furnace to lower the moisture content. [13] Rice also produces husks during the milling process which can be used as fuel. Millet husks come from seed-bearing grasses that exist in a variety of species, including pearl millet, foxtail millet, finger millet, etc. The husks are removed through winnowing, and can then be collected and used as a solid biofuel.

Oilseeds

Oilseeds include soybeans, peanuts, palm trees, and canola seeds. This text will focus on soybeans and canola seeds. The stalks from canola and soybean plants also are high in hemicellulose, making them prime candidates for pyrolytic processing into ethanol.

Cotton

Cotton stalks may be harvested for use as a low quality wood, or alternatively chipped and processed into pellets which can then be combusted. As in corn stover, drying the wood results in a better energy content. Cotton production yields high amounts of waste, including the leaves, stalks, and seeds. As cotton makes up around 40% of global fiber production, it is a viable source of agrobiomass.

Tobacco

Excess plant matter left in the field after tobacco harvesting, including leaves and stems, can be collected, dried, and burned directly, or else digested to create gaseous biofuel.

Coffee and Cocoa

Coffee and cocoa husks are both separated from the beans during roasting or winnowing, respectively, and can be used as a solid biofuel to generate heat. Cocoa harvesting also involves harvesting pods which are then split to extract the beans, which also provide a source of solid biofuel. In the process to make pellets, raw material is dried, crushed, and milled.

TABLE 1: ANNUAL CROP PRODUCTION

	Sugar Cane	Sugar Beet	Sorghum	Rice	Wheat	Corn	Millet	Rye	Barley	Cotton	Tobacco	Canola	Soybean	Coffee	Cacao
US	3.6	2.7	8.46	11.56	44.79	383.94		0.3		3.81	0.18	0.0	114.7		
India	389		3.48	116.48	103.6	32.5	11.5		1.67	5.77	0.75	10.8	11.9	0.31	
China	8.7	0.9	3	21.21	131.44	257.17	2.81		2	6.1	2.24	13.28	0.02	0.12	
Brazil	576		3.04		7.7	116				2.36			126.0	4.19	0.21
Russia		47.1			75.16	15.23	0.36	1.72	17.51			2.57	4.31		
EU 27	235	16	1.01	1.84	138.42	70.5		7.96	51.97			17.15	2.74		
Japan	54.62		4.7	0.31	3.28	27.6				0.26				0.21	
Mexico				7.64	1.1	0.01			0.23			0.0	0.24		
Turkey		19.5		0.54	17.7	6.5		0.2	4.5	0.83	0.07	0.14	0.18		
Nigeria	0.07		6.8	0.09	7.94	11.6	1.92			0.08			1.12		0.27
Côte d'Ivoire				1.2			0.07			0.24				0.09	2.2
Annual Total	1266.99	86.2	30.49	160.87	531.13	921.05	16.66	10.18	77.89	19.45	3.24	43.95	261.21	4.93	2.68
Global Total	1889.3	278.5	62.3	513.6	779.	1217.9	29.5	12.5	147.2	26.4	5.9	72.1	352.7	10.6	5.2
Percentage (%)	67.1	31	48.9	31.3	68.2	75.6	56.5	81.4	52.9	73.7	55.1	61	74.1	46.5	51.5

[4][5][6][7][8][26][27][28][30][31][32][33][34][35][36][37][38]
note: blank cells in the table indicate no data was available or production was negligible

GLOBAL AGROBIOMASS ESTIMATION

The crop totals displayed in Table 1 were calculated based off of national reports and data by the USDA between 2018 and 2021. These numbers are compared with the global yearly production values to demonstrate the limited scope of this report. The percentage of agricultural mass that is accounted for in these calculations varies from 31-81%. In the final energy output calculation, it should be noted that only these portions of available agricultural matter was included.

Table 2 calculates annual bioenergy output based on the crop totals on Table 1. The ratio product- residue (RPR) reflects how much waste matter is produced for each unit of a particular crop. Lower and upper bounds have been selected for each crop based on data from 16 countries. [3] Estimated available biomass is calculated by multiplying the total yearly production with the RPR. In order to account for losses by inefficient collection and matter allocated for compost and animal feed, the available biomass is decreased by a factor of 0.5. For simplicity, only a lower estimation for the low heating value (LHV) of each crop is included, from which the total energy output can be extrapolated.

