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The Necessity of Biomass Application for Developing Combined Heat and Power (CHP) with Biogas Fuel: Case Study

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***Abstract*—**The daily increase of organic waste materials resulting from different activities in the country is one of the main factors for the pollution of environment. Today, with regard to the low level of the output of using traditional methods, the high cost of disposal waste materials and environmental pollutions, the use of modern methods such as anaerobic digestion for the production of biogas has been prevailing. The collected biogas from the process of anaerobic digestion, as a renewable energy source similar to natural gas but with a less methane and heating value is usable. Today, with the help of technologies of filtration and proper preparation, access to biogas with features fully similar to natural gas has become possible. At present biogas is one of the main sources of supplying electrical and thermal energy and also an appropriate option to be used in four stroke engine, diesel engine, sterling engine, gas turbine, gas micro turbine and fuel cell to produce electricity. The use of biogas for different reasons which returns to socio-economic and environmental advantages has been noticed in CHP for the production of energy in the world. The production of biogas from the technology of anaerobic digestion and its application in CHP power plants in Iran can not only supply part of the energy demands in the country, but it can materialize moving in line with the sustainable development. In this article, the necessity of the development of CHP plants with biogas fuels in the country will be dealt based on studies performed from the economic, environmental and social aspects. Also to prove the importance of the establishment of these kinds of power plants from the economic point of view, necessary calculations has been done as a case study for a CHP power plant with a biogas fuel.

***Keywords*—**Anaerobic Digestion, Biogas, CHP, Organic Wastes

I. Introduction

IN recent years, the growing trend of energy consumption has created energy crises in the world.

The increasing consumption of energy resulting from fossil fuels , though bringing about fast economic growth of different communities, but due to the dissemination of pollutants resulting from the combustion of fossil fuels and increase of dioxide carbon in atmosphere and its consequences, has made world facing with threatening changes.

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On the other hands, the limitation of fossil sources and the non-renewability of these sources have created a situation in which the policy makers and planners of energy section by doing structural studies to put the replacement of energy carriers and moving towards clean fuels in the top of their blueprint. One of these options is to use the energy carries resulting from biomass sources like biogas which has features fully similar to natural gas with the help of different pretreatment technologies [1]. Biogas can be used for the generation of electricity or heat. In the process of production of electricity usually heat is also produced in line with that, so that the heat recycling in such a process is possible. These kinds of power plants are termed as CHP-Combined Heat and Power plants [2].

Today in many countries in the world, the importance of this subject is proved and activities are done in these areas [3]-[4]. At present, UK produces more than 100 million tonnes in a year of organic materials including food wastes, sludge of waste water and energy crops which can be used for the production of biogas. The plan of this country is to generate 0.8 TWh power in a year through biogas resulting from anaerobic digestion in biogas CHP [5].

In the countries of the Eastern Europe such as Bulgaria, Greece, Croatia, Romania, Latvia, the most appropriate method known for the production of energy from biomass is biogas CHP plants with. The most important factors which attract the attention of countries to this technology are the high efficiency of the energy production and its economic position due to recycling of the produced heat. Usually, part of the heat is used for warming the digester and the rest is used for other applications [3].

In USA also, so many studies and researches have been done on producing biogas in the method of anaerobic digestion and the construction of biogas CHP. The results of these studies has shown that this country by using the existing biomass sources such as the waste water of diary industries, manure of livestock farms and energy crops is able to generate 3 GW electricity with the establishment of biogas CHP power plants [6]-[7].

In Iran, since 1974, sporadic studies have been conducted by research and academic institutions which have led to the construction of many biogas equipments in an experimental

form. The first digester of 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 of the village and used to supply the fuel for the neighboring public bathroom. Since 1982, the research Center for renewable Energies has made specific researches in this areas including the construction of 10 biogas units in Sistan and Baluchestan , Ilam and Kurdistan provinces. By the way, the establishment of one biogas equipment in Chinese model with a capacity of 13 cubic meters was designed and manufactured in 1998 in pilot form for Service Company of Kish. That set was using solid and liquid bio-wastes. In 1980's, Ministry of Jihad of Agriculture took certain measures. That was in this manner that from the beginning of the year 1984, a trial sample was built in Heydarabad in Karaj. Then a real sample 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 (19 provinces) of which only 18 units have reached to the state of generating gas. In 1999, the Organization of Renewable Energies of Iran defined a project on the establishment of a biogas power plant in Saveh. It started its work with the construction of the research site of biogas with 3 equipped reactors and labs. So, the primary steps to reach the biogas power plant technology were taken in the country. Since the improvement of energy efficiency in producing energy and correction of power generation are considered as basic policies of the country, so the necessity of study to spread the establishment of CHP power plans in particular with biomass sources is felt. With regard to this subject, in this article, a biogas CHP power plant with anaerobic digestion technology is studied from the economic, social and environmental viewpoints.

