MSc Program
Environmental Technology & International Affairs

TU WIEN
CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

Carbon Dioxide Reduction Potential of Sugar Cane Bagasse in Guatemala

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Univ.-Prof. Dipl.-Ing. Dr.techn. Helmut Rechberger

Luis Fernando Ramirez Santa Cruz

0226884

Vienna, 13 Juni 2011

Affidavit

I, **LUIS FERNANDO RAMIREZ SANTA CRUZ**, hereby declare

1. that I am the sole author of the present Master's Thesis, "CARBON DIOXIDE REDUCTION POTENTIAL OF SUGAR CANE BAGASSE IN GUATEMALA", 60 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 14.06.2011

Signature

Acknowledgments

I'd like to start by thanking my parents and my grandparents, whose unconditional support and love are the reason why I've made it so far. Gracias Mama, gracias Papa, gracias Mamma Mia, gracias Mamma Marta! Also love goes out to my sister Mónica and my brother Carlos for being there for me whenever I have needed their help. Without further due, I must thank all of my friends who I love as much as if they were family (in alphabetical order to avoid misunderstandings): Ana B; Arturo A; Bianca C; Boris B; Claudia M; Flo S; Fanni H; Eri K; Erich H; Irene P; Jóse A; José M; Marielos G; Miki K; Nobue T; Sabine I; Saki U; Simon R; Stefan B; Tim L; Yaxin X; Yutaka S; Xtof Z. And I wouldn't have had as much motivation without being inspirated by Lady Gaga. She's a real inspiration for this world's youth, however provocative her acoustical art might be.

I'd also like to thank the staff at the Vienna Technical University's Continuing Education Center, as well as the staff at the Diplomatic Academy of Vienna for their support and tutoring. Including Prof. Dr. Helmut Rechberger for his support and guidance during the process of writing this work.

Abstract

Guatemala is a country with a large amount of renewable resources the potential for greenhouse gases reduction is promising. At the same time renewable resources have been recently gaining notability as law makers increasingly foster them by providing tax advantages and incentives. In Guatemala, biomass is used in various forms; such is the case of fuel-wood and bagasse. Yet CO_2 and other GHGs' emissions continue to be a problem. This work focuses on sugar cane bagasse which is the source of 3% of the final energy consumption and its potential in GHG emission reduction by identifying four possible usages. In the year 2009 Guatemala produced 18 million tonnes of sugar cane. This resulted in an output of 3 million tonnes of bagasse for that year. Out of which, 60% was converted into electricity; the rest was disposed of, sold to cattle ranchers or used as fertilizer. In this work the author tries to identify the advantages or disadvantages of using bagasse in each of the four alternative usages by taking into consideration the available technologies and their potential in reducing greenhouse gas emissions.

Table of Contents

Nomenclature and Abbreviations

Biomass: By definition of the Ministry of Energy and Mines, biomass means all renewable organic material of plant, animal or from natural or artificial transformation of it. The biomass energy is then all the energy that it can be obtained either through its direct burning or processing to get another type of fuel.

Bagasse: in this work "bagasse" refers exclusively to sugar cane bagasse. Bagasse is what it is left after sucar cane has been extracted of its juice.

CENGICAÑA: Centro de Investigación de la Caña de Azúcar. The Research Center for Sugar Cane is the most prominent research center for sugar cane in Guatemala.

CLACDS: Centro Latinoamericano para la Competitividad y el Desarrollo Sostenible, Latin-American Center for Competitively and Sustainable Development.

CH_4: Methane, a principal component of natural gas. It has a CO_2 equivalence of 72 times (over a horizon of 20 years) or 25 (over a horizon of 100 years).

CIEE: Cuenta Integrada de Energía y Emisiones. Integrated Account of Energy and Emissions is a component of the Guatemalan Integrated Environmental and Economic Accounting System, which complements the System of National Accounts (SNA). It is an accounting framework that provides a detailed description of the interrelationships between the environment and the economy by providing information on energy stocks and flows.
http://www.infoiarna.org.gt/article.aspx?id=160

CEPAL: Comisión Económica para América Latina y el Caribe. Economic Commission for Latin America and the Caribbean.

CEPALSTAT: Statistical datasets maintained by the CEPAL, similar in nature to the FAOSTAT datasets.

CO_2: Carbon Dioxide

DEORSA: Distribuidora de Electricidad de Oriente is a privately held company supplying electricity.

DEOCSA: Distribuidora de Electricidad de Occidente is a privately held company supplying electricity.

DIECA: Dirección de Investigación y Extensión de la Caña de Azúcar. The Sugar Cane Research and Extension Directorate of Costa Rica.

EEGSA: Empresa Eléctrica de Guatemala S.A is a privately held company supplying electricity.

FAO: Food and Agriculture Organization of the United Nations

FAOSTAT: Statistical datasets maintained by the FAO.

GHG: Greenhouse gases.

IARNA: Instituto de Agricultura, Recusos Naturales y Ambiente. The Agriculture, Natural Resources and Environment Institute at the Rafael Landivar University in Guatemala City.

IEA: The International Energy Agency's mandate is to implement an international program of energy cooperation among 28 member countries of which Guatemala is not a member.

INDE: Instituto Nacional de Electrificación. The National Electrification Institute is public counterpart to EEGSA.

N_2O: Nitrious Oxide. It has a CO_2 equivalence of 298 times over 100 year horizon.

OECD: The Organization for Economic Co-operation and Development is an international organisation helping governments tackle the economic, social and governance challenges of a globalization. Guatemala is not a member of this cooperative.

OLADE: Organización Latinoamericana de Energía. The Latin-American Energy Organization maintains dataset throught its SIEE program

SIEE: Sistema de Información Económica Energética. Economic Energetic Information System maintained by the OLADE, similar to CEPALSTAT.

List of Tables and Figures

Tables

Figures

1. Introduction

Guatemala is a country with a large amount of renewable resources which have great potential to be turned into energy as electricity or heat. The energy source with the highest demand is firewood. Unfortunately, the open burning of firewood is a serious source of CO_2 emissions which cannot be ignored. It is estimated that the country's forest coverage reaches 37.000 km², or 34% of the national area, the annual deforestation rate is currently at 2.1%. In Guatemala, biomass is used in various forms; such is the case for fuelwood, bagasse co-generation, and other bio-digestion systems. The national energy balance (this comprises electricity, heat, fuel and other forms of energy) shows that firewood makes out for 63% of all final energy consumption forms. Next in importance is diesel with 12%; gasoline accounts for 8%; fuel oil and electricity 4%, each; and finally sugar cane bagasse and liquefied petroleum gas (propane) with 3% each. The high consumption of firewood is due to the fact that most of the population lives in rural areas. Most of them have a low income, leaving them without proper access or purchase capacity for other energy sources. Moreover, there is also a cultural tradition that is reflected in their eating and cooking habits: the use of a type of stove called "Three Stones" for cooking (which is basically three stones on the ground supporting a pot on top, arranged as a triangle with the firewood in the middle), the use of clay pots that suits the open fire, the tendency to prefer taste of food cooked by firewood and the relative easy availability of the resource.

This work focused on sugar cane bagasse, the remains of sugar cane after it has been depleted of it sweet juice, that will later turn into sugar crystals and that is sometimes called honey in Latin-American countries. Yet, rather than being waste it can also be called a by-product of sugar cane. Nowadays, sugar cane producers make use of the produced bagasse in several different ways that were not in common use in the previous decades. The most widely practiced usages in Guatemala are the conversion of bagasse into electricity, and its use as food for cattle. In other countries Latin-American, especially Brazil and Mexico, bio-ethanol is also produced from the sugar cane. However, there are other less productive uses for bagasse that are commonly seen in Guatemala. Sometimes bagasse that will not be further processed will brought back from the processing plant to the field in the hope that it will decompose and thus be absorbed by the soil and function as fertilizer for the next harvest. It might also get simply be disposed of as municipal trash. In order to see how effective bagasse is being used in Guatemala, this work takes two things into consideration. First how much electricity is being produced out of bagasse and what is its potential to displace other sources such as coal or even firewood in an effort to reduce CO_2 emissions; and secondly, what other sensible usages exist, for example, whether the practice of feeding bagasse to cattle is more efficient than common nourishment in terms of energy availability, or how bagasse can contribute indirectly in the other industries' emission reduction.

1.1. Research Questions

The main research question is in one sentence, what is the best way to utilize bagasse produced in Guatemala? To answer this question we need to take into consideration what the pros and the contras are of post-processing bagasse. That is to try to gain something after the main objective of handling sugar cane, the extraction of its sweet juice, has been achieved. Obviously the burning of any fuel produces GHG, as it does with bagasse. Does the energy produced through bagasse justify these additional GHG emissions? This question is interesting due to the fact that Guatemala has a high reliance on geothermal and hydraulic power generation, both of which generate virtually no GHG at all. On the other hand, apart from firewood, petroleum remains as an important fuel. Thus will the energy produced by bagasse reduce Guatemala dependence on petroleum and is it more environmental friendly? As the Guatemalan population continues to expand, so does its demand for energy. This kind of pressure has led the government in the past to ease the law and the rules in the energy market to allow the private sector to come up with its own initiatives. This might have been a good idea, but has the government neglected its duties towards the poorer parts of population and is therefore sabotaging its own emission reduction efforts? A poor infrastructure and the lack of proper access to the grid continue to be the most important reason behind the heavy consumption of firewood. Through an efficient utilization of bagasse and an enhanced access to the grid, is it then possible to lower GHG emissions to the environmental, especially that of CO_2 caused by the burning of firewood? Coupled to the fact that sugar cane production has been found to be even more profitable thanks to this newly used byproducts, we need to take into consideration that the land use for sugar cane is predicted to increase over the next decades. Not only because it's more profitable now than it used to be before but also due to global food demand predictions. It goes without saying that no land use can be performed without GHG emissions (Harvey and Pilgrim 2011: 40-51). So what are the implications of increasing the land used for sugar cane plantations?

1.2. Current State of Affairs

This topic draws the attention of scholars and professionals at virtually all locations where sugar cane is planted. There are different approaches on how other communities handle the problems and opportunities that arise from it. For example, Brazil has been successfully producing ethanol from sugar cane, which has been being used as a biofuel for cars and other machines for a couple of decades already. Brazil is currently the best example of ethanol production as a biofuel, and as such its production has been scrutinized for its effects (Fischer et al. 2008: 29-47). The evidence found suggests that most of the expansion of production has been due to increased productivity of the refining and production processes as well as the change in land use from pasturage to sugar cane production.

1.3. Methodology

This work is based on primary and secondary literature analysis. The data are from several research institutions in Guatemala, including official data from ministries. This work also relies on studies conducted in other regions of the world with similar scenarios. These data sets are then compared to find correlations between the terminal use of bagasse and its influence on the environment. In this work four different usages for bagasse have been identified. Its conversion into electricity, its usage as a nutriment, its usage as a fertilizer, and the usage of its ash as an additive in the cement industry. In order to be able to compare these four alternatives, the results are translated into units describing their potential for CO2 emission reduction.

The conversion of bagasse into electricity is by far the most promising and widespread usage and is therefore given more attention, including background information on the energy landscape in Guatemala and its view on bagasse as renewable resource.