Based on the crop production data from these countries, the lower estimation for yearly energy production comes to just under 12,000 petajoules of energy. The upper estimation is approximately 38,000 petajoules per year.

As more resources are invested into converting agrobiomass into energy, the global capacity of agrobiomass will expand. Both the greatest challenge and greatest advantage of using agricultural waste as a fuel is that the sources are widespread and diverse. These techniques have the potential to provide power to remote rural areas, improving the quality of life for millions of agricultural workers, their families, and their communities.

TABLE 2: ANNUAL ENERGY FROM CROP WASTE									
	Annual Total (MMT)	Agricultural Waste	RPR low	RPR high	Biomass low (million MT)	Biomass high (million MT)	LHV (Mj/kg)	Energy per Year Low (PJ)	Energy per Year High (PJ)
Sugar Cane	1266.99	tops & leaves	0.1	0.3	63.3	190	15.8	1000.9	3002.8
		bagasse	0.1	0.3	63.3	190	8.6	544.8	1634.4
Sugar Beet	86.2	leaves	0.12	0.14	1.8	6	15.5	28.4	93.5
Sorghum	30.49	stalks	1.40	2.62	21.3	39.9	13	277.5	519.2
Rice	160.87	straws	0.45	1.75	36.2	140.8	8.8	318.5	1238.7
		husks	0.2	0.27	16.1	21.7	12.9	207.5	280.1
Wheat	531.13	straw	0.5	1.75	132.8	464.7	13.9	1845.7	6459.9
Corn	921.05	stover	0.7	2.5	322.4	1151.3	13.8	4448.6	15888
Millet	16.66	straw	1.4	3	11.7	25	12.5	145.8	312.4
Rye	10.18	straw	0.99	0.99	5	5	17.4	87.7	87.7
Barley	77.89	straw	1.08	1.36	42.1	53.	17.5	736	926.9
Cotton	19.45	stalks	1.1	3.5	10.7	34.	14.6	156.2	496.9
Tobacco	3.24	stems & leaves	2.27	2.27	3.7	3.7	16.3	59.9	59.9
Canola	43.95	stalks	1.6	1.8	35.2	39.6	17.1	601.2	676.3
Soybean	261.21		0.76	3.5	99.3	457.1	14.9	1479	6811
Coffee	4.93	husks	1.0	1	2.5	2.5	12.6	31.1	31.1
Cocoa	2.68	husks	1.0	2.1	1.3	2.8	15.5	20.8	43.6
							Total Energy per Year	11989.5	38562.4

[3][4][5][6][7][8][9][10][11][12][13][15]
note: biomass = total production × RPR × 0.5
energy per year = biomass × LHV
1,000,000 MT × 1000 kg/MT × Mj/kg = 1,000,000,000 Mj = 1 Pj

CHALLENGES

The current market prevalence of fossil fuels is the greatest hurdle to overcome in order to implement agriculture-based bioenergy on a global scale. Fossil fuels currently benefit from robust existing infrastructure and lower costs. In order for the switch to bioenergy to be financially feasible, collaboration from governments would be necessary, to impose restrictions on the use of fossil fuels and to subsidize biofuels.

The diversity of agricultural biomass sources presents a challenge, as gathering techniques and bioenergy technology for each crop varies widely, and would need to be adapted on a localized basis. Many small farms in remote areas would need to be included in order to gather a sufficient supply of agricultural biomass. The technological and mechanical requirements for many of these processes is not trivial, and in addition to the funds required for the equipment for energy production, teams for management and maintenance of these plants will need to be sourced and trained. Though this will require a substantial investment, these plants can provide job opportunities, and additionally allows for for smaller nations to become less dependent on foreign sources of energy.

The current uses of agricultural waste as compost, animal feed, and in cookstoves also pose a challenge. In the interest of soil quality protection and biodiversity, some waste matter should be left on the fields. However, excess matter left in fields can become a fire hazard, and is additionally at risk of rotting and emitting methane gas and unpleasant smells. Both in low technology cookstoves and as animal feed, the energy potential of agricultural biomass is inefficiently used, and may ultimately lead to more emissions from inefficient combustion or animal waste. It is important to consider these uses when redirecting agrobiomass towards energy production as these uses will need to be compensated by alternative methods.

