Bagasse as a Fuel for Combined Heat and Power (CHP): An Assessment of Options for Implementation in Iran.

Chapter One

Introduction

The non-permanent nature of fossil fuels and the rise in their consumption due to the increase of the population of the World have brought about a situation in which researchers are constantly searching for appropriate alternative resources to replace fossil fuels.

At present, increasing the global concern about pollution has given rise to a desire to establish cleaner production. As a result, efforts have been concentrated on mitigating the pollution consequences arising from the use of fossil fuels, and to the issue of using renewable energy sources.

Renewable, sustainable energy resources can be good alternatives for fossil fuels. Biomass resources are unique among the renewable energy resources, since they are the only sources which can be easily converted into useful solid, liquid and gas fuels (Page, 1994).

Using biomass as an energy resource is attractive, not only for socio-economic reasons, but also because of environmental considerations. Biomass utilization can reduce forest management costs, help mitigate climate change, reduce risks to life and property, and help provide a secure, competitive energy source (Bartuska, 2006). Shifting to a homegrown, renewable energy economy provides opportunities for growth and expansion, especially for rural communities, as these renewable feedstocks are directly connected to agriculture and forestry (Bartuska, 2006).

The availability of affordable energy and materials supplies is crucial to sustain steady economic growth; it has become desirable to maximize the use of known and easily available resources. Current research in the World's agricultural and forestry industries is concerned with the development of new uses for, and the added value of farm and forestry products for greater economic benefits (Chiparaus, 2004).

Today the sugar cane industry has found an important position, not only in Iran but also in the World. The importance of this industry is due to its by-products such as bagasse, molasses, and filter mud. Bagasse is the fibrous residue of the cane stalk obtained after crushing; and the extraction of juice in the form of wood chips, and is straw yellow (its specifications are explained in detail in chapter 5). Each of these by-products has various applications in side industries. Out of these by-products, bagasse has been of particular interest, for two reasons. Firstly, bagasse is produced in large quantities production (each tonne of sugar cane produces 250 kilogram of bagasse) (Paturau, 1998) and secondly, due to its diverse applications (some of the most important applications are in the paper, chemical industries, and as a source of energy). Figure 1.1 shows some important applications of bagasse.

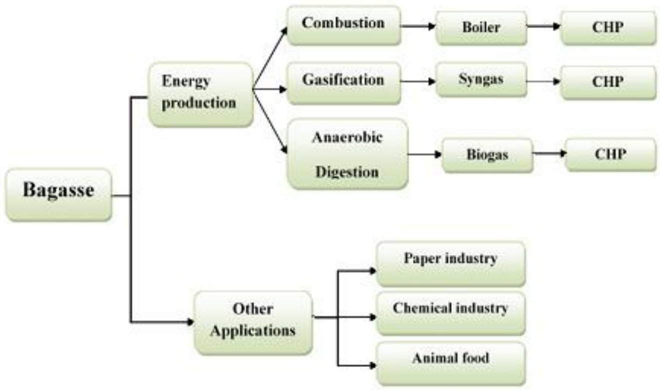

Figure 1.1 Some important applications of bagasse

Good examples of countries with experience of the sugar cane industry are Brazil, India, China, Australia, Cuba, and Japan. These are mainly located in tropical and sub-tropical areas. In such areas, climate conditions are suitable for the cultivation of sugar cane (WADE, 2004). With regard to the history of these countries, it is found that the first application of bagasse has been as an energy source for the production of the heat and power required to run the sugar factory which are explained completely in Chapter Three. The energy needed by the factories was supplied by burning bagasse directly inside furnaces, which had a very low output. The growing trend of sugar cane production and the increase of bagasse production created opportunities for further applications, including in the paper industries (Tail and Francis, 2000). Since the majority of sugar producing countries are importers of fossil sources, this fact made them pay attention to technologies with higher energy outputs. An example of such a technology is Combined Heat and Power

(CHP) which has a higher efficiency as compared with the older technologies (WADE, 2004).

Iran is among the countries producing sugar cane, and was ranked 20th for the annual rate of sugar cane production in 2004. The history of this country in sugar cane plantation dates back more than a half century. The selection of bagasse as biomass source for this research is based on two reasons. Firstly, despite the fact that bagasse is used in side industries a great amount of it (about 1,500,000 tonnes) is destroyed annually without being used. Secondly, sugar cane production industries in Iran depend on fossil fuels, in particular natural gas, for energy supply and annually they spend a significant amount of money on fuel. Thus, if additional bagasse could be converted into power and heat by using the high efficiency technology, it will not only help with these industries but will also make use of the waste bagasse.

The sugar industry requires both heat and power, so CHP is a good energy generation technology for these industries (WADE, 2004). The most important energy conversion technologies, which are usable in CHP and appropriate for bagasse, are anaerobic digestion, gasification, pyrolysis, and direct combustion (Kiatkittipong, Wongsuchoto and Pavasant, 2009; Quaak, Knoef, and Stassen, 1999), so that, determining the most suitable technologies for Iran with regard to experience and facilities can increase the efficiency of energy production from bagasse.

By comparing and analysing these technologies, it is clear that anaerobic digestion will be well suited (Ministry of Energy, 1999), because as a result of anaerobic digestion, the organic components in bagasse are converted into biogas, which has features similar to natural gas and will be a good alternative source of fuel.

The main aim of this project is to consider the economic and environmental merits of bagasse as an energy source by using selected energy conversion technology supplying CHP fuel. An important component of the research has involved the design of an exemplar small scale biogas plant system using anaerobic digestion. The exemplar biogas plant was envisaged to be linked to a CHP unit and then this biogas CHP plant was considered from economic and environmental aspects. Using biogas linked to a small scale CHP plant is in harmony with the environment; such a biogas-CHP plant is nominated here to determine its economic and environmental merits. It is worth mentioning that design and selection were made on a small scale to demonstrate the attraction and feasibility of the project, which would be even more attractive and feasible if implemented at a larger scale.

The importance of this project is to show that bagasse, as a part of a huge source of biomass, can serve as a good model for the implementation of similar projects in industrial, residential and commercial areas and even remote areas with no access to fossil sources. Of course, Iran differs from other countries producing sugar cane as it enjoys the benefits of huge resources of fossil fuels. However, due to the limitation of these sources, and the cost of purchase and transfer of these sources to the users of industries, it may still be more profitable to use existing biomass sources for energy generation. In this respect, this project's study of Iran provides a case study which is transferable to other developing countries which plant sugar cane.

1.1 Importance of Distributed Combined Heat and Power (CHP)

Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel (coal or gas powered), nuclear or hydropower plants (IEO, 2009). These plants have excellent economies of scale, but usually transmit electricity long distances and can affect the environment adversely. Most centralized power plants are built far from the place of consumption due to a number of economic, health, and safety, logistical, environmental, geographical and geological factors. For example, coal power plants are built away from the populace to reduce their impact on people. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature, limited to operating at sites with sufficient water flow.

Low pollution is a crucial advantage of combined cycle plants that burn natural gas. Their low pollution permits them to be sited near enough to large settlements to be used for district heating.

The International Energy Agency (IEA) (2002) specifies five major factors contributing to this evolution: developments in distributed generation technologies; constraints on the construction of new transmission lines; increased customer demand for highly reliable electricity; the liberalization of electricity markets; and, concerns about climate change. At present, environmental policies or concerns are probably the major force driving the demand for distributed energy generation units in Europe (Pepermans et al., 2003). Environmental regulations force players in the electricity market to look for cleaner energy and cost efficient solutions. So, distributed generation can play a role, as it may be the optimal way to provide energy to locations that have a large demand for both heat and electricity.

Most governments have policies that aim to promote the use of renewable technologies for distributed energy generation (Pepermans et al., 2003). Installing distributed energy generation allows the exploitation of cheap fuel; for example, with the proximity of landfill sites, distributed generation could burn landfill gas. Also, locally available biomass may be utilized in distributed energy generation units.

The main benefits of distributed energy generation are as follows. Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated close to where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed. Typical distributed power plants have low maintenance, low pollution and high efficiencies. As Figure 1.2 shows central power plants have an efficiency of about 30%-45%. In contrast CHP central power plants' efficiencies are about 60%-70% (Wu, and Wang, 2006). In general, distributed generation exhibits an efficiency of about 35%-45%. In contrast, the efficiency of distributed CHP increases to 80%-95%. Overall, some renewable CHP have high efficiency above 80% (Wu, and Wang, 2006). Renewable CHP, such as biomass CHP, whose biomass resources can be used as a fuel directly or indirectly, has minimum pollution and maximum economic benefit. For example, in indirect form biomass used in a bioreactor and produces biogas that can be used for CHP to provide local heat and power.

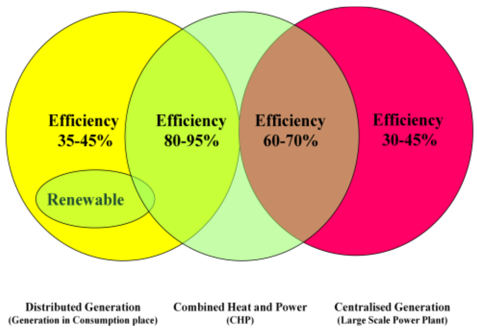

Figure 1.2 Comparison of the efficiency of different power plants

1.2 Motivational Factors for the Establishment of Biogas-CHP in Iran

There are many factors which encourage the application of biogas in biogas-CHP. The major ones are the high potential of biomass sources, energy production for the reduction of natural gas consumption, reduced difficulties in disposal of waste materials and the hidden costs of energy production from fossil fuels. These are dealt with in subsequent sections.

1.2.1 Existing Potential of Biomass Sources

The main sources of biomass include agricultural residues, urban residues, animal wastes and urban and industrial sewage (Boyle, 2004). Table 1.1 highlights the potential importance of these sources in producing biogas in Iran.

Table 1.1 Potential for the annual production of biomass sources and biogas production in Iran (Ministry of Energy, 1999)

Biomass source	Annual production	Potential for the production of biogas (million m^3)
Animal wastes	74946(Thousands tonnes)	8668
Urban sewages	25176(Thousands tonnes)	108-245
Industrial sewages	36245(Thousands litres)	82-280
Agricultural residues	23147(Thousands litres)	5475
Urban garbage	13.87(Million tonnes)	1646

In this thesis, the type of biomass selected for use in biogas combined heat and power plant is bagasse. Details of the potential of bagasse in Iran are described in Chapter Five.

1.2.2 Energy Production for the Compensation of part of Natural Gas Consumption

The total potential producible methane gas from bio production in Iran is about 9175 million cubic meters (with an assumption that 60% of biogas is methane). This is equivalent to 15% of Iran's energy consumption in residential, commercial, and industrial sectors of the country. This rate, in comparison with the consumption of natural gas in all power plants in the country in 2007, is about 25% (Ministry of Energy, 2007).

1.2.3 The Problem of Disposing of Waste Materials

One of the most important factors that encourage the use of bagasse for the production of biogas is the removal of potentially polluting waste materials. These waste materials become food for the digesting units (bioreactor) and will produce biogas. At present, a large amount of Iranian bagasse (about 1,500,000 tonnes) has to be destroyed annually.

In other words, materials which are non-consumable waste in ordinary conditions are potential sources of energy. Therefore, use of these kinds of materials has two types of benefits for the societies which use them. The first benefit of their application is the considerable reduction of the financial costs of collecting and disposing of the waste, and also the reduction of environmental cost (such as pollution) produced by the waste disposal process (Abdoli, 2008). Their second advantage is the production of the biogas, which provides energy for the community.

1.2.4 Hidden Cost of Energy being Produced from Fossil Fuels

At present, the production of energy from fossil fuels is accompanied by various hidden costs. One of the most important of these costs is the environmental damage, caused by these energy sources. The social and environmental costs of the fossil fuel power plants in Iran was more than 18 million US$ in 2007 (Ministry of Energy, 2007). The replacement of prevailing fossil fuel power plants with biogas power plants will be very useful from both social and environmental aspects, and will reduce these environmental costs.

1.3 Structure of the Thesis

This thesis has seven chapters. This first chapter; is an introduction, which deals with the main aim and importance of the project. The second chapter presents the objectives and method, and explains the main activities of data gathering and analysis. In this section (Chapter Two), the process of the implementation of activities related to the objectives has been explained in detail. The third chapter reviews the experiences of countries with sugar cane industries. The fourth chapter describes the desirability of replacing fossil fuels with biomass sources. In the fifth chapter, the applications of bagasse and its potential for application in Iran are put forth and the side industries of bagasse are introduced. In addition, the process of production of sugar from sugar cane is described in an Iranian sugar cane plantation and industry company. The potential of sugar cane production and by-products; and the quality of their application in these industries, and additional rate of bagasse in sugar cane plantation and industry companies are discussed in this chapter. In the sixth chapter, which is the key chapter of this research, bagasse energy conversion technologies are introduced and compared with each other. The merits of these technologies based on prevailing views and different parameters are evaluated, and the most appropriate method is selected for using bagasse in Iran, which is found to be a bioreactor using bagasse, linked to a CHP unit. A typical biogas system is designed for bagasse by the author. Then this biogas system links to CHP, which will be suitable to the size of the bioreactor and it is analyzed both economically and environmentally. In the seventh chapter, a general review is made on data analysis. Various results, including reasons for the selection of bagasse, energy conversion technology, the economic calculation related to CHP units, and their economic and environmental advantages are put forth in the same chapter. In addition, two appendices are presented which are related to a design of anaerobic digestion system (Appendix I) and a paper related to research, presented in the International Conference on Energy and Environment (ICEE 2010, 28-30 July, 2010, Paris) (Appendix II).

Chapter Two

Objectives and Methods

2.1 Research Strategy

Traditionally, the sugar cane industry has focused on maximizing sugar output in terms of financial returns, based upon efficiencies in yield per hectare, and sugar extraction. In recent years, however, sugar cane has become a resource extending beyond the production of sugar for domestic consumption. Sugar cane by-products and co-products (both energy and non-energy) have gained in importance. The sugar industry is now a producer of energy, food, feed, and fibre.

One of the important sugar energy co-products is bagasse. In most cases, bagasse has been used to produce electricity and process heat for sugar factories. There are instances, however, where it has been used in the paper and pulp industry; and in countries like Japan, it has been used for ethanol production (World Bank - ESMAP, 2006). Ethanol production from cellulosic feedstock such as bagasse is not yet commercialised, and research is ongoing (Junginger et al, 2006; Jolly, 2006). Therefore, in the short term, the value of bagasse as a sugar cane co-product will mostly be confined to electricity production (Yamba and Matsika, 2003).

Sugar cane factories have other potential for re-development, due to their by-products, bagasse, molasses, and filter mud, and the various applications of them. At present, in Iranian sugar cane factories, a significant amount of baggase is destroyed annually.

Therefore, this research began with the question, “How could Iranian sugar cane industries use extra bagasse more efficiently?” In order to determine this, data gathering was started by reviewing documents on the Iranian and World sugar cane industries.

The information which was gathered by interview, observation, and reviewing Iranian sugar cane documents, shows that Iran has a large bagasse production that is suitable for use as an energy source. The energy available can best be developed when the energy conversion technology is combined with CHP. Therefore, different types of energy conversion technologies need to be compared and the one most suitable for Iran selected.

2.1.1 Main Aim

The main aim of the research was determined as “the economic, technical, and environmental study of the application of bagasse as an energy source by using selected energy conversion technology supplying CHP fuel”, and Iran chosen as a case study. In this research the rate of CO_2 emission from substituting bagasse for fossil fuel will be determined in an environmental aspect survey. The main focus however will be on economic and technical aspects.

2.1.2 Objectives

The objectives of the research were described as follows:

1. Study and review different types of biomass resources and their benefits
2. Review the biomass resources for energy production
3. Practical and theoretical study of the sugar production process

4. Identification of bagasse applications

5. Determination of the bagasse production and consumption potential in Iran

6. Study and review of the experiences of other countries using bagasse

7. Study and review of the bagasse energy conversion technologies and selection of the most applicable method for using bagasse in Iran

8. Technical design of a suitable typical biogas digester

9. Economic study of the application of a bio-digester and biogas CHP

The selected methods of data collection in this research include secondary data collection, interview (interview with the informed experts and officials in the field of research) and observation of relevant sugar cane centres and industries. In addition, the latter part of the investigation (objectives 8 and 9) involved the design of an exemplar biogas CHP plant. The specific method of doing each objective is presented in Figure 2.1. In addition, Table 2.1 also shows which chapter discusses the findings relating to each of these objectives.

Table 2.1 The relationship between Objectives, Methods and Chapters

Objectives	Methods	Chapter
6	Secondary data collection	Three
1,2	Secondary data collection	Four
3,4,5	Secondary data collection, Interview, Observation	Five
7	Secondary data collection,	Six
8	New Result	
9	New result	

2.2 Method Overview

With regard to the data, needed to implement these activities as in Figure 2.1 including both types of numerical and non-numerical data, the mixed methodology was selected for data collection. The application of a mixed methodology in this project is logical because; firstly, the application of bagasse in a country like Iran provides case study, which is part of qualitative research. Secondly, statistical data has been obtained on the potential of sugar cane, and bagasse produced, the rate of bagasse consumption in side industries, the price of fossil fuels in the World and Iran, and many other types of numerical data, which are relevant to the final economic analysis.

Each method has certain limitations, but by combining other methods, support can be obtained by triangulating data sources, and a more effective, accurate and insightful result is obtained.

The selection of the method of analyzing the existing data in the mixed methodology research depends on the selected strategy for the project. In the case of this project, the strategy of concurrent triangulation, shown by Figure 2.2 has been used for the analysis of quantitative and qualitative data (Creswel, 2003).

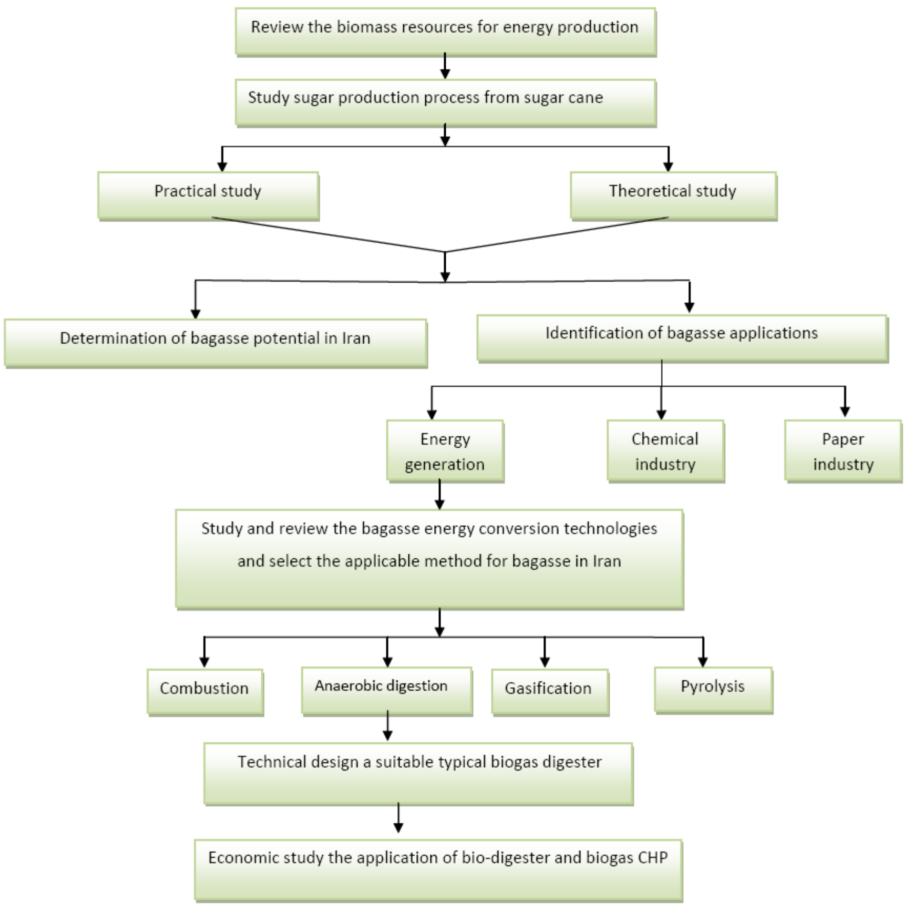

Figure 2.1 A system diagram showing the activities considered in this study

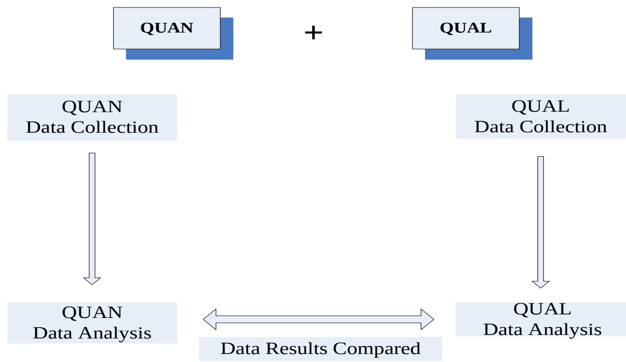

Figure 2.2 Concurrent triangulation strategy

2.3 Method for Examining the Sugar Cane Industry in Iran

2.3.1 The Sugar Cane Industry in Iran

Bagasse was selected as the biomass source that would be investigated due to its annual significant rate production and capability for energy generation. For further study of bagasse and its production process, it is necessary to become familiar with sugar production from sugar cane. Sugar cane plantations and industry complexes in Iran were identified and correspondence established with those complexes and head offices. Three sugar cane plantations and industry complexes exist in Iran; Haft Tapeh, Karun and Sugar cane and Side Industries Development. The oldest complex is Haft Tapeh and the newest and largest ones are the Sugar cane and Side Industries Development Complex. Arrangements were made to visit to Haft Tapeh sugar cane plantations and industry complex. Before visiting the Haft Tapeh complex to get more familiar with the sugar cane process to enable proper analysis and ensure relevant questioning, a literature review was undertaken of sugar production both in Iran and in other countries. The internal references were mainly taken from the libraries of Ministry of Agriculture and the Sugar cane and Side Industries Development Company. June was chosen for the visit as, at that time, the factory would be in full production. During the visit, the Haft Tapeh Production manager explained the sugar production process and answered questions. The data, which was obtained in this visit, was important from the viewpoints of understanding the sugar, and its by-products production process and energy consumer stages. It was also important to obtain from the data the annual rate of sugar, bagasse, molasses, and filter mud production, the quantity of energy needed for the process, sources of energy, and cost of the fuel required by the factory. The rate of bagasse production and the method of its application in the Haft Tapeh complex are presented in Figure 2.3.

