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Theoretical Estimation of Bio-Ethanol Potential of Wet Coffee Processing Waste (Pulp Juice and Mucilage)

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Abstract: **This study aimed to quantify the wet coffee processing waste and estimate its bio-ethanol potential in Ethiopia and also evaluate the feasibility of bio-ethanol production from wet coffee processing waste. Green coffee production in Ethiopia is increasing from year to year (from 2007 to 2012) and reached 5.6% of world production. There are about 1026 operational wet coffee processing industries and many industries under construction in Ethiopia. In 2012 the estimated amount of wet coffee processing waste from operational industries in Ethiopia is about 291,600,000 and more waste will add up when the industries under construction become functional. Lingo-cellulosic biomasses with the large amount of glucose convertible material are potential feedstock for bio-ethanol production. Lignocellulosic biomass feeds are a highly available, cheaper alternative to corn for use as feedstock for the production of ethanol. These feeds are reliable and sustainable and provide a source for fuel to meet the needs of society and contribute to energy security in an increasingly environmentally sound manner.**

Keywords: **Bio-Ethanol Potential, Coffee Waste, Wet Coffee Process, Feasibility.**

I. INTRODUCTION

Depletion of fossil fuels, environmental concerns caused by increased emissions and the steep climb in the price of petroleum products have become one of the most serious problems faced by the world today (Senthur, Ravikumar et al. 2010). Meeting the energy demand for a transportation, heating, lighting and industrial process is becoming the greatest challenge for the growing society and has significant impact on the environment. (Asrat G.W, Gizachew S. et al. 2013). Production of green energy from waste material has played an important role in recent days due to the depletion of non-renewable energy resources (Nazim Ali, PravinUbhrani et al. 2009). Cellulosic-based biofuel is a potential alternative over food derived bio-ethanol in the transport sector.

Ethiopia imports its entire petroleum fuel requirement and the demand for petroleum fuel is rising rapidly due to a growing economy and expanding infrastructure. The annual consumption of petroleum fuels amounts to 2 million tones. Imported petroleum products accounts for a large share of the total import expenditure and absorbs total export earnings. (Forum for Environment (FfE) 2011)

The negative impacts of fossil fuel on the environment and the unstable oil market are the factors that lead to the constant search for alternative fuels (Nazim Ali, Pravin Ubhrani et al. 2009). Ethanol produced from biomass is considered as one of the modern forms of biomass energy that has the potential to be a sustainable transportation fuel for gasoline engines. It has a number of advantages over conventional fuels. Some of these are: (i) it comes from a renewable resource, (ii) blending with petrol will reduce heavy reliance on oil producing nations, and (iii) it is biodegradable and far less toxic than fossil fuels.(Asrat G.W, Gizachew S. et al. 2013)

Biofuels are promoted in Ethiopia with the objective of improving energy security, creating employment and incomes. Commercial scale liquid biofuel production in Ethiopia dates back to the 1990s when production of fuel grade ethanol from sugar cane molasses was initiated at the Fincha Sugar Factory. Production was limited to a few million liters and most of the produce was exported to Italy as there was no domestic market for fuel ethanol. Beginning around 2005 there appeared widespread global interest to introduce liquid biofuels as substitutes to petroleum fuels for both energy security and greenhouse gas emission reduction reasons.(Forum for Environment (FfE) 2011)

Bio Ethanol Technology:

Bio-ethanol can be produced either from conventional or advance biofuel technologies depending on the state of sugar polymerization. The second generation bio-ethanol or cellulosic ethanol could be produced from abundant low-value material. The bioethanol process has to undergo several treatment steps which normally involve pre-treatment, extraction of fermentable sugars (hydrolysis) and fermentation.

Bio-Ethanol From Lignocellulosic Biomass:

Interest in using biomass as feedstock for biofuel production has been increasing recently due to concerns about volatile oil prices, climate change, and the impact of diverting crops from food to fuel. The utilization of lignocellulosic biomass for ethanol production necessitates the large-scale production technology to be cost effective and environmentally sustainable.(Anuj K., Chandel et al. 2013).

