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Treatment of municipal organic solid waste in Egypt

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Abstract
The objective of this review is to overview and formulate the problem of Egyptian MOSW which forms about 56% of total MSW and to highlight the benefits of managing this waste in Egypt adequately. In addition this review has been prepared in order to enable the policy makers in Egypt such as Ministry of State for Environmental Affairs (MSEA) to have a wider vision about treatment options of municipal organic solid waste (MOSW) including agricultural solid waste that forms the greatest portion of municipal solid waste (MSW) in Egypt. With respect to the great efforts that have been done by government to solve environmental problems, in this paper there is a try to contribute in improving the management of MOSW in Egypt in a proper way. The previous investigations in the field of MOSW were only descriptive without mentioning to crucial outlines for solving the problem integrally. This pilot study is not only descriptive but also indicative because it was based on the problem formulation of the Egyptian MOSW and in addition scopes on the currently applied biological treatment technologies and their benefits. The most important conclusion of this paper was that the proper management of Egyptian MOSW leads to the volume reduction, production of a feasible amount of compost which can substitute the shortage of compost demands, and biogas production which is a great addition to the energy networks.

Keywords: biogas from waste in Egypt, waste to compost, organic waste treatment in Egypt

1. Introduction
Effective waste management is among big challenges in most Arab countries, including Egypt, due to high population growth rate and rapid urbanisation. As an accompanying feature, implementation of such management systems is usually hampered by lack of several crucial ingredients, such as information, organization, financial resources, complexity, or system multidimensionality [1]. According to published data and information collected from local sources, there is no definitive or common rate for all Arab countries at which wastes
are generated, as this differs from one country to another and among different regions within the same country, according to community characteristics, social conditions and average income in each area. Despite a large number of research studies have been undertaken to determine influential factors affecting waste management systems in cities in developing countries, only few gave quantitative information [2]. In 2008 the Arab Forum for Environment and Development reported that statistics and data on quantities of solid waste in most Arab countries are not available. With regard to solid municipal waste, the gross generated quantity from Arab countries is estimated at 81.3 million tonnes annually on the basis of an average rate of around 0.7 kg per capita daily. According to available data, the quantity of municipal solid waste which is adequately treated is less than 20%, while recycled waste does not exceed 5% of the gross quantity of residues [3].
MSW can be domestic, commercial, industrial or agricultural in origin. Many efforts have been done by the Egyptian government to treat agricultural solid waste (ASW) to keep up with the growing population, intensified urbanisation and increased standard of living. Fortunately, the existing and mature composting technology already offers economically and environmentally interesting solutions that could substantially improve the hitherto used system of waste management. The core of the waste management system is the technology which is applied to the waste from its generation to disposal [4].
In February 2010, presidential directions were made to the Prime Minister and the Ministerial Committee responsible for solid waste management to handle the problem of escalation of waste accumulation. The action

plan proposed by MSEA and committee members addresses three headlines: collection planning, waste treatment planning and inspection and control.
The collection planning contained new contracts with the informal sector and new contracts with the international companies. The waste treatment planning dealt with establishing five sanitary landfills outside Cairo, two transfer stations with capacity 2000 ton/day and construction of composting plants at the locations of the new landfills for recycling the organic waste and allowing further waste treatment technologies (e.g. biogas and waste-to-energy). Inspection and control by increasing the number of inspectors, adding 30 new monitoring and control unites, automation of both inspection and control and implementing capacity building program for inspectors [5].
However, its successful application requires that the problem is thoroughly analysed and carefully stated with all potential risks highlighted. At present, there is no overview of Egyptian MSW problem focusing on critical links in the system and conceiving new opportunities for making further headway in optimizing the approaches used.