Figure 2.3 Quantity of bagasse production and consumption in the Haft Tapeh Complex

As shown above, in this complex, the Pars Paper factory consumes the produced bagasse, so that there is no surplus.

For other complexes, the necessary data was obtained by interviewing relevant officials. For example, in respect of the Karun sugar cane plantation and industry complex, an interview was held with the Production Manager to determine the rate of sugar production and its by-products and type of energy used. In Figure 2.4, the production and application of bagasse in the Karun sugar cane plantation and industry complex is presented.

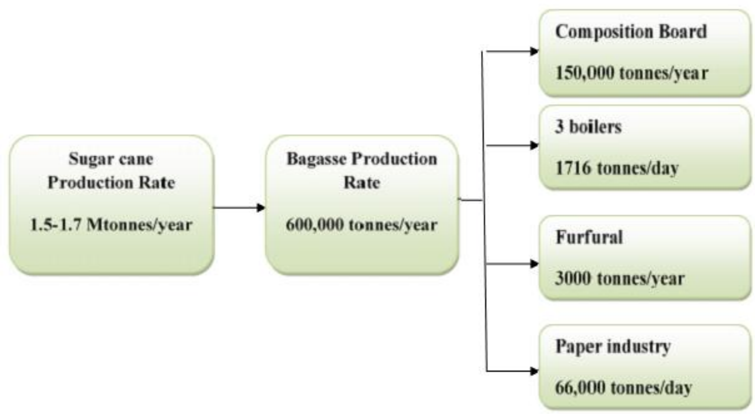

Figure 2.4 Quantity of production and application of bagasse in the Karun Sugar cane Plantation and Industry Complex

In the Karun sugar cane plantation and industry complex, two projects using bagasse for the production of furfural and paper are under implementation. Only one boiler using bagasse as a fuel has been instigated. It consumes 1716 tonnes of bagasse daily. Therefore, at present some bagasse remains unused. However, there was no data available on the exact amount of surplus bagasse, so that a case study could not be made.

The largest of the sugar cane plantation and industry complexe, has a head office in Tehran. In a meeting with the Manager of this complex, statistical data was obtained relating to the production of bagasse, molasses, filter mud, and their applications Figure 2.5 shows the quantity of the production and application of bagasse in this complex.

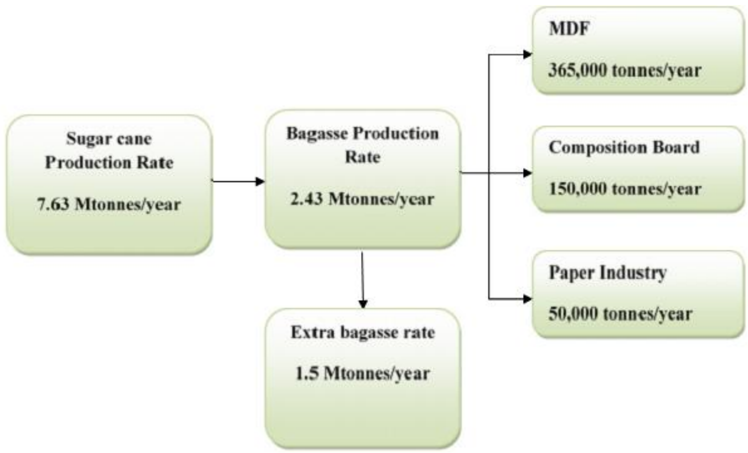

Figure 2.5 Quantity of bagasse used in the Sugar cane and Side Industries Development Complex

Due to the clear and exact statistics and data from the Sugar cane and Side Industries Development complex, this complex was selected for the case study. In relation to the extra bagasse from this complex the typical biogas system will be designed and an economic calculation for a biogas CHP will be done.

Overall, six persons were interviewed for data gathering; the Production Managers of Haft Tapeh, Karun, and Sugar cane and Side Industries Development companies, and the Environment Managers of Haft Tapeh, and Sugar cane and Side Industries Development companies. Moreover, the Biomass Manager in the Ministry of Agriculture in Iran was interviewed. Visits were made to a sugar cane factory (Haft Tapeh sugar cane factory), and

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numerous documents were examined. The data collected through these various methods then enabled realistic assumptions to be made for the design of the exemplar biogas-CHP facility.

2.3.2. Sugar Cane Industry in other Countries

In order to complete the study of bagasse production and applications, sugar cane producing countries and those with experience in this area were investigated. The aim of this activity was to gain familiarity with the experiences and achievements of other countries so that comparison could be made with Iran and the best application could be determined for Iran. For this purpose, secondary data collection was used.

In this regard, the most experienced countries, that produce sugar cane, were studied and reviewed. In summary, based on those studies, the following points were established:

1- These countries have limited resources of fossil fuels and are mostly are importers of these fuels. Therefore, the first application for bagasse in these countries was to produce energy to enable factories to produce sugar from sugar cane. Moreover, in order to promote the output of energy from bagasse, the application of CHP was in progress. Other secondary applications include papermaking and chemical use.
2- Most of these countries are developing countries.

The results of studies up to this stage show that in Iran the issue of energy supply is also an important application for bagasse due to the high rate of energy consumption involved in producing sugarfrom sugar cane. Since fossil fuels are costly, so their replacement with bagasse can reduce these costs and help improve competitiveness and so enable further progress for this industry in Iran. Therefore, the most appropriate applications which can be considered for additional bagasse in sugar cane plantations and industry complexes is to generate energy and to provide an energy supply for the sugar factories.

2.3.3 Bagasse Application as a Source of Energy

The key point will be to establish how use bagasse as a fuel for energy production and a fuel for energy production with maximum efficiency. In other words, what is the most appropriate energy conversion technologies for bagasse? In order to determine this, the study of different types of bagasse energy conversion technologies and the selection of the most appropriate ones for Iran, or other countries, was explored. Necessary information from various internal and international references was reviewed and the experiences of other countries were used.

This investigation showed that the application of the old methods of direct combustion for the production of heat for the sugar factories was common. However, in the sugar cane industries, in addition to heat, there is also need for electricity, with the result that the use of CHP has been developed in recent times. Therefore, the use of modern technologies for the production of fuel with a higher output, which has the possibility of usage in CHP, has been considered. The bagasse energy conversion technologies, which are prevailing in the World, are gasification, anaerobic digestion, pyrolysis, and combustion.

2.3.4 Choosing Energy Conversion Technology for Bagasse in Iran

In Iran, a specific project has been conducted by the Ministry of Energy in the Renewable Energy Research Centre in which different conversion technologies for biomass have been studied (Ministry of Energy, 1999). The results of this comparison show that the best methods are gasification and anaerobic digestion. In the case of Iran, with regard to the experiences of manufacturing anaerobic digestion units, this technology is preferred because the method of gasification requires high level technology and there is a need for technology transfer from abroad. Thus, the result of this part of the research about choosing the best energy conversion technologies showed that anaerobic digestion will be the appropriate technology for bagasse in Iran. To enable the design of a typical biogas for this project, the system was studied and the necessary components for an energy system design were identified. The basic part of this system is the bioreactor in which the process of anaerobic digestion is carried out on existing organic compounds as substrate. The output is biogas production. The composition of biogas is similar to natural gas but with a little impurity. However, with a little treatment, it is possible to obtain a gas suitable to use in CHP plants. Anaerobic digestion, not only produces biogas, but also fertilizer for crops. This issue is important both economically and environmentally.

The design of this exemplar bio-gas plant was undertaken by the author.

2.3.5 Economic Study of a Designed Biogas CHP Plant

The size of the biogas production unit needs to be considered. Here the assumption has been made that the rate of produced biogas for a CHP plant should be on a small scale. The reason is that this may prove that the implementation of this project on a small scale is attractive. At larger scales, the attractiveness and feasibility of these projects are likely to be much more. On the other hand, the installation of such kinds of system with this scale in all location including near factories, farms, animal husbandry units, residential and commercial units are prevailing. Thus, small-scale plants are likely to be more widely applicable. In order to prove the feasibility and economic application of this technology, a biogas unit with a volume of 431 cubic meters was assumed. It is linked to a CHP unit with a capacity of 111 kW_e. A design for a biogas unit was made and is presented in Attachment I. This design has been based upon both Iranian and foreign experiences for designing a biogas system.

At the final stage, economic calculations have been made to assess the economic perspective of a biogas CHP plant. Capital costs, operating, consuming costs, annual income of power plant and the payback period of investment in a selected small-scale plant have been calculated and presented in section 6.14.

This research shows that a biogas CHP plant using bagasse has a payback period of less than six years. Economically, technically and environmentally, it appears to be an attractive proposition, both in Iran and in other developing tropical countries where sugar cane can be grown. In addition, it will be a good pattern for the application of other biomass resources in the Country for energy production in biogas CHP plants.

Chapter Three

The Sugar cane Industry Situation in the World and Iran

3.1 Introduction

Today, sugar cane is planted in vast quantities in equatorial and semi equatorial regions from 35º northern in Spain to 35º southern in South Africa (WADE, 2004). In this chapter six countries that are suitable for the cultivation of sugar cane are studied. Also, the history of sugar cane in Iran is explained. The three largest sugar producing countries are Brazil, India and China respectively, which are responsible for half of the World's production of sugar cane. Table 3.1 shows the production quantities and output of the 11 top sugar cane producers in the world (WADE, 2004).

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Table 3.1 Main sugar cane producing countries (WADE, 2004)

Country	Area Harvested(ha)	Production ranking	Yield (tonnes/ha)	Production (tonnes)
Australia	423,000	8	85.13	36,012,000
Brazil	5,303,560	1	73.83	386,232,000
China	1,328,000	3	70.71	93,900,000
Colombia	435,000	7	84.14	36,600,000
Cuba	1,041,200	9	33.33	34,700,000
India	4,300,000	2	67.44	290,000,000
Mexico	639,061	6	70.61	45,126,500
Pakistan	1,086,000	5	47.93	52,055,800
Philippines	385,000	11	67.10	25,835,000
Thailand	970,000	4	76.36	74,071,952
USA	403,390	10	77.29	31,178,130
Other	4,091,132	---	---	244,581,738
TOTAL	20,405,343	---	----	1,350,293,120
Average	---	---	68.53	---

In 2004, Iran with 6.5 million tonnes of sugar cane, ranked 20th in the World, representing approximately 0.54% of the World's production. More than 300 million tonnes of bagasse was produced in the World in 2004, which was mostly used as fuel in sugar cane factories (WADE, 2004).

The total amount of produced sugar cane was increased to 1,743,092,995 tonnes for the 10 top sugar cane producers from 2004 to 2008 (FAO, 2008).

In this chapter the situation relating to the sugar cane industry in Iran and other experienced sugar cane producing countries is reviewed. Information about the sugar cane industry in Iran is dealt with in chapter five, therefore only a brief account is provided in this section.

3.2 History of the Sugar Cane Industry in Iran

In 1951, the Planning Organization, which was responsible for the implementation of sugar revival in the Khuzestan province, invited FAO experts to conduct studies on sugar cane there.

Figure 3.1 shows the location of Khuzestan province in Iran where sugar cane is cultivated.

Figure 3.1 Location of the sugar cane plantation region in Iran

In 1952, Dr. Van Dochure who was one of the well-known experts on sugar in the World taught Iranian experts the general principles of the cultivation and care of sugar cane for six months in Iran. During 1953 and 1954, studies on planted sugar cane continued. A Japanese group also completed a separate study on sugar cane in Khuzestan and announced that Khuzestan had the potential to produce 900 thousand tonnes of sugar from sugar cane. The results of trials showed that sugar cane in Khuzestan could be planted and used despite the winter coldness and it was possible to grow varieties with a high percentage of sugar in the region. The studies concluded that sugar cane plantations could be commercially viable in Khuzestan.

In 1956, continuing studies and the preparation of a plan to establish a sugar cane sugar factory were shifted to an American consulting engineering company. A plan was made by Dr. Karnoos Shardan to have 12000 hectares of lands of Haft Tapeh under plantation and to support industrial sugar production. By 1970-71 with an increase of sugar production, changes in the factory and the addition of some machinery, more than 3000 tonnes/day of sugar cane was processed.

Utilization of the Haft Tapeh sugar cane project was successful and led to further development of this industry in the Country. Also the daily needs of the Country for sugar made new plans for sugar production from sugar cane more desirable. For this purpose, in 1971, new studies were assigned to the Organization of Water and Electricity of Khuzestan. The study of two units with 100000 tonnes sugar cane in Dimche region in Khuzestan was considered and the consulting engineering company of Havaein Agronomix were asked to undertake this.

In 1982, at a seminar on sugar issue in Haft Tapeh Khuzestan, it was concluded that sugar plantations in the Khuzestan province would be economically viable. Preliminary studies on the development of sugar plantation led to the formation of the "Sugar Council". Following that, experts began their studies with the formation of a project on "the development of sugar cane and side industries" in Khuzestan.

The project for the development of sugar cane and side industries of Khuzsetan was thus approved. The plans included 7 sugar production units named: Amirkabir, MirzaKoochakkhan, DoabalKhazaee, Farabi , Ghazali, Dehkhoda and Danial Plantation and Industry and one research centre for sugar cane, in addition to 22 factories related to the by-products.

3.3 Experiences of the World in the Sugar Cane Industry

Sugar cane is a biomass source, which is grown as a commercial product. In comparison with other crops, it has the highest level of efficiency of bioconversion of sun light capture through photosynthesis (FAO, 1994). In many countries, in the process of obtaining of sugar, bagasse is burned to supply steam and generate electricity for the energy needs of sugar cane factories. In the course of time, sugar factories have improved efficiency and energy usage with a view to producing additional sugar cane residue in order to use it as the material for paper, pulp paper and board, or to generate additional electricity to sell to the electricity network.

In the following sections the experiences of sugar cane production and its side industries in countries such as Brazil, India, China, Australia, and Cuba have been reviewed and studied.

3.3.1 The Sugar cane Industry in Brazil

Today, Brazil is the largest sugar cane producer in the World. This sector alone produces about 5 billion dollars of income in this Country. Also it has a reduced dependency on oil.

Studies in Brazil indicate that this industry not only supplies its own energy but also that it can produce additional energy for other sectors (WADE, 2004). The importance of sugar cane is shown in Table 3.2. The table shows, the average energy needed for the cultivation and process of sugar cane opposite to the energy obtained from the ethanol produced from sugar cane and bagasse. The output energy is almost ten times greater than the input energy.

Table 3.2 Input and output average energy for the burned sugar cane and resulting ethanol in Sao Paulo (MJ/t) (Tail and Francis, 2000)

	Input fossil energy	Output energy
Plantation and harvesting sugar cane (agriculture)	190	--
Sugar cane process (industrial)	46	--
Produced ethanol	--	1996
Additional bagasse	--	175
Total	236	2171

Bagasse has long been burned to produce steam. In some cases, it has been burned in a combined heat and power plant, to meets the needs of industry. For example, 350-500 kilograms of steam and 15-25 kilowatt hour of electricity has been produced in per tonnes of sugar cane (Tail and Francis, 2000).

The development of combined heat and power plant using bagasse was started in about 1970, as a result of the oil crises, when Brazil was very dependent on crude oil imports and sugar factories were encouraged to produce their own electricity.

Before 1999, it was not possible to export electricity from Brazilian sugar factories. Industries with 2-100MWe units with low pressure and efficiency were only able to supply the local needs of factories. Almost all sugar and alcohol distillation factories in Brazil had bagasse burning steam turbine systems supplying 21 kg/cm^2 steam to produce steam and electricity for the factory. All of these units date back to the 1980_s (WADE, 2004). With a new energy policy in Brazil, which has been promoted by the government plans, additional electricity is sold to electricity distributors. One of these plans is PROINFA, which is created from the energy of renewable, including cogeneration power plants with bagasse as a fuel. The development of these power plants will continue to progress (WADE, 2004).

In 2007, sugar cane bagasse CHP accounted for 3.03% of the total Brazilian energy matrix. Recent analysis by Frost & Sullivan in 2008 of Brazil's sugar cane bagasse usage for power generation showed that the market reached 3.0 GW in 2007, with estimates that it could reach 12.2 GW in 2014. Hence, bagasse CHP is likely to become a significant part of Brazil's energy matrix over the coming years.

Though energy production might be the major use of bagasse, other applications have been considered in Brazil (Paturau, 1982). For example, some sugar cane bagasse might supplement animal feeding. If the bagasse fibres are digested in a reactor the food value can be increased. In such a reactor, cellulose cells are broken down. The digested bagasse is then compressed into pellets that are easily handled and can be eaten by animals.

Brazil is the seventh largest of producer of paper pulp and ranks 12th in paper production. The paper pulp is produced from wood. Other fibre materials, which are used to produce pulp in a smaller scale, include sugar cane bagasse, cotton wastes and rice straw (Tail and Francis, 2000).

3.3.2 The Sugar cane Industry in India

India, with an average production of 280 to 300 million tonnes of sugar cane, ranks second among the World's sugar cane producers (Pandey, 2007). The notable point is that all 450 sugar production factories, active in India use sugar cane. Due to lack of access to fossil fuels, most of these factories are using bagasse as fuel. In addition, electricity power plants are working 10 to 15 kilometres distant from sugar factories, which use bagasse and filtered mud as a fuel. About 20-30 percent of the bagasse is used for energy production and the remaining bagasse is burnt without any usage. It is notable that most brick-making kilns use bagasse fuel.

The application of gasifier units has become prevalent in India (Mukundaet al., 1999) and many other countries (Hasler, and Buher, 1999; Elliot, 1999). Most of the fuel used by these gasifier units is wood, wood wastes or rice crusts. The new types on a commercial scale, with a thermal efficiency of 1080 MJ/h, are built and use sugar cane leaves and low density sugar cane residues, such as bagasse.

Since 1990, work has begun in the field of combined heat and power plants in India. In this area, some governmental, national and international organizations have been actively promoting the technology. The bagasse CHP plants have started their work as one of the projects related to renewable energy aiming to produce about 10% of the grid's energy by 2012 (Mishra, 2000).

Thirty-four bagasse CHP plant projects with capacity of 210MW had been commissioned in India by 2001. The average export capacity of these plants is 6MW per plant (Banerjee, 2006).