II. BIO-FUEL AND ITS STRATEGY IN ETHIOPIA

Ministry of Water and Energy (MoWE) of Ethiopia has developed bio-fuel strategy recently. The objective of the strategy is enhancing energy security and access to transport fuels. The program will also promote an agriculture based industry for increased agricultural and industrial outputs, employment and exports.

Main Goals of Bio-Fuel Program in Ethiopia:

The main goals of bio-fuel program in Ethiopia are (i) coordinating the production to gain 194.9 Million Liter at the end of strategic period, (ii) expanding bio-fuel blending facility through oil distribution companies, to have 8 benzene-ethanol blending stations at the end of the strategic period, (iii) enhancing benzene-ethanol blending level to reach 25% and to use 64.4 million liter of bio-ethanol for blending, (iv) rising awareness and attract private investors on bio fuel development by hosting international forums and conferences, and (v) addition of 25 project designs on already existing 3 projects and coordinating bio-fuel project designs to reduce GHG emission and make the country beneficiary from CDM Program.

Table 1. Five Years Bio-fuel Development Program

Goal Indicators	Unit	Base Year	5 Years development program					Total
		2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	
Bio-ethanol product	ml	-	7.08	24.8	50.3	56.3	64.38	241.07
Bio-ethanol blend amount	ml	7.08	20.5	22.9	35.2	49.53	64.8(25%)	64.38
		-5%	-5%	-10%	-15%	-20%		

Source: Water and Energy Minister, Ethiopia.

Current Bio-Ethanol Activities in Ethiopia:

Current bio-ethanol activities in Ethiopia are (i) since October 2008 the E-5 blending has been started distribution around Addis Ababa, Ethiopia, (ii) since March 2011 the E-10 blending has been started distribution around Addis Ababa, Ethiopia, and (iii) existing 2 benzene-ethanol blending facilities through oil distribution companies (namely: Nile petroleum and Oil Libya).

Table 2.Total blended quantity in liters at Sululta depot

Period	MGR	Ethanol	E-5	E-10
2008	31,318,326	1,648,333	32,966,659	-
2009	97,786,179	5,146,642	102,932,821	-
2010	140,106,882	7,374,046	147,480,928	-
2011	29,894,370	1,571,208	31,465,577	-
2012	18,888,709	2,098,745	-	20,987,454

Source: Water and Energy Minister, Ethiopia.

Table 3. Petroleum products import and consumption data

	Years						
	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Petroleum Import / metric tons/	1,406.90	1,475.10	1,643.90	1,881.30	2,011.40	2,034.20	2,006.75
Petroleum Consumption /metric tons	1,366.30	1,536.50	1,655.80	1,880.70	1,910.60	2,035.6	2,090.39

Source: Water and Energy Minister, Ethiopia.

Table 4. Time series of Kerosene Consumption

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ton	226,120	208,934	208,934	212,550	229,898	242,925	265,664	272,304	257,022

Source: Water and Energy Minister, Ethiopia.

Coffee is one of the most important and economic crops in Ethiopia. The international coffee organization estimates that 8,676,660 tons of coffee beans were produced worldwide in 2012; of which contribution of Ethiopia was about 486,000 tons, 5.6%. Coffee production provides livelihood to millions of people, but the organic waste generated threatens their environment. Developing countries are facing a serious problem in proper disposing of the waste produced by production of coffee. Coffee wastes and by-products constitute source of severe contamination and a serious environmental problem. (Rathinavelu and Grazioni 2005)

III. Coffee Processing

There are two ways of coffee processing - dry processing and wet processing. The dry process, is the oldest method of processing coffee but it is now limited to regions where water or infrastructure for machinery is scarce. Wet processing is regarded as producing a higher

higher quality product.

Residues Generated in the Coffee Industry:

In the wet coffee process the coffee pulp is the major solid by-product. 1000 units of fresh cherry yield about 432 units of pulp in terms of weight and mucilage represents about 5% of the dry weight of the coffee berries.

