International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:12, No:5, 2018

Valorization of Residues from Forest Industry for the Generation of Energy

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***Abstract*—**The use of biomass to produce renewable energy is one of the forms that can be used to reduce the impact of energy production. Like any other energy resource, there are limitations for biomass use, and it must compete not only with fossil fuels but also with other renewable energy sources such as solar or wind energy. Combustion is currently the most efficient and widely used waste-to-energy process, in the areas where direct use of biomass is possible, without the need to make large transfers of raw material. Many industrial facilities can use agricultural or forestry waste, straw, chips, bagasse, etc. in their thermal systems without making major transformations or adjustments in the feeding to the ovens, making this waste an attractive and cost-effective option in terms of availability, access, and costs. In spite of the facilities and benefits, the environmental reasons (emission of gases and particulate material) are decisive for its use for energy purpose. This paper describes a valorization of residues from forest industry to generate energy, using a case study.

***Keywords*—**Bioenergy, forest waste, life-cycle assessment, waste-to-energy, electricity.

I. INTRODUCTION

NOWADAYS, several global environmental challenges faced by society are related to the activities of the energy sector, both on the supply as well as the demand side. The effects of climate change require a considerable reduction in greenhouse gas (GHG) emissions, while identifying and reducing the environmental footprint caused by the energy sector. The electric generation industry has been identified as one of the main sources of polluting emissions in Mexico. In response to this phenomenon, the Mexican State promotes policies, programs, actions and projects aimed at achieving greater use and exploitation of renewable energy sources and clean technologies, promoting energy efficiency and sustainability, as well as the reduction of Mexico's dependence on hydrocarbons as a primary source of energy. One sustainable way to obtain energy is transforming biomass residues from forest industry.

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This paper focuses on the following aspects: a) the forest industry in Mexico, b) general considerations on forest residues, c) forest harvest residues, d) waste from wood processing, e) energy use of forest residues, f) energy use of forest biomass, g) energy characteristics and h) an estimate of the energy potential of forest biomass in Mexico.

It is important to clarify that Mexico was taken as a case of model study due mainly to its extensive forest areas and because it is a country, where waste is usually not valorized, so an estimation of the potential electricity generation from waste is required.

II. THE FOREST INDUSTRY IN MEXICO

The surface area covered by forests and jungles within the national territory place Mexico in the eighth position in forest extension worldwide, second in Latin America. Mexico possesses a territorial surface of 196,437,500 hectares (ha), of which the forest area is 141,745,168 ha [1], [2]. Of this surface 41% are arid zones, 16% are disturbed areas and 3% are hydrophilic and halophilic vegetation zones, while 21% are coniferous and hardwood forests and 19% are jungles of diverse vegetation ranging from evergreen to thorny. The sum of the areas with the greatest potential for forest exploitation is forests and jungles, which represents ~ 40% of the total forest area, located mainly in Durango, Chihuahua, Jalisco, Michoacán, Guerrero and Oaxaca. This figure represents 28.9% of the total area of the country. Fig. 1 shows the global behavior per year of forest production in Mexico, which is estimated to have stabilized at around 6 million cubic meters rolls (Mm^3r).

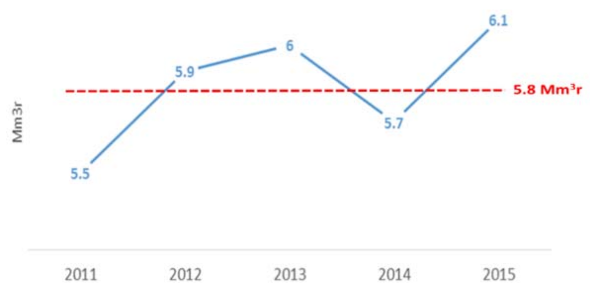

Fig. 1 Production of forest wood in Mexico

The main producer states in 2015 were: Durango (28.5%), Chihuahua (18.1%), Michoacán (7.0%), Jalisco (6.7%) and Oaxaca (6.7%), which contributed 67.0% of total production, equivalent to 4 million m3r. The main products that were obtained were: the wood for sawing with 73.2% of the production (4.5 million m^3r), the fuels (firewood and coal) with 11.8% (721 thousand m^3r) and the remaining 15.0% (918 thousand m^3r) was destined to cellulosics, sheet and plywood, posts, piles and morillos [1]. From these data, it is identified that the states of Durango, with 28.5% and Chihuahua, with 18.1%, represent 46.6% of all national production.