2. Status of Energy Resources in Guatemala

This chapter gives the reader a quick overview of the energy situation in Guatemala, where energy consumption has been rising constantly. Had it not been for the global crisis in the late 2000's, the economic slump and its consequences on the manufacturing, and foreign trade industries -among others- in the country the tendency would probably had continued without interruption. Nonetheless the trend of an increasing demand is once again visible. The following table, Table 1, shows where the energy (be it as electricity, fuel, or heat) consumed in Guatemala comes from:

Energy Offer (in thousands of Barrels of Oil Equivalent)										
Type \ Year	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2.009*
Petroleum	7.583	7.707	9.018	9.041	7.395	6.738	5.851	5.544	5.122	4.941
Natural Gas	176	...	...	...	...	...	...	...	...	...
Mineral Coal	...	...	...	...	...	...	...	...	...	...
Hydro	1.652	1.720	1.307	1.686	1.974	2.262	2.558	2.335	2.846	2.277
Geothermal	126	150	81	1.208	1.203	906	1.011	1.630	1.823	2.395
Firewood	23.317	23.317	23.317	26.113	25.612	26.014	25.817	26.219	26.634	28.292
Bagasse	6.041	6.041	6.041	5.095	5.214	4.022	3.981	5.073	4.374	8.661
Others	188	188	188	...	...	...	205	...	...	...
Primary Production	39.083	39.123	39.953	43.144	41.398	39.943	39.422	40.801	40.799	46.565
Electricity	3.747	3.629	3.836	4.376	4.620	4.846	5.058	5.424	5.401	5.601
Liquefied Gas	70	67	43	...	...	...	...	...	0	...
Gasoline / Alcohol	1.136	1.118	847	...	...	5	4	2	0	1
Kerosene and Turbo	314	258	203	8	5	...	5	7	5	8
Diesel Oil	2.126	2.017	1.520	100	180	188	165	188	163	183
Fuel Oil	2.183	2.046	1.445	...	...	...	...	...	...	...
Coke	...	...	...	...	...	...	...	...	...	...
Charcoal	144	144	144	144	148	148	157	177	289	308
Gases	93	98	71	...	...	...	...	...	...	...
Others	...	...	...	...	...	...	...	...	...	...
Secondary Prod.	9.993	9.746	8.412	5.192	5.339	5.463	5.659	6.145	6.068	6.489
TOTAL OFFER	**49.076**	**48.869**	**48.365**	**48.336**	**46.737**	**45.405**	**45.082**	**46.946**	**46.866**	**53.054**

Table 1: Energy Offer in Guatemala

Source: OLADE: SIEE; CEPAL – CEPALSTAT
The value of one thousand Barrels of Oil Equivalent is 5,7~6,1 TJ[1].

This table gives us a detailed breakdown on the sources of energy, where primary energy sources are those sources that are directly captured or extracted as they are. Secondary energy sources haven been first transformed from another one[2].

---

[1] As defined by the US Internal Revenue Service http://www.irs.gov/pub/irs-drop/n-99-18.pdf
[2] UN, Concepts and Methods in Energy Statistics, New York, 1982.

The table shows the amount of energy within each component as Barrels of Oil Equivalent. 1000 Barrels of Oil Equivalent correspond to 5,7~6,1TJ. For example hydro had an offer of 2.277.000 BOQ, corresponding to 12.980~13.890 TJ. One has to understand that even if the amount of energy within a certain component is high, that does not necessarily translate into the same amount of energy provided in its final usage due to the differences in the conversion efficiency. In other words even the highest resource of energy, firewood, will end up delivered about 5%~20% of its original energy content due to its extremely inefficient usage. Geothermal plants have an efficiency of 15% and hydro plants an efficiency of about 80%-95%, depending on the size and age of the plant[3].

Additionally, as one can deduce from the table above, Guatemala has considerably lowered its demand and dependence on petroleum by one third while at the same time increasing the share energy available from renewable sources. Sadly, the amount of firewood used has not ceased to increase. This serious problem will be discussed in the following section.

2.1. Energy Usage

One of the most import forms of energy consumption is the use of firewood. Not only is it one of the most resource intensive forms, but also one of the most polluting ones. It could be used for home cooking, semi-industrial cooking (such as a local bakery), industrial heating, or any other form of burning. They are mostly carried out in inefficient ways. For example, the most common way wood is used as fuel used for cooking is highly inefficient, 81% of households who use wood as fuel use a stove called "Three Stones", which wastes nearly 90% of the wood's calorific value. In regards to how much CO_2 is emitted to the atmosphere, it is difficult to come up with an approximate number, since the population will use any kind of wood, or even woody plants that they can find in their vicinity. Nonetheless there are generic guidelines on how to calculate approximated emissions. In a research of 41 different types of wood trees conducted by Lamlom and Savidge, it was found that the carbon content of hardwood trees ranges from 46,27% to 49,97%; and for softwood trees it ranges from 47,21% to 55,2% (Lamlom and Savidge 2006:385).

[3] Woodbank Communications http://www.mpoweruk.com/hydro_power.htm

Taking into consideration that carbon C has a molar mass of 12 grams, 462,70 kg of C are found in one tonne of firewood (at 46,27% carbon content), translating into 38558 moles of C. i.e the same amount of CO_2 moles with a molar mass of 44g per mole. This results in a minimal emission of 1696 kg of CO_2, and a maximal emission of 2024 kg per tonne of firewood burnt. In 2006 a little more than 21 million tonnes of CO_2 were emitted into the environment by the burning of firewood in households alone, providing them with 188.501 TJ of energy (CIEE 2009).

Apart from CO_2 the burning of firewood emits carbon monoxide, methane, nitrous oxide and particulate matter. It is worth mentioning that even though the open burning of firewood is highly inefficient and polluting, seen from an economic and environmental point of view, it serves other more positive social aspects that can remain hidden at first glance. The population that uses firewood for cooking are almost without exception of low income and their houses are accordingly poorly build. In villages with cold climates, such as those on high mountains, the heat emitted by the stove is used to maintain a comfortable temperature inside the house and the soot generated by the fumes tends to stick to the roof, which is commonly made out of tatch (i.e. layers of straw, bound together with ropes), thus giving the roof a sort of coating that causes rain drops to slide easier, preventing water leaks through the roof. In houses close to water bodies, the smoke from the fire repels mosquitoes and an open fire is an invitation for people to gather around and can serve a socializing function.

Apart from firewood and timber residues the only source of biomass widely used for energy production power in Guatemala has been the sugar cane bagasse. In the last decades, there had been other attempts to turn biomass into electricity or heat. About 800 family-type biogas digesters (most of which are Chinese-type digesters) in rural areas have been built, but they have not been operated correctly, and people continue to rather use the manure as fertilizer rather than to process it and turn it into energy (FAO 1996).

2.2. Renewable Energy Sources

As the demand for electricity increase the government has been keen on increasing the share covered by renewable energies. It is estimated that the country's natural resources for electricity generation are shown on Table 2.

Type	Available	Currently in Exploitation
Hydro	10.890 MW	425 MW
Geothermal	1000 MW	40 MW
Bagasse	3×10^{6} t	7×10^{5} t
Wind	7.800 MW	0.1 MW
Alcohol Fuel	45×10^{6} l	0 l (all exported)

Table 2: Natural Resources' Exploitation
Source: Ministry of Energy and Mines

Guatemala is to 29,5% dependent on electric power provided by the public sector, the Guatemalan Institute of Electrification (INDE).On the other hand, the private sector such the Guatemala Electric Company (EEGSA), and other regional companies such as the Oriental Electricity Distributor (DEORSA) and the Occidental Electricity Distributor (DEOCSA) together with smaller companies contribute with the remaining 80,5%. According to EEGSA the electricity demand for 2010 was 3.314 GWh[4]. Electricity is generated mainly by hydroelectric plants with an installed capacity of 52%, charcoal or otherwise powered thermal power plants with 40% and co-generators (mostly bagasse fueled generators) with the remaining 8%. It is important to mention that due to discrepancies in the available data sources, this numbers might be different to the actual values. Most sources agree that hydroelectric plants provide 40-52% of the total electricity, co-generators however might be actually providing with up to 20% of the total offer.

Despite a large part of the population having a poor income and relying heavily on firewood electric service coverage is surprisingly high, reaching 85% on a national level, with the capital and some surrounding provinces reaching over 95%, and other provinces below 50%. The per capita consumption is about 550 kilowatt-hours annually[5].

[4] Newspaper Siglo21 http://www.s21.com.gt/node/14104
[5] World Bank http://datos.bancomundial.org/indicador/EG.USE.ELEC.KH.PC

2.3. Legal and institutional framework for renewable energy sources

Apart from importing energy, many of the natural resources the country has been exploited through history, but in the early 1970's they began to be used on a more generalized level. Since then the use of solar wind, hydro, geothermal and anaerobic bio-digestion to produce biogas as fuel have been forms that have been promoted. The increasing energy demand prognoses exceed supply levels, thus this development has raised concern in both the public and the private sectors. Concerned because of this problematic, the government, and more specifically the Ministry of Energy and Mines which is responsible for defining the national energy policy to lay out the actions that needed to be followed, has been negotiating possible plans of action. The Department of Energy Planning and Development Unit of the ministry is responsible for the study, promotion, management, supervision and control of everything related to renewable energy. In 1986, the oil crisis affected Guatemala as it exacerbated its dependence on imported petroleum products, therefore the government needed to create a law to promote the use and exploitation of renewable sources of energy. Consequently during that year the Decree Law 20-86 - the Law for the Promotion of New and Renewable Sources of Energy - declared as a public utility and as a necessity the implementation of energy policies to promote the development, promotion and efficient use of new and renewable sources of energy. Decree Law 20-86 has been an instrument through which the actions of development projects that are executed and the use of renewable resources promoted and coordinated. Such as: solar radiation, wind, water, biomass and any other energy source other than nuclear energy or the production by hydrocarbons. Benefits to the owners of private entrepreneurship owners in the form of tax incentives have also defined in this milestone decree.

This Decree's main objectives are:
- The reduction of domestic oil consumption;
- The enhancement of energy supply in rural areas;
- The improvement of the living standards of the population and;
- The rational use of natural resources.

Additional benefits were obtained through the decentralization of power supply, economic benefits (bigger competition) and also greater reliability in the electrical system thanks to the geographic decentralization of service, with meant a significantly lower probability of blackouts. In Guatemala and throughout Latin-America in general, the greater the number of available plants and the greater the geographical dispersion means a lower chance of blackouts.

The regulation of the Law on the Promotion of Development of New Sources and Renewable Energy stipulates that individuals or legal entities involved in the development implementation and maintenance of projects, must submit to the Directorate General of Energy Planning and Development, a proper written request containing:

- The identification of the individual or entity interested in implementing a project;
- A description of the benefits sought and time required: a detailed list, specifying description, quantity, cost tariff heading and purpose or use within the project, machinery and equipment;
- A study of the technical and financial feasibility of the project;
- An Environmental Impact Assessment, adopted by the National Environment Commission, for projects within the following cases: hydroelectric power plants over 1 MW which involve the construction of dams, tunnels or slopes; projects designed for the burning of biomass; projects that use wind energy for electricity generation with an installed capacity of 50 MW or more; projects that use solar tracking system with automatic orientating panels that use Freon-12 or other similar contaminating fluid; projects based on solar temperature gradients whose purpose is to obtain mechanical power of 500 kW or more;
- So-called energy forests of a single specie over a continuous area more than 0,5 km^2 or such forest that would grow into another energy forest, that if combined would have an area greater than 0,5 km^2; projects with photothermal panels of more than 5 kW of power, located in the same area; projects of photovoltaic panels more than 500 kW or a panels area of 7.000 m^2; projects whose biodigestion anaerobic fermentation volume is greater than 500 m^3 per unit of fermentation;
- For water projects with a capacity of over 10 MW: A geological description by person trained in geology, hydrogeology or geotechnical engineering, related to the dam, landslides and slope stabilization; hydrological study for a period of time to establish the feasibility of the project; description of the construction specifications of the dam, spillways, canals, adduction, sedimentation tanks, pipe tunnels and pressure, according to project.

2.4. Cogeneration in Guatemala

Coming back to the generation of electricity, cogeneration is increasingly gaining on importance. Cogeneration in the context of energy production commonly means "the production of electricity and heat through the use of the by-products that result from a process in an industrial or manufacturing plant[6] that is connected to the grid. The most common products can be wood waste (sawdust), the bagasse from sugar cane and others that can be later on be burnt as fuel. The systems commonly used include industrial cogeneration using waste heat from the plants processes as well as total energy systems, i.e. the plants are feeding the surplus in energy back to the grid. Developing countries such as Guatemala are actively promoting the participation of the private sector in electricity generation, which has been traditionally managed by the public sector. Cogeneration from biomass offers a higher performance both from an energy and economic point of view, and it also has environmental benefits and a greater reliability, since it allows for a decentralized power generation. Moreover, as it is a (by)product of a renewable resource within countries border, it saves on foreign exchange, lowering the country's dependence on major imported products. Such imported products are for example gasoline and petroleum products.

Cogeneration in Guatemala is carried out by burning sugar cane bagasse as a source of biomass at the many sugar cane processing facilities (such facilities are widely called *ingenios* in several Latin-American countries). Due to the seasonal nature of sugar cane cultivation, it can only be optimally exploited during the months from November to May when the harvesting is done. However, for both the *ingenios* and the country, it is necessary to have a stable source of electricity. Today there are twelve *ingenios* that have been qualified by the Department of Energy Planning and Development to operate; six of them hold a contract with the Guatemala Electric Enterprise, for the cogeneration of electric power linking their facilities completely with the national grid. After having signed such contract some of the *ingenios* even had to reform their facilities, which could be seen as a sign that the costs of reforming are lower than the profits received.