Figure 3: Sugar cane harvesting in Brazil. *Shutterstock.* Mato Grosso. 2008.

CASE STUDIES

Cofiring in Sugar Mills in India

India is one of the largest growing energy markets in the world, both as a consumer and as a supplier. Though the primary energy sources currently in use in India are coal, oil, and natural gas, India has the resources and potential to generate a large amount of energy from its waste products, particularly in the agricultural sector.

Sugar mills around the world have adopted boilers as an additional fuel processing unit with the ability to utilize biomass as an additional fuel source. Studies done in India found that combining coal with different biomass feedstocks- sugar bagasse, tops and leaves, coconut shell, and wood chips- reduces emissions of sulfur oxides, nitrogen oxides, and suspended particulate matter. Varying ratios of the different materials in combination with coal gives different results with regard to emissions as well as the amount of fuel consumed. This could be adapted on a case-by-case basis for sugar mills depending on the biomass resources available in that area and the needs of the individual mill.

The rapid industrialization of India over the past several decades has caused a heavy reliance on fossil fuels, as the accelerated energy demand required immediate, efficient fuel sources with large capacity, and fossil fuels have market precedence and the most established infrastructure. However, this has led to several adverse effects for India, as it has become one of the largest emitters of greenhouse gasses, as well as one of the most heavily polluted regions of the world. The harmful effects to the environment and human health and well being of this is well documented. As a large agricultural producer, India has ample biomass resources that present a substantial supply of supplementary fuel for cofiring. The issues of climate change and human health will only become more pressing, and biomass cofiring presents a viable option for mitigating these effects and responding to any future environmental legislation that limits emissions. [16]

Sugar Cane Bagasse Cofiring in Brazil

Brazil boasts some of the greatest biomass quantities of the world's nations, particularly as the largest sugar cane producer in the world market. Sugar cane production generates residue in the form of tops and leaves, which are typically left in the field as compost, and bagasse, which is the fibrous residue produced in sugar mills after processing raw canes. In Brazil, bagasse has been directed towards pulp and paper production, second-generation ethanol production, and most of all, cofiring to produce electricity and steam. Cofiring is a method of combustion of a base fuel with a supplementary alternative fuel as a source of energy. By supplementing coal or other fossil fuels with renewables like biofuel, the emissions from the sugar mills can be reduced. Investment in more advanced boilers has made the production of steam from bagasse more efficient and profitable for producers, and the vast majority of bagasse is now used in this process.

Bagasse cofiring to produce power in sugar plants has allowed all of the registered sugar and ethanol plants in the country to become completely self-sufficient, and surplus energy can be added to the national power supply or sold privately. This additional profit helps offset instability in the sugar and ethanol markets.

The Brazilian government's Electric Energy Regulating Agency responded to this new capacity for energy by establishing a system by which energy futures can be bought and sold on the market. The added energy supply from sugar cane bagasse decreases Brazil's reliance on hydroelectric power which becomes inconsistent during drier seasons, and furthermore decreases the country's greenhouse gas emissions by offsetting fossil fuel use. [14]

Coffee Biomass Potential in Columbia

The coffee production process yields a variety of waste products, including husks, pulps, grounds, and stems. This waste can become hazardous in quantity if not disposed of properly, but additionally offers a potential energy source. The husks, pulps, and grounds are most commonly used for compost. Stems, however, have not been researched as thoroughly as a source of bioenergy. Researchers have modeled the use of coffee stems in downdraft gasifiers and shown they could generate enough energy to power each individual coffee farm, with a net output of approximately 0.7 MWh per month. Furthermore, coffee pulp can be processed through anaerobic digestion to produce biogas. As each tonne of coffee harvested yields approximately 0.436 tonnes of pulp, and each tonne of pulp yields approximately 0.10 MWh of energy, this represents a substantial resource for bioenergy. [3]

Columbia is one of the largest producers of coffee in the world, and also has over a million people, just over 2% of its population, living without electricity access. Furthermore, a significant amount of the country's energy supply relies on solar, wind, and hydropower, all of which become destabilized during the El Niño weather event, which heavily affects Columbia. This can cause power outages and leads to Columbia relying on fossil fuels. Columbia has made legislative efforts in the past several years to diversify its energy supply sources. Currently coffee stems are used in cookstoves or burned off as a method of disposal, both of which lead to harmful emissions and do not efficiently utilize the energy potential within the material. Taking advantage of its resources for bioenergy could help supplement the energy supply, particularly in agricultural regions currently without electrical infrastructure. [17][18]

Figure 4: Coffee farm in Columbia. *Flickr.* US Fish and Wildlife Service. 2008.