2. MSW generation and performance in Egypt

2.1 MSW Generation in Egypt

Egyptian Environmental Affairs Agency (EEAA) estimated the generation of Egyptian MSW with 0.3 to 0.8 kg/day/capita, with an annual growth of 3.4%. In addition, there is 6.2 million ton/year industrial waste including 0.2 million ton of hazardous waste and 23 million ton/year of agricultural waste [6]. The country report on the solid waste management in July 2010, which has been prepared for the Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries (SWEEP-Net), stated that Egypt is the second most populous country in Africa, with 78.2 million inhabitants (May 2010), with the majority of them residing along the Nile Valley and Delta. The urban population comprises 43% of the total population. According to the country report of 2010, the total annual MSW generation in Egypt has increased more than 36% since 2000, to the current level (2010) of 20.5 million ton per year (Table 1).

Table 1: MSW generation in Egypt 2010

Region	Governorate	MSW (ton/day)	MSW (million ton/year)
Greater Cairo	Cairo	11000	4
	Giza	4000	1.6
	Helwan	4000	1.6
	Qalyubia	3500	1.4
	6th October	2500	0.91
Alexandria and Matruh	Alexandria	3700	1.35
	Marsa Matruh	250	0.1
Canal, Sinai and Red Sea	Ismaïlia	600	0.21
	North Sinai	200	0.073
	Port Said	650	0.23
	Red Sea	450	0.16
	South Sinai	350	0.12
	Suez	400	0.14
Delta	Beheira	3000	1.1
	Dakahlia	4500	1.64
	Damietta	900	0.3
	Gharbia	3000	1.1
	Kafr El-Sheikh	2500	0.91
	Monufia	2000	0.73
	Sharqia	1800	0.65
Upper Egypt	Al-Minya	1000	0.36
	Aswan	650	0.23
	Asyut	700	0.25
	Beni Suef	750	0.27
	Fayoum	600	0.22
	Luxor	250	0.09
	New Valley	100	0.03
	Qena	1000	0.36
	Sohag	900	0.32
Total		55250	**20.453**

The estimated breakdown of MSW generation at the different regions is as follows: Upper Egypt 10%, Canal & Sinai 5%, Delta 31%, Greater Cairo 47%, Alexandria & Matruh 7% [5].

2.2 MSW Performance in Egypt

A study that has been done through Mediterranean Environmental Technical Assistance Program (METAP) in Egypt resulted that MSW collection covers 0–35% in rural areas and 40–95% in urban areas. Out of 8 landfills, there are only 5 in operation and 3 are under construction. There is one unit for treating hazardous industrial waste. One ton of MSW costs from collection till disposal approximately 100 to 110 LE in Cairo and Alexandria, and less than 60 LE in the other governorates. The average cost recovery is around 70 LE/tonne and the total cost recovery is about 200 million LE/year [7] . The selling price per ton of sorted waste depends on the waste type (Table 2) [8].

Table 2: Selling prices of sorted recyclables in Egypt

Waste type	Selling price (E.P./ton)
Newspaper	100–150
White paper	400
Mixed cardboard	150–200
Mixed plastic	1200–1500
Polyethylene plastic	900–1800
Polyethylene plastic injection	2000–2300
PET bottles	1500–3000
Copper	5000–5500
Aluminium	1200–8000
Tin cans	200–250
Iron	800–1000
Textiles	100–300
Glass	210
Bones	250–300

Some of the organic fraction is generally used to feed the household's feedstock in the rural areas. The non-usable fraction is dumped in empty land, along roads, irrigation and water course. A few municipalities in some villages use trucks and tractors to collect municipal solid waste, which is dumped in open dumpsites, where it is burned to reduce its volume, or left to be rotten naturally [8]. MSW Final destination is 9% composted, 2.5% recycled, 5% landfilled and 83.5% open dumped. Country report of 2010 included that MSW in Egypt contains about 85% easy recyclable materials such as organics, glass, metals and paper and the rest of 15% (others) must be specified in order to be able treating them in a proper way. Paper, glass, metals are collected and separated from the source and sent to factories for recycling. The main portion of the Egyptian MSW here is the organic waste which forms about 56% of the total MSW (12.88×10^6 tonnes). Recycled organic waste does not exceed 20%, so there is an urgent need to manage the rest of organic waste otherwise this will serious environmental and public health problems. In fact, the improper disposal of solid waste in opened dump sites, waterways and drains (Fig. 1,2) has led to the contamination of water supplies which hinders Egypt's natural resources, heritage, and the health and welfare of its people. The waste generation is projected to exceed 30 million tons annually by 2025. The performance of recycled organic waste does not exceed 20% despite the large number of 66 composting plants [5].