[6] Websters Online Dictionary http://www.websters-online-dictionary.org/definitions/COGENERATION

To this, the national congress approved Decree Law 57-95 –The Alcohol Fuel Act– not long ago that allows companies to generate electricity from energy sources of *any* kind during periods in which there is no availability of renewable energy sources, while allowing certain companies to continue to enjoy the benefits that the law provides them during their operation of renewable sources. This provision addresses the issue of cogeneration of electricity from the burning of sugar cane bagasse. However, one of the objectives of the Law on Promoting the Development of New and Renewable Sources of Energy is "the reduction of domestic consumption of oil", as such there is a contradiction with the substance of this newer law, as this other provision authorizes the use of hydrocarbons in times of shortage of renewable energy source exists.

3. The Sugar Cane Industry

This chapter provides an overview about sugar cane and its importance in the Guatemalan market.

Sugar cane (saccharum officinarum) is a plant originally from south-east Asia. It was brought to Europe during the Muslim expansion. Later the Spanish took it to the Canary Islands and then to the American continent. The cultivation first started in countries such as Cuba, Brazil, Mexico, Peru, Ecuador, Colombia and Venezuela, who are nowadays among the largest producers of sugar in the world. The juice of the cane is the source of sugar. After harvesting the cane, it passes under shredders, and then it moves onto the mills, where the juice is extracted. The juice is purified by a series of filters, then subjected to a clarifying treatment and placed in vacuum cooking tanks where the juice is concentrated and, finally, it turns into dense crystallizing sweet juice, known in Guatemala by the sugar producers as "honey". Once the sugar has crystallized, the remaining water is removed thus leaving the standard white sugar that is commonly known as table sugar.

In Guatemala, in areas where sugar cane is harvested, people also enjoy chewing on fresh sugar canes for its juice, and also its fresh juice is sold in paper cups or cones shortly after it has been removed using a machine for that purpose.

Sugar cane is widely cultivated in the southern parts of the country. It is grown in tropical and subtropical climates, and it grows best in warm climates with a lot of sun exposure. Different organisms in the sugar cane's roots can fix atmospheric nitrogen, allowing its cultivation in many areas even without any application of nitrogen fertilizers. The current plantation area is 2.134,5 km² with a calculated potential of 3.420 km², located on the coastal plain of the Pacific Ocean between coordinates Latitude N 14°00'-14°40', and Longitude W90°30'-91°45). This area is heterogeneous in nature due to the gradients altitudinal that begin at the ocean and rise to 800 m above sea level, the different soil types and a rainfall of 1500mm to 4000mm per year. Moreover the yield of sugar by km²-unit is different when these are grouped by altitude. However, a relationship between the altitude gradients with different climatic factors, soil types, different rainfall patterns and sugar yields allow the identification of three layers limited by their altitude. Following layers were identified in a study by: Layer 1 or High Zone> 300 meters over sea level; Layer 2 or

Zone Medium 100 to 300 meters over sea level; and Layer 3 or Zone Low Below 100 meters over sea level (Orozco 1995:7). The exact location of current sugar cane plantations and processing facilities can be found on the maps provided in chapter 3.1.

Sugar cane can grow in almost any soil but does best in loamy, deep and well drained soils. It should be planted preferably in soils with a pH value of 7,4 but it can be grown in soils with a pH range of 5,5 to 7,8. The sugar cane's high nutritional requirements, in regard to the high amount of green and dry matter that it produces, depletes and exhausts the soil quickly and thus requires a proper fertilization program. On the other hand, it is very efficient in its use of sunlight. Sugar cane requires also large amounts of water yet it is at the same time relatively efficient in its use. The minimum precipitation is 1500 mm per season. If rainfall is not sufficient to cover that amount, it can be artificially irrigated as well. It usually grows at a height of between 0 and 1000 meters above sea level. It requires a warm humid climate, alternating with dry periods and temperatures between 16 and 30 degrees Celsius. Its harvesting can be mechanical or manual, or a combination of both (Pérez J. and Pratt 1997:4-5). In spite of increasing competence from other sweeteners, sugar production is still highly important to the national economy. According to official data, sugar accounted for 8.6% of all exports, bringing 726 million US dollars to the economy[7].

The cultivation of sugar cane is widespread in the Americas due to advantageous weather conditions, which lead to its popular production. Some countries in Latin America are nowadays successfully working with a further by-product, ethanol. The most prominent example is Brazil, which has become the largest producer of ethanol from sugar cane. In 1975, Brazil the *Proálcool* program began as a response to the oil crisis of that time. Through this program the government took a series of measures such as supporting investment and ensuring demand and prices. In 1990, *Proálcool* ceased to exist as a governmental program and between 1997 and 2002 its support mechanisms were withdrawn. Currently, ethanol is competitive with fossil fuel and consumes half of the sugar cane harvest for ethanol production. Colombia began its ethanol program in 2001 with Law 293, which states that gasoline must contain oxygenates such as alcohol compounds fuels. The program included a series of incentives and government policies. The use of exploitation of

[7] Ministry of Economy 2011 http://www.mineco.gob.gt/Presentacion/Estadisticas.aspx

this by-product has also been attempted in Central America. Three countries, Guatemala, El Salvador and Costa Rica produced ethanol in the 80's, but were unsuccessful due to poor quality and marketing, among others factors. Currently, they are pushing back the production of ethanol and the relatively small amount that is produces is rather exported it to other countries, than being further processes or exploited.

The following Table 3 gives us an overview of the sugar cane production in Guatemala for the period 1989 to 2009 based on data from the Food and Agriculture Organization of the United Nations.

Sugar Cane Production in Guatemala					
Year	*Production (tonnes)*	*Production Yearly Δ*	*Harvested Area (km²)*	*Area yearly Δ*	*National Area*
1989	7.615.300	...	888,3	...	0,816%
1990	9.603.100	26%	1.120,0	26%	1,029%
1991	10.798.800	12%	1.225,0	9%	1,125%
1992	11.307.600	5%	1.259,3	3%	1,156%
1993	11.741.100	4%	1.291,5	3%	1,186%
1994	11.862.400	1%	1.295,0	0%	1,189%
1995	15.443.800	30%	1.386,0	7%	1,273%
1996	15.582.900	1%	1.785,8	29%	1,640%
1997	17.687.000	14%	1.540,0	-14%	1,414%
1998	18.189.400	3%	1.800,0	17%	1,653%
1999	17.012.800	-6%	1.820,0	1%	1,671%
2000	16.552.400	-3%	1.820,0	0%	1,671%
2001	16.934.900	2%	1.820,0	0%	1,671%
2002	17.489.900	3%	1.863,4	2%	1,711%
2003	17.400.000	-1%	1.920,0	3%	1,763%
2004	20.000.000	15%	2.260,0	18%	2,075%
2005	23.454.000	17%	2.715,5	20%	2,494%
2006	18.721.400	-20%	2.333,3	-14%	2,143%
2007	16.548.200	-12%	1.901,9	-18%	1,747%
2008	16.226.400	-2%	1.885,8	-1%	1,732%
2009	18.391.700	13%	2.134,5	13%	1,960%
Increase 1989-2009		242%		240%	

Table 3: Sugar Cane Production in Guatemala
Source: FAOSTAT 2011

Compared to twenty years ago, production has increased by more than doubled and is currently at around 20 million tones of sugar cane. The median value of production for the years 1999 to 2009 was 18.066.518 tonnes and a median harvested area of 2.043 km², which translates to 8.843 tonnes of harvested sugar cane per square kilometer on average. In regards to GHG emissions, it might interesting for the reader to know that increasing the cultivated area does not increase the amount of CO_2 emitted, but it does so for N_2O, as it the fertilizers used contain this particular gas, this will be discussed in chapter 3.2.3. CO_2 on the other hand increases because of the use of fuel powered machines used for transportation.

Each tonne of sugar cane produces 13,5% (Stanmore 2010:1) of its weight of fibrous bagasse (dry weight, or 30% of its wet weight), i.e. 135 kg of dry bagasse per tonne of sugar cane, which as a result gives us an estimated 2.483.000 tonnes of dry bagasse for the year 2009. According to Stanmore the specific energy content is approximately 19 GJ per tonne of bagasse.

Theoretically, the amount of bagasse produced in 2009 contains almost twice as much energy, as the whole country required for 2010, 28.375 TJ (7.882 GWh) [8]. In practice, the currently installed technology at sugar mills thought the country delivers a conversion efficiency between 5% to 20%. Differences in the technology used (age of machinery, human error, etc) and in the molecular constitution of the baggage itself (water, lignin, glucose content, etc) are the reasons behind the wide changes in efficiency, with water content, in other words, the moisture level in the bagasse, being probably the most weighting parameter. Water content, more often than not, accounts for 50% of the bagasse weight. Even at a low conversion efficiency of 5%, the amount of bagasse produced in 2009 would have been enough to cover 10% of the country's electricity demand. The reason why this number is not being reached might be the fact that there is an excess of bagasse that surpasses the current processing capacity of the furnaces, so that surplus bagasse that can neither be stored on site nor burnt needs to be transported away from the *ingenio*, to be either sold to cattle ranchers or simply thrown away.

In the following chapter we will take a look at the core of this work, at the sugar cane bagasse. How it is created, processed, disposed of as well as its emissions through burning and emission reduction potentials.

---

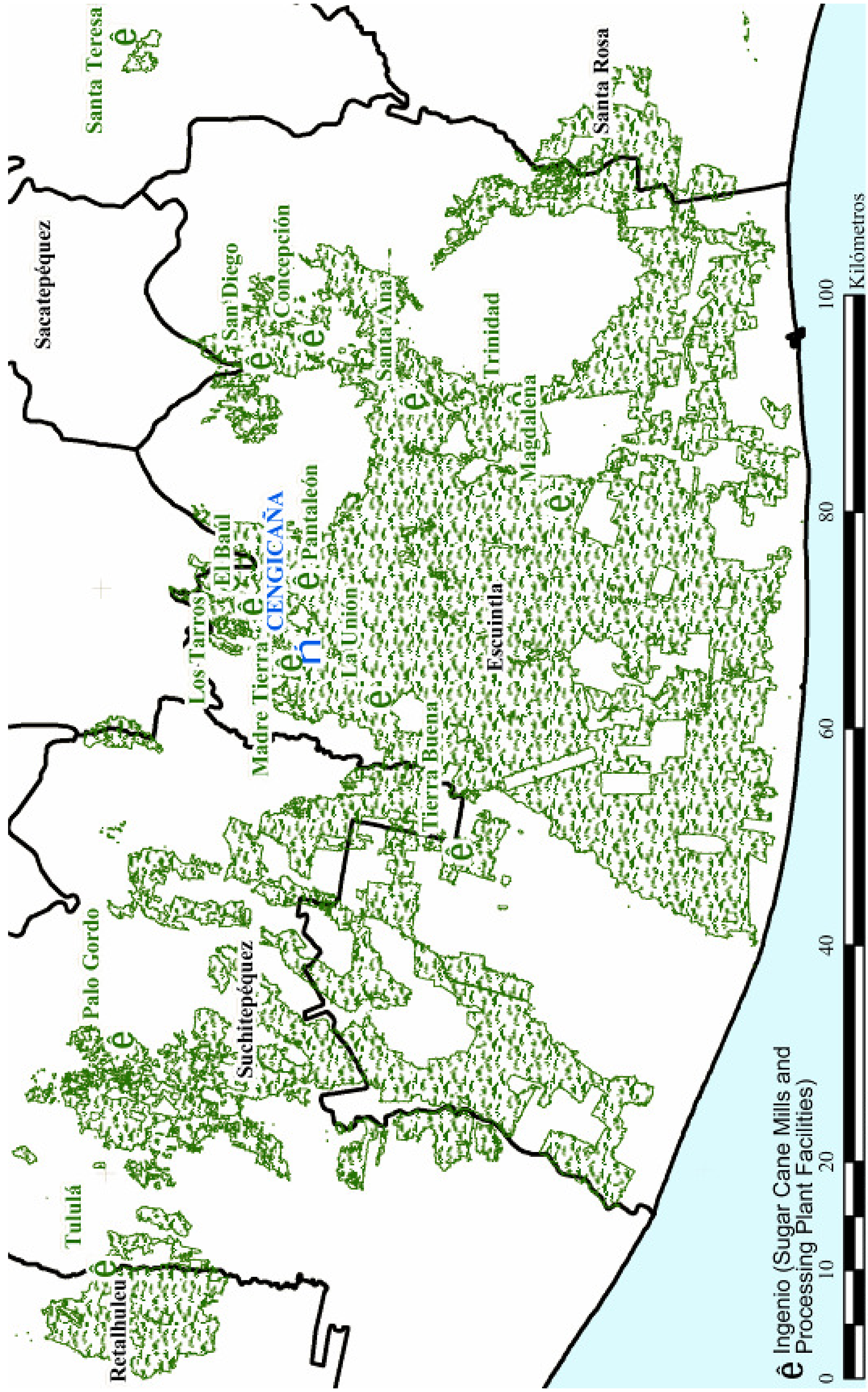
[8] National Energy Commission (CNEE) http://www.cnee.gob.gt/xhtml/informacion/Estadistica-mercado.html

3.1. Maps and Sugar Cane Processing Facilities

Source: United Nations Department of Peacekeepeing Operations, Cartography Section 2004; and Cengicaña 2006

Map 1: Map of Guatemala and its Land Use for Sugar Cane (in green).