The analysis also shows that wood production in Mexico is mainly destined for sawmills, reaching a little more than 73% of the total national production.

A. Considerations on forest Residues

Forest residues originate in part from the maintenance and improvement of forests, mountains and forest stands, when pruning, cleaning, etc., as well as the waste resulting from cutting trees and preparing logs to make wood products. These activities generate waste that must be removed from the forest to avoid risks of spreading plagues and forest fires. This waste is generated by forest needs and consists of materials that do not have sufficient quality for other applications than energy [3].

B. Forest Harvest Residues

In general terms, it is considered that, for several species, the biomass of the tree is distributed in four parts (Fig. 2):

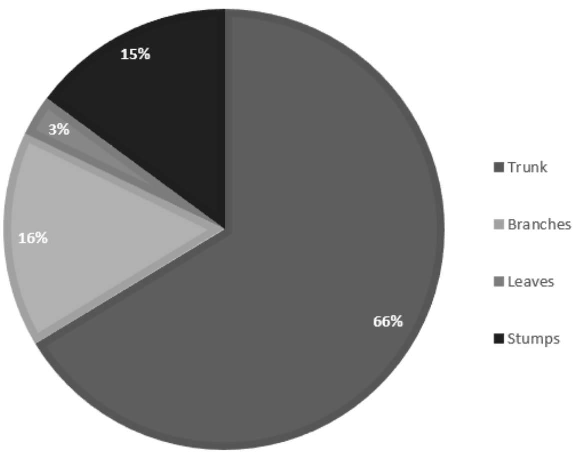

Fig. 2 Average tree composition [3]

The branches that are generated during cutting or pruning are of very different diameters. In general, branches with diameters greater than 7.5 cm are used in the conglomerate or cellulose industry. While fine branches are considered as waste and must be removed from the forest to prevent pests or fires. The production of stumps and roots may be of interest in some forest exploitation systems, based on the integral extraction of the tree for later use in the pulp industry.

C. Waste from the Harvest Process and Use of Wood

This waste group includes the waste generated by the forest industry, which can be used as fuel. Among these industries are sawmills or first processing industries, manufacturers of products made from wood, manufacturers of cork products and paper mills.

The residues of the wood harvesting and sawing process reach up to 75% of the production volume of standing timber from a plantation, being 50% logs, and 25% industrial waste from the sawmill [3], while harvesting and mechanical rubbing works also generate waste (foliage, branches, pruning, logs, bark, stumps among others). Therefore, the waste can be divided into two classes: 1) Those from the collection and extraction of logs from the forests, and 2) Those generated by the forest industry itself, for example:

a) Those generated in forestry operations: branches, needles, leaves, stumps, roots, rotten and poor quality wood, cuttings and sawdust.
b) Those generated in the sawmill: bark, sawdust, cuttings, split wood, shavings, sanders.
c) Those generated in the production of boards against veneers: bark, sawdust, cuttings and sheet metal residues, panel cuts, sanders, and finally,
d) Those generated in the production of particle boards: crusts, screening machines; giblets, panel cuts, sawdust, sanders.

Table I summarizes the distribution of products and parts of the tree in the process of harvesting and harvesting of forest operations. This approach allows making a quantitative estimate on which products or residues are of most interest for valorization.

III. Energetic Use of Forest Residues

The use of residual biomass energy requires simple technologies that make possible the management of waste, because they are materials with low commercial value, difficult and expensive to manage due to their low density, and because of the difficult access to make their collection possible. However, its energetic potential or the costs that its elimination demands to avoid environmental contamination, visual, propagation of harmful faunas and forest fires, etc., can make this use viable.