Bagasse CHP plant projects could be of interest under the clean development mechanism (CDM) because they directly displace greenhouse gas emissions while contributing to sustainable rural development. The Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Purohit and Michelowa's estimate indicates in 2007 that there is a vast theoretical potential of CO_2 mitigation from using bagasse for power generation through the combined heat and power process in India. Preliminary results indicate that the annual gross potential availability of bagasse in India is more than 67 million tonnes. The potential for electricity generation through bagasse CHP in India is estimated to be around 34TWh i.e. about 5575MW in terms of the plant capacity. The annual carbon emission reduction (CER) potential of bagasse CHP in India could theoretically reach 28million tonnes. Under more realistic assumptions about the diffusion of bagasse CHP based on past experiences with the government-run programmes, annual CER volumes by 2012 could reach 20–26 million tonnes (Purohit, and Michaelowa, 2007).

3.3.3 The Sugar cane Industry in Australia

Australia has 37 sugar mills, of which all bar one are in Queensland or near its border. The mills crush over 40 million tonnes of cane each year, producing 6 million tonnes of raw sugar, 80% of which is exported (Pickering, 2000).

Plans have been made for the long term development of the sugar cane associated industries in Australia, which will increase income and reduce costs of sugar production (Arthington, and Marshall, 1997). Figure 3.1 shows the processes of the sugar cane industry, which are expected to develop in Australia for the 21st century (Arthington, and Marshall, 1997).

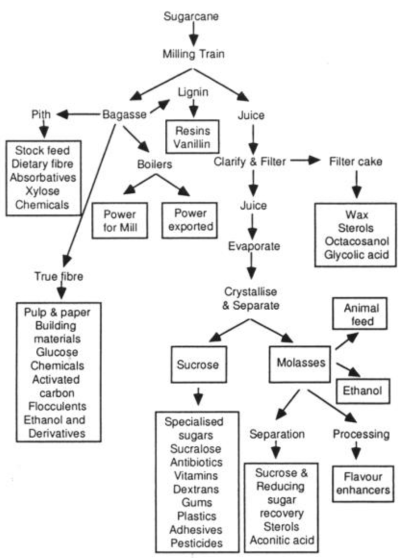

Figure 3.2 Process of the application of side products from the sugar cane industry of Australia in the 21st century (Arthington, and Marshall, 1997)

Bagasse combustion has long been a part of the Australian sugar industry but, until recently, output was only consumed as waste heat. Rocky Point sugar mill was Australia's first bagasse CHP plant project. It generates up to 180GWh per year of electricity from bagasse (Sims, 2002), providing an annual supply of electricity to more than 10,000 homes, and steam and electricity to the nearby Beenleigh Rum Distillery whilst reducing GHG emissions by up to 155,000 tonnes (WADE, 2004). As sugar cane crushing is a seasonal event, Rocky Point sugar mill is configured to co-fire green waste and wood waste to ensure year-round operation.

Since bagasse CHP plant can add significant value to sugar production, electricity sales can potentially match, or even surpass, revenues from Australian sugar sales. Bagasse CHP can also reduce the capital costs of sugar mill expansions in future by pushing for greater economies of scale (WADE, 2004).

3.3.4 The Sugar cane Industry in China

With a production rate of more than 10 million tonnes a year sugar is considered one of the main agricultural commodities in China. With this rate of sugar production, China is the third largest producer of sugar in the World.

During 2002-2003, sugar cane products reached approximately 82.45 million tonnes in China and about 20 million tonnes of bagasse was also produced. Almost 90 percent of bagasse is burnt in traditional form in inefficient old boilers to produce energy to power the grinding operations. The remainder is used for other applications such as mulch and mushroom cultivation.

Today, utilization of bagasse in China is centred on two aspects, i.e. use of it as a fuel in sugar factories and in the production of paper. Using bagasse in paper production is concentrated in the Guangxi province, one of the largest sugar cane producing estate. In 2000-2001, two million tonnes of dry bagasse was produced, of which 25 percent was used to produce paper pulp. Almost, 250 thousand tonnes of pulp was prepared with bagasse (Cao, 2002). Almost 20 thousand tonnes of the capacity of paper production from bagasse has been allocated for the production of newspapers and tissues. This kind of utilization in most sugar factories has been converted into an important and useful part of production.

Other applications of bagasse are the production of insulation and MDF boards. Also in recent years, degradable dishes have been made from bagasse to support the environment (Yang et al., 2001). Production of MDF from bagasse, which was developed by Guangxi University is under consideration in a pilot project. The nano-cellulose being built from bagasse in the labs of the Institute of Guangzhou is a favorable packing material for high quality clothes. Xylitol and xyloligosacarides resulting from bagasse are under consideration (Bao, 2004).

3.3.5 The Sugar cane Industry in Cuba

In slightly over three decades, the sugar cane by-products production capacity has doubled, involving some 70 factories and nearly 300 facilities, most of them using local technology.

Cuba has one of the largest numbers of technologies for manufacture of by-products, in addition to the ability to generate new knowledge in this field, which allows further development in the production of new derivatives (Almazan et al., 2000).

At present, Cuba has 152 factories for producing raw sugar, 16 factories for sugar filtration, 10 factories to produce pulp materials, 141 units for the production of cattle food, 16 units for alcohol distillation, 9 factories for compact boards, fibre from sugar cane bagasse and 5 factories to produce paper and paper pulp (Almaza et al., 2000).

Cuba is 75% dependent on oil to produce electricity. Using oil in supplying electricity has many negative impacts. Oil is polluting both locally (such as emission of SO_2) and globally (CO_2). Cuban oil sources are limited, so this country is interested in diversifying its energy sources.

3.3.6 The Sugar cane Industry in Mauritius

Mauritius produces just less than 5 million tonnes of sugar cane each year (WADE, 2004). Bagasse cogeneration was partly pioneered in Mauritius and, by 1926-27, 26% of Mauritius' electricity generation was in sugar factories (WADE, 2004). Bagasse cogeneration is an ideal source of energy for Mauritius, as the country has no indigenous oil, natural gas or coal deposits and currently needs to import 75% of its primary energy requirements (Bhalla, 2004).

The Mauritian government has recently asserted that the Country wants to develop local energy supplies (Bhalla, 2004). Bagasse CHP projects co-firing with coal are being developed to ensure year round operation.

3.4 Conclusion

A study of these countries shows that the main use of bagasse is to provide a source of energy, and other applications are of secondary importance. In the beginning, bagasse was used only to provide heat to the sugar cane factories by burning it in boilers. However, improving technologies of CHP plant and the development of more efficient energy conversion technologies has allowed bagasse to provide not only energy for the factory, but also extra energy for the electricity grid. The main aim of these countries is to reduce fossil fuel consumption, for economic and environmental reasons.

Chapter Four

Necessity for the Substitution Biomass Resources for Fossil Fuels

4.1 Introduction

Today, the World is facing various problems, including the increasing need for energy; the limitation of fossil fuels sources and rise in the prices of these fuels; global warming and the destruction of environment. Amid this situation, the World is in need of an appropriate alternative for fossil fuels and renewable energies may be the best solution. Biomass energy resources, which are a group of renewable energies, exist in different shapes such as agricultural wastes, municipal solid waste, and industrial wastes. Biomass utilization can reduce forest management costs, help mitigate climate change, reduce risks to life and property, and help provide a secure, competitive energy source (Bartuska, 2006).

Biomass is capturing solar energy in living plants; therefore, energy in biomass can be harvested and stored for subsequent release. Biomass production systems are frequently focused on the production of food, animal feed or fibre, although in some cases there is an energy by-product. All biomass residues can produce bio-energy.

Bio-fuel is a term used to describe biomass processed into a more convenient form for use as a fuel. It commonly applies to liquid transport fuels, but could also include gas and solid fuels such as wood pellets. While many types of biomass can be converted directly into heat or power, some types of biomass are more suited to conversion or refinement into an intermediate bio-fuel. These fuels may have a range of desirable properties such as better storage, ease of handling, greater convenience, compatibility with existing fuels, or higher energy density (IEA, 2005).

The subjects reviewed in this chapter, include reasons for selecting biomass as an appropriate alternative for fossil resources in order to produce energy and other primary materials in other industries.

4.2 Biomass

Biomass is solar energy stored in organic matter. As trees and plants grow, the process of photosynthesis uses energy from the sun to convert Carbon Dioxide into carbohydrates (sugars, starches and cellulose). Carbohydrates are the organic compounds that make up biomass (IEA, 2005). Biomass is a renewable energy source because the growth of new plants and trees replenishes the supply.

Using biomass as a fuel does not increase the long-term quantity of Carbon Dioxide in the atmosphere, as the growing plant absorbs the same amount of carbon as that released when they are consumed as a fuel (Twidell, 1998; WBCSD, 2006).In addition, biomass can be used to generate electricity with essentially the same equipment or power plants that are now burning fossil fuels. Biomass is potentially an important source of energy and is the most important fuel worldwide after coal, oil and natural gas. Biomass use for power generation is projected to more than triple by 2030 (WBCSD, 2006).

Scientists are exploring the advantages of biomass energy as an alternative energy source as it is renewable and free from net carbon dioxide emissions and is abundantly available in the form of agricultural residues, urban waste, cattle dung, firewood, and industrial wastes. Bio-energy, in the form of biogas, which can be derived from biomass, is expected to become one of the key energy resources for global sustainable development (Page, 1994).

4.3 Biomass Sources

The main biomass sources, which are used, consist of wood, agricultural waste, municipal solid wastes and manure. These sources are shown in Figure 4.1 (EIA, 2006).

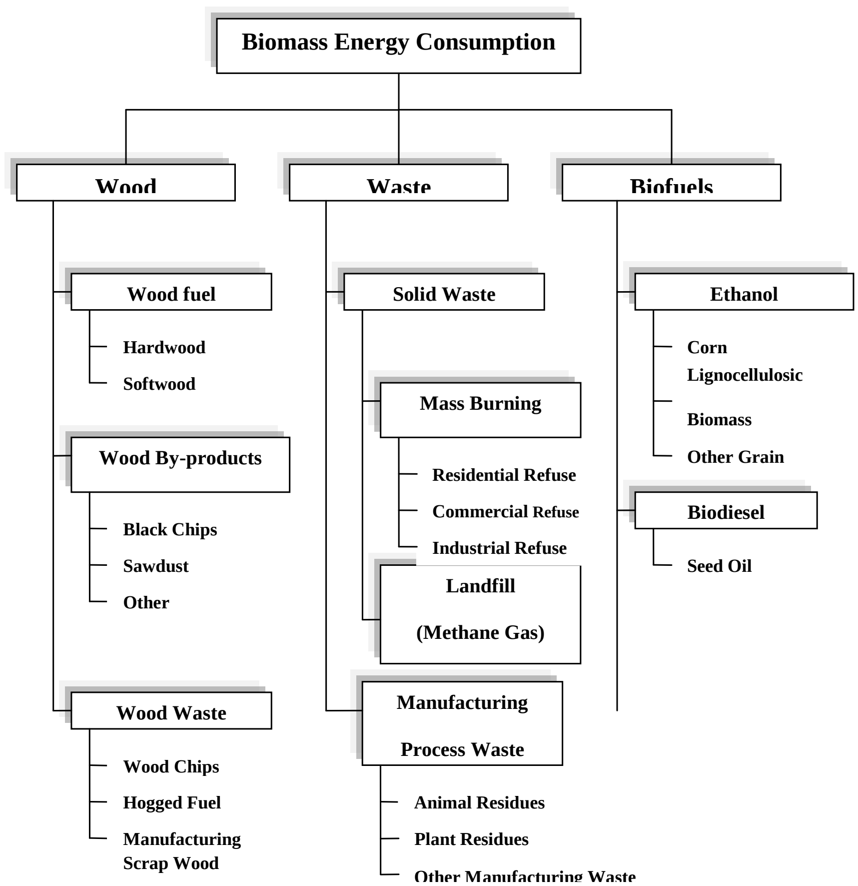

Figure 4.1 Biomass energy resources

4.4 Fossil Fuels Consumption

Human activity and interactions at all levels require the acquisition and consumption of energy and fuels. Increasing population and a preference for energy-rich lifestyle, there is a growing demand for high-quality fossil fuels (Klass, 1998).

The International Energy Outlook projects strong growth for worldwide energy demand over the 24-year projection period from 2006 to 2030 (IEO, 2009). Total World consumption of marketed energy is expected to expand from 472 quadrillion British thermal units (Btu) in 2004 to 552 quadrillion Btu in 2015 and then to 678 quadrillion Btu by 2030, a 44 percent increase over the 2004 to 2030 period as shown in Figure 4.2 (IEO, 2009). Total energy demand in the non-OECD countries increases by 73 percent, compared with an increase of 15 percent in the OECD countries.

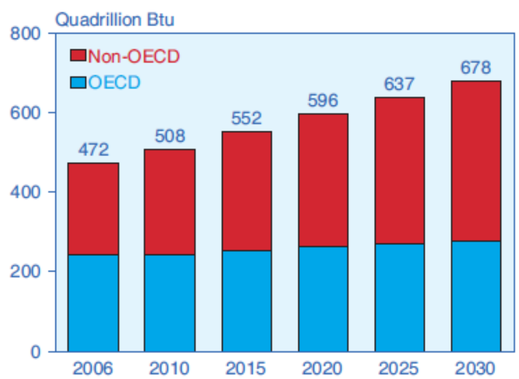

Figure 4.2 World marketed energy consumption, 1980-2030(IEO, 2009)

The IEO in 2009projects increased World consumption of marketed energy from all fuel sources over the 2006 to 2030 projection period (Figure 4.3). Fossil fuels (liquid fuels and other petroleum, natural gas, and coal) are expected to continue supplying much of the energy used worldwide. Liquids supply the largest share of World energy consumption over the projected period; however, their share falls from 36 percent in 2006 to 32 percent in 2030, because of increasing World oil prices. Therefore, it leads many energy users, especially in the industrial and electric power sectors, to switch away from liquid fuels.

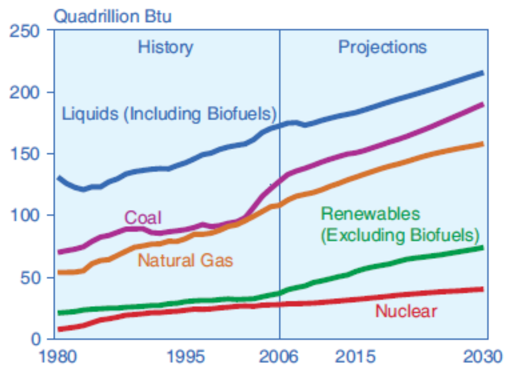

Figure 4.3 World marketed energy use by fuel type, 1980-2030 (IEO, 2009)

4.5 Peak Oil and World Oil Price

It is thought that mineral oil is almost at peak production and that within the next decade it will probably steadily decline. Oil deposits will be steadily exhausted and in terms of oil being a bulk energy resource, it will cease to be dominant around 2050 (Mobbs, 2005).

The key variable in predicting the date of Peak Oil is the global assessment of total oil reserves: namely, how much oil is out there to extract. Various studies of the date of Peak Oil exist, and these predict a range of dates from 1996 to 2035, depending upon the total oil reserve figure used. For example, Hubbert in 1977 predicted a global peak in 1996. Another study by Colin Campbell and Jean Laherrere placed the peak in 2005 (Campbell, and Laherrere, 1998), based upon a total global resource of 2,000 billion barrels.

The International Energy Agency (IEA) in 2001, according to the assumptions of the US Geological Survey (USGS), determined Peak Oil would occur beyond 2020 (IEA, 2001). However, the USGS study has been criticized because it places too much emphasis on the discovery of unknown oil reserves, and the development of more efficient technologies of oil extraction.

There are some other criticisms about IEA assumptions, which should be mentioned. Obtaining good estimates of oil reserves is difficult, because there is no procedure to verify the figures, which are received from oil companies (Laherrere, 2003). Another criticism by oil specialists is that both the IEA and the USGS have switched the emphasis in their estimate of oil reserves from conventional oil to non-conventional oil resources. Moreover, these surveys have been singled out for criticism because instead of a single figure for the proven level of production, as many other studies use, the reserves quoted in USGS studies may have a 95%, 50%, or 5% chance of producing the quoted volumes of oil (see Table 4.1) (Mobbs, 2005).

In practice, the true level of total oil production is likely not to be known until we are well past the peak of conventional oil production, and the figures demonstrate that the World cannot produce the same volumes of oil as were produced before 'Peak Oil'. Therefore, if we wish to plan for how we as individuals will manage following the date of Peak Oil, we are limited to the data produced by specialists who study oil production. Which set of data you accept, like other forms of value judgment, is largely linked to which statistical method you believe provides the most valid approach.

Table 4.1 The USGS World oil reserves projection (USGS, 2000)

Oil and Gas Liquids, billion barrels				
Chance of Recovery	95%	50%	5%	Mean
Undiscovered conventional sources	495	796	1,589	939
Improved recovery from Conventional sources	205	654	1,102	730
Remaining known reserves	-	-	-	959
World oil production to date	-	-	-	717
Total	-	-	-	3,345

As an example, Laherrere's data suggests that World oil production will peak at around 80 to 90 million barrels per day around 2010 to 2015 (global oil consumption was already in excess of 82 million barrels per day in 2005)(Campbell, and Laherrere,2000). Also in 2003 Laherrere's findings for the total level of oil production are represented in Figure 4.4 by Boyle and his colleagues.

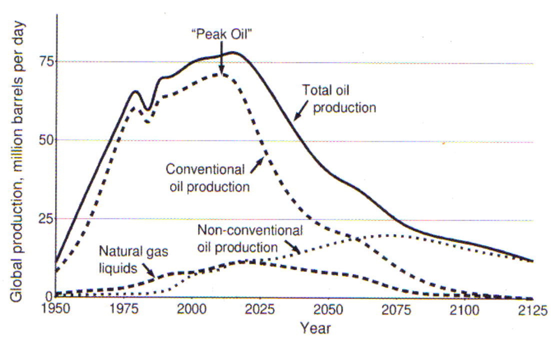

Figure 4.4 A projection of future World oil production (Boyle et al., 2003)

The precise figure will depend on the oil price. For example, if the price rises in advance of the peak, depressing demand, then a higher production figure might be reached.

There are some projections for predicting oil price rise following Peak Oil. According to the European Commission's figures (EC, 2001), prices will rise as more marginal sources of oil are exploited. Taking oil production costs as one quarter of the total cost; this would raise prices by at least 25% over the next five years. In the view of Colin Campbell (Campbell, and Laherrere, 2000) as we pass the date of Peak Oil, and organizations like OPEC can no longer keep control over the oil price because of the shortage of oil, prices will rise by approximately 75% purely because of speculation in the oil market.

The average World oil price increased each year between 2003 and 2008. Spot prices reached $147 per barrel (in nominal dollars) in mid-July 2008, when they were well above the historical inflation-adjusted record price for a barrel of oil, which was set in the early 1980s. After reaching the July 2008 high mark, however, prices fell sharply (IEO, 2009). As the World's economies recover, World oil prices are assumed to be likely to rebound and rise in real terms through to 2030. In the IEO2009reference case, the price of light sweet crude oil in the United States (in real 2007 dollars) rises from $61 per barrel in 2009 to $110 per barrel in 2015 and $130 per barrel in 2030. World oil prices in 2030 in the IEO2009reference case are 80 percent higher than projected in IEO2008 (Figure 4.5) (IEO, 2009).

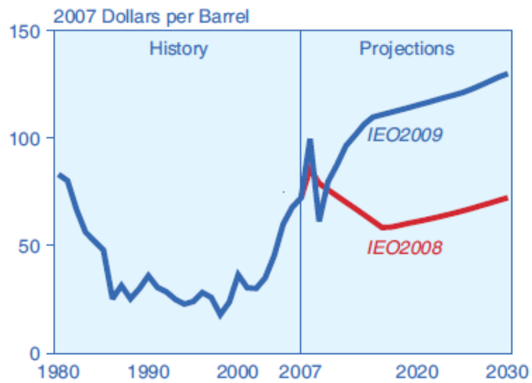

Figure 4.5 World oil prices in the IEO2009and IEO2008 reference cases, 1980-2030

The most significant impacts of the higher or lower World oil price assumptions are on the mix of energy fuels consumed, particularly liquids and coal as shown in Figure 4.6. In the high price case, total World liquid consumption in 2030 is about 34 quadrillion Btu, lower than projected in the reference case, natural gas consumption in 2030 is 9 quadrillion Btu higher, and coal consumption is 2 quadrillion Btu higher than in the reference case (IEO, 2009). According to the IEO projection in 2009 the amount of nuclear power and renewable energy consumption between the two cases is very small, especially in the near to mid-term, primarily because both energy sources are strongly influenced by government policies and incentives, and prices do not have a large impact on their development (IEO, 2009).