Map 1 shows us the land coverage dedicated to the plantation of sugar cane. It growths in areas with a tropical or subtropical weather, with a height of 0 to 1000m over the sea level. This location is dictated by the plant's particular requirements. It grows best in areas with a high solar exposure and requires large quantities of water, a precipitation of at least 1500mm per harvest and a humid and warm climate, alternating with a dry season and temperatures between 16 and 30°C.



Map 2: Close-up with Detailed Locations of Sugar Cane Mills and Facilities (*ingenios*)
ê marks the location of *ingenios*, and ñ marks the Centicaña research center

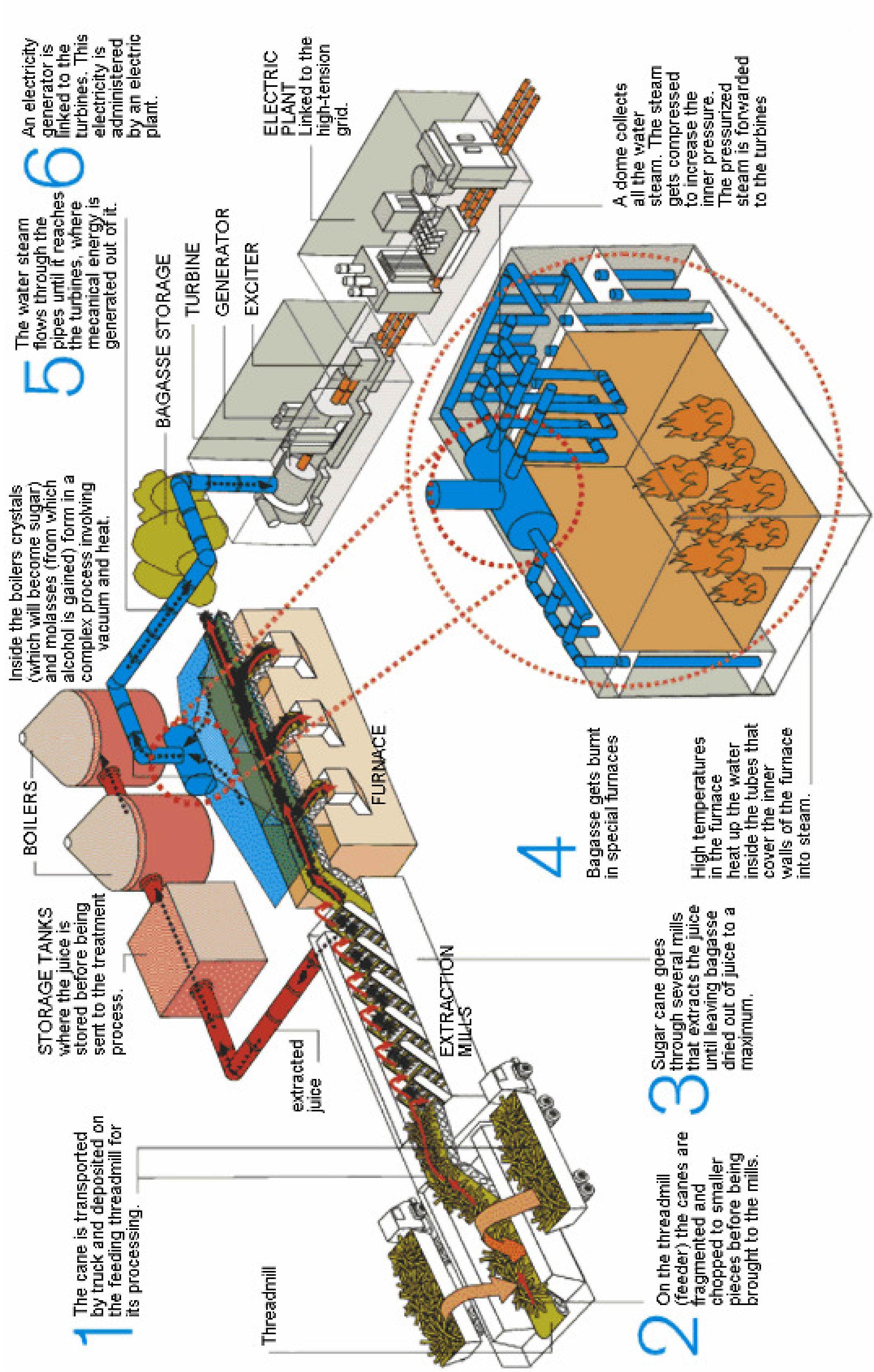
3.1.1. From Sugar Cane to Bagasse

As defined by the Encyclopædia Britannica bagasse is the "*fiber remaining after the extraction of the sugar-bearing juice from sugar cane. […] In modern use, the word is limited to the end product of the sugar cane mill. Bagasse may be used as fuel in the sugar cane mill or as a source of cellulose for manufacturing animal feeds. [..]*"[9]. As the by-product of an agricultural process, the properties of the produced bagasse can differ greatly. First comes the harvesting, where the large canes are cut and collected with trucks and brought to the mill plants. Once at the plant, the canes are inspected to determine the quality of the sugar cane crop, as well as its sucrose, fiber and impurity contents. It is weighed and washed. Some of the shipment is sent away for storage and later use. If the canes are to be processes immediately, they are put through a chopper, where the naturally large canes are chopped down into smaller pieces. The sugar cane finally arrives at the mill, the most important part of the sugar extraction process. Here the sweet juice is extracted from the cane by pressing it out. Hot water is used during this to extract the sucrose, which contains fibrous material. Bagasse is what is left over from this process. If the bagasse at a particular plant is to be used as fuel, this is the step during the process where it would take place. The surplus bagasse is sent to storage. The bagasse to be used as fuel is sent to the furnace, where it is burnt using different mechanisms. The heat produced causes water that runs through pipes inside the furnace to heat up into vapor. This vapor is then forwarded to the cogeneration part. The level of moisture in the bagasse must be brought and maintained at 50%. If not properly controlled moisture levels are most likely to increase, which would then result in poor and inefficient results during combustion. The steam, or vapor, is then used to turn turbines, and then the turbines turn the mechanical movement into electricity by turning a generator. The generator is connected to a linkage plant that is connected to the grid. The linkage plant "sells" excess electricity to the grid, and "buys" if there is a shortage. This process is explained with more details on the picture on the following page (Diagram 1).

The surplus bagasse is later used during off-season operation of the plant. If the bagasse is neither turned into energy nor stored for later use, the bagasse might be disposed of as industrial trash at the municipal landfill or be sold to ranches as food for their cattle.

---

[9] Encyclopædia Britannica Retrieved 22.Mai.2011 **http://www.britannica.com/EBchecked/topic/48728/bagasse**



SOURCE: CASTA.net; original diagram by Byron Moreno ©2007 Grupo Nación GN, S.A.; Traduction and adaptacion by author.

Diagram 2: Sugar Production Process

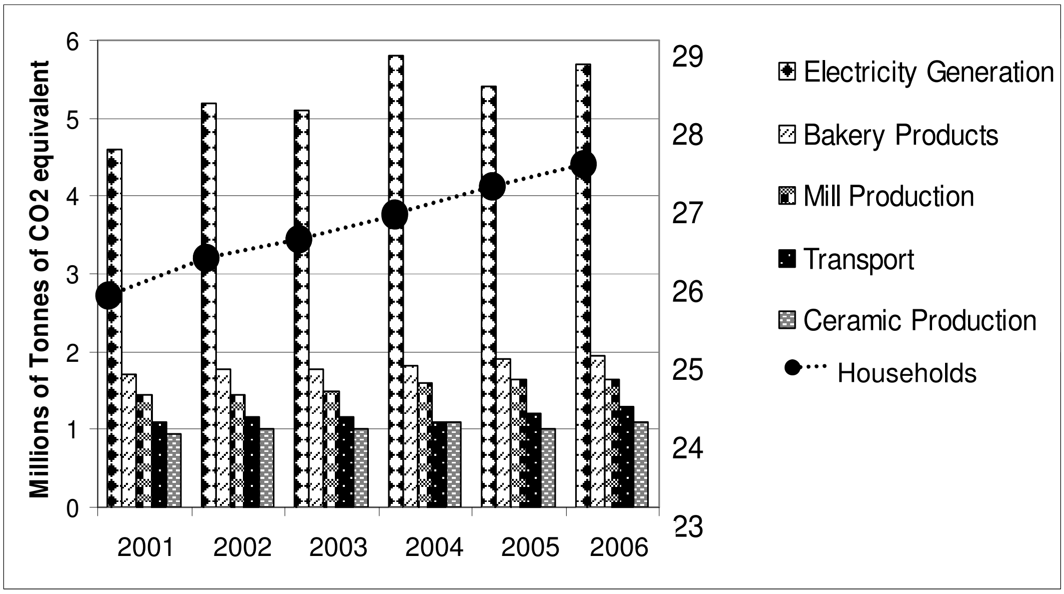
3.1.2 Emissions from the Sugar Industry

There has been extensive talk and research on biofuel production and its potential to reduce emissions of greenhouse gases, which can be sold on the international market through the Clean Development Mechanism as specified in the Kyoto Protocol. Emission reductions generated by replacing fossil fuels with biofuels is possible, although there is a certain amount of emissions caused by the activities in the entire chain of production of a biofuel project. The use of fertilizers, which generate N_2O, the carbon content of methanol and others, generate significant emissions of CO_2, so it must be maintained that with the combination of all factors there is actually a net reduction in emissions. It was also estimated net reduction value of 2,45 t CO_2 per tonne of biodiesel. This is true for countries that have and advances biofuel sector, such as Brazil or Venezuela, but not for Guatemala with a virtually non-existing biofuel market.

An additional way of reducing emissions is provided by the absorption capacity of carbon that the plant possess, due to the fact that the plantation sequestrates carbon during photosynthesis. This is why an increase of the land used for the plantation does increase CO_2 emissions, other that the ones generated indirectly. This represents an important factor in the reduction potential, with the precondition that there has been no deforestation for the planting. (Ramírez 2008:3).