II. The Biogas Plant For Anaerobic Digestion Process

Main part of a biogas plant is in fact a bioreactor (or anaerobic digester). Fermentation on input organic materials such as agricultural residues and animal wastes which is shown in Figure 1 is performed and on the other hands, the resulting gas (including Methane) and the remaining sludge (rich of fertilizers of soil such as potassium, nitrogen and phosphor) are exited. In general, various bioreactors can be found in the industry and in each of these procedures is necessary to have a resistant bioreactor which can avoid of sudden changes of substrate and temporary stop of operation and to have the fixed load of methane.

III. CHP Power Plants With Biogas Fuels

The application of CHP for biogas units is very common. Concurrent with the production of electricity, heat is also produced in a less or more percentage depending on the technology of power generation. Almost 50% of the installed biogas CHP units in Europe are working with four stroke ignition (SI) engines and about 50% of compression ignition (CI) engines [2]. More modern technologies like fuel cells or micro gas turbines are rarely used. The general efficiency, i.e. the total thermal and electrical output is typically between 85-90 percent for new CHP power plants. 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 I.

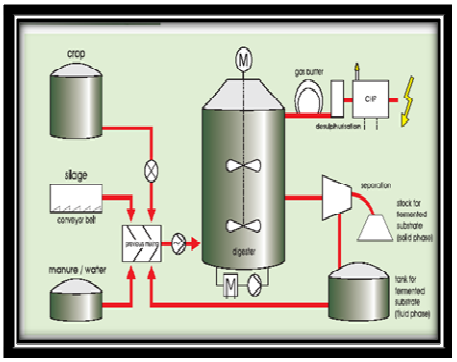


Fig. 1 A type of biogas plants for agricultural and animal wastes

TABLE I
ADVANTAGES AND DISADVANTAGES OF BIOGAS CHP POWER PLANTS RELATED TO ANAEROBIC DIGESTION

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

IV. Motivational Factors For The Establishment Of Biogas CHP In Iran

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

A. Existing Potential of Biomass Sources

All materials which are placed in the classification of biomass sources are organic materials and have ability to be subject to anaerobic digestion to produce biogas. The main sources of biomass include agricultural wastes, urban residues, animal wastes and urban and industrial sewage.

The quality of energy available from biomass will vary depending on the region. For example, the percentage of organic waste materials in the Iranian urban residues is about 75% whereas it is only 25% in the USA [8]. This feature of the urban residue of Iran makes it suitable for the application of anaerobic digesters for the production of biogas. With regard to the considerable quantities of the annual production of biomass sources in Iran which is referred to in Table II, highlights the importance of the use of these sources to produce biogas.

B. Energy Production for Compensation of Part of Natural Gas Consumption

The total potential producible methane gas from bio-waste in Iran is 9175.2 million cubic meters which compared with the natural gas final use in home, business and industrial sectors of the country forms 15% of its consumption. This rate in comparison with the consumption of natural gas in all power plants in the country in 2007 is about 25% [10].

TABLE II
POTENTIAL FOR THE ANNUAL PRODUCTION OF BIOMASS SOURCES AND BIOGAS PRODUCTION IN IRAN [9]

Biomass source	Annual production	Potential for the production of biogas (million cubic meters)
Animal wastes	74946 (Thousands tons)	8668
Urban sewages	25176 (Thousands tons)	108-245
Industrial sewages	36245 (Thousand liters)	82-280
Agricultural wastes	23147 (Thousand liters)	5475
Urban garbage	13.87 (Million tons)	1646

C. The Problem of Disposal of Wastes

Of the most important encouraging factors is the use of biomass sources for the production of biogas, removal of pollutants waste materials which are in fact foods for the digesting. Actually, the materials which in ordinary conditions are unusable, wastes, and pollutants, are potential sources of energy. So, the use of these kinds of materials has two types of benefits for the societies which apply them.

The first benefit of their application is the considerable reduction of the costs of collecting, disposal and environmental costs. Their second advantage is the consumption of the biogas produced in different sectors. With regard to the daily production of garbage of about 40 thousand tons in the country, the cost of collecting, processing and disposing of these volumes which will be an astounding figure will be deleted. For example if the density of garbage in Iran and the average of the depth of burying is 350 kilogram per cubic meter and 5 meters, the rate of land which is necessary for the sanitary burial of such a garbage is about 21715 square meter and annually about 793 hectares. The cost of burying alone (i.e. the cost of collecting, separating and transportation has not been included) will be about 14 million US$ per year.