In the low oil price case, consumers increase their use of liquids for transportation, and there is less incentive for movement away from liquids to other energy sources in sectors where fuel substitution is fairly easy to achieve (as opposed to the transportation sector, where there are few alternatives to liquid fuels). Total liquids consumption in 2030 is 28 quadrillion Btu higher in the low price case than projected in the reference case, reflecting increased demand in all the end-use sectors (IEO, 2009).

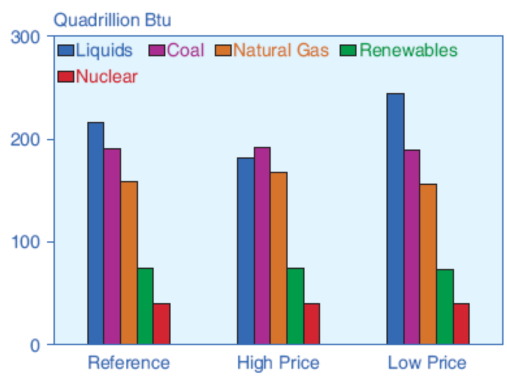

Figure 4.6 World marketed energy consumption in three world oil price cases, 2030 (IEO, 2009)

The rapid increase in world energy prices from 2003 to 2008, combined with concerns about the environmental consequences of greenhouse gas emissions, has led to renewed interest in the development of alternatives to fossil fuel (IEO, 2009). World oil prices are expected to return and growth in demand for liquids and other energy expected to resume when economies begin to recover from the current global downturn. Renewable energy is the fastest-growing source of World electricity generation in the IEO2009reference case, supported both by the expected high prices for fossil fuels and by government incentives for the development of alternative energy sources (IEO, 2009).

4.6 Environmental Issues of Fossil Fuels

Burning of fossil fuels is the largest manmade source of emissions of carbon dioxide, for example, in the United State; more than 90% of gas emissions come from the combustion of fossil fuels (EPA, 2000). Carbon dioxide is one of the green house gases that allows radiative forcing and contributes to global warming. The atmospheric concentration of carbon dioxide is increasing, raising concerns, that infra-red radiation will be trapped and the average surface temperature of the Earth will rise in response. Fossil fuels also contain radioactive materials, mainly uranium and thorium, which are released into the atmosphere. In 2000, about 12,000 tonnes of thorium and 5,000 tonnes of uranium were released worldwide from burning coal (Gabbard, 2001).

Furthermore, combustion of fossil fuels leads to the formation of sulphuric, carbonic and nitric acids, which fall to earth as acid rain, affecting both ecosystems and the built environment.

World carbon dioxide emissions are projected to rise from 29.0 billion metric tonnes in 2006 to 33.1 billion metric tonnes in 2015 and 40.4 billion metric tonnes in 2030, an increase of 39 percent over the projection period (IEO, 2009). With strong economic growth and continued heavy reliance on fossil fuels expected for most of the non-OECD economies, much of the increase in carbon dioxide emissions is projected to occur among the developing, non-OECD nations. In 2006, non-OECD emissions exceeded OECD emissions by 14 percent. In 2030, however, non-OECD emissions are projected to exceed OECD emissions by 77 percent (IEO, 2009) (Figure 4.7).

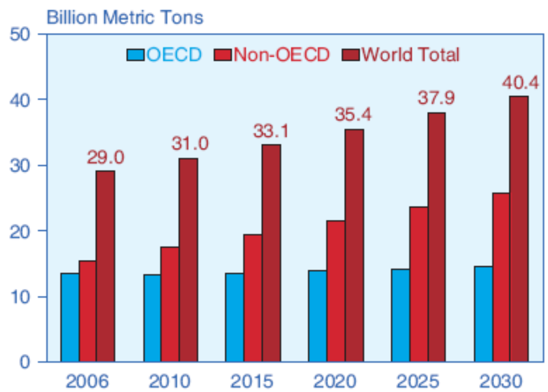

Figure 4.7 World Carbon Dioxide emissions, 2006-2030 (IEO, 2009)

The relative contributions of different fossil fuels to total energy-related carbon dioxide emissions have changed over time. In 1990, emissions from petroleum and other liquid combustion made up an estimated 42 percent of the World total. In 2004, the petroleum share was 40 percent, and in 2030, its share is projected to be 36 percent, of the World total (IEO, 2009). Carbon dioxide emissions from natural gas combustion, which accounted for 19 percent of the total in 1990, increased to 20 percent of the total in 2004. That share is projected to rise to 21 percent in 2030as Figure 4.8 shows.

Coal's share in 2004 was the same as its share in 1990, at 39 percent; however, its share is projected to increase to 43 percent in 2030. Coal is the most carbon-intensive of the fossil fuels, and it is also the fastest growing energy source in the IEO 2007 reference case projection (EIA, 2007).

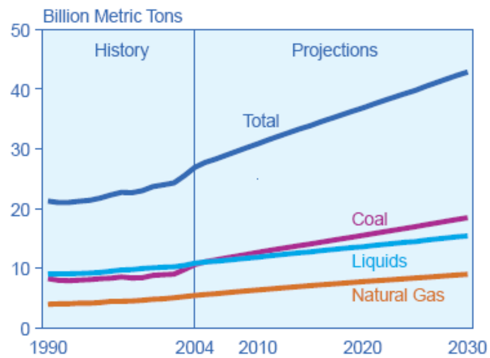

Figure 4.8 World Carbon Dioxide emissions by fuel type, 1980-2030 (IEO, 2009)

4.7 Biomass as an Alternative for Fossil Fuels

The 20th century was the century of the petrochemical economy. Gasoline and diesel (made from petroleum) powered almost all vehicles (Werpy, and Petersen, 2004). Many plastics made from petroleum or natural gas were used to make clothes, carpets, food packaging, and increasingly, car parts and building materials.

In the 21st century, the use of biomass plants and plant-based materials, produced by photosynthesis within biological rather than geologic situation will have the potential to significantly offset this petrochemical dependence. Biomass cannot fully replace the huge volumes of petroleum and other fossil fuels that we now use, but it can significantly influence the growing demand for fossil fuels (Werpy, and Petersen, 2004).

4.7.1 Biomass Resources as Fuel

As mentioned earlier, fossil fuels (oil, coal and gas) are key contributors to global warming, causing direct climate change and threatening agriculture and other human activities in a number of ways. Furthermore, fossil fuel reserves are not sustainable. These facts alone mean that the search for alternative sources of energy has to be urgent.

There are many different kinds of biomass fuels from the traditional fuel wood used for cooking, to sophisticated modern bio-fuels, which are produced from purposely grown biomass. When biomass is burned, the chemical energy in biomass is released as heat.

However, burning biomass is not the only way to release its energy. Biomass can be converted to other usable forms of energy such as methane gas or transportation fuels like ethanol and bio-diesel. Methane gas is the main ingredient of natural gas. Decomposing municipal solid waste, agricultural residues, and human waste, under appropriate conditions, release methane gas also called "landfill gas" and "biogas". Crops such as maize and sugar cane can be fermented to produce the transportation fuel, ethanol. Bio-diesel, another transportation fuel, can be produced from leftover food products like vegetable oils and animal fats, or directly from oilseeds, grown specifically for the purpose.

According to a 1984 report by the Hawaii Natural Energy Institute, of the clean renewable energy alternatives, "only biomass energy holds promise to provide liquid fuels for transportation in the near future" (Phillps et al., 1989).

Sugar cane is a high moisture herbaceous plant. It is well suited for bio-chemical conversion technology (fermentation), which can produce ethanol. High moisture plants can also be fermented to produce methane, which may be used for heating or generating electricity.

Research in Hawaii (Phillps et al., 1989) showed that sugar factories supplied most of the electrical power on all the major islands near Ohau from the beginning of the 20th century, by burning the hydrocarbon rich sugar cane waste, bagasse, in steam co-generators.

4.7.2 Biomass for Chemical Feed Stocks

The U.S. chemical industry consumes more than 7% of America's petroleum and natural gas liquids to manufacture over 54 million metric tonnes of primary chemicals. The chemical industry plays a major role in the maintenance of the Western World's standard of living. Thousands of ordinary products used every day in every American household are made from a handful of primary chemical feedstocks (Lipinsky, 1981).

Biomass could compete favourably with fossil fuels, in the chemical feedstock industry. Biomass has several advantages over fossil fuels as a raw resource for this industry, as it is a renewable, flexible and adaptable resource. Moreover, crops can be grown to satisfy changing end-use needs (Lipinsky, 1981).

Pulpwood is the chief resource for cellulose production. Demand for pulpwood by the paper industry has caused prices to increase. Dewey and Marrillin 1916projected that at the rate the U.S. was using paper, the USA would deplete its forests within human lifetime. So they looked for an alternate agricultural resource for paper products to prevent the anticipated disaster. Some chemical manufactures are looking at alternative crops, for example, bagasse is used as an alternative for making paper. This process requires no bleaching, is more biodegradable, easier to recycle, and overall has less impact on the environment than the process of wood pulp.

4.8 Biomass Energy and the Environment

Unlike any other energy resource, using biomass to produce energy is often a way to dispose of biomass waste materials that otherwise would create environmental risks. Thus, using biomass for energy can deliver unique environmental dividends as well as useful energy.

4.8.1 Reducing Greenhouse Gases

The current patterns of energy use, and associated links to emissions of greenhouse gases and climate change, are of major global concern. The Earth's climate is changing; the average global temperature has risen by 0.6 degrees Celsius since the beginning of the 20th century (UNESCO, 2005). Biomass is fuel derived from plant material. Although CO_2 is released into the atmosphere when plant material is burnt, an equivalent amount will have been taken from the atmosphere during growth. The carbon in biomass fuel does not therefore increase atmospheric greenhouse gasses

Compared with CO_2, methane has 21 times the global warming potential. Natural decomposition of organic material, especially in wetlands, releases methane(IEA, 2005).For example, solid waste landfills, manure and industrial wastes such as dairies are the greatest sources of human-caused methane emissions. The global atmospheric concentration of methane increased 6 percent from 1984 to 1994, and it is thought that humankind is responsible for most of this increase (IPCC, 2003).

Using biomass-derived methane to produce useful energy consumes methane and reduces the risk to the environment. In addition, generating electricity with biomass-derived methane fuel can offset power produced from fossil fuels and reduce the net CO_2 emissions from electric power generation.

4.8.2 Reducing Air Pollution

Field burning of agricultural residue emits particulate matter and other air pollutants. Grass, straw and other agricultural residues are potential biomass fuels. These materials are suitable as fuel for appropriately designed combustion boilers to produce heat, steam or electric power. They are also potential feedstock for conversion to ethanol.

Smoke emissions from forest fires and slash and burn agriculture also adversely affect air quality. Removing biomass from forested areas where an excess of dead wood has accumulated reduces forest fire risk. Compared to the smoke emitted from fires and slash and burn farming, the emissions from using wood fuel for energy are far less harmful.

4.8.3 Reducing Acid Rain and Smog

Air pollution from burning fossil fuels is a major cause of acid rain. Co-firing biomass with coal can reduce SO_2 and NO_x emissions at coal-fired power plants. The level of NO_x emissions from biomass combustion facilities depends on the design of the facility and nitrogen content of the feedstock. Pollution control equipment can further reduce NO_x and particulate emissions.

Table 4.2 shows the emissions of sulphur dioxide by source in the UK from 1990 to 2004, and the percentage change between the two dates (DTI, 2007). Sulphur dioxide emissions have fallen from all sources, and in most cases have at least halved. In the UK in 2004, around three fifths of sulphur dioxide was produced by the combustion of coal, primarily in the generation of electricity at power stations. Emissions from power stations fell by 82 per cent between 1990 and 2004. The main cause was a fall in the amount of coal used in electricity generation, from 49.84 million tonnes of oil equivalent (Mtoe) in 1990 to 31.30 Mtoe in 2004(EWP, 2006). Also if fossil fuel is substituted by other sources such as biomass or methane, emission of a large amount of green house gasses will be prevented.

Table 4.2 Estimated emissions of sulphur dioxide by source category in 1990 and 2004 (EWP, 2006)

SO_2 emissions (thousand tonnes of SO_2)			
Source category	1990	2004	Percentage change between 1990 and 2004
Total energy sources	**3,645**	**818**	**-78**
Power stations	2,729	496	-82
Refineries	153	65	-58
Manufacturing industries & construction	422	158	-63
Transport	95	39	-59
Other sectors including domestic & services	212	46	-78
Other energy sources	6	4	-33
Fugitive emissions from fuels	28	10	-64
Total non-energy sources	**53**	**15**	**-72**
Production processes	46	14	-70
Others	7	1	-86
All sources	**3,699**	**833**	**-77**

4.9 Conclusion

Biomass energy is one of the renewable energies that can be a suitable substitute for fossil fuels. One of the outstanding benefits of biomass resources is that they have the ability, not only to produce energy, but also to supply materials for some industries. Moreover, they are less harmful for the environment and increase the economic and social well being of societies.

Chapter Five

Bagasse Applications and its Potential in Iran

5.1 Introduction

Nowadays, sugar cane has become very important from a commercial point of view, especially because of its by-products. The sugar cane industry produces not only sugar as a main product, but by-products such as bagasse, molasses, and filter mud that can be used as raw materials for other industries (Nguyen et al., 2009).

Among these by-products, bagasse is produced in a large amount with different applications. It may be used as fuel in the sugar cane mill or as a source of cellulose for manufacturing animal feeds. Paper is produced from bagasse in several Latin American countries and in the Middle East. Bagasse is the essential ingredient for the production of pressed building board, acoustic tile, and other construction materials and also in chemical industries.

This chapter provides information on Iran's sugar cane industries and bagasse production potential. Furthermore, the specifications of Iranian sugar cane plants, bagasse characteristics, and bagasse applications are explained.

5.2 Sugar Cane

Sugar cane is the common name of a species of herb belonging to the grass family. It is common in tropical and subtropical countries throughout the world. The plant stems are 3-5 m, and are jointed with very fibrous stalks (Figure 5.1) (Weg, 2000). Figure 5.2 shows the composition of a sample of fully-grown sugar canes, which are controlled genetically.

Figure 5.1 Shape of the sugar cane plant

Fibre 16%	
Non sugar compounds	
Pure juice	Sucrose 15.5%
	Water 65%

Figure 5.2 Composition of a sample of fully-grown sugar cane (% by weight)

5.3 The By-Products from the Sugar Cane Factory

The main product from sugar cane manufacture is sugar but, in addition to sugar, the factory produces bagasse (30%), molasses (3%), and filter mud (3%).

5.4 The Physical and Chemical Properties of Bagasse

5.4.1 Characteristics of Bagasse

Bagasse is the fibrous residue of cane stalk obtained after crushing, and the extraction of juice in the form of wood chips and is straw yellow in colour as shown in Figure 5.3. Each tonne of sugar cane yields 250 kg of bagasse (WADE, 2004).

Figure 5.3 The appearance of bagasse (yellow straw)

The composition of bagasse varies with the variety and maturity of the sugar cane, as well as with the harvesting method used and the efficiency of the sugar mill in processing the sugar cane (Paturau, 1989). Bagasse consists of fibres, water and some soluble solids. The properties of bagasse are presented in Table 5.1.

Table 5.1 Bagasse properties

(Paturau, 1989; Gollakota and Sobhanbabu, 2002; WADE, 2004)

Water	46-62%
Fibre content	43-52%
Soluble solids	2-6%
Average density	150 kg/m^3
Low Heat Value	1780 kcal/kg
High Heat Value	4000 kcal/kg

The fibre of the bagasse is insoluble in water; and it consists mainly of cellulose, pentosans, and lignin.

5.4.2 Calorific Value of Bagasse

The calorific value of bagasse is measured in relation to the amount of water and fibres contained in it. The calorific value of bagasse has been determined by numerous investigations. Some of the more reliable estimates have been made by Pritzelwitz van Der Horst in 1927 and Hesseyin 1937 who determined the following relationships.

- Van Der Horst

Gross Calorific Value: 19037-42S-190.4W in kJ/kg

Net Calorific Value: 17791-42S-200.8W in kJ/kg

- Hessey

Gross Calorific Value: 19397-51.5S-194W in kJ/kg

Net Calorific Value: 18092-51.5S-205W in kJ/kg

The values are expressed in kJ/kg, where W is the moisture in the bagasse and S the soluble solids (mainly sugar) expressed as percentages.

Note that the Net Calorific Value (NCV) takes into account the impossibility in practice of cooling down the products of combustion sufficiently to condense the moisture present and recover its latent heat. Hence, the NCV is the more realistic measure of the heating power of the fuel considered.

With the present extension of mechanical harvesting, bagasse contains more extraneous matter than previously and this has a negative effect on the calorific value. A new formula, proposed by some African scientists (Don, et al., 1977) takes into account the significant influence of ash as follows:

Gross Calorific Value: 19605-31.14Bx-196.05 W-196.05A (defined at 20°C)

Net Calorific Value: 18309-31.14Bx-207.3W-196.1A in kJ/kg

In the above formula A is the ash content in a bagasse sample, and B is the brix content in the bagasse sample by the percent of mass. The formulae by von Pritzelwitz van der Horst and by Hessey aligns with the values obtained by the present formula only if the ash content of the sample is low. As the ash content of bagasse increases the values derived by the von Pritzelwitz van der Horst and Hessey formulae move further and further away from the true values. The present developed formula, containing ash as an independent variable, is therefore preferred (Don, et al., 1977).

Under average conditions, it can be assumed that the Gross Calorific Value of normal millrun bagasse is equal to 9600 kJ/kg, while the Net Calorific Value is 7600 kJ/kg.

5.5 The Sugar Production Process

The process of sugar production from cane is outlined in Figure 5.4. The process is very energy intensive, requiring inputs of both heat and power at many stages.

This process is effectively illustrated by considering the Haft Tapeh Sugar cane Plantation and Industry. Haft Tapeh is one of the Iran’s oldest sugar cane plantations and industries, which studied by the author.

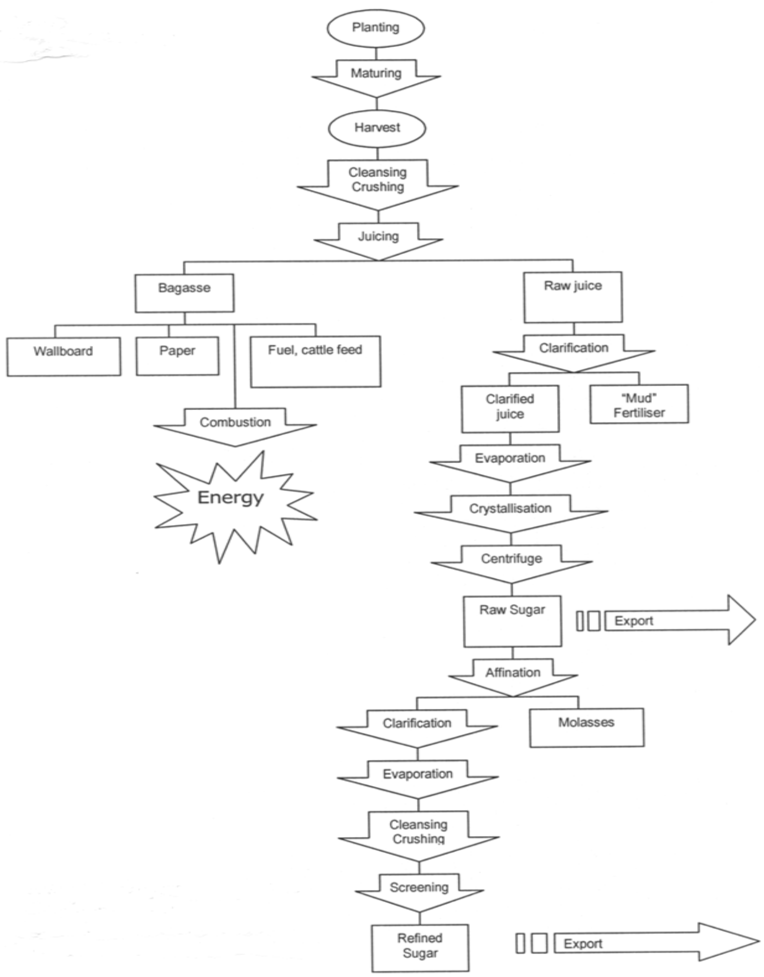

Figure 5.4 Flow chart of the sugar production process (WADE, 2004)

5.6 The Process of Producing Sugar from Sugar Cane in the Haft Tapeh Sugar Cane Plantation and Industry

The process of producing sugar cane is explained based on visits that I made the Haft Tapeh Sugar cane Plantation and industry.