When it comes down to the different GHG emitted by the industry, we need to bring carbon dioxide, nitrous oxide and methane among many others to a common denominator to gain a better overview of the extent of their damage potential since these gases are closely linked to the processes of global warming and climate change. For this purpose the reports drafted by the CIEE have aggregated these gases according to their equivalence in terms of the global warming potential of carbon dioxide over a 20 year horizon. It has been reported that the Guatemalan economy contributed a total amount of 45,6 million tones of carbon dioxide equivalent in 2006 through all greenhouse gases emitted through human origin activities. Although in general terms, it is less than 0,34% of total emissions in the world, it is important to consider the sources of these emissions, given the agreements and negotiations that may result from initiatives like the Kyoto Protocol, which can bring financial and other types of assistance, benefits or obligations

(IARNA 2009:6). The extensive use of firewood in households as a source of energy has already been brought forward, and once again we must focus our attention to it. Within the five most GHG-intensive economic areas and their specific activities household energy consumption and its emission are on top of the list. It considerably exceeds emissions to that activity in second place as Diagram 2 shows:



Source: Instituto de Agricultura, Recusos Naturales y Ambiente, Universidad Rafael Landivar
Diagram 2: Energy Consumption by Activity

The left axis (with the values 0-6) shows for the bars, the amount of millions of tones of carbon dioxide equivalent that the five heaviest emitters within economic all activities generate, at the same time the right axis (23-29) shows for the dotted line the emissions of households. As it can be seen, households emit a much higher level than other activities. For example, in the year 2006 27 million tones of CO_2 equivalent were emitted by households, compared to 5,8 million tones for the generation of electricity. This is due mainly to the high carbon content of firewood and its widespread of firewood use by the Guatemalan population, although these households are also strong emitters from the combustion of gasoline, as there are virtually no rail connections in the country and the use of bicycles is limited to short rides. Additionally, the major pollutants among the bar indicators are interestingly those emissions that come from the activity of electricity generation, exceeding twice the activity that follows, i.e. the production of bakery products. This situation is consistent with the same problem of the still widespread use of fossil fuels in that activity. The preparation of bakery products in this list, this as well is linked to its high consumption of fuelwood, especially on the country side, outside of urban hubs, where the bakers bake their products in traditional ovens. If we were to ignore the consumption of firewood in this figure, bakeries and other grain mill products would disappear from the list, and be replaced by cement manufacturing and wholesale trading. Additionally, transport and its high emissions from the combustion of diesel and gasoline also play an important part in this context, like the ceramic manufacturing industry, given its high consumption of fuel oil to run the boilers (CIEE 2009).

3.1.3 Emissions from Bagasse Burning

This chapter refers to the emissions caused by the burning of bagasse. There are different methods to fire up the boilers. Such option could be fuel cells, horseshoe boilers or spreader stokers. Fuel cells and horseshoe boilers are commonly found inside older facilities. In such mechanisms bagasse is fed down through chutes by gravity and piles onto a hearth. The primary air for the combustion flows through openings in the walls, and the burning begins on the top most pile. In the newer facilities, bagasse is burnt in “spreader stoker” boilers, where it enters through a fuel tube and is spread around the furnace where parts of it burn while flying. At the same time part of bagasse that are too thick and are not burnt right away fall onto a bed on a grate, where a flame burns the larger pieces (US Environmental Protection Agency 1996 1.8-1).

Emissions levels depend highly on the technology used and on the properties of the processed bagasse. Relevant data from the power plant was collected either from daily reports of the power plant or experimental analysis. The relevant data consist of all of materials consumed and emissions to the environment. Energy, water and material balances were drawn in this step, which are useful to account for all the energy and material flows in the system.

In regards to the actual energy made available through the burning of bagasse, it has been argued that a tonne of sugar cane produces about 300 kg of bagasse with a calorific value of 7900 GJ / t, which is lower than that of dry wood (16 000 kJ / kg). On the other hand, the production rate of bagasse is faster. Bagasse is being used for the production of electricity at most of the *ingenios* in the country since the performance of some of the facilities enables them to even operate autonomously from the electricity grid. From a world wide perspective, the exploitation of 1500 mega tonnes of the bagasse produced that produce 200 million tonnes of bagasse represent a theoretical energy source of 3,8 $\times 10^9$ GJ. (Stanmore 2009:1).

Compared with fossil fuels burned at power plants, sugar cane bagasse has the interesting property of being of a bagasse without sulfur dioxide, being a by-product that used to be considered waster material, and not emitting the CO_2 made available to it during its growth, i.e. releasing a near-zero quantity or zero in most cases because the cane absorbs CO_2. The CO_2 absorbed and retained inside its tissues trough autotrophic processes are stored in the sugar and thus removed once the sweet juice has been extracted.

Additionally to GHG emissions, there are also more locally important pollutants, such as particulate matter. Particulate matter that is caused by the turbulent movement of gases during the combustion inside the boilers is the most significant pollutant. Sulfur dioxide and nitrogen oxides emissions are low when compared to fossil fuels because bagasse itself contains only low amounts of these molecules. Problems can arise during preparation or production process, e.g. the sugar cane is improperly washed. When the bagasse contains too much water to sustain combustion, it might have to be replaced by fuel oil, natural gas, or other residues available. These variations in the process can lead to abnormal combustion condition that result in increased emission of carbon monoxide, unburned organics (volatile organic compounds and total organic compounds).

There problems are countered by applying filtering mechanisms, such as collectors and scrubbers. The removal efficiency of such mechanical collectors is 20%-60% at time on installation but will decrease over time due to the abrasive nature of the bagasse's fly ash. Wet scrubbers have an efficiency of about 90%. Widely used wet scrubbers are the impingement type, which is more energy efficient and develops less problems than other types, such as the venturi scrubber type. Fabric filters and electrostatic precipitators, have on the other hand, not been widely used in combating particulate matter from the bagasse-fueled boilers as they are more expensive. Fabric filters are also dangerous, as they can pose a fire hazard.

Moreover indirect fuel emissions occur when transporting the sugar cane from the fields to the facilities using very old trucks.

Pollutant Emissions from bagasse-fired boilers kg/t			
Pollutant	Uncontrolled	Controlled	
		collectors	wet scrubber
PM	7,02	3,78	0,63
PM10			0,612
CO_2	0,702		
NO_x	0,54		
Polycyclic organic matter	0,00045		

Table 4: Pollutant Emissions from Bagasse Fired Boilers
Source: US Environmental Protection Agency

Table 4 shows how many kg of pollutants are emitted into the local environment by burning one tonne of bagasse using different filtering methods.

The operations of the sugar production processes that cause CO_2 emissions to the environment can be grouped into the following two impact categories: those that represent a net contribution to the level of CO_2 in the atmosphere and that come from burning fossil fuels. Such processes are for example harvesting, transportation, fertilizer and pesticides and herbicides; and secondly those processes associated with the sugar manufacturing process, where the source of energy is bagasse and CO_2 emissions are offset by sequestrating it during its growth.

The processes that emit CO_2 during the sugar production are: combustion of bagasse in the boiler, and combustion of alcohol production, and production and combustion of biogas. The amount of CO_2 emitted during combustion of bagasse is 885 kg CO_2 / t of bagasse, at 50% humidity. We know that 60% of the produced bagasse is used as fuel, generating 1.352 GWh (for 2009). Those 1.352 GWh were generated out of the annual production of 2.483.000 tonnes of dry bagasse, out of which 1.489.800 tonnes ultimately burnt for cogeneration. At 50% humidity they caused 659.236 tonnes of CO_2 according to these calculations. Therefore the tradeoff is 659 g of CO_2 emissions per 1 kWh. This fares relatively well when compared to coal 800-950 g CO_2/kwh, or 350-650g CO_2/kwh for gas[10]. Moreover these emissions do not take into consideration the negative emissions cause by the sequestration during the plant's growth, that is now stored in the sugar.

[10] Parliament Office of Science and Technology
http://www.parliament.uk/documents/post/postpn268.pdf

3.2. Possible Usages

This chapter deals with the identified possibilities of the possible usages for bagasse in different scenarios.

Depending on who owns and runs the facilities, the age and the capabilities of these facilities, there are different extended usages for bagasse. The bagasse could be, for example, brought back to the fields, dumped along with the harvest's residues and left to decay under aerobic conditions (left to the uncovered, exposed to the wind and weather). It could also happen that the field owner covers up the residues with enough soil that its decay becomes anaerobic. Older facilities might burn the bagasse without capturing the energy release by its combustion, be it with or without emission filters. If the facility is equipped for this purpose, the bagasse will be burnt directly at the site and the energy released from this process captured and transformed into electricity or heat. This electricity can be fed back to the grid in the process of co-generation; the heat is used in the facilities' boilers[11].

Moreover, there are further options that are not that widespread at the moment in Guatemala. The bagasse could be used at paper manufacturing plants, as it has a high fibrous content. The biomass from the process can be used to generate biofuels. One more newly developed process is to carbonize the dried bagasse in an steel kiln and to compress the charcoal fines into briquettes used later for cooking (Ramirez 2005:8).

3.2.1. Usage as an Electricity Source

As it has been expressed before, the use of bagasse as fuel for the production of electricity has never been more widely used before, and there are good reasons for that. This section will not focus on how the electricity is generated, nor on what their emissions are, for these topics have already been discussed in sections 3.1.2 and 3.1.3. It rather focuses on historical statistics that provide us with a clear picture of the trends in the development of bagasse cogeneration.

[11] Avant-Garde. Engineers and Consultants http://www.avantgarde-india.com/techpapers/Bagasse_Cogeneration.pdf

The continuing oil price hikes and the dependence of Guatemala and other Latin-American countries on fossil fuels have led the search for alternative energy sources to meet their needs. In this regard Guatemala has had luck, since most of its neighbors do not have such an extended sugar cane production. Table 5 below gives us an overview of the continuously increasing bagasse cogeneration for the previous twelve year.

	Energy Production (GWh)		
Harvest Year	**Bagasse only**	**with Fuel Oil**	**TOTAL**
1997-1998	332,55	192,25	524,91
1998-1999	351,79	296,17	648,54
1999-2000	411,51	347,61	759,13
2000-2001	403,70	245,65	657,83
2001-2002	547,61	195,00	726,15
2002-2003	541,99	189,92	734,50
2003-2004	718,48	105,53	824,01
2004-2005	886,60	98,71	985,31
2005-2006	957,00	62,80	1.038,22
2006-2007	1.199,95	46,14	1.246,09
2007-2008	1.215,23	34,23	1.249,47
2008-2009	1.363,52	38,34	1.401,86

Table 5: Energy Production in the Sugar Cane Industry
Source: Guatemala Center for Sugar Cane Research and Training CENGICAÑA. Statistical Bulletin Year 10 Nr. 2 November 2009

One can see the use of bagasse has increased more than a four-fold while its dependence of fuel oil has dropped by four fifths. These numbers are indeed exciting. Nonetheless not all of the energy that was produces is made available to the grid. The next table, Table 6, gives us a more detailed break-down of how the energy generated by the burning of bagasse comes from and also where it ends up.

Total Electricity Produced by Bagasse Only (in GWh)												
Ingenio	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Concepción	38,82	38,05	33,16	29,09	44,39	61,84	82,18	98,84	93,25	124,15	110,89	123,27
La Unión	N	79,99	83,02	86,84	105,03	109,54	135,45	162,57	148,53	180,97	170,35	198,43
Magdalena	68,82	57,31	85,87	64,27	96,17	102,14	122,43	154,52	227,54	240,34	285,59	371,07
Pantaleón	109,39	96,12	113,02	116,03	152,73	139,37	205,63	278,16	251,15	289,66	267,36	257,15
Santa Ana	64,74	41,88	52,54	60,73	69,26	65,21	93,35	98,77	106,09	152,63	168,22	186,25
Madre Tierra	50,79	38,45	43,89	46,74	51,31	43,69	53,1	64,41	96,86	119,68	99,75	103,88
Tulula	...	...	...	...	28,94	20,21	26,33	29,34	33,59	53,96	48,87	55,27
San Diego	...	...	...	...	...	...	0,31	2,48	2,29	10,92	14,42	13,35
Trinidad	...	...	...	...	...	...	...	...	12,81	27,65	45,71	43,96
Total	**332,55**	**351,8**	**411,5**	**403,7**	**547,83**	**542**	**718,79**	**889,08**	**972,1**	**1.200**	**1.211**	**1.352**
Electricity Consumed Internally (Bagasse and Fuel Oil combined; in GWh)												
Ingenio	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Concepción	28,15	23,51	23,75	20,47	22,52	25,14	27,62	32,19	30,62	36,91	36,17	39,1
La Unión	N	28,56	25,4	29,12	34,61	38,28	42,09	51,6	47,4	57,11	53,78	70,87
Magdalena	28,02	24,74	32,12	31,57	45,87	54,99	61,31	71,15	98,06	133,91	144,06	153,34
Pantaleón	44,08	35,08	38,15	39,78	51,86	50,34	72,27	98,1	88,14	99,9	89,03	108,34
Santa Ana	32,24	36,04	30,78	33,05	31,86	35,61	35,45	38,33	36,76	53,15	54,94	60,74
Madre Tierra	12,22	11,98	11,73	12,53	12,33	23,42	19,61	21,54	18,93	23,55	21,7	23,81
Tulula	...	...	...	...	10,15	9,15	8,47	7,44	N	17,47	12,35	21,04
San Diego	...	...	...	...	...	...	...	...	N	9,54	11,66	10,78
Trinidad	...	...	...	...	...	...	...	...	N	9,96	17,78	13,85
Total	**144,71**	**159,91**	**161,93**	**166,52**	**209,2**	**236,93**	**266,81**	**320,35**	**319,92**	**441,52**	**441,49**	**501,86**
Surplus Electricity Sold to the Grid (Bagasse and Fuel Oil combined; in GWh)												
Ingenio	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Concepción	56,32	72,48	136,47	94,06	100,82	87,53	85,77	84,71	72,75	92,71	83,95	98,53
La Unión	N	123,81	107,47	85,95	106,74	117,3	108,05	121,2	113,37	126,16	116,05	122,72
Magdalena	37,53	32,19	58,42	51,08	52,9	57,32	61,72	80,34	133,54	129,45	141,72	232,67
Pantaleón	63,12	103,84	113,59	115,66	117,15	109,5	134,55	178,78	159,67	178,44	167,5	142,5
Santa Ana	125,58	66,94	82,81	67,96	61,8	68,97	75,27	89,42	85,27	109,79	111,37	125,98
Madre Tierra	74,2	82,4	80,15	62,73	49,21	39,3	45,04	56,07	68,66	80,21	64,17	66,37
Tulula	...	...	...	..	18,79	11,06	17,86	19,02	33,59	38,53	33,07	39,98
San Diego	...	...	...	...	...	...	0,31	2,48	2,29	1,38	2,76	2,58
Trinidad	...	...	...	...	...	...	...	...	12,81	17,98	23,88	28,02
Total	**356,75**	**481,65**	**578,91**	**477,44**	**507,41**	**490,98**	**528,57**	**632,03**	**681,93**	**774,66**	**744,48**	**859,34**