Another example of the application of biomass sources is urban and industrial sewages which are produced annually about 4.6 billion cubic meters. The cost of collecting, filtration and disposal of this volume of sewage is at least 180 million US$ [11].

D. 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 environmental damages which these sources of energy create. The social and environmental costs of the fossil fuel power plants in Iran was more than 1.8 million US$ in 2007 [8]. The replacement of prevailing fossil fuel power plants with biogas power plants will be very useful from social and environmental aspects, and will reduce these costs.

V. THE IMPORTANCE OF BIOGAS CHP FROM THE SUSTAINABLE DEVELOPMENT VIEWPOINT

The application of biogas CHP has many advantages from the economic, environmental and social perspectives. Of the most important of these advantages, one may refer to the reduction of environmental impacts with the management of organic waste materials, the promotion of society welfare by generating jobs and generation power and heat with a less costs and improvement of energy efficiency. So, biogas power plants will be able to play an effective role in the improvement of the society towards sustainable development. With regard to this specific importance, in the following sections, the economic, environmental and social impacts of the application of these power plants are dealt with.

A. Economic Study of the Establishment of One Sample of Biogas CHP (Case Study)

The most basic challenge which biomass energy is facing is its economic problems. At present, the cost of the energy generation of biogas usually with regard to the technology in use is a little bit more than fossil fuels. Though the cost in recent years due to the advancement of technology has decreased significantly and in the case of continuation of this trend, the process of growth of energy production from biogas will increase [12].

In order to make an economic study of biogas CHP power plants, all the data relating to the cost of plant which should be considered are presented precisely in Table III.

Furthermore, the case study of this power plant is made in an example which its feeding source is agricultural residue and animal dung. In this case study, the volume of the sample bioreactor and the nominal capacity of biogas CHP power plants are calculated respectively 431 cubic meters and 111 kWe.

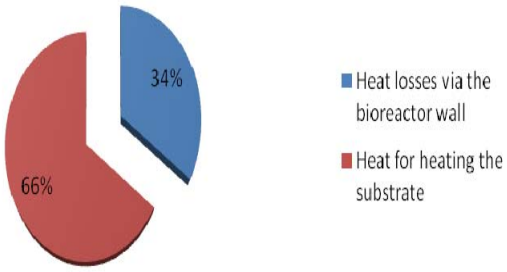
TABLE III
TYPICAL FIGURES FOR COSTS OF AGRICULTURAL BIOGAS PLANTS

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

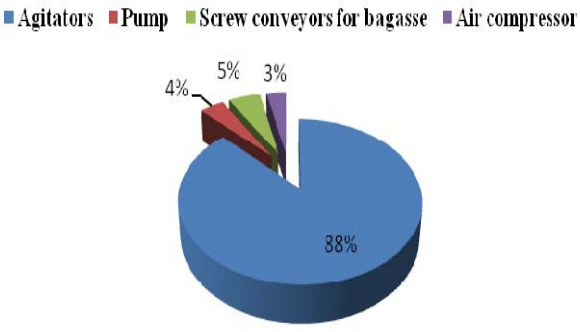
	construction)
Invest. Costs per 1 kW installed power	2400 US$(large plants>300kW) 6000US$(small plant)
Invest. Costs per 1 m^3/h biogas	4000-7000US$(plant alone) 5500-9000Us$(including silo for maize silage)

According to the Table III, the costs of investment for reactor is 464 US$/$m^3$ and also the cost of special investment for CHP in electrically energy unit for a simple CHP power plant is determined to be about 650 US$/$kW_e$. In the economic calculations, the cost of investment without considering CHP is estimated to be about 200000 US$ and for the installations related to CHP is 72000 US$. The costs of the CHP system include the costs of electrical connection between the power plant and electrical network based on connection being available at a short distance. So, the total cost is estimated to be equal to 272000 US$. In the CHP with biogas fuel system under investigation, energy is consumed in form of electricity and heat and in the Figure 2; the consuming power of electricity and heat is estimated to be 15.3 and 22 kW, respectively.

In Figures 3, 4, 5, and 6, the capital costs, consuming costs, operational costs, and the annual income in details are calculated for the biogas power plant.