5.6.1 Process of Producing Yellow Sugar

The stems of sugar cane are transported from farms by tractor and are discharged in the reception area. The stems of sugar cane are then placed on feeder table and transferred into the washing stage by carriers in order to have as much mud as possible removed (Figure 5.5).

Figure 5.5 The stage of transporting sugar cane by carrier

The washed stems then enter two parallel milling lines, where the knives slice the canes to enable the fibres of the stalks to be chopped (Figure 5.6). Next, the fibres of cane are cut into even small pieces to help with juicing. The two lines have six stages with three-roller mills (Figure 5.7). The distance between rollers in the first stages and second stages is greater than that of the following stages, so that the cutting of sugar cane stems is improved. The distance between rollers is subject to erosion and therefore 2 or 3 times in a year, precise measuring should take place. Juicing is carried out by mills from the first stage to the sixth stage. In order to have the maximum of juice extraction, in the fifth and sixth mills, hot water is added, so that the possible remaining sugar can be removed. The remaining fibrous material after the removal of sugar is called bagasse. The sweet liquid accumulates below the mills at stage 6 and is poured into the stage 5 mills, in this way, the sweet liquid resulting from stage 5 flows into the entrance of stage 4. This process is continued for all the stages until all the juice is collected.

Figure 5.6 The stage of cutting canes by knives

Figure 5.7 Cutting sugar canes using three-roller mills

After the milling is completed in accordance with Figure 5.8, bagasse is detached and placed over carriers and transferred to the Pars Paper Factory.

Figure 5.8 The transport of bagasse by carriers to Pars Paper Factory

The sweet extracted juice is called brix. This needs to meet specified standards of concentration. If it is too dilute, the brix water will need to evaporate. This step consumes large amounts of energy. Evaporation is done by heaters. With regard to existing pollutants in sugar cane such as microorganisms, poisons and fertilizers, the acidity and polarity of the liquid is high, therefore, the liquid should be regulated, and this action is achieved by clarification. The sweet liquid from the heaters is entered into a flash tank and at this stage, CO_2, and lime sweet liquid are added, so that the pH is brought up to 7. The calcium carbonate produced causes sedimentation of mud and its wastes in the form of colloidal sediments. The output of the flash tank is moved into the clarifier for de-sedimentation. This stage is shown in Figure 5.9.

Figure 5.9 Filtration of sweet liquid by CO_2 and lime

The detached mud contains some sucrose, which is separated by adding sweet water and theact of centrifuge. The detached mud at this stage is called filter mud. The filter mud is shown in Figure 5.10. The juice separated from the filter mud is returned to the container of open syrup. At this stage, the pH is 7-7.2 and polarity about 3.5% is ideal.

Figure 5.10 Detachment of filter mud from the sweet liquid

The next processing stage in the production of sugar takes place in the units, which consist of five boilers. Pumps transfer the syrup to the first stage. Heating is supplied by exited steam from steam turbines (for electricity generation) whereas other stages are fed by the resulting steam from the previous stage. The sweet liquid at this stage is called syrup. The concentrated sweet liquid is entered into the syrup storage tank. At this stage, there is another tank called a Magma tank, shown in Figure 5.11, and it is used to collect the molasses from the baking boilers.

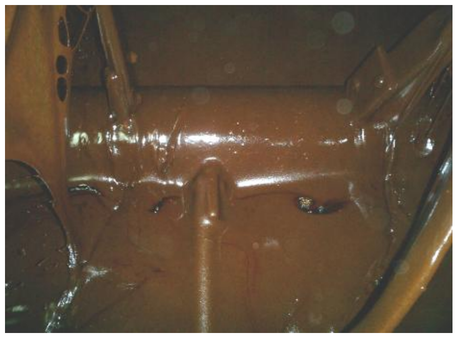

Figure 5.11 Magma reservoir tank

The baking system has three parts; A, B and C. The syrup in the baking pan A reaches 98% sugar concentration. The hogwash from baking pan A creates the syrup entering baking pan B that produces slighter grains. The hogwash from baking pan B then forms the material processed in baking pan C.

The outlet of the baking pans A, B, after becoming cold at the crystallizer, produces sugar and molasses (Figure 5.12) by centrifuge pumps. Also, the outlet of baking pan C, after becoming cold, produce the final molasses and sugar of baking pan C. The sugar of baking pan C is mixed with water, and dissolved and poured into baking pans A and B. Its molasses are also extracted after scaling. Baking pans A, B, and C, are entered into centrifuge pumps after the crystallizer, and there, by using centrifuge, sugar is detached from its accompanying liquid. The products from the centrifuges of A and B baking pans are molasses and yellow sugar, which shows in Figure 5.13. At baking stage C, there are also centrifuges, which work constantly. The sugar of baking C, in a melted of sugar which functions constantly, by injecting steam is changed into syrup which is called Magma and used as baking of A and B. The exiting molasses of C is the final molasses, which is entered into the molasses reservoir.

Figure 5.12 Detached molasses

Figure 5.13 Centrifuge to detach the crystals of yellow sugar

5.6.2 Process of Filtration of Raw Sugar

The sugar filtration unit converts yellow sugar into white sugar. At the beginning of this procedure, raw sugar is weighed and then mixed with sweet water in order to produce ultra saturated liquid or crystals of yellow sugar. This mixture is called Magma. The resulting smoothed syrup is entered into a flash tank, and limejuice is added for the clarification operations. At this stage, CO_2 gas is also added in order to reduce the pH.

As a result of the increase of lime water, the suspended impurities inside the syrup are more easily detached. The flow of syrup from the first tank becomes overflow and enters into the second tank and thereafter it moves to the third tank. The outlet syrup, after reaching an ideal temperature is moved towards carbon pressing filters, which undertake the final act of syrup filtration.

The filtered syrup is firstly entered into the receiving tank by pressing filters and then transferred into the processing tanks. The operations de-colour carried out in these tanks are to reduce the pH by about one unit and to the syrup. For this purpose, activated carbon and SO_2 gas are used; this stage is shown in figure 5.14.

Figure 5.14 The tank behind the women's heads is used for de-coloring the syrup of yellow sugar by activated carbon and SO_2

When the syrup becomes a brix, the condensed syrup in the evaporation unit is entered into the storage tank for baking operations. The baking operations are done in the vacuum baking pans. The baking pans have a significant role in the creation of sugar crystals, because, at this stage, the final product is shaped and crystallized. The centrifuge unit has a basket to detach hogwash from white sugar. Also a nozzle has been installed to wash the crystal level and one small shovel to detach sugar from the basket as shown in Figure 5.15.

Figure 5.15 Centrifuge to detach white sugar

The detached sugar at this stage is wet sugar. The resulting wet sugar is directed into the dryers. The act of drying and cooling sugar is undertaken by airflow blowers. The final sugar is packed into bags each holding a specified weight as shown in Figure 5.16.

Figure 5.16 packing sugar in bags

5.7 Utilisation of By-products of Sugar cane

Figure 5.17 shows the main products and applications of these by-products.

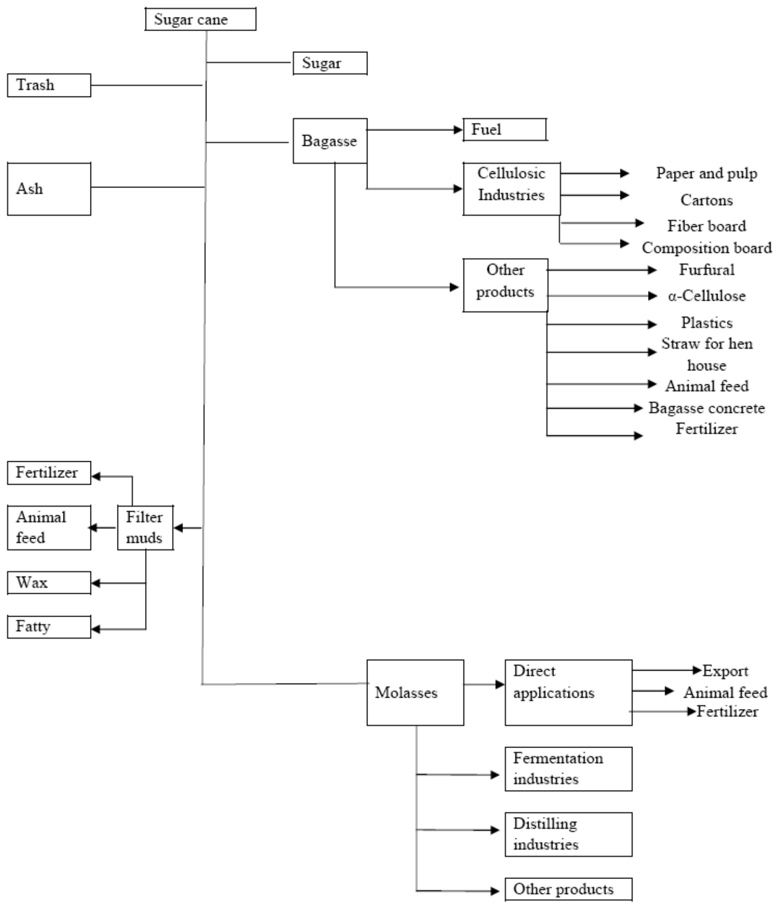

Figure 5.17 By-products and sugar cane side- industries

5.8 Bagasse Utilisations

The main applications of bagasse are its use as a fuel, as a raw material in cellulose industries, chemical industries, and as a fertilizer or animal feed, respectively.

5.8.1 Bagasse Utilisation as Fuel

5.8.1.1 Bagasse CHP

Burning bagasse in order to produce steam in sugar cane factories and using steam at medium and high pressure for power generation in the sugar cane industry is a prevailing and standard practice. Until recently, the objective of burning bagasse in the sugar cane industry was only to achieve self-sufficiency of factories in respect of fuel needs. However, in recent years, in particular after the energy crises, and the extraordinary increase in the World oil price, many factories which produce sugar from sugar cane began thinking that by increasing the efficiency in using bagasse as fuel, they could produce considerable quantities of additional bagasse and used them to produce the surplus electricity to sell to the power network (Tail & Francis, 2000; Deephand, 2005). In order to achieve this aim different energy conversion technologies are used, which can combine with CHP, as was shown in figure1.1. Combined Heat and Power (CHP) generally refers to systems sequentially generating electrical power and thermal energy. Their combined production has been utilised by sugar estates with the supply of electricity to irrigation and utility services and the provision of surplus process steam to adjacent distilleries (Paturau, 1989).

5.8.1.2 Briquettes (Pressurized Bagasse)

One direct method of using bagasse instead of other fuels is to press the bagasse into blocks, that are transportable that can be used as a substitute for fire wood in regions facing shortages of fire wood and other fuel sources (Hulscher, 1994).

Some technical difficulties are associated with the bagasse briquettes long-term integrity. The bagasse has high moisture content; nearly 50 percent is considered the greater negative factor when briquetting is considered (Rossillo-Calle et al., 2000). The few industrial presses, which have been in operation with bagasse, consist of three successive operations-fiber preparation, drying and briquetting, which have an effective capacity of about 1 tonne of briquettes per hour (Paturau, 1989).

5.8.1.3 Producing Coal from Bagasse

Another method for the direct use of bagasse as a fuel is to convert it into coal.

5.8.1.4 Methane Production (Biogas)

For over a century, methane gas production has been investigated by bacteriologists and chemists. Methane and carbon dioxide are gases produced by the fermentation and decay of cellulose materials and wastes.

The methane produced in a bioreactor is a mixture of methane gas and carbon dioxide with an average ratio of 65 percent methane and 35 percent carbon dioxide, which is known as biogas. Biogas has a calorific value about 22,000 kJ/kg, or 27500 kJ/m^3. Also, 100 m^3 of biogas is equivalent to 70 litres of gasoline or 62 litres of diesel fuel in energy generation (Paturau, 1989).

5.8.1.5 Producer Gas from Bagasse

Producer gas is made by heating fuel to ash in a mixture of air and steam to produce a gas consisting of burnt and combustible gases. Coal is the fuel generally used, but soft fuels like wood, sawdust or bagasse have been successfully used in various countries (Rossillo-

Calle et al., 2000).The average composition of producer gas from bagasse is mentioned in Table 5.2.

Table 5.2 The average composition of producer gas

:Components	Average composition (%)
Carbon dioxide	11
Carbon monoxide	17
Methane	6
Hydrogen	6
Nitrogen	60

The calorific value of producer gas is about 5000 kJ/kg or 3800 kJ/m^3 at N.T.P. (Tromp, 1940, Paturau, 1989).

5.8.2 Using Bagasse in Cellulose Industries

For centuries, the main source of paper production was wood from trees. Unfortunately, excessive and over use of wood resources has led to the destruction of natural forest. Therefore, the developed countries, and in particular developing countries, are seeking other resources, including non-prevailing natural fibres (Khristova et al., 2006). Therefore, the naturally produced fibres in, for example, agriculture wastes have found prominent positions, because, these fibres are produced in great numbers annually.

Currently, around 5–10% of paper production worldwide is produced from agricultural crops; valuing agricultural paper production at between $5 and $10 billion (Rainey, 2009). One of the most important crop residues used for paper production is bagasse. Paper production is the second largest revenue stream from bagasse, after electricity cogeneration. Using agricultural crops rather than wood has the advantage of providing a new income stream and of helping to reduce the rate of forest destruction.

The fibres present in bagasse vary in length depending on the country and cane variety but are typically about 1.3 to 1.7mm long. Bagasse fibers are well suited for tissue paper, corrugated paper, newsprint, and writing paper (Covey et al., 2006). Bagasse newsprint paper is a low-grade, low-priced, and appropriate for high-speed printing presses (Romanoschi, 1998). Furthermore, bagasse has been used to produce box board, fibre board, composition board, and cement boards.

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5.8.3 Other Bagasse Production

5.8.3.1Furfural

Furfural is obtained mostly from the materials, which have botanical origin, and with pentose, such as bagasse from sugar cane, cluster corn, rice bran, and peanut bran (Praturau, 1989).

Furfural is a colourless, inflammable, volatile, aromatic liquid produced from a number of plant materials containing pentosans - in the case of bagasse, 90 percent being xylan. With acid hydrolysis the xylan yields xylose which subsequently loses 3 water molecules to form furfural according to the following simplified equation:

$$\underset{\text{Xylan}}{C_5H_8O_4} + H_2O \longrightarrow \underset{\text{Xylose}}{C5H_{10}O_5} \longrightarrow \underset{\text{Furfural}}{C_5H_4O_2} + 3H_2O$$

In practice about 25 tonnes of mill-run bagasse are required to produce 1 tonne of furfural. Furfural has many industrial uses, one of them being as a selective solvent for the refining of lubricating oils and another as an intermediate in the production of nylon 6.6 and resins used for moulding powders.

Furfural on hydrogenation yields furfuryl alcohol, which can produce inexpensive, heat-stable and corrosion-resistant resins. Furfuryl alcohol is also used in the pharmaceutical, fungicide, insecticide and solvent fields.

5.8.3.2 Xylitol

Xylitol is a naturally occurring sugar with a wide array of interesting applications. Xylitol can be chemically characterized as a five-carbon sugar alcohol (1, 2, 3, 4, 5pentahydroxy pentane) with a molecular formula: $C_5H_{12}O_5$.

There is a possibility of commercially extracting xylitol from bagasse. Bagasse contains pentosans, which are mainly composed of xylan and araban. Xylan is a structural polysaccharide of plant tissue, which on complete hydrolysis is converted to D-xylose. Xylitol can then be obtained by the high-pressure hydrogenation of xylose (Virol, 1985, RaoManohar, 1997).

5.8.3.3 α-Cellulose

The traditional way of preparing cellulose with high purity is to use cotton linter. α-cellulose from cotton linter is almost 99 percent pure and has high condensation. Since access to cotton linter materials is relatively difficult and expensive, so there is a tendency towards using cellulose pulp from fat materials, which is both cheaper, and considerably more accessible. At present to the relative shortage of cellulose pulp of a soft type gradually more attention has been paid to the use of the fibres of hard cellulose (like bagasse) to produce α-cellulose.

5.8.3.4 Plastics

Plastics is a generic name applied to those organics which have a specific molecular structure or a set of long chains. They become flexible under pressure and heating and are capable of taking shape in different forms. Bagasse contains materials that exhibit plastics qualities; therefore, offer potential for development (Praturau, 1989).

5.8.3.5 Applications of Bagasse as Straw for Hen houses

One of the uses of bagasse is to provide litter for the floor of hen house. Each year more than 200 thousand tonnes of dry bagasse is used in the world for hen litter, in particular in North America (Praturau, 1989). Bagasse is particularly suitable to use in hen houses because of its softness, dryness and low dust content.

5.8.3.6 Application of Bagasse as a Corrective and Stabilizer of Soil

Using the wastes of agricultural products is a prevailing and usual activity in the improvement of agricultural soils. Bagasse can be incorporated into soil to boost the soil organic content (Paturau, 1989). It can also be used as a mulch to reduce soil erosion and to retain soil moisture.

5.8.3.7 Bagasse Concrete

Almost all sugar cane producing countries have made attempts to use bagasse in construction products. One of these ways is concrete bagasse. The method, which has been used in this process, is basically a simple method in which the bagasse particles are mixed with Portland cement without using pressure or heating. This product is known as concrete bagasse, which can be used as a low priced material and a light material in filling between the walls in the form of a mortar (Paturau, 1989).

5.8.3.8 Composite Bagasse (Biologic Fertilizer)

Bagasse can be composted to form an organic fertilizer for soil conditioners, because it is a natural organic material. Bagasse with an appropriate combinational formula of concluded molasses, filter mud, leaves and twigs of sugar cane together with microbial activities is converted into composite (Paturau, 1989).Composite produced is used as an environment organic fertilizer with an ideal productivity.

5.8.3.9 Bagasse for Animal Feed

The high fibre content of bagasse influences its use as an animal feed. However its nutrient value can be increased if the fibres are pre-digested. This can be carried out in a reactor where the cellulose cells are broken down and hydrolysed. The hydrolysed bagasse is then composed making pellets, which are easily handled and readily eaten by the animals (Paturau, 1989).

5.9 The Current Status of Sugar Cane and its By-Products in Iran

Iran has a vast potential capability to grow sugar cane, especially in the Khuzestan province where yields per unit area of the land are extremely high. The average yield in this province is about 100 tonnes of cane per hectare. The maximum yield is as high as top sugar producing countries in the World such as Brazil. This province has long-term history of sugar cane production.

5.9.1 Haft Tapeh Sugar Cane Industry and Plantation Complex

The area under plantation in the Haft Tapeh complex is equal to 12000 hectares and annually about 9-10 thousand hectares of cane is planted. These plantations currently produce about 1,000,000 tonnes of sugar cane. Table 5.3 shows the rate of production of the Haft Tapeh Industry and Plantation Complex.

The current uses of by-products from this factory in side-industries are as follows:

- The produced bagasse is annually 370,000 tonnes, which is delivered to the Pars paper factory in order to produce paper. About 30% of bagasse is made of pith which is detached in the Pars paper factory and given to the cattle feed factory.

- About 37,000 tonnes of molasses is also produced each year, of which about 21,000 tonnes is used along with the pith produced at Pars factory to produce cattle feed. The extra molasses is annually sold to exporter companies.

- Approximately 30,000 tonnes per year of filter mud is used to produce fertilizer.

Table 5.3 Rate of production of the Haft Tapeh Industry and Plantation Complex

Type of product	Annual production (tonne)
Sugar cane	1,000,000
Raw Sugar	100,000
Bagasse	370,000
Molasses	37,000
Filter mud	30,000

5.9.2 Karun Sugar Cane Industry and Plantation Complex

Karun sugar production factory operates on a larger scale using, more modern and complex technology than the Haft Tapeh factory. It began the first experimental utilisation of the new sugar production process in its mills in 1977.

The area under sugar plantations at this complex is about 18,000 heaters and at present 1.5-1.7 million tonnes sugar cane is produced annually. It is forecast that this quantity of production should reach about 2 million tonnes. Table 5.4 shows the rate of production of by-products in the Karun Sugar Cane Industry and Plantation Complex.

The applications, which have been considered for the by-products are production of energy, compact boards, cattle feed, furfural, paper manufacturing and alcohol production. The production of energy using bagasse is already being implemented in the Karun sugar factory, with the bagasse is used as the fuel for steam furnaces. Steam is used to drive turbines, heat and evaporate syrups and for cooking.