Source: Guatemala Center for Sugar Cane Research and Training CENGICAÑA.
Table 6: Electricity Generated at the Ingenios
Statistical Bulletin Year 10 Nr. 2 November 2009

Table 6 gives use an overview of the electricity generated by the 9 most important *ingenios* in Guatemala over a period of twelve years. Overall, a clear upwards tendency in the generation of electricity becomes obvious. The only year were this seems to be false, is the year 2008, during or after the economic slowdown. It is important to note that the continued increase of bagasse cogeneration is not linked to an increase in the production of sugar cane, i.e for the year 1998 18 million tonnes of sugar cane were produces, yet the generated electricity was 332,55 GWh.

For the year 2004 20 million tonnes were produced, generating 719 GWh, and for the year 2009 again 18 million tonnes of bagasse generated 1,35 TWh. Therefore not a larger offer of the byproduct is the cause of an increase production, but rather an improvement in the technology or skills were here at work.

For the year 2009 1,35 TWh of electricity were produced from bagasse alone. Let us remember that only 60% of bagasse that is generated is ultimately burnt and turned into electricity. Thus if we assumed the maximum value of 100%, up to 2,25 TWh of electricity could be generated. Then we substract 502 GWh (plus the electricity generated by the added fuel oil) that are required for internal usage that leaves us with 1,74 TWh that could theoretically be fed back to the grid, provided this additional generation has no production losses. That would provide cover almost half of the national electricity demand for 2010 of 3,3 TWh.

3.2.2. Usage as Nutriment

About 60% of the bagasse produced is used as fuel in sugar mills, the rest is to be sold to cattle ranchers (Pandy et al. 2000:69), if possible. The ranchers feed then their livestock with bagasse. Only adult ruminants are capable of digesting the high-fiber bagasse. The FAO categorizes bagasse as forage of low quality, due to their poor nutritional values. Normally bagasse only helps to prevent loss weight in animals, or at least to maintain them alive during food-shortages. However, in case of shortage of food, bagasse can be relied upon. In experiments carried out, it has been shown that by combining bagasse with other already-available by-products it is possible to increase the weight of cattle. In the experiment by Naseeven, mixing bagasse with sugar cane silage (fodder preserved through fermentation in a silo[12]), molasses, urea and small amounts of additional ingredients yielded good results (Naseeven 1986, and Gonzalez-Valadezm et al. 2008:1). However, digestion of bagasse by young ruminant consumes more energy than it is able to supply the animals as has been proven by some studies. Digestibility of its dry matter is usually only 25% but varies greatly from one cow to another; this figure is attributed generally to the spinal matter content with a digestible total of 20% -25% of its weight. It can be used for cattle with food rations high in concentrates, but unusable for dairy cows whose diet should contain at least 14% (of its dry matter basis) of fibers. In normal cattle, it can go up to the dose of 27,5% without affecting their production significantly. The taste of bagasse is improved by mixing the bagasse with molasses (a kind of sugar syrup), up to 55% where this is maximum palatability. The palatability can also be increased by the addition of citrus flour. Molasses is also a by-product of the sugar extraction from sugar canes. Molasses can be produced if so desired by boiling the extracted sweet juice from the canes until it concentrates[13].

It seems that the animals over two years benefit more from bagasse. The digestibility of dry matter for them often reaches 50%. It is comparable to that of hay and therefore used successfully for fattening. However, the addition of ammonia may reduce palatability. Urea appears to prefer as a source of non-protein nitrogen, because when mixed with molasses it does not affect palatability.

---

[12] Dictionary.com 2011 http://dictionary.reference.com/browse/silage
[13] Dictionary.com 2011 http://dictionary.reference.com/browse/molasses

Bagasse and bagasse pith (the soft, spongy central cylinder of tissue in the stems of plants[14]) do well in combination with molasses and there are many blends being produced. Moreover the use of bagasse simplifies transport and handling of molasses, which is normally very liquid and sticky. In hot and humid climate, these products are however likely to absorb water and ferment. It is essential that the water content is maintained below 10% and the storage is done dry. One of the most common blends, the *Camola*, consists of four parts of bagasse pith and ten parts of molasses. The *Molascuit* contains more molasses than any other mixture. It is made by saturating the marrow with excess molasses followed by centrifugation. The proportion by weight of molasses is 6,25 for 1 pith bagasse. (FAO NN)

[14] Dictionary.com 2011 http://dictionary.reference.com/browse/pith

3.2.3. Usage as Fertilizer

Whether bagasse is good for the fields as fertilizer has been a controversial topic, partly because not much was known about the elemental composition of bagasse as it became tradition, and partly because other usages become unavailable from time to time. This chapter tried to shed some light on why bagasse is not such a good fertilizer, and what should be used instead of them.

Sometimes, *ingenios* do not know what to do with the surplus bagasse they have on their hands if they cannot sell it to cattle ranchers. If disposing of it as municipal waste turns out to be too expensive or too tedious, or in the hope that the bagasse will return to the soil and do some good, they might transport the bagasse back to the field and let it decompose. Organic matter normally makes for a good fertilizer. However when it comes to bagasse this is not the case, the elements contained in bagasse are close to zero in terms of nutrients left in the soil left future crops:

Carbon	Oxygen	Hydrogen	Sulfur	Nitrogen	Phosphorus	Potassium	(Ash)
47-48%	44-45%	6,2-6,5%	0-0,35%	0%	0%	0%	0,7-3,2%

(Jaén 2006; Universidad de Oriente)

The nutritional needs of any cane are determined by the total amount of nutrients that will be removed from the soil during their growth and development to achieve a high production. Sugar cane has high nutritional requirements due to its high production capacity of plant material (stems, leaves, strain and roots) and the prolonged duration of its cycle, which is why a high extraction performed soil nutrients, can reach levels of 70-100 t of nutrients per km² and year, highlighted by their number some micronutrients, such as those listed in table 7 ahead.

For this reason, the plantation requires the implementation of an appropriate program of fertilization, which would restore the soil's nutriments extracted by the crop; that is what is lost when the raw material is harvested and processed in the mill.

Concentration requirements for micro and macro nutrients in the tissues (leaves and canes) of sugar cane		
Element	*Critical*	*Optimal*
	in % of dry weight	
N	1,00-2,00	1,50-2,70
P	0,08-0,21	0,08-0,35
K	0,62-1,20	0,62-2,00
Ca	0,13-0,20	0,18-0,76
Mg	0,06-0,12	0,08-0,36
S	0,12-0,14	-
	in ppm of dry weight	
Cu	0,6-5,0	4,0-100
Zn	10,0-18,0	15,0-50,0
Mn	10,0-20,0	12,0-400
Fe	5,00-50,0	20,0-600
Mo	0,04-0,14	1,0-30,0
Si	0,10-1,00	0,05-4,0

Table 7: Concentration Requirements for Sugar Cane
Source: Chavez, DIECA 2009

Table 7 shows what the concentration requirements are for sugar cane (in its dry matter). For this reason the current recommendations by Cengicaña research center suggest a fertilization of 6-8 t/km² for Nitrogen. (Pérez O. 2008:3) .

As Table 7 has shown us, of the many nutrients needed for proper growth and development of sugar canes that are found in all sugar cane areas of the world, the most important in terms of crop response are nitrogen and potassium[15] due to their interactions on growth and yield.. These interactions can be explained by their effects in the growth processes within the plant at celular levels. Even tough potassium is not applied too often keeping it at an adequate level over the long term is important because a deficiency makes the evenly distribution of fresh potash fertilisser difficult throughout the layers of soil where the roots would pick it up. If the sugar cane becomes saturated with water, it will remain turgid and upright provided that its cells contain sufficient solutes to maintain osmotic concentrations within the cell sap. The turgidity (rigidity) is very important for sugar cane to growh high to intercept light. Also, potassium has an additional role when it comes to achieving optimum sugar yields. It is required for the transportation of sucrose the leaf, where they are produced, to the growing parts and to storage organs, in this case, the cane itself. The relationship between potassiuma and nitrogen is that plants will use the

[15]The Potash Development Association http://www.pda.org.uk/notes/tn19.php

later less efficiently and are not able to handle stress caused by heat, water-logging and wind as efficiently. For this purpose it is important to sample and index the soil and its potassium concentration in long intervals and replenish it accordingly.

Policies regarding the replenishment of fertilizer intervals can change from *ingenio* to *ingenio*, even though there are generalized recommendations. Common practice is that the fertilization in Guatemala concentrates on nitrogen. Phosphor gets replaced every 5 to 6 years, potassium even more seldom, or when a new field is established at each one of them.

Nitrogen is one of the most important constituents of the plant as part of amino acids, proteins and other organic components. Its deficiency causes yellowing of leaves, vines of little force and a drastic reduction in yield of cane sugar. The main effects of nitrogen application in the sugar cane fields have been demonstrated in a larger and faster tillering (a larger population of stems, a lesser content of leaves), and also in a more natural rate of increase (more leaves and greater height and more weight per stalk), which determine a higher yield of cane and sugar per km^2. Experimental results have shown that it would be practical apply and average of 8 tonnes / km^2 (5 to 15 t / km^2 depending on soil type) when using the appropriate dose and if it is applied at the time advised. This means an expectation of increased production from 10-40% compared with the same batch unfertilized. For these reasons, producers must assume that fertilization with nitrogen is a technology that can not be neglected if they aspire to achieve economically acceptable yields. The requirements and the amount of nitrogen to be applied depend on the age cane, expected yields, soil type, climate and the presence of constraints such as poor drainage, compaction and salinity, among others. Over 50% of the total nitrogen used by the cane is produced by the mineralization of the organic matter in the soil and the rest should be provided by fertilization. But only between 20% and 50% of the nitrogen applied as fertilizer is actually used by sugar cane. The nitrogen recovery efficiency is closely related to the tonnage of cane per km^2 obtained. Though nitrogenous fertilizers are needed for and good crop yield, the also release N_2O nitrous oxide as a result of microbial action in the soil. For the purpose of calculating how much of this GHG is emitted to the atmosphere the Intergovernmental Panel on Climate Change has established values that could be used to calculate such emissions from nitrogenous fertilizers. This value was set at

1,25%[16] (Officer et all. 2010) for most cases. This amount of the nitrogen applied to the soil for its fertilization is lost to the environment. For the 2.134,5 km² that were cultivated in 2009, between 12.807 and 17.076 tonnes of fertilizer must have been applied (2134,5 times 6 to 8 t of N per km²), causing an emition of 160-213 tonnes of N_2O-N to the environment, equivalent of 47.680- 63.474 tonnes of CO_2 equivalent over a 100 year horizon (at a conversion factor of 298g CO_2 / 1g N_2O). Thus each cultivated km² emits 22-30 tonnes of CO_2 equivalent each year through its fertilization.