Figure 1: Open dumping (Ahram, 28-05-2013. year.137..nr. 46194)

Fig. 2. Burning in the open air (Ahram, 28-05-2013. year.137. nr. 46194)

Egyptian MSW is characterized by its high organic content of about 56%, paper of 10%, plastics of 13%, glass of 4%, metals of 2% and other materials of approximately 15% (Fig. 3).

Although the Egyptian government commenced several initiatives to develop the waste management sector with the start of the new millennium, their efforts resulted in little improvement. Less than 65% of that waste is managed by some form of public or private sector collection, disposal or recycling operation. The remainder accumulates on city streets and at illegal dumping sites. Physical and chemical characteristics are determined according to the waste and the place of generation such as paper, textiles, plastic, glass, food residues, rubber, metal, etc. Moreover, the management of this waste remains, for the most part, both inefficient and inadequate [5].

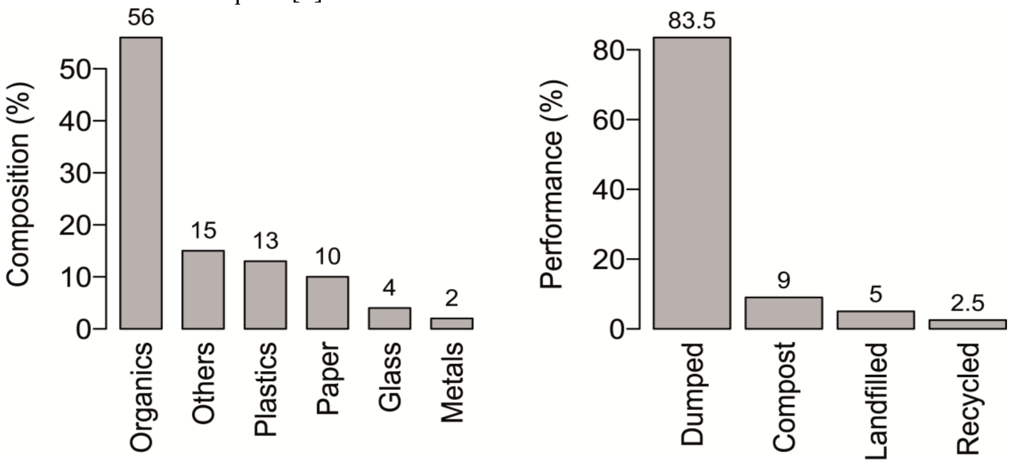

Figure 3: Composition (left) and performance (right) of MSW in Egypt as reported in 2010

3. Agricultural solid waste ASW generation and performance

3.1. Generation of ASW in Egypt

Egypt generates massive amounts of agricultural solid waste every year. The disposal of ASW is one of the most pressing environmental problems currently facing the country. This waste is characterized as Coarse plant by products and big size, chemically low in protein and fat contents. Also it is high in lignin and cellulous contents. The problem of agriculture wastes becomes very obvious and aggregated after the harvest of summer crops. That is because at this time of the season, the farmer is in a rush to re cultivate his land therefore getting rid of the wastes has his highest priorities, usually by burning. This method, burning not only is considered an economic loss but also has harmful effects on the environment because of emissions to the air. Furthermore, it reduces the microbial activities in the soil. In addition, storing these wastes in the field leads to reproduction and growth of pests and pathogens that will attack new crops [9]. There is a large variety of ASW (Table 3) that are generated every year. These include post -harvest waste, the six largest crops in Egypt alone generate more than 10.5×10^6 tons of ASW per year [10].