Table 5.4 Rate of production of the Karun Sugar Cane Industry and Plantation Complex

Type of product	Annual production (tonne)
Sugar cane	1,500,000-1,700,000
Raw sugar	150,000-170,000
Bagasse	600,000
Molasses	55,000
Filter mud	60,000

The by-products in the Karun Plantation and Industry Complex are utilised as follows:

- 220 tonnes/day of bagasse is used in the production of compact boards, which equals about 150,000 tonnes annually. The capacity of the factory is 100 cubic meters of bagasse per day. About 42,000 tonnes of bagasse is used annually for cattle feed. The Karun factory has three boilers. Currently, one of the boilers using modern equipment has been powered by bagasse and consumes about 1716 tonnes bagasse daily. In the next two years two boilers will use bagasse as fuel. A project to produce furfural is in the process of being launched and the production capacity of furfural is planned to be 10 tonnes per day and 3000 tonnes per year. The rate of bagasse use will be 220 tonnes per day or about 66,000 tonnes per year. The paper-manufacturing factory is still not complete.

- The molasses is processed into cattle feed and consumes 14,400 tonnes annually. The alcohol factory, which will also use molasses as a raw material, has not been built yet.

- The filter mud resulting from the process of production of sugar is used as fertilizer in the fields.

5.9.3 Sugar Cane and Side Industry Development Company

The implementation of the project of the Sugar Cane and Side-industries Development was started in 1970 with the objective of meeting the needs of the growing population of Iran. At present, the land under sugar cane plantation in the Sugar cane and Side-industries Development project is 84,000 hectares.

This project includes seven units as follows:

- Imam Khomeini unit, which includes one sugar factory along with an industrial park, that consisted of two factories producing MDF and cattle feed.
- Amir Kabir unit, which includes one sugar factory that has two associated factories to produce cattle feed and paper.
- Daabal unit, which includes one sugar factory that has four factories producing cattle feed, alcohol, yeast and compact board.
- MirzaKoochakkhan unit, which includes one factory producing sugar along with two factories producing cattle feed and paper.
- Salman Farsi unit which includes one sugar producing factory and two factories to produce cattle feed and paper.
- Farabi unit that includes sugar production and two producing cattle feed and paper.
- Dehkkhoda unit that is merely consist of two factories; sugar and cattle feed.

The capacity of the 22 existing factories in the project is as follows:

- 7 sugar factories using sugar cane with an annual capacity for 100 thousand tonnes of which 6 factories are active and 1 factory is in the process of launching.
- 7 factories to produce cattle feed with the capacity for annual production of 100 thousand tonnes.
- 1 factory to produce alcohol with the capacity for 33 million litres per year (daily production 100,000-litre alcohol).
- 1 factory producing MDF with the capacity for 100 thousand tonnes per year (this factory is the first MDF producing factory using bagasse in the Country).
- 1 yeast factory with the capacity for 10 thousand tonnes per year.
- 1 factory producting compact boards with the capacity for 10 thousand tonnes per year.
- 4 factories producing paper which have the capability of producing 88,750 tonnes per year of paper for printing and writing. Up to now only one of the factories namely, Salman Farsi has been financially credited and executive operations have begun to establish it. The other paper factories have not yet been started.

The rate of annual production of sugar cane from 70 thousands hectares of lands is 7,630,000 tonnes. The area under plantation at each of these seven units is equal to 12,000 hectares and in each year, only 10,000 hectares is planted.

Table 5.5 Rate of production of the Sugar Cane & Side-industry Development Company

Type of product	Annual production (tonne)
Sugar cane	7,630,000
Raw sugar	763,000
Bagasse	2,436,000
Molasses	280,000
Filter Mud	305,200

The bagasse produced in each unit is 34,800 tonnes and, as a result of depithing, in each unit about 104,400 tonnes of pith with 50% humidity is detached (assuming that 30% of bagasse is pith). The remaining fibre from the depithing operation is used in paper manufacturing and compact board and MDF units. If the four paper factories are established, the total fiber resulting from the produced bagasse in each unit is utilised. The composition board factory consumes 150,000 tonnes per year of bagasse and in the MDF factory, 365,000 tonnes of bagasse is used. Therefore, at present, about 1,500,000 tonnes of bagasse is not being fully utilised.

The molasses produced in this complex in each unit is about 40,000 tonnes. The molasses is used in the cattle feed factories and alcohol factory.

The filter mud is mixed with bagasse and is used to improve the soil of the farm and in the production of cattle feed.

5.10 Conclusion

One of the important by-products of the sugar cane process is bagasse because it has the enough potential for use in several different industries, For example fuel, production of numerous paper products and as a raw material for the production of chemicals.

At present, the main sugar cane plantation and industry complexes in Iran are Haft Tapeh, Karun, and the Sugar Cane & Side-industries Development. The overall area under sugar cane plantation is 114,000 hectare with the capability to increase in the future. The annual production of sugar cane in recent years is about 10,000,000 tonnes, and the total bagasse produced is about 2,500,000 tonnes. Bagasse utilisation in Iran has been concentrated in different aspects, but annually about 1,500,000 tonnes of it is destroyed due to non-utilisation.

Chapter Six

Suitable Energy Conversion Technology Using Bagasse for Developing Combined Heat and Power (CHP) in Iran: A Case Study

6.1 Introduction

A great volume of plant residues are produced every year throughout the World, which in the main part remain unused. One of the most important agricultural residues is rice bran, which forms 25 percent of rice by volume. Other botanical wastes include bagasse from sugar cane, bran and shells of coconut, the shells of peanut, and straw.

Sugar cane is a suitable plant for the energy production. This plant converts solar energy into chemical energy and stores it in itself in the form of carbohydrates. The energy existing in sugar cane can be retrieved in a variety of ways.

Sugar cane as an energy-generation product is not only very important, but also its wastes, i.e. bagasse hold a very good potential as a source of energy being used directly or indirectly for the production of power and heat. It can be burned directly or used to produce biogas. This gas may be used as a fuel in CHP plants, which produces both electricity and steam. At present, much of the bagasse produced in sugar cane plants is used as a fuel to produce heat. Unfortunately much of the steam produced in these plants does not have sufficient utilisation, so a great amount of bagasse, which could be used in other side products, is wasted. Some corrective methods have been presented to deal with this inefficiency, one of which is biotechnology, which can produce methane from the bagasse.

The methane produced from bagasse is then used in fuel boilers and turbines to produce electrical energy. The aim of this chapter is to survey the possible conversion technologies for energy generation from bagasse, and determine which technology is potentially beneficial for Iran. Moreover, the chosen energy conversion technology combined with CHP for electricity and steam production will be studied from economic and environmental views.

6.2 Using the Agricultural Wastes in Energy Production

The traditional method of using agricultural wastes is to burn them with firewood. Burning dry plants and charcoal in traditional furnaces or home fires has a history as long as human life. In the underdeveloped and developing countries on a large scale, and in advanced countries to a lesser extent, plant materials are still used in traditional ways. The old and traditional methods have a low efficiency, and usually less than 10% of the energy in the biomass is converted into useful energy. However, methods that are more efficient have been developed in the industrial countries and are now being widely adopted. Biomass is gradually regaining its value as one of the renewable sources of energy materials.

The output of modern methods is between 15 to 70 percent and sometimes access to the side products in addition to energy is possible. The main energy conversion technologies, which can be applied on agricultural wastes include:

- Combustion
- Gasification
- Anaerobic digestion

- Pyrolysis
- Alcohol extraction

Figure 6.1 shows the energy conversion technologies, which can be used for energy production from baggase.

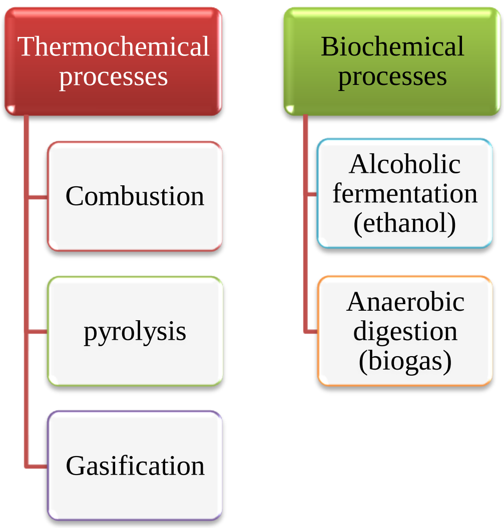

Figure 6.1 Various energy conversion technologies from bagasse

6.3 Thermo-Chemical Processes for Bagasse

These technologies produce energy by giving heat to bio-wastes in the presence or absence of auxiliary materials. The auxiliary materials in these technologies can be steam, air, oxygen, hydrogen or solid materials. The energy produced can be in the form of heat or energy producing products such as solid, liquid or gas fuels. The most important thermo-chemical technologies are combustion, pyrolysis and gasification. These are considered in turn below, and the advantages and disadvantages of each method are appraised in section 6-6. The appraisal is drawn from Ismail, and Quick, 1991; Tchobanoglous, and Tyssen, 1993; Hulscher, 1994; Gef, 1996; Bormlan, 1998; Lin, 1998; Boyle, 2004; Kirck, and Attmer, 1980; Bridgewater, and Grassi, 1991; Beenackers, and Vamswaay, 1986; Kinoshita, 1997, and Lin, 1998.

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6.3.1 Combustion

Combustion is the most common direct method for converting biomass such as, bagasse, into usable energy, and it is used in many applications.

The oldest method of burning bagasse, is to oxidize it so as to produce completed combustion. Various types of furnaces have been invented and proposed for the promotion of efficient combustion. In all of these, the issue of removing ash from inside the furnace has been considered. Many brazier furnaces are at work at present. The following comparison has been made on the methods of combustion of small and big masses of bagasse in volcano furnaces, which are one of the common types.

Advantages:

- The feeding instruments for the furnace do not yet exist and hence the furnace must be fed by hand, so it has a simple technology.
- Only a small quantity of soft ashes is produced. Smoke from combustion is rarely a pollution problem.

- The brazier furnaces are made of great quantities of refractory materials and are able to maintain high quantities of heat in themselves. So, they can even burn wet bagasse.

Disadvantages:

- High-unburned wastes resulting from the existence of a high percentage of carbon create more ash, so the percentage of additional air needed for the completed combustion.
- Sometimes very soft bagasse from the modern instruments used to treat sugar cane is not available.
- Maintaining the furnace heating of refractory materials causes the production of steam to continue after the reduction of the intake fuel load and so some of the steam will be lost. If this does not happen and water does not reach the boiler, the steam boiler will be damaged.
- During the de-ashing, the rate of the steam produced by the furnace will decrease or stop.

6.3.2 Pyrolysis

Pyrolysis is a thermo chemical decomposition of organic material at elevated temperatures in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above 430 °C (800 °F).The process of pyrolysis is in general a procedure in which the raw materials are subjected to high temperatures and are formed into new materials with different shapes such as gaseous, liquid and solid combinations. By making changes in the conditions of reaction, various quantities of these materials are obtained. Sugar cane bagasse is one of the materials which can be used as biomass for pyrolysis.

6.3.3 Gasification

The basis of this procedure is quite similar to pyrolysis, but the priority is given to the production of gas. The act of giving heat continues up to the destruction and decomposition of the maximum of raw materials. This is achieved by adding materials called a gasifier agent, such as oxygen, air, steam, hydrogen, methane.

Gasification of biomass looks simple in principle, and many types of gasifiers have been developed. The production of a gaseous fuel from a solid fuel with attractive properties such as easy handling and combustion that produce low levels of contaminants (possibly it can be used in internal combustion engines) makes gasification very attractive.

However, the biomass fuels used in gasifiers vary widely, and include many reactants and many possible reaction paths. The reaction rates are relatively high. All these factors contribute to the complication of effective gasification and make the process hard to control and operate satisfactorily (Quaak et al., 1999).

The methods of gasification of biomass can lead to the production of three main types of synthetic gases which include:

- ❖ Low Thermal Value gas (LTV)
- ❖ Medium Thermal Value gas (MTV)

- High Thermal Value gas (HTV)

In gasification with air, the amount of air supplied is constantly less than the quantity which theoretically is necessary for full burning of the raw materials.

The thermal value of gas depends on its composition. The following relationship expresses the thermal value of the synthetic gas as a function of the volume percent of its forming components (Filippis et al., 2004).

$$L.T.V\ (gas) = 12.809\ (CO) + 10.225(H_2) + 36.76\ (C_xH_y)$$

The figures inside the parentheses, is the volume ratio of the mentioned gases. This relationship calculates the thermal value of gas in terms of MJ/m^3.The production of gas with a high thermal value demands the application of purification and improvement methods of gas and removal of neutral gases such as CO_2, SO_2, CO. It demands a high technical knowledge and its complexity is high. Sometimes, steam is mixed with air and sent into the reactor. In this condition, air and water steam are combined with charcoal according to the following reactions:

$$2C + O_2 \rightarrow 2CO + 53.6\ kcal_{heat}$$

$$C + H_2O + 28kcal_{heat} \rightarrow CO + H_2$$

The thermal value of the gas obtained from this reaction is 5.9 MJ/m^3. These methods are usually used for the production of synthetic gas with a low thermal value. The gases, which have low thermal value, combine a high percentage of carbon dioxide and nitrogen. In this technology, energy output as a production of the original energy in raw material is about 70%.

Gasifying for the production of gas with medium thermal value is performed with the help of oxygen or water steam or a mixture of both. One of the technologies in this area is the three-district gas tower.

The tiny particles of charcoal and ash or tar should be removed from the gas. For the purification of gas from impurities, methods of water washing, cyclone, electro filter, catalytic exchange and absorptive bed are applied. For the production of gas with a high thermal value, hydrogen gas is added to upgrade the product.

6.4 Biochemical Processes

Biotechnology or bio-industries include a set of techniques, which produce various products needed by medical science, agriculture and industries by utilising particular microbes and single cell organisms. Bagasse is one of the materials, which can be used as a raw material for biochemical processing.

One of the main macromolecules in bagasse is cellulose and for the effective performance of enzymes a high quantity of cellulose is needed. Bagasse is not easily exposed to attack by microorganisms due to high quantities of lignin (Shu-bin, Yi-li, 2006). The use of pre-filtration methods to reduce the contents of lignin is therefore useful and effective. This facilitates the digestibility of the bagasse by the enzymes used in the bioprocesses. Due to the pre-filtration processes, the surface area is increased allowing hemicelluloses more opportunity to digest the raw material.

6.4.1 Fermentation Processes

The processes involving cultivation of microbes on bagasse can be classified into two groups; processes based on liquid fermentation or submerged fermentation (SMF), and processes based on solid-state fermentation (SSF).SMF can be divided into two categories: one in which the whole bagasse is used as the substrate, and others in which bagasse is hydrolysed and the hydrolysed bagasse is used as the substrate. SSF can also be divided into two sub- groups. In one of these sub-groups: bagasse is used as the source of carbon (energy), and in the other it is used as an inert solid support.

Another application of bagasse is the production of Single Cell Protein (SCP) (Pandeyet al., 2000). In this process, a combined procedure of sacrification and fermentation take place concurrently. The resulting biomass from the fermentation can have about 35% raw proteins with a high digestibility making it an excellent cattle food. One of the components of bagasse is hemicellulose, which is more appropriate than many other organic materials for the growth of fungi. The hemicelluloses extracted from bagasse can be used for the production of ethanol with the help of fermentation.

6.4.2 Anaerobic Digestion

Anaerobic digestion is a complex, natural, four-stage process of degradation of organic compounds through a variety of intermediates into methane and carbon dioxide, by the action of a consortium of microorganisms (Gujer, 1983; Noykova, 2002). The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide (Kottner, 2001).

Biogas is produced through the microorganism's activities and it is used as fuel. In comparison with other organic wastes, bagasse is an appropriate raw material for the process of bio-methanisation via anaerobic digestion. In this process, the organic fuel is produced in gas form and the remaining material forms organic fertilizer. The organic fertilizer contains nitrogen, phosphorous, and potassium and is a valuable fertilizer for use in agriculture. In sugar cane factories, the resulting biogas is used for fuel instead of bagasse (Singh, and Prerna, 2009).

6.5 Standards to Compare the Technologies of the Conversion of Biomass into Energy

In order to make an appropriate comparison of the energy conversion technologies of biomass, some standards need to be set, which make possible a proper logical comparison.

In selecting the standards, the needs and conditions of Iran have been a leading consideration. Some factors which are of greater importance in Iran include supply of energy for remote areas and those which are in need of it; efficient use of wastes, possibility of undertaking the technology inside the country, relative simplicity and reduction of need to import technology, compatibility with other conversion technologies and consumption of energy.

The issue of simplicity and the ability to undertake the conversion of biomass into energy may be determined by reviewing the type of the equipment being used in the technologies. Some of the most important factors affecting the complexity and ability of the performance of the technology are:

- Temperature of operations
- Need to include process such as drying, crushing, screening to improve raw materials before the main procedure
- Need for constant control of the procedure
- Need to add auxiliary materials to the process such as air, steam, types of gas, liquids and etc
- Need for purification or improvement of energy products
- Operational pressure of the status of undertaking procedure from the viewpoint of ordinary pressure or under pressure

6.6 Comparing the Advantages and Disadvantages of Different Energy Conversion Technologies

Comparison between the advantages and disadvantages of combustion, pyrolysis, gasification, anaerobic digestion , and alcohol production technologies are presented in the following Tables 6.1, 6.2, 6.3, 6.4, and 6.5. These Tables show the results which were obtained by the author through studying, and analysing information about these energy conversion technologies in different references.

Table 6.1 The advantages and disadvantages of combustion technology (Ismail, and Quick, 1991; Tchobanoglous, and Tyssen, 1993; Hulscher, 1994; Gef, 1996; Bormlan, 1998; Lin, 1998; Boyle, 2004)

Advantages	Disadvantages
-Speed in converting biomass into energy -Capability of producing thermal energy, steam and electricity -There is a little need to process the biomass. -The equipments being used can be simple -There is a long experience of the technology. -It has the ability to be used at the level of small enterprises, home use as well as on a large scale.	-There is no possibility to save energy -It spreads pollutants in the air -In the ordinary methods, the useful energy output is low. -The advanced methods of combustion need greater and more complex equipment.

Table 6.2The advantages and disadvantages of pyrolysis technology (Kirck, and Attmer, 1980; Bridgewater, and Grassi, 1991; Techobanoglous, and Tyssen, 1993)

Advantages	**Disadvantages**
-Diversity in energy producing products. -Capability to save energy in the form of gas, liquid and solid products. -Reduction of the volume of the biomass. -Good output up to 70% energy conversion. -The relative speed in energy conversion. -The possibility of implementation and expansion of coal making as a relatively simple process.	-A need to dry and chopping the biomass. -The complexity of processes and a need to use the advanced technical equipment. -The shortage of experiences in this field. -A need for precise observation of procedures and expert staff. -A need to purify the products.

Table 6.3 The advantages and disadvantages of gasification technology (Kirck, and Attmer, 1980; Wan Swaaij, 1980; Ismail, and Quick, 1991; Tchobanoglous, and Tyssen, 1993; Cuenea, 1995; Stassen, 1995; Beenackers, and Vamswaay, 1986; Kinoshita, 1997; Lin, 1998)

Advantages	**Disadvantages**
-Ability to save energy in the form of gas. -The ability to transfer energy via pipeline. -The ability to be combined with the power stations or electricity generators. -The ability of application in a cogeneration power plant. -A relatively high speed in energy conversion. -The ability to builtat different scales and in different places.	-A need for drying and chopping the biomass. -A need to filter the gas. -A need to adjust and control the product constantly. -The necessity for the application of educated human work.

Table 6.4 The advantages and disadvantages of anaerobic digestion technology (Kottner, 2001; Deubleon, and Steinhauser, 2008)

Advantages	Disadvantages
-Diversity in usable raw materials. -A relative simplicity in the equipment in use. -A relatively cheap price. -The production of side products as fertilizer. -The possibility of saving energy in the form of gas and the ability to transfer via pipeline. -Ability to be developed in small and large units. -Ability to be developed in rural, urban and industrial communities.	-Sensitivity to temperature, chemicals and environmental factors. -A low rate of conversion of materials into energy. -Producing toxic gases such as Hydrogen Sulphide. -It is not usable for wood and Ligno-Cellulose biomass. -There is a need for a constant control of the process. -The output of energy consumption is less compared with other technologies

Table 6.5 The advantages and disadvantages of alcohol production technology (Paul, 1980; OECD, 1984; Vonsivers, and Zachi, 1996)

Advantages	Disadvantages
-The possibility of producing fuels for the transportation industry. -Possibility of selling products in local and World markets. -The possibility of making an optimal use of plant residues and other organic wastes such as fruits. -The possibility of the application of side products as the food of cattle or fertilizer. -The relative speed in energy conversion.	-The process is too complex. -There is a need to set and precisely control procedures. -The energy output is less than 70%. -The production of polluted waste water is high. -The production of alcohol from Lingo Cellulose materials is complex and costly.