There is great political and social pressure to reduce the pollution arising from industrial activities. Almost all developed and underdeveloped countries are trying to adapt to this reality by modifying their processes so that their residues can be recycled. Besides to add value to these unused materials, finding alternative forms to use them would be useful to decrease their impact to the environment. (Sudhaker D., Kartikeya D. et al. 2014)

Chemical Composition of Coffee Wastes Coffee Pulp and Mucilage:

Coffee pulp is rich in carbohydrates, proteins and minerals and it also contains appreciable amounts of tannins, polyphenols and caffeine.

Table 5. Chemical composition of pulp

Components	Coffee pulp(%)	Mucilage (%)
Carbohydrates	44-50	4.1
Proteins	8.5-12.1	8.9
Fat	1.5-2.0	
Caffeine	1.3	-
Tannins	1.8-8.56	-
Lignin	17.5	
Cellulose	17.7	
Pectin	12.4	0.91

(Rathinavelu and Grazioni 2005)

Some studies are conducted on feasibility of bio-ethanol production from wet coffee processing waste in other countries. However, similar study is not conducted in Ethiopian. Also its environmental impact assessment has not been studied. Therefore, this study aim: (i) to quantify the wet coffee processing waste and estimate its bio ethanol potential in Ethiopia and (ii) to evaluate the feasibility of bio-ethanol production from wet coffee processing waste.

IV. Economic Feasibility of Bio-Ethanol

An alternative fuel to petrol or diesel must be technically feasible, economically competitive, environm-ental friendly and abundantly available. Biomass contribu-tes about 60% to the total production cost which is the highest contributor to the cost of bioethanol. Therefore, the main focus here is to estimate the effect of raw materials price on the cost of bioethanol. (Senthur N. S., Ravikumar T. S. et al. 2014).

Cost of Lignocellulosic Biomass:

Assessing various costs of mobilizing lignocellulosic biomass which include collection, pre-processing and transportation can be mobilized at globally competitive costs. Biomass resources are in general abundant and are typically not in the human food chain making these materials relatively inexpensive feedstocks for ethanol production.(Fatoni, Elkamel et al.)

Cost of Sulfuric Acid and Recovery Charge:

Sulfuric acid is the largest expenditure of raw materials in the process of making bio-ethanol from lignocellulosic biomass. Nonetheless, the current technology enables the acid-sugar solution from hydrolysis separated into acid and sugar components.

The separated sulfuric acid is re-circulated and re-concentrated to the level required by the de-crystallization and hydrolysis steps. Using this technology almost up to 100% of the sulfuric acid can be recovered from the process.(Adebayo A.O., Jekayinfa S.O. et al. 2014)

Ethanol Production Cost:

Ethanol production cost includes costs associated with capital recovery, operation and maintenance, raw materi-als, and biomass delivered cost. Feedstock and capital recovery are the two major cost components, accounting for about 38% and 34% of the total production cost, respectively.

Ethanol Price:

Ethanol price is critical to the evaluation of a cellulosic ethanol facility. Logging residue had greater impacts on ethanol production cost in contrast to mill residue because more logging residue could be delivered to the utilization facility. Ethanol production costs increased as stumpage costs of logging residue increased. The production cost would increase 3.4–4.9% from the base case depending on the biomass handling system used.

Ethanol Production Cost Versus Capital Cost:

Ethanol production costs increase proportionally as total capital costs increase. If total capital costs increase by 5% compared to the base case, the ethanol production costs would increase 1.8–1.9%, depending on the biomass handling system used.

Ethanol Production Cost Versus Plant Capacity:

Average ethanol production costs decrease as plant use of biomass increase. As plant scale increased, the average cost related to plant investment decreased due to economies of scale.

Ethanol Production Cost Versus Ethanol Yield:

Technologies that convert biomass to cellulosic ethanol are in varying stages of development and comm-ercialization(Periyasamy S., Venkatachalams S. et al. 2009). Ethanol yield from one ton of biomass could vary from 0.216 to 0.432 ton depending on conversion technology and other operational conditions (Franca A., Gouvea B. et al. 2008)

V. Other Implications

Security of Feedstock Supply:

Feedstock supply stabilization is critical to the success of biomass-based facility. Sorting residue has been considered an underutilized resource with limited value; however, more biomass would be needed and higher stumpage costs of sorting residue would be inevitable as the biomass market develops for ethanol or other bio products.