If the sugar cane soils have low phosphorus content, it has been established that in these cases the application of additional phosphate fertilizers enhances the harvest yield and soil performance. (Romero, et al. 2004:1-10).

[16] Emission Factor: 1,25% kg N2O-N/kg of N appied as define gy IPCC guidelines http://www.ipcc-nggip.iges.or.jp/public/gp/english/4_Agriculture.pdf

3.2.4. Usage in the Cement Industry

One study conducted by Fairbairn and other from the Department of Civil Engineering of the Federal University of Rio Janeiro methodology established by the United Nations Framework Convention on Climate Change (UNFCCC) presents a way or replacing to some extent cement with bagasse ash from sugar cane. This would mean a reduction of CO_2 emission to the environment in that particular part of the industry. Guatemala has a developed cement and concrete industry of considerably size. In 2009 three million tones of cement were produced. According to the study, bagasse ash maintains or improves the durability of product based on cement.

Using their model and feeding the respective parameters of Guatemala into it, it is possible to estimate the kind of CO_2 reduction potential the Guatemala cement and concrete industry would have if it were to enter into cooperation with the sugar cane industry.

Cement, along with other aggregates and mineral and chemical ingredients are the component of concrete. When mixed together with water, this components react to form a hardening reaction that combines all the aggregates.
There are three mains steps in cement production: obtaining the raw materials; producing an intermediate material called “clinker”; grinding and mixing clinker with other components to create cement. The main raw materials for cement manufacturing come directly from the quarries near the production plants. These materials consist of limestone and shale that are extracted using explosives or tractors. To control the quality of the materials a geo-statistical computer model of the chemical composition of the quarry is used, which ensures the rational use of resources in the short, medium and long term. The next process involves the reduction of size of the materials from the quarry which can have sizes up to 1 meter in diameter by crushing it, during this stage already the first mixture of limestone and shale can be achieved, according to chemical standards for a given type of cement being produced. The feedstock is analyzed to reduce variations in the ratios and stored accordingly. During the grinding, the size of the pieces in the feedstock are reduced further and at the same time humidity is removed before the mixture is send to the furnace. The mills received the crushed minerals, where the feedstock is sprayed and mixed at the same time. The resulting product is a very fine powder,

called “raw flour” with the chemical composition suitable for the type of cement being produced with the least possible variation, for which undergo final homogenization in special silos. The raw “flour” from the silos is fed into rotary furnaces where the material is calcined and semi-molten when subjected to high temperatures (1450℃). Here chemical reactions between the different oxides of calcium, silicon, aluminum and iron occur which combine to form new compounds that are cooled rapidly at the end of the oven. The cooled product has the name of clinker and is usually granular, rounded, of dark gray color. The next step in the process of cement production is the grinding of clinker produced in the furnaces, together with other minerals that confer specific properties to the cement. The gypsum, for example, is used for the setting (or hardening) of the mixture of cement and water, to allow its handling. One can also add other materials as pozzolans or volcanic sand, or as it is being discusses, sugar cane bagasse ash, which produce a more durable, waterproof concrete with a lower heat of hydration than Ordinary Portland Cement, that composed only of clinker and gypsum[17]. The main pozzolans currently used are fly ash from coal-fired and silica fume from metallurgical processing facilities. Other kinds of pozzolans are also being used to a lesser extent (Fairbairn 2009:1).

Concrete is used all over the world as one of the most consumed construction materials, produced in over 80 countries, with the most commonly used type being Ordinary Portland Cement. This is due to its malleability and ease of handling, but also due to its durability, and mechanical properties. Like its raw materials, cement is relatively inexpensive. Unfortunately, its production causes a significant amount of CO_2 emissions with each tonne causing approximately one tonne of CO_2 (Malhotra 2002:22, Hewlett 2005:5) thus the cement industry is responsible for about 5% (sic) of global CO_2 emissions (Worrell et al. 2001: 305). The second step in the cement production (the production of clinker) is the most energy intensive of all and can account for half or more of the emissions from the cement production (OECD/IEA 2000:45). During the process of turning the raw materials into clinker, CO_2 is released due to the heating of limestone $CaCO_3$ that turn into calcium oxide, which is the main oxide in the Ordinary Portland Cement. In this case, to reduce the emissions caused by limestone other mineral additions that would act as

[17] Cementos Progreso “Cement Production” http://www.cementosprogreso.com/main.php?id_area=61

cementitious materials could be used as alternatives to clinker (Malhotra and Mehta and Malhotra 1996:5).

The use of bagasse ash to directly or indirectly reduce CO_2 emissions by acting as an admixture the cement, since it mainly consists of silica SiO_2 (Fairbairn 2009:2). Sugar cane bagasse ash is yet another by-product of the sugar industry that is normally thrown away in Guatemala. If we take into consideration that each tonne of sugar cane produces around 300kg of bagasse (Stanmore 2010:1) and that one tonne of bagasse results in 6,6 kg of ash (Cordeiro et al. 2008:488), we can compute an estimated amount of bagasse ash available. In the year 2009 the industry produced 18.391.700 tonnes of sugar cane, which produced 2.482.879 tonnes of bagasse. This then translates into 36.416 tonnes of ash for that year, that the sugar cane industry could have provided the cement industry with.

According to the model by Fairbairn, how much of a reduction in the emission the inclusion of CO_2 would have can be simulated by simulating a new type of cement; one with a lower amount of clinker (let us not forget that clinker production is one of the most energy intense steps) and that contains sugar cane bagasse ash. As a reference, we need to observe the current practices in the Guatemalan industry. The current practice is that there is 80% of clinker in a tonne of cement by mass. The remaining 20% consist of so-called intersticial material (porous material subject to filling by water), i.e. mineral additives (15%) and gypsum (5%) (Chavarría Moreno 2004:1). This tells us that 2,4 million tonnes of clinker, 450.000 tonnes of mineral additives and 150.000 tonnes of gypsum were produced in 2009 for the 3 million tonnes of cement that were produced.

The production standard for cement in Guatemala NGO 41 005 which is the equivalent to the European EN 197-1 allow for cement production containing mineral additives (i.e. pozzolans, slag and fillers) varying from 6-35%[18] for all type II cements (the restricted type I cement type must contain clinker to a level of 95-100% and additional components for a maximum of 5%). Taking the current standard requirements in Guatemala into account we set the amount of mineral additives to a conservative value of 30% for the cement actually being produces, we would end up with a cement type with 30% mineral additives, 5% gypsum and 65%

[18] European standards EN 197-1 Cement Composition
http://www.interbulk.ch/NR/rdonlyres/A6EF7C06-6E15-488B-8655-08766B702F0E/0/1EuropeanstandardsEN197cementcomposition.pdf

clinker, a savings of one fifth of clinker. We need to assume that the amount of mineral additives, gypsum and the amount of cement demand in the country remains the same. Therefore we assume that the amount of mineral additives remains the same and take the amount of that was produced for 2009, 450.000 tonnes and then use it completely to produce our new test type with a 30% content, we end up with 1,5 million tonnes of cement having needed 1,2 million tonnes of clinker. Half of the amount of cement that Guatemala produced for that year, leaving us with a shortage of 1,5 million tonnes. At a maximum mineral additive content of 35% and 1 million tonnes of clinker produced we would have a shortage of 1,7 million. To fill in for the shortage, another type of cement is created in the model, this one containing sugar cane bagasse ash. In the model a simulation type containing 15% in mass of bagasse ash as mineral additive is created, this creates a new test type of cement with 80% clinker, 15% bagasse ash and 5% gypsum. Hence, to produce the 1,5 million tonnes of cement that are missing the industry would need 225.000 tonnes of bagasse ash, far exceeding the 36.416 tonnes available at the current production level. Importing ash would not be a solution, since this would be linked to transport emissions. However, if we do the calculation in reverse, i.e. trying to compute the best fit for our available ash, we can come up with a ratio that is within the standards and that allows for a reduction in the emissions, however small. For this purpose we go back the current practices in Guatemala of using the ratio 0,80 parts of clinker per 1 part of cement. Thus by "injecting" the amount of available bagasse ash to that of available mineral additive and gypsum (both of which we assume to be unchangeable) it is possible to bring down the amount of clinker needed. Therefore we directly replace clinker by bagasse ash. This results in a mixture of 78,78% of clinker, 15% of mineral additives, 5% gypsum and 1,22% of bagasse ash by mass. Well within the limits of regulating standards. What having used all of the available sugar cane bagasse ash how much CO_2 has been saved? A standardized value for CO_2 emissions for each tonne of clinker does not exist, as it depends heavily on what technology and which fuels are used. Nonetheless it is known that clinker production accounts for at least half of the energy consumption in that industry (OECD/IEA 2000:46). The energy consumption in 1988 was 116 kWh/tonne of cement (Garcia and Torres 1990:3). Even if outdated, if we take the value for 1988 and apply it for the year 2009's production we come up with an energy consumption of 348 GWh in 2009. If clinker required at least half of it, this means that the 2,4 million tonnes of clinker required 174 GWh in 2009. Replacing some of that clinker with sugar cane bagasse ash would then have saved 2,65 GWh.

The reduction potential at a CO_2 emission value of 0,335 kg / kWh (IEA 2010) is therefore 889.922 tonnes of CO_2 per year that is not emitted into the atmosphere if sugar cane bagasse ash replaces 1,5% of the clinker used to produce cement.

4. Future Prospects

Apart from the four extended uses of bagasse that could be suitable at the moment for Guatemala, there is also a fifth one. The production of ethanol, in the same fashion as it is being produced in other countries.

Not only is the use of bagasse as fuel of interest when thinking about reducing the burden on the environment. Even though this paper does not focus on it, another highly important byproduct is ethanol, yet its use is not widespread and there is no interest by the policy makers as this has already been attempted in the past, but it did not gain acceptance. The use of sugar cane byproducts in general and bagasse as source for energy generation in Guatemala has been slow when compared to other countries, but is has been successful. Countries where the technology and the processes have already gone through many stages of innovation are already harvesting the fruits of the technology. Guatemala could frog-leap some of these stages by importing and adopting know-how from such countries. The use, not the production, of ethanol is a hot topic on the discussion table of politicians. There is no law or decree that promotes the use of biofuels; the Ministry of Energy and Mines is currently analyzing proposals to tackle Guatemala's dependence on petroleum-derivated fuels. Most the dehydrated alcohol produced from sugar cane is exported. In 2008 200.000 liters were produced daily. At this rate, Guatemala would be theoretically capable of supplying the domestic and Central American demand of ethanol for a ethanol-gasoline mixture that could be theoretical used for cars. Yet, this is at the moment no possible due to several problems that need to be taken into consideration first. These problems range from misbranding, to the lack of investment capital. Misbranding occurs when a fuel sellers tries to sell their products as biofuel. The sellers benefit from the lower taxes on such fuels, without having first changed its formula or not having used improper ratios. This is a problem in countries where law enforcement is weak. The lack of investment willingness, especially in the distribution infrastructures is also a mayor obstacle. A new tax structure and pricing system also makes it difficult for all parties involved to reach consensus (Tay 2009:2-4).

5. Conclusion

Let us take a quick look back to the main research question. What is the best way to utilize bagasse produced in Guatemala? To answer this question we had to take into consideration what the pros and the contras of further processing bagasse. Four different possible solutions were identified and discussed.

Let us review its current and increased usage as source of electricity. The continuous increase of cogeneration is not linked to an increase in the production of sugar cane meaning using more bagasse to generated electricity will not have an impact on land use or land use emissions, as the bagasse is already available. At the first glance it would appear that increasing the percentage of bagasse that is burnt for electricity from the current level of 60% to a hypothetical level of 100% would also increase the emissions of CO_2 by the same ratio. At 60% exploitation cogeneration emitted 659.236 tonnes of CO_2 in the year 2009 which at 100% exploitation would jump up to 1 million tonnes of CO_2 for the generation of 2,25 TWh. These calculations do not take into consideration the sequestrating effects of sugar cane, which, if they were to be taken into consideration would dramatically lower the carbon footprint of bagasse cogeneration.