6.7 Comparing Technologies from Different Points of View

By studying and comparing different technologies based on biomass, the processing of raw materials, temperature and operational pressure, energy output, facilities to convert energy consumption and the complexity rate, it will be possible to determine which of these technologies are most advantageous in Iran. This ranking has been carried out by the Iranian Ministry of Energy.

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In order to measure the technologies complexity, first they will be compared with the need to process the raw materials (presented in Table 6.6). The complexity of each possible operation has been ranked on a scale of 1 to 10 (see bottom row of Table 6.6). This ranking is done according to the simplicity (1) and complexity (10) of technology. The complexities associated with each technology can then be calculated (see right hand column of Table 6.6).

In order to dry biomass, there is a need to use a dryer or kiln. In order to optimize the size of materials sieves, mills and chopping equipment are required. Changing the nature of biomass is a more complex process, which is used in alcohol production technology to detach lignin from cellulose prior to conversion into sugar.

Table 6.6 Comparing the technologies from the viewpoint of raw material processing needs (Ministry of Energy, 1999)

Type of technology	**Need to dry**	**Size limitation**			**Need to change the nature of raw materials**	**Complexity of technology**
		small	**Average**	**Unlimited**		
Fixed Bed combustors	—	—	—	×	—	1
Atmospheric fluidized Bed combustors	×	×	—	—	—	12
Pressurized fluidized bed combustors	×	×	—	—	—	12
Pyrolysis	×	×	×	—	—	16
Gasification	×	×	×	—	—	16
Anaerobic digestion	—	—	×	—	—	4
Alcoholic Fermentation	—	×	—	—	×	17
Complexity	5	7	4	1	10	—

The complexity of the operational temperature is ranked from 1 to 10. With the increase of temperature, the performance of materials such as steel comes closer to its performance limits. Consequently, the need to adopt protective measures such as liming with refractory materials increases and this adds to the complexities of the set up. A similar situation also applies in terms of pressure and its increase requires the reinforcement of reservoirs, pipes, other components. This also increases the complexity of the system. The scale from 1 to 10 has been selected only for the purpose of comparison.

Table 6.7 Comparing the technologies from the viewpoint of temperature and operational pressure (Ministry of Energy, 1999)

Type of Technology	Temperature (°C)					Pressure		Complexity of Technology
	<70	70-250	250-500	500-900	> 900	Normal	High	
Fixed bed combustors	—	—	—	—	×	×	—	11
Atmospheric fluidized bed combustors	—	—	—	×	—	×	—	8
Pressurized fluidized bed combustors	—	—	—	×	—	—	×	14
Pyrolysis	—	—	×	—	—	×	—	6
Gasification	—	—	—	×	—	×	×	15
Anaerobic digestion	×	—	—	—	—	×	—	2
Alcoholic Fermentation	—	×	—	—	—	×	×	11
Complexity	1	3	5	7	10	1	7	—

Table 6.8 shows comparisons of technologies from the viewpoint of the control of processes required. Various states and options are shown in these fields for each status, and complexity has been ranked from 1 to 10.

Table 6.8 Comparing the technologies from the viewpoint of managing the process

(Ministry of Energy, 1999)

Type of Technology	Process control		Adding co-substrate				Pretreatment		Complexity of Technology
	Continuous	Split	Continuous	Split	Normal	High pressure	Physical	Chemical	
Fixed bed combustors	×	—	×	—	×+	×+	—	—	16
Atmospheric fluidized bed combustors	×	—	×	—	—	×	×	—	23
Pressurized fluidized bed combustors	×	—	×	—	—	×	×	—	23
Pyrolysis	×+	×+	—	×	×+	×+	×	—	14
Gasification	×	—	×	—	—	×	×	×+	28
Anaerobic digestion	—	×	—	×	×	—	—	×+	9
Alcoholic Fermentation	×	—	×	—	×	×	×	×	34
Complexity	8	2	5	1	1	5	5	10	—

Note: In the boxes the signs +x, the average complexity has been considered.

Table 6.9 Comparing the technologies from the viewpoint of compatibility with raw materials and auxiliary material needs (Ministry of Energy, 1999)

Type of technology	Physical status of material	Chemical status of material	Type of main co-substrates	Specific limits
Fixed bed combustors	Dry or semi dry	Almost unlimited	Air (oxygen)	--
Fluidized bed combustors	Dry	Cellulose and LignoCellulose	Air (oxygen)	--
Pyrolysis	Dry	Cellulose and LignoCellulous	Types of gases (optional)	--
Gasification	Dry	Almost Unlimited	Types of gases (obligatory)	--
Aerobic digestion	Dry or wet (unlimited)	Degradable	Water	--
Alcoholic fermentation	Dry or wet	Degradable	Water and enzyme	Sugar material required

The efficiency of energy conversion (efficiency here, means the recoverable thermal energy with the heating value of the produced fuel to the thermal value of raw biomass) is presented in Table 6.10. In this table, the ability of energy transfer or energy products has been compared. The thermal energy resulting from combustion has a low capability of transfer to other locations. In contrast, liquid fuel can be easily transferred and transported to other locations. Gas fuel also has ability to be transferred by pipelines or in pressured mobile tanks. Solid fuel is easily portable but tends to occupy larger space due to its low specific mass.

Table 6.10 Comparing the technologies from the energy efficiency viewpoint

(Ministry of Energy, 1999)

Technology (Tech.)	Efficiency (%)			Products transportability			Tech. score
	<40	40-70	>70	Good	Medium	Weak	
Fixed bed combustors	—	×	—	—	—	×	7
Fluidized bed combustors	—	—	×	—	—	×	10
Pyrolysis	—	—	×	×	—	—	14
Gasification	—	—	×	—	×	—	12
Anaerobic digestion	—	×	—	—	×	—	9
Alcoholic Fermentation	—	×	—	×	—	—	11
Score	2	5	8	6	4	2	—

The compatibility of the produced energy has been compared in Table 6.11 with the facilities of conversion and consumption of energy. Electricity has been allocated the highest score due to the simplicity of its transfer and its vast application in various uses.

Summing up of the technical comparisons of the technologies of conversion of biomass into energy has been reached by scoring and summing to obtain a total score. These scores are simple. Scoring for technology complexity has been made in accordance with the Table 6.12.

Scoring based on the limitations of compatibility with raw materials and specific limits has been done as presented in Table 6.13. The final results of scoring for technical comparisons are presented in Table 6.14.

Table 6.11 Comparing the technologies from the viewpoint of compatibility with the facilities of conversion and consumption of energy (Ministry of Energy, 1999)

Technology	Electricity production				Residential consumption	Industrial consumption		Trans ..port	Total score
	Internal combustion engine	Steam turbine	Gas turbine	Fuel cell		Steam	Heat		
Fixed bed combustors	—	×	—	—	—	×	×	—	11
Atmospheric fluidized bed combustors	—	×	—	—	—	×	××	—	11
Pressurized fluidized bed combustors	—	×	×	—	—	×	×	—	17
Pyrolysis	×	—	—	—	—	×	×	—	18
Gasification	×	×	×	×	×	×	×	—	38
Anaerobic digestion	×	—	—	×	×	×	×	—	27
Alcoholic Fermentation	×	—	—	—	×	—	—	×	17
Rating	4	5	6	9	8	3	3	5	—

Table 6.12 Scoring the technologies based on complexity (Ministry of Energy, 1999)

Total complexity	Score
Under 20	20
21-35	15
36-50	10
Up to 51	5

Table 6.13 Scoring the technologies based on compatibility with raw materials and specific limitations (Ministry of Energy, 1999)

Limitations in physical state of raw material	**Limitations in chemical state**	**Special limitations**	**Score**
—	—	—	20
+	—	—	15
+	+	—	8
—	+	+	5
—	+	—	13

Table 6.14 shows that from the technical point of view first placed is gasification and anaerobic digestion, second placed is fixed bed combustion and third placed is pyrolysis. The result of the technical study shows two technologies are joint leaders (gasification and anaerobic digestion). But in order to choose which one is best, the possibility of using these technologies in Iran should be considered.

Table 6.14 Summing up the technical scores for technologies of conversion of biomass into energy (Ministry of Energy, 1999)

Kind of Technology	Complexity Score	Scores technology based on complexity	Score of compatibility with raw material	Score of energy efficiency	Score of compatibility with facilities	Total Score
Fixed bed combustors	28	15	15	7	15	52
Atmospheric fluidized bed combustors	43	10	8	10	11	39
Pressurized fluidized bed combustors	49	10	8	10	17	45
Pyrolysis	36	10	8	14	18	50
Gasification	59	5	15	12	38	70
Anaerobic digestion	18	20	13	9	27	69
Alcoholic Fermentation	62	5	5	11	17	38

In Iran, since 1974, sporadic studies have been conducted by research and academic institutions, which have led to the construction of many biogas plants in an experimental form. The first anaerobic digester for the production of methane gas in Iran was built in Niyazabad village in Lorestan in 1975. This equipment had a capacity of 5 cubic meters, and was fed by cattle dung from the village and used to supply the fuel for the neighbouring public bathroom.

Since 1982, the Rresearch Centre for Renewable Energies has undertaken specific researche in this area. It has constructed 10 biogas units in Sistan and Baluchestan, Ilam and Kurdistan provinces. Incidentally, biogas equipment on the Chinese model with a capacity of 13 cubic meters, was designed and manufactured in 1998 in pilot form for the Service Company of Kish. This plant used solid and liquid bio-wastes. In the 1980's, the Ministry of Jihad of Agriculture took measures to evaluate different plants. In 1984, a pilot plant was built in Heydarabad in Karaj. Then a full scale plant was built in 1985 in one of the villages of Gorgan city. Also, Jihad of Construction established 40 other digesters in different regions of the Country (in 19 provinces) of which 18 units have already reached the stage of generating gas (ChikhGasemi, 1996; Omrani, 1996; Chikholeslami, Keshtkar, 1998). In 1999, the Organization of Renewable Energies of Iran defined a project to establish a biogas power plant in Saveh. It started its work with the construction of the research site for biogas with 3 equipped reactors and labs. However, gasification is still a new technology in Iran, and there is little experience of it. So, the priority technology for Iran will be anaerobic digestion. The following section provides further information about this technology.

6.8 Biogas

Biogas is a mixture of gas produced by methanogenic bacteria, acting upon biodegradable materials in an anaerobic environment. It is composed of 50 to 70 percent methane, 30 to 40 percent carbon dioxide and a low amount of other gases as shown in Table 6.15.

Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650 to 750 °C. It is an odourless and colourless gas that burns with a clear blue flame similar to that of LPG gas. It is a valuable gas and has a high thermal value of more than 4000 kcal/m^3.

Table 6.15Composition of biogas (FAO,1997)

Substances	Formula	percentage
Methane	CH_4	50-70
Carbone dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen sulphide	H_2S	Traces

6.9 Bio-digesters

The bio-digester is a physical structure, commonly known as a biogas plant. Since various chemical and microbiological reactions take place in the bio-digester, it is also known as a bioreactor. The main function of this structure is to provide anaerobic conditions within it. As a chamber, it should be air and water tight. It can be made of various materials and in a variety of different shapes and sizes. Construction of this structure forms a major part of the investment cost.

The size of bio-digesters can vary from a small household system to large commercial plants of several thousand cubic meters. The size of the digester depends on the required gas output, and the availability and amount of biomass (Fulford, 1988). Figure 6.2 shows a typical agricultural biogas system.

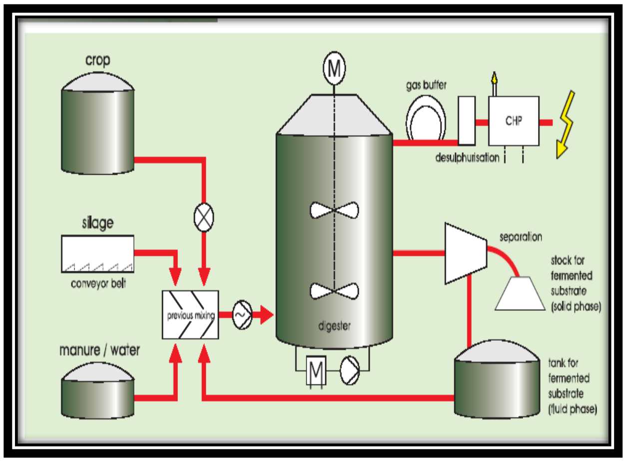

Figure 6.2 An agricultural biogas system

6.9.1 Benefits of a Biogas Plant

Like natural gas, biogas has a wide variety of uses, but, as it is derived from biomass, it is a renewable energy source. There are many other benefits to be derived from the process of converting bio-wastes into a biogas plant.

Biomass that is not needed is often left to break down naturally, but everything containing energy can be turned into bio-fuel. By using biogas plants emission of a large amount of greenhouse gases is avoided. The greenhouse effect of CH_4 is 20 times more than CO_2 (Table 6.16).

Table 6.16 Relative greenhouse effect of greenhouse gases (IPCC, 2003)

CO_2	1
CH_4	21
N_2O	310

With aerobic degradation, the low -energy compounds CO_2 and H_2O are formed, and much potentially useful energy is lost.

Using a bioreactor can reduce landfill and so protect groundwater from the polluting leakage of organic waste materials. The material to dispose of is reduced possiblyby 96%, leaving only 4% sludge when the residue is squeezed off and the waste water from the biogas plant is recycled into the waste water treatment plant (Figure 6.3).

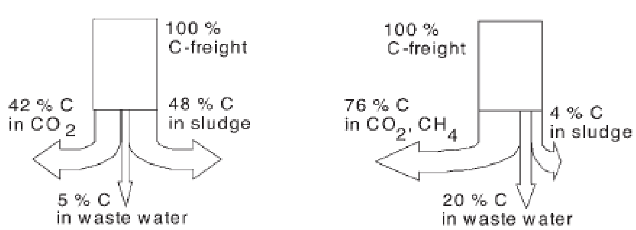

Figure 6.3 Biomass degradation process with aerobic (left), and anaerobic activity (right)

This process can substantially reduce the disposal costs of organic wastes, because the quantity of biomass decreases significantly. Moreover, the sludge is also a useful fertilizer. If plant materials are used as co-substrates for biogas production the residues are recycled to agriculture, no mineral fertilizer need be bought, as a cycle of nutrients is created and nitrate loss is reduced.

When storing the residue from the fermentation plant, there is much less odor, methane and nitrous oxide emissions (N_2O).

6.9.2 Efficiency of Biogas Plant

The efficiency of agricultural biogas plant installations depends on their characteristics, especially installation:

- The capacity or size of the plant
- The fraction of autonomously generated power
- Installation standard and automatic level

The relationship between installation performance and available biomass can roughly be estimated based on the figures given in Table 6.17.

Table 6.17 Typical figures for the design and operation of an agricultural biogas plant (Abdoli, 2004)

Biogas yield	
1 animal unit	200-500(800)m^3biogas/a
Ensilaged maize from 1 ha	8000-10000 m^3biogas/a(biogas amount from 20 animal units)
1ha meadow grass	6000-8000 m^3biogas/a
1000 kg liquid manure	20-40 m^3biogas
1000 kg liquid maize	170-200 m^3biogas
1000 kg liquid grass	80-120 m^3biogas
Bioreactor size	
100 animal units	Volume: Horizontal cylinder reaction: 150m^3 Volume: vertical cylinder, 250m^3
1 ha ensilaged maize	ca. 10 – 20 m^3 volume
Bioreactor volume load	2 – 4 (max.7) kg oTS / m^3.d at 38 ° C
Energy yield	
1 animal unit	0.15 – 0.20 kW installed power
Ensilaged maize from 1 ha	3 – 4 kW installed power
12 – 15 m^3 /d biogas	1 kW installed electrical power

A typical figure given in Table 6.18 can help in performing a rough estimate of the initial planning of a bioreactor installation.

Table 6.18 Typical figures for the costs of agricultural biogas plants (Abdoli, 2004)

Cost basis	Typical figure
Invest. costs for CHP per kW_{el}	500-1500 US$
Invest. Costs per 1 m^3 reactor volume	300-500 US$
Invest. Costs per 1 animal unit	450-700 US$(self construction) 650-1800 US$(industrial construction)
Invest. Costs per 1 kW installed power	2400 US$(large plants>300kW) 6000US$(small plant)
Invest. Costs per 1 m^3/h biogas	4000-7000US$(plant alone) 5500-9000Us$(including silo for maize silage)

6.10 Conventional Generation Versus CHP

The essential benefitof combined heat and power versus conventional generation is related to its efficiency and reduction of CO_2 (see in Figures 6.4,and 6.5).

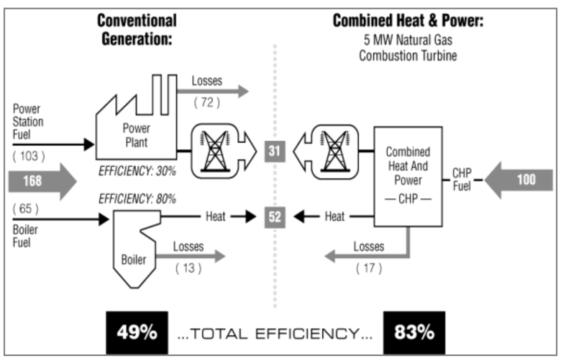

Figure 6.4 Efficiency advantages of CHP (Bluestein, 2003)

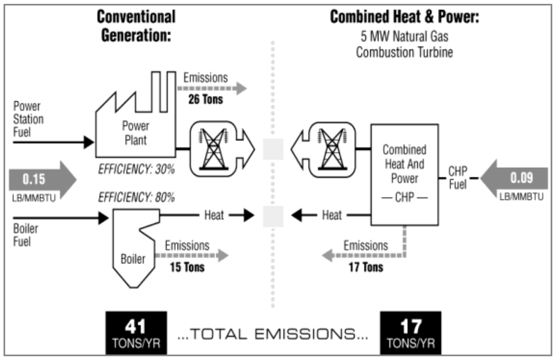

Figure 6.5 Environmental benefits of CHP (Bluestein, 2003)

6.11 Power Plants for Sugar Milling

As shown in Fig. 6.6, sugar cane bagasse is one of the most abundant crops residues, because sugar cane is the highest ranked agricultural products (FAO, 2005). This figure does not consider the harvestable sugar cane leaves and tops that, in the majority of the sugar cane-producing countries, are usually burnt in the fields before manual cane cutting. When machine harvest is possible the quantity of residues can be increased. Sugar cane has an important potential to support sustainable development and modernisation on a large scale in developing countries.

The sugar cane residues, if used in situ, are subjected only to the last three part of the biomass chain (pretreatment, conversion, and end use) entailing more profitable energetic, environmental and economic production costs (Orecchini; and Bocci, 2007).

The use of these wastes to provide energy for the sugar factory has many advantages. These are: no new production and transport costs (near-zero fuel costs, as they are both produced and used in the factory); favourable conditions of the enterprises; diversification and more secure supply of electricity (using local resource); greater employment for local populations; lower emissions of CO_2 and other gases (compared with conventional fossil-fuel generation) (Morand et al., 2004).

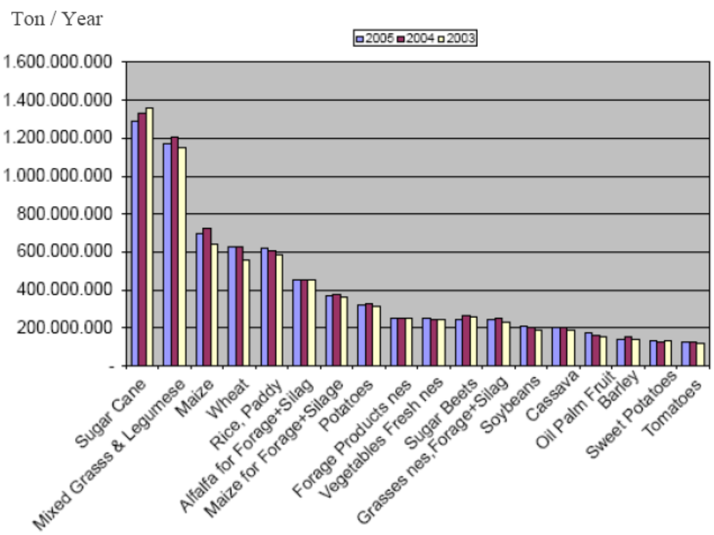

Fig.6.6 World crops production (FAO, 2005)

Today bagasse is used as fuel via different methods such as combustion, gasification and anaerobic digestion to generate combined heat and power (CHP). The combined CHP system generates process steam and the great part of the electricity for the mill. Nevertheless, the potential of bagasse based cogeneration, considering the high efficiency energy production, remains largely unexploited.