Government Policies:

Government subsidies will be essential to the market success of bio mass based facilities initially. The agreement implemented by Policy Energy Act (PEA) followed by the Energy Independence and Security Act (EISA) aims to reach 36 billion gallons of bioethanol by the year 2022. Rising concern over depleting fossil fuel and GHG limits has resulted in a high level of interest in non-conventional fuel originating from bio-renewable sources. (Ajoko and J. 2014).

Lignocellulosic biomass materials constitute a substantial renewable substrate for bioethanol production that do not compete with food production and animal feed. These cellulosic materials also contribute to environmental sustainability. (U.S. Department of Energy Biomass Program 2009).

VI. Theoretical Estimation

Agricultural and agro-industrial residues constitute 15% of the total energy consumed in Ethiopia. As a result of the washed processing method, two distinct types of residue are generated: wet coffee pulp and mucilage. For 100 kg of ripe cherries, 60% by mass ends up as washed coffee pulp with the remaining 40% consisting of the green bean and endocarp (parchment). Of this 60% washed coffee pulp, only 20 kg remains after sun-drying of the bean and parchment. The average residue production per ton of wet red cherry is about 600 kg.

VII. Methodology

The study involved semi structured interviews, field visits and document review. Formal and informal discussi-ons were also conducted. The methodology also employed reviewing bio-fuel development related sectoral and cross-sectoral policy and strategy documents, procla-mations, regulations, relevant guidelines and official reports. The sources of the policy information documents are Ministry of Agriculture (MoA), Ministry of Water and Energy (MoWE), Ethiopian Commodity Exchange (ECX) and different archives. Interviews were also conducted with knowledgeable individuals in search of policy, strategy and legal information and materials. Field visits were conducted in various woreda (districts) within the regions (SNNPR and Oromia) where wet coffee process-ing is going on. The quantity of waste generated from wet coffee processing industries was estimated and also the bio ethanol potential of coffee waste was estimated.

VIII. Result and Discussion

Table 6.Wet coffee processing Industries in Ethiopia

No	Region	Private owned	Association owned	Government owned	Total
1	Oromiya	297	95	15	407
2	SNNPR	470	146	-	616
3	Gambela	3	-	-	3
Total		770	241	15	1026

Source: Ethiopian Ministry of Agriculture.

As it can be seen from Table 6, there are about 1026 operational wet coffee processing industries in Ethiopia which are particularly situated at Oromiya, SNNPR and Gambela regions of the country. In addition, numbers of new wet coffee processing industries are under construc-tion. From the data, it is possible to conclude that there are considerable numbers of industries which produce huge waste in the country. It can be projected that the amount of waste that will be generated will increase considerably when the industries under construction become operational.

Table 7: Green coffee production (ICO, 2013, MoA).

Production (ton)	Year					
	2007	2008	2009	2010	2011	2012
World	6,987,300	7,718,220	7,376,460	8,001,420	8,048,400	8,676,660
Ethiopia	358,020	296,940	415,860	450,000	407,880	486,000
Percentage	5.12 %	3.85 %	5.64 %	5.62 %	5.07 %	5.60 %

Table 7 shows that the amount of green coffee production in Ethiopia is increasing from year to year (from 2007 to 2012) which also shows dramatic increase of coffee waste generation accordingly (around 600 kg per ton).

Table 8: Estimated amount of waste generated from wet coffee processing in Ethiopia

Year	Amount of waste (kg)
2007	214,812,000
2008	178,164,000
2009	249,516,000
2010	270,000,000
2011	244,728,000
2012	291,600,000

From Table 8, it can be seen that the amount of waste generated from the wet coffee processing industries in Ethiopia is generally increasing from year to year. Since a number of processing industries are under construction and becoming operational very soon, more waste will add up to the current amount.