Potential of Cocoa Pod Husks as Bioenergy

Cocoa, similar to coffee, is a highly profitable industry, where much of the demand is in post-industrial regions like Europe and the United States, while the actual product is largely grown in the global south in nations, with the top largest producers being Côte d'Ivoire, Ghana, Ecuador, and Nigeria, and Cameroon.

Ghana is the world's second largest producer of cocoa. 13% of the population is reliant on cocoa for income, though typically cocoa farmers live in rural areas with little access to electricity. The government of Ghana has a monopoly over the

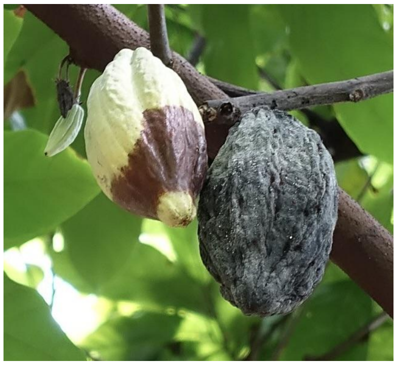

Figure 5: Cocoa pods with black pod rot. *Wikimedia.* Scot Nelson. 2016.

production of cocoa, and therefore is in the position to implement widespread infrastructure for the collection and processing of cocoa residues for bioenergy. Of the material harvested, only a small fraction of it is actually used to produce cocoa; a majority of the weight, about 76%, is unused and left to decompose. These large amounts of accumulated waste can lead to cases of black pod rot disease, which causes a reduction in the cocoa harvest of about 20-30% annually. Research has found that cocoa husks have a high energy content, with lower concentrations of sulfur and nitrogen than coal, and are largely comparable to sawdust when processed into pellets. The volatile matter content of cocoa husks is also fairly high, resulting in a faster ignition potential. Gasification also is a promising technique for processing cocoa pod husks, as the high ash content requires more refined technology for thermochemical conversion in order to avoid blockages. [19][20]

Figure 6: Ghanian farmer with harvested cocoa beans in the Ashanti region of Ghana.*Wikimedia.* King Bangaba. 2018.

Figure 7: (left) China's first biomass cofiring pilot project at Xiangyang coal-fired power station, China Hefei Debo Bioenergy Ltd. Xing Zhang. *IEA.* 2020.
Figure 8: (right, above) Coal-cocoa pod husks pellets made from intermediate particle size and organized by the cocoa content in the blend. Carlos A. Forero-Nuñez. *Ingenieria e Investigación.* 2015
Figure 9: (right, below) Bales of corn stover in the United States. eXtension Farm Energy Community. Dennis Pennington. *Flickr.* 2009.

CONCLUSION

Integration of bioenergy into the energy supply will be an essential component of the transition to renewables in the near future. Agricultural biomass represents a substantial contribution to the feedstock supply, and its current uses are often counterproductive to sustainable environmental practices. Particularly as many regions where agrobiomass is available in quantity are also regions without stable electricity access, it is all the more important that there is a collective effort to implement bioenergy technology. Due to its usefulness in cofiring capacities, agricultural biomass is an important factor in reducing fossil fuel dependence. Furthermore, greater utilization will allow smaller nations to become independent from foreign energy. From the estimations discussed in this report, limited to the crops and countries considered, up to 21,000 petajoules of energy could be produced yearly. This is a conservative estimation, as in addition to the limited scope of the data, this estimation utilizes conservative estimations for the ratio to product residue and the low heating value for each crop. With more efficient gathering techniques and refined processing technology, these numbers can be improved so that more material is available with greater potential for energy output.

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SOURCES

Tables and Figures:
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