TABLE I
Distribution, Parts and Tree Products Generated During the Process of Harvesting and Forest Harvesting of Wood [2], [3]

Tree part	Proportion (%)
Left in the forest	
Cup, branches and foliage	23.0
Stump (excluding roots)	10.0
Sawdust	5.0
Left in the sawmill	
Chips, coastal and cut-outs	17.0
Sawdust and giblets	7.5
Various losses	4.0
Cortex	5.5
Sawn wood	28.0
Total	100

The technologies for the energetic use of the waste must be adjusted to the intrinsic characteristics of the waste and mainly, to its physical state and moisture content. For solid waste, the most advisable techniques are combustion, pyrolysis or carbonization and gasification, while for liquid or pasty waste, the techniques of methane digestion would be the most appropriate.

The combustion is the process of energy use of waste or waste more favorable and extended at present, when direct use of biomass in its area of origin is possible, without the need to make large movements or transfers of the raw material. Many industrial facilities can use agricultural or forestry waste, straw, chips, bagasse, etc. in its thermal systems without making major transformations or adjustments in the feeding of the ovens, making this waste an attractive and cost-effective option in terms of availability, access and costs. In spite of the facilities and benefits, the environmental reasons (emission of gases and particulate material) are decisive for its use and energy use.

The combustion requires that the calorific value of the waste is greater than 5 MJ/kg and this depends on the chemical composition and physical characteristics (elemental and proximal analysis). The calorific value reflects the amount of stored chemical energy and the energy potential of the raw material. Table II shows the average chemical composition of forest biomass.

A. Energy Potential

The energy potential of the biomass, like that of any other fuel, is measured based on the calorific value of the starting raw material, or, depending on the calorific value of the resulting product. As an example, Table III shows the lower calorific value, for different moisture contents, of some of the most common biomass residues.

TABLE II
FOREST BIOMASS: CHEMICAL COMPOSITION OF ANHYDRA WOOD WITH CORTEX [3], [5]

Chemical composition (%)			Molecular composition (%)	
Element	Average	Variation	Cellulose/Hemicellulose	50-60
C	50	49-53	Lignin	20-30
O	42	40-43	Proteins	0.5-3
H	6.2	5.8-6.3	Resins/Waxes	0.7-3
N	0.8	0.2-1.1	Ashes	0.2-3
Ashes	1	0.2-3		
S+P	traces	traces		

TABLE III
LOWER CALORIFIC VALUE (LCV) OF DIFFERENT PRODUCTS [3]-[5]

Product	LCV (MJ/kg) at different moisture (M) content (%)					
	M	LCV	M	LCV	M	LCV
Firewoods and Branches	0	19.353	20	15.006	40	10.659
Sawdust and shavings	0	19.069	15	15.842	35	11.537
Conifer bark	0	19.437	20	15.257	40	11.077
Leafy bark	0	18.225	20	14.087	40	9.948

In general terms, it should be mentioned that forest waste often suffers marked changes in the moisture content, prior to its use as fuel. A first drying is usually done in the field, delaying its collection after being chipped. A freshly cut tree contains a humidity between 50-60%, content that is reduced by open-air drying following a decreasing exponential curve, and can lose up to 40% humidity in 12 months depending on the relative humidity of the area or storage place. The minimum humidity that can be reached in practical terms is 20% and the normal is 25%, after 6 months of storage.

IV. ENERGY POTENTIAL OF THE FOREST BIOMASS IN MEXICO

In the last 40 years, primary energy consumption in Mexico has increased by 60% [6]. However, the use of forest biomass as an energy source currently represents less than 10%, and its use as a primary source of energy is focused on domestic applications and small industries (e.g. brick kilns and potteries).

The calorific value of these residues (forest biomass) makes it possible to substitute one tonne of oil equivalent (1 tep) for 2.5 to 3.5 tons of agricultural or forestry waste. The lower calorific value (LCV) of the biomass allows to obtain approximately 15.0 MJ/kg, with an average humidity <25% (equivalent to just over 3.5 Mcal / kg), see Table III. The LCV of the diesel is ~ 42 MJ/kg and that of gasoline is approximately 44 MJ/kg. That is, for each 2.8 or 2.9 kilograms of biomass, one kilogram of diesel or gasoline could be substituted, respectively.