Table 3: Cultivated areas and annual agricultural solid waste production for major crops in Egypt between 2003 and 2004

Crop	Cultivated area in thousands hectares	Solid dry waste (2008) (ton/hectare)	Total
Rice	745.1	4.3	3,203,930
Maize	821.8	4.3	3,530,740
Sorghum	154.1	4.5	693,450
Cotton	131.3	3.8	498,940
Sugar	108.2	8.1	876,420
Tomato	240.2	7.6	1,825,520
Total	2200.7	**-**	**10,629,000**

In addition to the crops waste, there is the animal waste (Table 4) which is estimated with 14.6×10^6 ton/year [10].

From the above table we could conclude the total amount of animals in agriculture in Egypt is around 18.7 million that produce around 14.7 million ton of waste per year.

Table 4: The amount of animal waste in Egypt per year

Category	The number of animals in Egypt in 2007	The amount of dry waste in (Kg/day/animal)	Total dry waste in kg/day
Cattle	8974466	4	35897864
Horses	65714	5	328570
Sheep	5467469	0.48	2624385.1
Goat	4210714	0.24	1010571.3

3.2. Performance ASW in Egypt

Available statistics indicate that only around 40% of generated ASW is currently utilized, while the remaining 60% is discarded as waste [6]. ASW should be recognized as a resource that might be utilized as animal food, natural compost or biogas with virtually no negative impact on the environment. Composting has been applied in a number of locations, using different materials. Prices vary depending on the constituents used. Aerobic fermentation is generally used with three examples of operational composting facilities are shown in (Table 5) [11].

Table 5: Summary of features of three composting plants

Facility	Location	Material	Fermentation process	Price/ton (E.P)
Abu Shadi	Qaha, Qalioubiya	Rice straw and cattle manure	Aerobic	250
El Khalil composting	El Khatatba, Buheira	Rice straw with cattle and chicken manure	Aerobic	250–300
CEOSS pilot project	El Gazaer, Minya	Banana leaves	Aerobic	150

3.3 Compost and gas in Egypt

There is a large demand for compost made from agricultural solid waste and the demand is growing. It has been estimated that the present demand for compost is around 53 million ton annually for the old Nile Valley land and 1.5 million ton a year for reclaimed land. The demand for compost for reclaimed desert land is expected to reach at least 30 million ton by 2017. With the present national production capacity of compost being only about 20.7 million ton per year, there is clearly a major shortage in the supply of compost [11].

The production of natural gas in Egypt has been doubled since 2004 (61×10^9 m^3 in 2012) from which 18% is exported. This situation has deteriorated rapidly since 2011 due to the ongoing increase in the consumption of oil products and the stagnation in production. Primary energy consumption has increased at an average annual rate of 5% since 2000 (9% for natural gas). Currently, natural gas production covers only an estimated 80% of consumption and export needs. LNG facilities are running at very low capacity and some have been shut down which will lead to that Egypt will not be longer in a position to meet its LNG supply commitments to international export companies[12].

The total energy consumption in Egypt by 2010 (Fig. 4) was amounted 81 million tons of oil equivalent (mtoe). Oil accounted for 36.3 mtoe, while coal and gas accounted for 0.7 mtoe and 40.6 mtoe respectively. Hydro and Renewables accounted for 3.2 mtoe and 0.3 mtoe respectively. In 2009, 24,519 mcm of natural gas was used for generating power. In this regard, natural gas accounts for over 70% of the total mix used for electricity generation. With the development of compressed natural gas (CNG) infrastructure and vehicles, the share of natural gas in the transportation sector is expected to grow[13].