According to a report from WADE 2004, bagasse-based cogeneration could deliver up to 25% of the power requirements of the World's main sugar cane producing countries. Also the overall potential share in the World's major developing country producers exceeds 7% (WADE, 2004).

6.12 Development of Biogas Technology in Iran

Biogas is a renewable source of energy that can be used as fuel for cooking, lighting, running vehicles and generators. Natural fossil fuel energy resources such as oil and gas are limited and harmful to the environment, and will be exhausted in the course of time. That is why many countries in the world consider their natural resources very precious and are cautious about extracting them. In Iran neither the decision-makers nor the experts pay due importance to the proper extraction and use of natural resources. With the present rate of consumption, natural energy resources like oil and gas are not permanent and it is now time to explore the use of alternative renewable sources if we want to meet future energy needs. Biogas has been found to be a proven renewable energy option.

6.13 Biogas CHP

In biogas CHP organic material can be used as a fuel in a Combined Heat and Power (CHP) systems. This process produces both heat and electricity from a renewable source.

CHP generators are normally furnished with a four-stroke engine or a diesel engine. Sterling engine or gas turbine; a micro gas turbine are alternatives.

The use of biogas in CHP units is very common. Concurrent with the production of electricity, heat is also produced in variable quantities depending on the technology of electricity generation. Approximately 50% of the CHPs installed in biogas plants in Europe run with four-stroke engines and about 50% with diesel engines. More modern technologies such as fuel cells or micro gas turbines are very seldom to be found. The general output for new CHP power plants, i.e. the total thermal and electrical output is typically between 85-90 percent of the energy in the original organic fuel. So, only 10-15 percent of biogas energy is wasted. The advantages and disadvantages of biogas CHP power plants linked to anaerobic digesters are presented in Table 6.19.

Figure 5.7 shows the range of capacities for the power generators, which are available on the market as pilot plants or on an industrial scale. The efficiency indicates the ratio of electrical power to the total energy content in the biogas. Efficiency figures are given for different manufacturers. Small capacity engines can result in lower efficiencies than high capacity engines.

Table 6.19 Advantages and disadvantages of biogas CHP power plants' anaerobic digesters

Disadvantages	Advantages
-Management of digester system (human forces , repair and maintaining) -Repair and maintaining CHP -Capital costs	-Removal of smell and noxious animals dungs -Management of waste materials -Being hygienic -Energy saving -Thermal saving -Reducing electricity costs

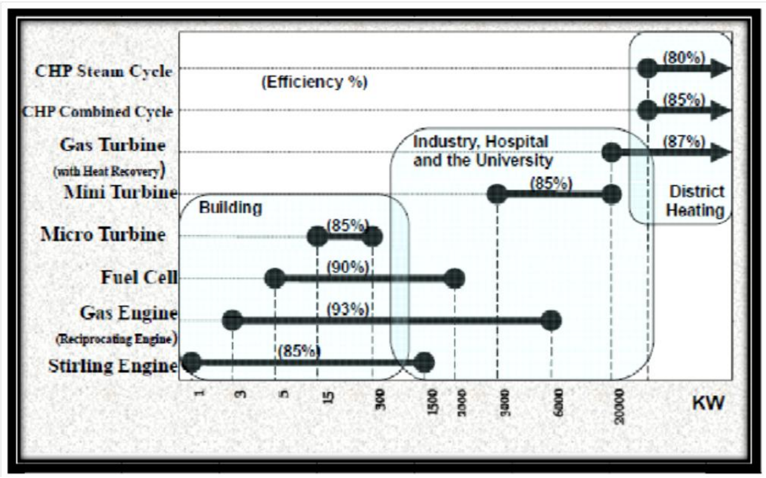

Figure 6.7The range of capacities for the power generators (Rezapour, 2008)

6.14 Economic Study of the Establishment of a Sample of CHP Power Plant with Biogas Fuel: A Case Study

As mentioned in chapter five, annually about 1.5 million tonnes of bagasse which is produced in the Sugar cane and By-products Development Company, is destroyed. Therefore, the key part of this research is limited to designing a typical biogas system. It is assumed extra bagasse is used as a substrate in an anaerobic digestion bioreactor for biogas production. Moreover, it is assumed that biogas produced is used as fuel in CHP. With this assumption, based on the daily rate of biogas and some additional assumptions that are mentioned in appendix I, a typical biogas system was designed by the author. Also, the suitable scale of CHP assumed for economic study this biogas CHP. This kind of designing and economic study about biogas CHP has been carried out for the first time by author. The result of this study would be useful for making a decision about investment on the development of this kind of biogas CHP in Iran, and other developing countries.

The most basic challenge facing biomass energy is its economic cost. At present, the cost of the energy production of biogas using current technology is more than the equivalent energy supplied from fossil fuels. However, due to the advancement of technology the cost in recent years has decreased significantly and in the case of continuation of this trend, the process of the growth of energy production from biogas will increase (Godfrey, 2004). In order to make an economic study of CHP power plants with biogas fuel, the data relating to the cost of a plant are presented in Table 6.18

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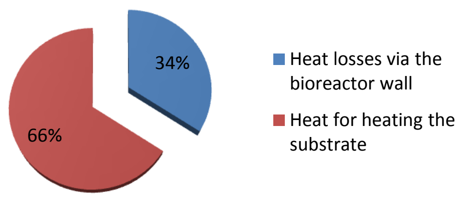
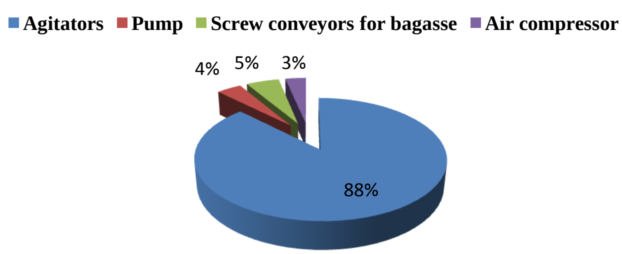
In this case study, the volume of the sample bioreactor and the nominal capacity of CHP power plants with biogas fuels have been set respectively as 431 cubic meters, and 111kWe.Here the size of biogas CHP is assumed small, because if it is proved that small scale is attractive and economic, so large scale will be more attractive and economic. According to the Table 6.18 (Abdoli, 2004), the costs of investment for a reactor is 464 US$/$m^3$ and also the cost of special investment for CHP in an electrical energy unit for a simple CHP power plant is determined to be about 650 US$/$kW_e$ (according to the data from companies such as Gascore, Duetch, and Perkins). In the economic calculations, the cost of investment without considering CHP is estimated to be about 200,000US$ and for the installations related to CHP is 72000US$. The costs of the CHP system include the costs of electrical connection between the power plant and the electrical network based on connection being available at a short distance. So, the total cost is estimated to be equal to 272,000US$. In the case of CHP using a biogas fuel system under investigation, energy is produced as electricity and heat, and in figure 6.8; the power consumption of electricity and heating estimated for the entire plant is 15.3 and 22 kW, respectively.



(a)



(b)

Figure 6.8 The percentages of heat (a) and electricity (b), consumption of biogas plant equipment

In Figure 6.9, 6.10, 6.11, and 6.12, the capital costs, consuming costs, operating costs, and the annual income in detail are calculated respectively for the typical biogas power plant by the author.

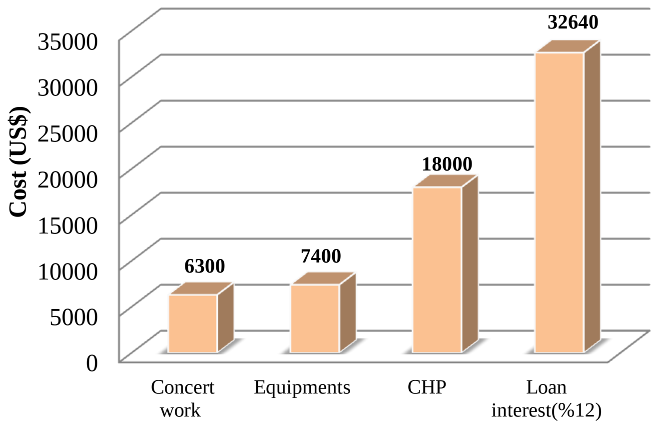


Figure 6.9 The annual capital costs (US$)

This power plant is of the type of suitable compression ignition (CI) engines type, which in a small biogas power plant will require about 10% of gasoil to be used. In Figure6.10, the rate of fuel consumption is 100 litres per day at a cost of0.025US$, (i.e. the real price) and without subsidies of fuel being considered.

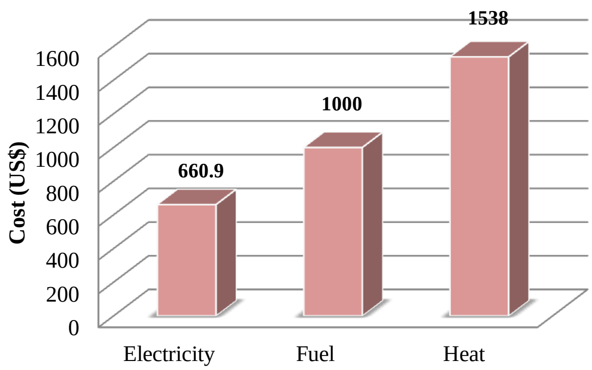


Figure 6.10 The annual consumption costs (US$)

With regard to the estimated costs, the total cost of this biogas power plant is estimated to be 83200US$ by the author. The power plant will be able to sell electricity and heat and the residue from the process of fermentation, which will be useful as fertilizer. All these outputs will generate income.

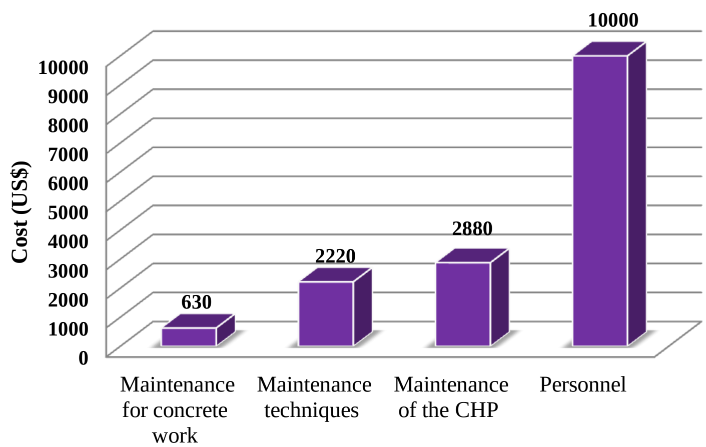


Figure 6.11 Theannual operating costs (US$)

This income generation is presented in Table 6.12 as annual receipts. In calculating this value it has been assumed that the power plant operates for 8640 hours per year and the rates of electrical and thermal practical generation capacity are 85.4 kW_e and 142kW_{th}, respectively.

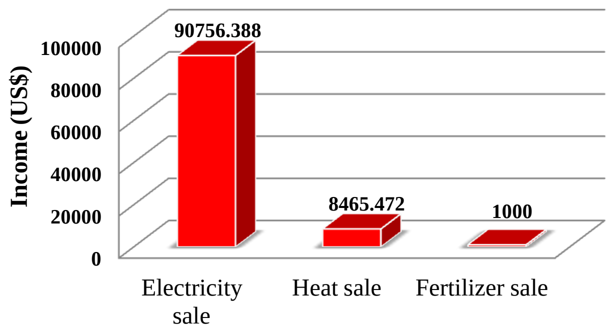


Figure.6.12 The annual income (US$)

Therefore, in respect of the annual income of the biogas power plant, whit regard to the rate of the electricity purchase for renewable energies, each kWh of electricity is calculated as 0.123 US$ and for thermal energy, each 10 thermal kWh is calculated equal to the price of 1 cubic meters of natural gas as 0.0690 US$ (according to the directive of Ministry of Energy). After deletion of the annual expenditures (83200US$ per year) from the annual income (100221US$), the annual benefit of the power plant will be 17000US$ per year which is justifiable economically. In terms of return of capital the plant should pay for itself in less than 6 years even without considering the benefits from the reduction of greenhouse gases and natural gas saving.

6.15 Environmental Benefits of Biogas CHP

Today energy is a driving force for socio-economic development for most societies. However, production processes and energy consumption, in particular from fossil sources, has negative impacts on the environment through types of pollutants and greenhouse gases. With regard to the increasing rate of energy consumption in the Country and its impacts on the environment (release of pollutants in water, soil, air, and climate change), it is necessary to reduce the negative impact. This may be done by using more renewable energy sources; using new technologies in particular bio and nano-technologies.

It is worth mentioning that in 2008in Iran the power plant sectors and transportation sector have had the highest rate of SO_2 emission, and power plants, residential, commercial and public sectors the highest rate of CO_2 emission. Power plants, transportation and industry sectors have had a considerable share of the production of SO_2 and NO_x such that about 97 and 89 percent of the total emission of these gases in Iran are related to these sectors. Therefore, substituting the fossil fuel consumed in power plants will have significant effects on decreasing greenhouse gasses.

The Clean Development Mechanism (CDM) provides industrialised countries with an incentive to invest in emission reduction projects in developing countries to achieve a reduction in CO_2 emissions.CDM also promotes sustainable development in the host country. Biogas CHP projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to sustainable rural development (Purohita, and Michaelowa, 2007). Studies show the carbon reduction for the biogas CHP plant considered in this study will be about 280 tonnes CO_2/year. Therefore, adapting large numbers of such power plants will have a positive effect on the environment.

Chapter Seven

Discussion and Conclusions

This thesis has assessed options for the use of bagasse as a fuel for combined heat and power in Iran. The findings of the work are discussed in relation to the objectives identified in Chapter 2.

Objective 1: Study and review different types of biomass resources and their benefits

As discussed in Chapter 4, due to the increase of World population, the limitations of fossil resources, and the environmental consequences resulting from consumption of fossil fuels, replacement of these resources is highly desirable. Renewable energy resources such as biomass are sustainable resources, and can be proper alternative resources for fossil fuels. Out of the renewable resources, biomass resources are unique, because they can be converted into fuels in gas, liquid and solid states. Since these resources are of high diversity and include materials, which may otherwise be inconsumable wastes, so using them, may decrease environmental pollution. However, if these waste materials are used as energy resources, they will not only reduce environmental pollution but also will be useful both economically and socially. The main types of biomass resources include agricultural residues, municipal solid wastes, urban and industrial sewages and industrial wastes.

Objective 2: Review the biomass resources for energy production

Chapter 4 also addressed this objective. It concluded that agricultural residues have various forms and high potential, even though every year a great quantity of them are wasted without being used. In the present study, bagasse, the by-product of the sugar process in sugar cane industries, was selected and studied based on the rate of production and diversity of application.

Objective 3: Practical and theoretical study of sugar production process.

In Chapter 5 it was highlighted how sugar cane holds a leading place in the expanding production of agricultural crops, which has been a feature of the World economy during the last 100 years. The primary use of sugar cane is to produce sugar, but it also produces many other useful products including bagasse, molasses and filter mud, which may be used for several purposes.

Objective 4: Identification of bagasse applications

Chapter 5 also discussed one of the important by-products of sugar cane processing that is, bagasse. Bagasse has the potential for many different applications: for example the production of numerous paper products, and as a raw material for production of chemicals, and as an energy resource.

Objective 6: Study and review of experiences of other countries using bagasse

At present, many countries have experience in this field. These countries are mainly located in tropical and semi-tropical areas. Of these countries, the most important ones are Brazil, India and China. It is clear that among sugar cane producing countries, the first application for bagasse has been using it as an energy source. The technology being used in these countries to produce energy from bagasse has been direct burning in furnaces. The produced heat has been used to procure heat for the sugar factory. At a more advanced level, it has been used to produce electricity and heat. However, the efficiency of energy production by this method is not ideal. In these countries attempts are made to use more efficient technologies for producing energy. In this regard, CHP has been developed. Using the heat required for electricity production will not only increase the energy efficiency of existing bagasse, and secure energy for factories, but also will make additional electricity which may be injected in to the electricity network and bring about a source of income for this industry. Beside this process, there are other applications for bagasse such as it's use in paper and chemical industries and for the production of animal food.

The importance of using bagasse as a source of energy production in these countries refers to its usage as a renewable energy resource with little environmental pollution and more importantly to the reduced use of expensive fossil fuels.

Objective 5: Determination of the bagasse production and consumption potential in Iran

Iran is a country with vast potential for sugar cane production, which can achieve extremely high yields per unit area. At present, the main sugar cane plantation and industry complexes in Iran are Haft Tapeh, Karun, and Sugar Cane & Side-industries Development. The overall area under sugar cane is 114,000 hectares, and there is a capacity to increase this in future. The annual production of sugar cane in recent years was about 10,000,000 tonnes, and bagasse production is about 3,000,000 tonnes. Though much of the bagasse is already being used in various ways, some is used inefficiently and about 1,500,000 tonnes remains unused and is destroyed annually. Suitable energy production technology from this extra bagasse ought to be economic for sugar cane factories. In this study different types of technologies such as combustion, anaerobic digestion, pyrolysis, and gasification were compared. Many factors influence the complexity and ability of technology performance, such as temperature of operations, need for retreatment, need for constant control of the procedure, need to add auxiliary materials, need for purification of improvement of energy products, and efficiency all of which are considered in this comparison.

Objective 7: Study and review of the bagasse energy conversion technologies and selection the most applicable method for using bagasse in Iran and Objective 8: Technical design a suitable typical biogas digester

The result of a technical comparison, suggests that two technologies compete to be the most attractive (gasification and anaerobic digestion). In order to prioritise one, the possibility of applying these technologies was reviewed and anaerobic digestion was chosen as the favoured option. Biogas production technology is particularly beneficial, when the resulting biogas is used in CHP power plants as a fuel. With the establishment of these types of power plants, large quantities of electricity and heat could be produced, but they will also produce thousands of tonnes of natural fertilizers for agriculture. Moreover, CHP power plants' economic and environmental benefits will be considerable. Economic calculations were carried out on a typical biogas CHP plant with a capacity of 111 kWe, which consumed biogas from a designated sample bioreactor of 431 cubic meters. The expenditures on this power plant, which includes capital, consuming and operating costs is estimated to be 83200 US$ per year, whereas the income of the power plant, which is restricted to the sale of electricity, additional heat, and fertilizer, is about equal to 100221

US$ per year. With regard to the expenditures and the annual income of the power plant, the annual financial benefit is 17000US$ per year. The calculations show that the establishment of biogas CHP plants should be economic and enjoys an acceptable payback period (under 6 years). Furthermore, by increasing the size of such power plants, economies of scale should help to ensure that even greater benefits should be obtained.

Objective 9: Economic study the application of a bio-digester and biogas CHP

The positive environmental impact of these power plants should also considerable, because the use of organic wastes rather than fossil fuels will cause the reduction greenhouse gases such as carbon dioxide and nitrogen oxide; so, boosting sustainable development in the Country.

It is considered that this research provides a good model for the implementation of similar projects for existing biomass resources in industrial, residential, commercial units and particularly in remote areas. This will have great benefits including helping with the promotion of economic development, improvement environmental conditions and enhancing the welfare of the society. This technology may also be applied to other developing countries with noticeable resources of biomass, and may also be important in replacing renewable fuels with fossil fuels in industries and other areas.

Conclusions

The main results of this research are mentioned as follow:

- Bagasse is important as a biomass resource, because of it's high production rate, and it's various applications.
- The technical study of the energy conversion technologies shows that the first priority is anaerobic digestion.
- The establishment of a biogas power plant is economic and enjoys an acceptable pay-back period (under 6 years).
- From an environmental perspective, it will be beneficial, because of reduced pollutions such as carbon dioxide. Studies show the carbon reduction for the biogas CHP plant considered in this study will be about 280 tonnes CO_2/year.
- Furthermore, by increasing the capacity of the power plant due to a reduction in cost of investment, it will bring more benefits.

Future Work

It is intended that the content of this project will be further developed into a PhD in the University of Tehran. In the continuation of the project at PhD stage, a comprehensive modelling will be made to compare all applications of bagasse for modern technologies and selection of their best ones. This modelling will be made and generated with due attention to the existing condition and forecasting future conditions, by using input data and considering technical, economic, social and environmental relations with the use of a computer code in a Matlab environment or Life Cycle Assessment (LCA).

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