(a)



(b)

Fig. 2 the Percentages of Heat (a) and Electricity (b) Consumption in Equipments of Biogas Plant

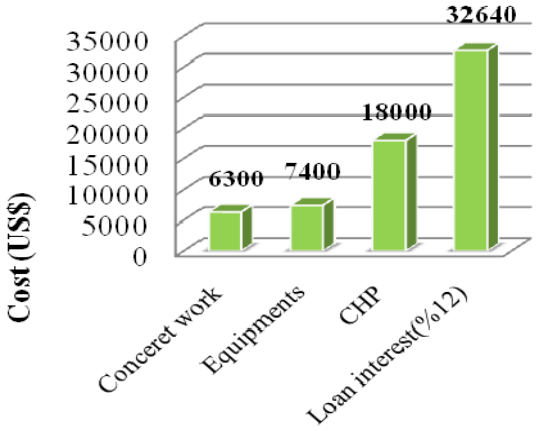


Fig. 3 the Annual Capital Costs (US$)

This power plant is of the type of suitable compression ignition (CI) engines which is a small biogas power plant require about 10% of gasoil to be used. In Figure 4, the rate of consumption fuel is 100 liters per day whose cost is 0.250 US$, i.e. the real price and without subsidies of fuel is considered for that.

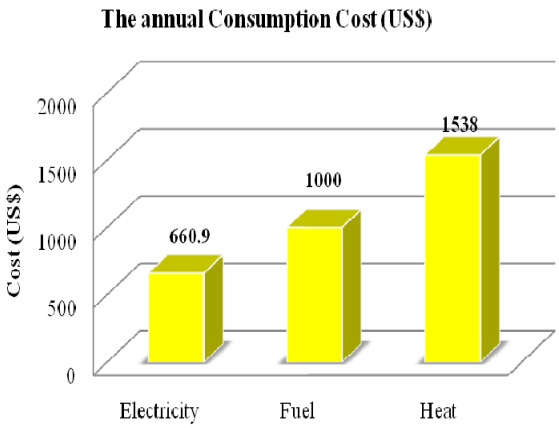


Fig. 4 the Annual Consumption Costs (US$)

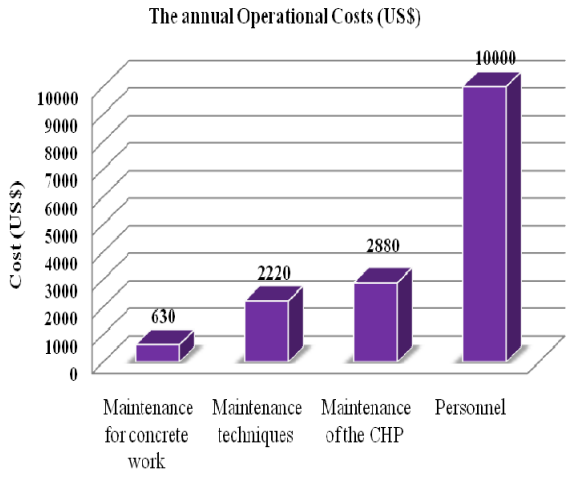


Fig. 5 the Annual Operational Costs (US$)

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

This income generation in form of annually is presented in Figure 6. By the way , in calculating the rate of the performance of power plant 8640 hours per year , the rate of electrical and thermal practical generation capacity power have been considered 85.4 kW_e and 142 $kW_{th,}$ respectively. So, the annual income of the biogas power plant which regard to the rate of the purchase of electricity for renewable energies, each kWh of electricity is calculated as 0.123US$ and for thermal energy each 10 thermal kWh is calculated equal to the price of 1 cubic meters of natural gas as 0.069 US$ (According to the Directive of Ministry of Energy).

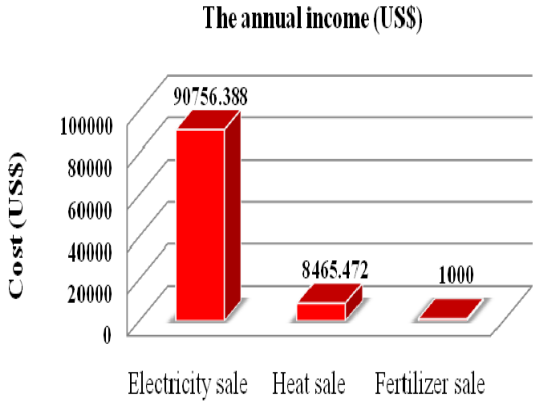


Fig. 6 the Annual Income (US$)

After deletion of the annual expenditures (83200 US$ per year) from the annual income (100221US$), the annual benefit of the power plant will be 17000US$ per year which is justifiable from economic aspect and its term of return of capital will be less than 6 years without considering the rate of reduction of green house gases and natural gas saving.