The usage as nutriment has gained on popularity in recent years, with more and more cattle ranchers feeding their cattle with bagasse. Rather than throwing the bagasse away, mixing it with molasses and urea and feeding it to the cattle is indeed a good idea, as it lowers the demand for other food by replacing it with a product that is already available. This is, however, only valid for ruminants, i.e. cattle, goats, sheep that are above the age of two years as studies have shown that feeding blended bagasse consumes more energy than it provides in younger ruminants.

The usage as a fertilizer will probably continue to be a difficult problem to be tackled. Years have passed and the old tradition of returning residues to the field where they were harvested still remains. Although this sugar cane residues are not necessarily bad for the soil, the field owner may opt to burn the contents rather than letting them decay in order to be able to plant something new for the season and so make a "better" use of their fields. Of course the burning of organic material not only pollutes but also takes away the few nutriments that were still available in the soil, with the remaining ashes being nothing but waste. The name given to the chapter, “Usage as Fertilizer” was indeed somewhat misleading, as it implied that such a usage could be a solution or an ultimate use for bagasse, but it is quite the opposite. Nonetheless, this section gave us an insight of what amount of GHG is emitted to the atmosphere by taking into consideration how much N_2O is released into environment after having applied the large amount of nitrogenous fertilizer that is needed for sugar cane to grow at a profitable rate. Each cultivated km² emits 22-30 tonnes of CO_2 yearly, that is 47.680-63.474 tonnes of CO_2 in the year 2009. As a comparison bagasse cogeneration emitted 659.236 tonnes of CO_2 in the same year.

The usage of sugar cane bagasse has been discussed so far, but let us not stop there, the next byproduct, the ash that is left from the burnt bagasse is likewise of interest. It represents a limited usability, but nevertheless if it was completely used as an additive in cement is 889 tonnes CO_2 for the year 2009’s production. A small amount indeed. It would be perhaps interesting, if not somewhat clever to investigate not only bagasse ash, but other kind of ashes can also be used as a mineral additive. For this, one would need the elemental composition of such ashes of course. Also for a proper approximation of the reduction potential levels, one need to know exactly the kind of fuels are used at the different plants, and also the kind of technology is being used. More important perhaps is what kind of cement is being produced (as some types required drastically more energy to be produces as others).

Quantitative Comparison of Usages			
	Usage as Electricity Source†	Land Use Change (Usage as Fertilizer)	Usage as Mineral Addition (Usage in the Cement Industry)
Current Used Units	1,5 megat. of baggase	2.134 km²	2.400 kilot. of clinker
Current Produced Output	1,35 TWh	13~17 kilot. of N	-174 GWh
In Scenario Used Units	2,5 megat. of baggase	3.420 km²	2.364 kilot. of clinker
In Scenario Prod. Output	1,74 TWh	21~27 kilot. of N	-171,35 GWh
Unit Difference	0,34 TWh	8~10 kilot. of N	2,65 GWh
Current CO_2 Balance	349 kilot. of CO_2	48~63 kilot. of CO_2e	57 kilot. of CO_2
Theoretical CO_2 Balance	582 kilot. of CO_2	76~101 kilot. of CO_2e	56 kilot. of CO_2
CO_2 Difference	233 kilot. of CO_2	28~38 kilot. of CO_2e	-0,89 kilot. of CO_2

Table 8: Quantitative Comparison of Usages
Source: Own calculations.
† Does not include offsetting by CO_2 sequestration.

By using Table 8, we can get a better overview of the saving potentials in each of the scenarios previously presented. This table show in a easy to compare fashion the different CO2 emission changes that would incur by changing the parameters from current values to does assumed to be maximum possible. From these calculations the usage of sugar cane bagasse as a source for electricity would seem to be the most polluting form of exploitation. However if we apply the consolidated methodology for electricity generation from biomass residues set as 261,1 kg CO2e / MWh as approved by the UNFCCC[19] we can expect a 88.774 t of CO2e in avoided emissions, that together with the sequestration properties of sugar cane offsets the cause emissions of 233000 t of CO_2.

A change in the land use to increase the area being used for sugar cane production to the maximum possible is linked to an expected increase in emissions in the range of 28.000-38.000 t. of CO2e. The only emission reduction potential that exists in this scenario is to increase the efficiency of harvest output while keeping fertilization levels constant.

Additionally, using bagasse as a metal additive does actually reduce the CO2 emissions caused in that industry, albeit at a very low scale.

There is, however, one usage that is not on the table. That is the usage as a nutriment. This is due to the fact that an increase in the consumption of bagasse as food for cattle would replace other kinds of feedstock. That feedstock is very variable in nature, it can range from corn, to wheat, etc. The ata on the production's electricity consumption would be needed to deduce the emission reduction potential of such a replacement.

I have mentioned a fifth option, the production of ethanol. However, at the time being the lack of political support based on a previous failure makes it seem very unrealistic at the moment. On the other hand ethanol provides a very good emission reduction potential, as many producing countries in the world have so proven.

---

[19] UNFCCC
http://cdm.unfccc.int/methodologies/DB/VREL7OE14N1ACV1JAW0J0G858FBGFN/view.html

Some questions still remain to be answered, for example does the energy produced by increasing bagasse cogeneration justify this additional GHG? In view of the fact that Guatemala still has untapped potential for more generation based on geothermal and hydraulic power generation, this might be a tricky questions but let us not forget that the bagasse will be produced one way or another, and that the CO_2 that has been sequestration has the ability to compensate for these additional emissions. A problem that makes it difficult to justify an increase in the sugar cane production is the N_2O emissions that are caused due to nitrogenous fertilization of the soil. The current plantation area is 2.134,5 km^2 with a calculated potential of 3.420 km^2, meaning it is still possible to increase the cultivated area by 160%, including its N_2O by that much as well. I believe that rather than increasing the cultivated area, a better fertilization know-how should be proliferated among the industry players to achieve better yield with the same amount of fertilizer, or the same amount of land use.

Yet, none of these suggestions provide for a solution to the main polluting sources of energy in Guatemala, the problem of the burning of firewood in households and small industrial facilities. I believe there is no quick solution without the proper involved by the government. Official figures tell of a national coverage of 85%, which is good. However, how reliable are these figures when compared against a backdrop that tells of tremendously large firewood consumption? Perhaps the figures mentioned in the official document only referred to those households that are registered. Since the two sources are rather contradictory we need to make our estimation. I believe that the private sector is doing a great job increasing and fostering the exploitation of renewable energies, especially that of sugar cane bagasse. At the same time, I believe the government should in an effort to lower GHG emissions come up with solutions on how to bring electricity to as many household as possible, and if the figures are accurate, additionally how to educate people on why the consumption of firewood should be avoided.

6. Bibliography

Chavarría Moreno, Juan Carlos

2004 Efecto del Clinker Reducido en el Cemento Portland Tipo I. San Carlos University of Guatemala. http://biblioteca.usac.edu.gt/tesis/08/08_0897_Q.pdf

Cordeiro, G.C., Filho Toledo, and Eduardo Fairbairn

2008 "Use of Ultra-Fine Sugar Cane Bagasse Ash as Mineral Admixture for Concrete" in *ACI Materials Journal* Volume 105 Pages 487-493.

Fairbairn, Eduardo, Branca Americano, Guilherme Cordeiro, et al.

2010 "Cement Replacement by Sugar Cane Bagasse Ash: CO2 Emissions Reduction and Potential for Carbon Credits" in *Journal of Environmental Management* Volume 91 Pages 1864-1871.

FAO

1996 "Informes de países" in "Memoria - Reunión regional sobre generación de electricidad a partir de biomasa". FAO: Roma.

NN *Saccharum officinarum*. FAO Repository http://www.fao.org/ag/AGA/AGAP/FRG/afris/Fr/Data/552.HTM

Garcia, J., and A. Torres

1990 "Outlook of Latin American Cement Industry," in *Energy Efficiency in the Cement Industry Journal*. Elsevier: London and New York.

Fischer, Günther, Edmar Teixeira, Eva Tothne Hizsnyik and Harrij van Velthuizen.

2008 *Sugarcane ethanol: Contributions to climate change mitigation and the environment* in chapter 2 "Land use dynamics and sugarcane production". Academic Publishers: Wageningen.

Gonzalez-Valadezm, M., G. Munoz-Hernandez, R. Sanchez-Lopez

2008 "Design and evaluation of an extruder to convert crop residues to animal feed" in *Biosystems Engineering* Volume 100 Pages 66-78.

Harvey, Mark and Sarah Pilgrim

2011 "*The* new competition for land: Food, energy, and climate change*"* in *Food Policy* Volume 36. Pages 40-51.

Hewlett, P.C.

2005 *Lea's Chemistry of Cement and Concrete*. Elsevier: Oxford.

IARNA

2009 *Cuenta Integrada de Energía y Emisiones (CIEE)*. Divulgating Series Nr. 6. Rafael Landivar University: Guatemala.

Jaén, René Lesme

2006 Combustión a Partir de Biomasa Cañera. University of the Orient: Cuba. http://www.cengicana.org/Portal/SubOtrasAreas/Cogeneracion/Presentaciones/CombustionPartirBiomasaCanera.pdf

Lamlom S.H. and R.A. Savidge

2003 "A reassessment of carbon content in wood: variation within and between 41 North American species" in *Biomass and Bioenergy* Volume 25 Pages 381-388.

Malhotra, V.M.

2002 "Introduction: Sustainable Development and Concrete Technology". *Concrete International* Volume 24 Page 22.

Mehta, P.K., and V.M. Malhotra

1996 *Pozzolanic and Cementitious Materials*. Gordon and Breach Publishers: Amsterdam

Naseeven, M.R.

1986 Sugarcane Tops an Animal Feed. FAO Repository: http://www.fao.org/ag/aga/agap/frg/AHPP72/72-106.pdf

OECD and IEA

2000 Emission Baselines: Estimating the Unknown. Organization for Economic Co-operation and Development and International Energy Agency: New York.

Officer, Sally, Frances Phillips, Roger Armstrong and John Graham

2010 “Nitrogen fertiliser increases nitrous oxide emissions from a semi arid Vertosol” distributed *19th World Congress of Soil Science* by Soil Solutions for a Changing World, Brisbane.

Orozco, H, G.J. Soto, O. Pérez at al.

1995 Estratificaión Preliminar de la Zona de Producción de Caña de Azucar (Saccarum spp) en Gautemala con Fines de Inverstigación en Variedades. Documento Técnico No. 6. Cengicaña: Guatemala.

Pandey, Ashok, Carlos Soccol, Poonam Nigam, Vanete Soccol.

2000 Biotechnological potential of agro-industrial residues. I: sugarcane bagasse. in Bioresource Technology Volume 74 Pages 69-80.

Pérez, José Manuel y Lawrence Pratt

1997 Industria Azucarera en Guatemala: Análisis de Sostenibilidad. CLACDS.

Pérez, Ovidio and Mario Melga

1999 Sugar Cane Response to Nitrogen, Phosphorus and Potassium Application in Andisol Soil" in Better Crops International Volume 12 Nr. 2.

Pérez, Ovidio, Cristian Ufer, Víctor Azañon and Edgar Solares

2008 Estrategias para la optimización del Uso de Fertilizantes Nitrogenados en el Cultivo de Caña de Azúcar en Guatemala. Cengicaña: Guatemala.

Ramírez, Miguel Ángel

2008 *Cultivos para la producción sostenible de biocombustibles: Una alternativa para la generación de empleos e ingresos. Módulo V: Caña de azúcar*. Comunica: Tegucigalpa.

Romero, Eduardo, Ignacio Olea, Jorge Scandaliaris, et al.

2004 "Recomendaciones para la Fertilización de la caña de azucar" in *Gacetilla Agroindustrial de la EEAOC* Volume 61 Pages 1-10.

Stanmore, B.R

2010 "Generation of Energy from Sugarcane Bagasse by Thermal Treatment" in Waste Biomass Valor Volume 1:77–89

Tay, Karla

2009 Guatema. Biofuels Annual. Biodiesel and Ethanol. Global Agricultural Information Network Nr.: GT9008. USDA Foreign Agricultural Service. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/General%20Report_Guatemala_Guatemala_5-26-2009.pdf

Worrell, E., L. Price, N. Martin, et al.

2001. "Carbon Dioxide Emissions from the Global Cement Industry" in the *Annual Review of Energy and the Environment* Volume 26, Pages 303-329.