IX. CONCLUSION

Lignocellulosic biomass has a higher bio-ethanol yield per ton feedstock (L/t) than most of the commercialized bio-ethanol feedstock. However, improvement had to be made on the conversion efficiency to obtained higher ethanol yield to make it more comparable with the sugar containing and starchy material. The composition of substance that can be converted to glucose played a big influence on the ethanol yield per tone feedstock. With the large amount of glucose convertible material and abundant availability, these lignocellulosic biomasses are potential feedstock for bio-ethanol production. In both instances, ethanol use can improve urban air quality. Enough waste materials can be made available to produce sufficient ethanol to replace all gasoline. Estimated amount of waste generated from wet coffee processing in 2012 in Ethiopia is around 291,600,000 kg. There are more processing industries under construction which will be operational soon, indicating huge amount of waste to add up to the existing amount.

The potential ethanol supply from biomass is substantial, and large scale application would thereby reduce the strategic vulnerability to disruption in oil supply, while substantially improving the balance of trade deficit for imported oil. Technologies have advanced significantly for the conversion of lignocellulosic biomass in to ethanol, so that the price of ethanol from lignocellulosic biomass is competitive with ethanol derived from corn. Ethanol production from lignocellu-losic biomass offers the added advantage in that no net accumulation of atmospheric CO_2.

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REFERENCES

[1] A.O. Adebayo, S.O. Jekayinfa, "Anaerobic Co-Digestion of Cattle Slurry with Maize Stalk at Mesophilic Temperature." American Journal of Engineering Research (AJER), vol.**3,** 2014, pp. 80-88.
[2] Ajoko and T. J. "Alternative Source of Cooking Gas – Conversion of Crop Waste to Energy." American Journal of Engineering Research (AJER) ,. Vol. 3**,** 2014, pp. 89-95.
[3] K. Anuj, Chandel, "Sustainable degradation of lignocellulosic biomass - techniques, applications and commercialization." Janeza Trdine, Croatia, 2013.
[4] G.W. Asrat, S.Gizachew, B.S. Chandravanshi,. "Bio-ethanol production from poultry manure at Bonga Poultry Farm in Ethiopia." African Journal of Environmental Science and Technology, vol. 7**,** 2013, pp. 435-440.
[5] R. Fatoni, A. Elkamel, "Techno-Economic Study for Lignocellulosic Biomass Processing and Ethanol Fermentation Refinery Design."
[6] Forum for Environment (FfE) (2011). "Assessment of biofuel development activities in Ethiopia."
[7] A. Franca, B. Gouvea, "Feasibility of ethanol production from coffee husks." J. Biotechnol. vol.136, 2008, pp. 269-275.
[8] Nazim Ali, Pravin Ubhrani,"A Step Towards Environmental Waste Management And Sustainable Biofuel (Ethanol) Production From Waste Banana Peelings." American Journal of Engineering Research , vol. 3, 2009, pp. 110-116.
[9] S.Periyasamy, S.Venkatachalams, "Production of Bioethanol from Sugar Molasses Using S. cerevisiae." Modern Appl.Science, vol. 3, 2009, pp. 32-36.
[10] R. Rathinavelu, and G. Grazioni, "Potential Alternative Use of Coffee Wastes and By Product." Coffee Organization: 2005, pp.1-4.
[11] N. S.Senthur, T. S.Ravikumar, "Eucalyptus Biodiesel; an Environmental friendly fuel for Compression Ignition Engines." American Journal of Engineering Research (AJER), vol.3, 2014,pp. 144-149.
[12] N. S.Senthur, T. S. Ravikumar, "Eucalyptus Biodiesel; an Environmental friendly fuel for Compression Ignition Engines." American Journal of Engineering Research, vol.3, 2010, pp. 144-149.
[13] D.Sudhaker, D.Kartikeya, "Physico Chemical Properties of higher polymers in petroleum Industry." American Journal of Engineering Research (AJER)U, vol. 3, 2014,pp. 01-07.
[14] U.S. Department of Energy Biomass Program "Annual total tonnages of biomass for biofuel in the U.S.", 2009.

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