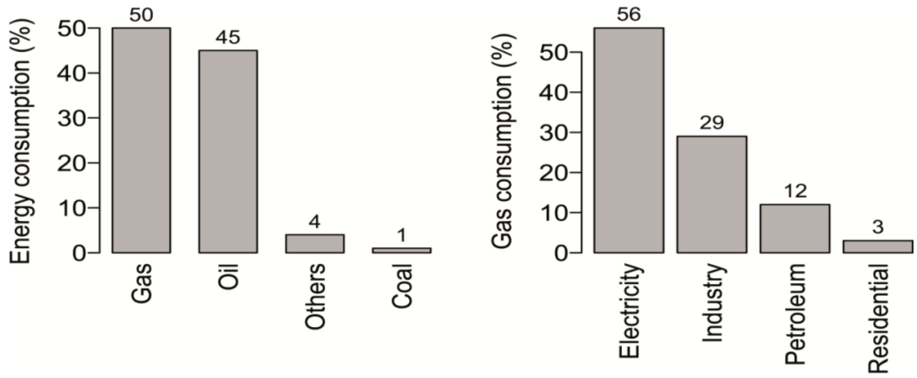

Figure 4: Total energy consumption in Egypt 2010 (left) . Others in energy consumption includes nuclear, hydro, geothermal, solar, biofuels and waste, electricity and heat [13] and total natural gas consumption in Egypt 2009 (right) [14].

4. Treatment technologies for use in Egypt

Organic waste is a biodegradable waste which is not very well suited for incineration because of their high water content, and creates problems when put in landfills (emission of gases and leachates). The degradation of the native organic matter by biological conversion gives different final products depending on the degradation's conditions. Controlled process maximizes the hygienization and biodegradation/mineralisation. The most common biological treatment options for organic part of MSW waste are rotting, aerobic and anaerobic digestion. Rotting is a biological drying of native organic matter to reduce the volume of the waste and stabilize its biological activities by evaporating the water molecules in the waste matter using the heat generated by aerobic decomposition. Aerobic digestion is a composting process that takes place by decomposition of organic materials in the thermophilic temperature range (40–65 °C). Anaerobic digestion (AD) is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen, it can greatly reduce the amount of organic matter and produces biogas, compost and digestate [15]. With regard to environment, both processes of AD or aerobic digestion (composting) facilitate carbon and other nutrients. Composting alone may result in a mature product while digestates usually are less stabilised and sanitised, and necessitate further aerobic treatment. On the other hand AD usually preserves nitrogen content and produces a digestate with a higher fertilising value than aerobic composts.

An AD plant can have a net energy yield equivalent to 100–150 kW heat/tonne feedstock whereas in composting an input of 30–35 kW heat/tonne feedstock is needed. Energy extraction from composting in the form of hot water has ranged between 4 and 10.9 MJ/kg input total solid waste (TS). However, the low form of that energy and the difficulties associated with its extraction has not encouraged further work on this topic. Air emission is another important parameter at play. Odour potential is low with AD, as processing takes place in air-tight containers and the biogas is stored before being utilised. Open composting may generate high-germ emissions at the work place. Any leachate or wastewater produced (the latter arising from AD only) can easily be treated by using wastewater treatment technology. Rather, the production of such effluents is of an economic importance.

In Europe, agriculture is the biggest contributor in organic rejects, followed by yard and forestry waste, Sewage sludge waste water treatment plant (SWWTP) that are usually homogeneous materials with low level of physical impurities. Food processing waste and organic fraction of Municipal solid waste (OFMSW). Organic waste separation is linked inexorably with the biological treatment of OFMSW, and its importance is reflected in the repeated failures associated with un-sorted MSW composting operations throughout the last 40 years. As a result, in countries such as Germany, Switzerland, Denmark, and The Netherlands, source separation schemes have been widely adopted . The degree of efficiency of the separation stage defines, to a certain extent, both the diversion rate of biodegradable organics and the quality of the waste [16].