B. Social Study of the Establishment of Biogas Power plants

The renewable systems of energy as compared to the systems of fossil fuels are in need of more working forces. By the way, out of the renewable energy technologies, jobs related to bio-energy technologies due to their difference with other technologies have more diversity and their numbers of job opportunities are greater. This subject is shown in Table IV.

Different jobs based on bio-energy projects include direct, indirect and induced employments. The direct jobs include the production of fuel, construction, operation, repair, maintaining units of conversation and transportation of fuels.

TABLE IV
THE ANNUAL JOB POSITION BASED ON100GWH OF ELECTRICAL PRODUCTION [14]

Fossil fuel technologies	1-6
Wind	15-20
Photovoltaic	50-54
Solar Heating	25-27
Small hydro	8-9
Biomass-Forest wastes	18-19
Biomass-Energy Crops	64
Biogas-Agricultural wastes	58

The indirect jobs are referred to all jobs resulting from the related activities. The induced jobs are jobs which are related with the sale of additional electricity. In Table V, some examples of the jobs resulting from bio-energy projects are presented.

TABLE V
EXAMPLES OF JOBS RESULTING FROM BIO-ENERGY PROJECTS [15]

Biomass project	Direct jobs	Indirect jobs	Induced jobs	Total jobs PJ
CHP Forest Wastes (France)	52	33	30	115
CHP industrial wastes (Italy)	41	11	13	65
CHP urban residue (Netherlands)	13	2	27	42

C. An Environmental Study of the Establishment of Biogas Power Plants

What distinguishes biogas energy from an environmental point of view as compared with other renewable energies is the collection and control of organic materials of the wastes of cities and industries, reduction of the impacts of greenhouse gases, prevention from the pollution of underground waters, removing the seeds of vain grasses and parasites. Also the use of organic wastes in the technology of anaerobic digestion causes the reduction of the production of methane, carbon dioxide and nitrogen oxide which the green house impact of these methane gases and nitrogen oxide is more than CO_2. For example, the greenhouse impact of methane is about 21 times of CO_2. This ratio is presented in Table VI.

TABLE VI
THE RATIO OF THE IMPACT OF GREENHOUSE GASES [3]

CO_2	1
CH_4	21
N_2O	310
SF_4	23900
PFC	6500-9200
HFC	140-11700

Also , the results of the studies on the sample of an animal husbandry unit with 2069 cattle in which daily about 20 cubic meters of animal wastes in one digester with a volume of 300 cubic meters are presented shows that in the best position , the produced biogas is 1198 cubic meter. With regard to the fact that 65% of the produced biogas , has been methane, so the methane volume in this position is 150 cubic meters per day , i.e. equal to 107/55 kilogram per day , i.e. or equal 39 tons CO_2 per year [16]. In these conditions, CO_2 with the rate of %35 is reduced.

VI. Conclusion

The production of the vast volume from biomass sources in Iran indicates the high capability of biomass for the production of energy in Iran. Amid this, the biogas production technology (anaerobic digestion) has been developed in the world very much, in particular, when the resulting biogas being used in CHP power plants as a fuel. With the establishment of these types of power plants not only annually a considerable rate of electricity and heat will be produced, but also it will produce thousands of tonnes of natural fertilizers for agriculture. Moreover, their economic, environmental, and social impacts will be considerable. The economic calculations were done for one sample of biogas power plants with a capacity of 111 kWe, which supplied the consuming biogas from a designated sample bioreactor of 431 cubic meters. The expenditures of this power plant which includes capital, consuming and operational costs is equal to 83200 US$ per year, whereas the income of the power plant, which is restricted to the sale of electricity, additional heat, and fertilizer, is equal to 100221.76 US$ per year. With regard to the expenditures and the annual income of the power plant, the annual profit is 17000US$ per year. The results of calculations show that the establishment of biogas power plant is economic and enjoys an acceptable payback period (under 6 years). Furthermore, by increasing the capacity of the power plan due to reduction in cost of investment in ratio to the production of electricity and heat, it will bring about more profits.

Also, the most important social advantage which can be enumerated for this biogas power plant includes the following cases:

The creation of more job opportunities for the public

Production of an improving fertilizer for soil (in particular with regard to the public poverty of the soil in the country)

The environmental impact of this power plant is also considerable, because the use of organic wastes in the digestion technology of anaerobic will cause the reduction of green house gases such as methane, dioxide Carbone and nitrogen oxide. So, the resulting consequence indicates the necessity of spread of biogas CHP, which will be a way towards sustainable development in the country.

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