The forestry sector in Mexico generates around 700,000 tons of dry matter per year (t DM / y) of forest residues, of which 85% corresponds to pine and 15% to Encino [4]. This forest biomass represents an energy potential of the order of 13.5 TJ.

From this general assessment and taking into account that, among the areas identified with the greatest potential for biomass generation, are the States of Durango, Chihuahua, Oaxaca, Guerrero and Quintana Roo, we have decided to carry out a particular exercise on the state of Durango, in order to highlight its importance and potential within the national panorama.

Statistics show that the state of Durango has a production of dry matter (forest biomass) in the order of 244,649,044 t/y [4], equivalent to an energy potential of ~ 4.7 TJ, which represents around 35% of the energy potential in Mexico.

Following this reasoning, we have developed a particular exercise focused on establishing the energy potential of a sawmill in the state of Durango. Such sawmill produces different types of biomass waste generated during processing, establishing that some of them, such as bark and chips, are sold, only to reduce the amount of waste generated. Emphasizing that:

- The splinter produced during the harvesting process is sold as a source of cellulose for the production of paper and the manufacture of agglomerated board.
- The bark is sold as residue for energy production, and another quantity is used by the company to feed its boilers and biomass for self-supply includes: sawdust, firewood slices, bark, wood (battens or block), used to generate heat in the operation of the plant.
- While unused waste is sawdust and wood burning, which are generated in the yard where the logs are cut to be processed.

Table IV shows information on the generation of residual forest biomass generated by a forestry company in the state of Durango. The analysis indicates that the company's case study produces about 15,569.36 tons of forest residues, which represents little more than 6.4% of the biomass forest residues of the state of Durango. In terms of energy, the company has a potential close to 0.23 TJ (the calculation is made considering a lower calorific value (LCV) of 15.0 MJ / kg, since not all the raw material is dry). This value represents just under 5% of the energy potential of the entire state.

TABLE IV
DATA FROM THE CASE STUDY IN DURANGO, MEXICO

Forest biomass (waste)	Origin	Dry weight (kg)	Use
Sliver for sale	Sawmill	856,977.26	Cellulose (Scribe)
	Sawmill	856,977.26	Fabrication of agglomerated board
	Guillotine sheet	1,288,160.39	Sale
	Total	3,002,114.92	
Bark for sale	Stripping of pieces	3,125,860.71	Sale
Biomass for auto supply	Sawdust and slices of firewood enabled for the plywood	1,781.12	Boiler feed
	Bark of pine from the debarked bark	371.712	
	Biomass for auto supply (sawdust of polishing, CH 5%) of the turning (production and classified of green sheet)	2,632,451.85	
	Biomass for self-supply (sawdust polishing, CH 80%) of the turning (production and classified of green sheet)	3,390,954.73	
	Fine sawdust, CH 20%.	34,978.66	
	Firewood in slats or blocks and sawdust, CH 8% from sawn wood to slatted boards	346,288.77	
	Sawdust 20%, CH 65%, from the sawmill	1,399,146.55	
	Polishing sawdust, CH 5% from turning (production and sorting of green veneer)	799,279.45	
	Total	9,356,591.22	
Unused residues	Sawdust and wood burning that remains in the yard from the cleared sawmill	84,793.63	

Note: It is considered that each cubic meter of roll, is equivalent to 350 kg, with the exception of the crust, whose equivalence is 380 kg.

Finally, it is important to mention that during the energetic valorization of any material, there is always the risk of making an under- or overestimation of the real potential, and the reliability of this analysis is in the statistics that are managed, so the information in this study is subject to validation with more up-to-date information.

ACKNOWLEDGMENT

The authors wish to thank Project Y.61025 CEMIE BIO Clúster biocombustibles sólidos (Instituto Mexicano del Petróleo) for the financial support.

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