The installed anaerobic digestion technologies in the Ecoparks of Barcelona can produce compost of 0.35 ton per ton of waste and 120 m^3 biogas per tonne of waste [17] . and the biogas yield of five types of food wastes for a potential centralized anaerobic digester system in the area of Sacramento, California to produce biogas energy. The wastes were from a soup processing plant, a cafeteria, a commercial kitchen, a fish farm, and grease trap collection service was between 530–750 m^3/ton [18]. The energy content of 1.0 m^3 of purified biogas is equal to 1.1 L of gasoline, 1.7 L of bioethanol, or 0.97 m^3 of natural gas [19]. A study into the yield of biogas from the organic component of municipal waste showed that a ton of waste will produce 180-220 cubic meters of biogas [20].

4.1Egyptian Experience

A practical experiment has been made by the Egyptian army to evaluate a special two-stage biogas digester designed to match the needs of one of the army camps in Egypt through actual operation, and consequently extract the technical knowledge needed to help optimize the plant design for future population. A two-stage biogas plant of 190 m^3 total capacity (150 m^3 digesting volume) was designed. The plant included a fixed film compartment (20 m^3). The plant was operated for 422 days. During this period, 203 tons of camp refuse was fed to the digester at the average rate of 480.9 kg/day fresh garbage, containing 248.5 kg/day total solids. The dry material consisted of 85.5 percent dry bread pieces, 9.8 percent kitchen refuses, and 4.7 percent spoiled cooked food. The plant produced 84668 m^3 biogas with the average of 200.6 m^3/day or 1.337 biogas/m^3 digesting slurry/day. The rate of bio-methanation was 1.009 m^3/kg VS added, which is very high. However, considering the fact that most of the materials used were very easy to decompose (baked bread and spoiled cooked food) this

efficiency falls within the expected range. Investment costs amounted to L.E. 20,000. Based on international fuel prices, preliminary economic evaluation indicates a pay-back period of less than six months. Such positive indicators encouraged the Ministry of Defence to finance an extended program for the popularization of biogas technology in the array camps of Egypt [21].
We believe that the example of the Egyptian army can be taken as a guideline for organic waste treatment in Egypt because it has been done by Egyptian materials, experience and in the prevailing temperature in Egypt along the year. In addition this digester has a high biogas yield which is 417 m^3 biogas/ton of waste.

5. Analysis

Thus far, we formulated the problem of organic solid waste in Egypt based on the previous information and data. The problem is that the annual growth of population leads to the growth of solid waste generation and consequently the organic solid waste including both domestic and agricultural waste. The rate and way of managing that waste are much less than the rate of waste generation. The increase of the solid waste accumulations everywhere in Egypt can hazard soil, air and water course. Hence there will be a negative impact on both public health and environment. Regarding the above mentioned techniques that have been used to treat organic solid waste in developed and under-developed countries and the results that have been achieved by applying those techniques, we propose to apply the biologic treatment technologies in order to solve the problem of organic solid waste in Egypt.
We have processed the data that are derived from the previous layout in order to show the decision makers in Egypt the profits that can be gained by using the biological treatment options to manage the organic solid waste in Egypt. As it is presented in section 2 (point 2.1), the total generated amount of MSW in Egypt in 2010 was 20.5 million ton per year with the annual growth of 3.4%. From these figure, it can be predicted that within next few years the produced amount MSW will further grow to attain 26.5×10^6 ton in 2017. The produced amount of non-processed organic solid waste NPOSW, which is 56% of the total MSW and based on annual growth of 3.4% will reach 14.8×10^6 ton in 2017.
The annual ASW as in section 3 (point 3.1, table 3,4) is 10.5×10^6 ton, and the annual animal waste is 14.6×10^6 ton. According to section 2 (point 2.2), the recycled organic waste does not exceed 20% of the total amount of the organic waste in Egypt. Hence we can calculate the amount of non-processed organic solid waste (NPOSW) as follows:
NPOSW= (MOSW + ASW + Animal waste) × 80%
NPOSW= $(14.8 \times 10^6 + 10.5 \times 10^6 + 14.6 \times 10^6) \times 80\% = 31.92 \times 10^6$ ton
As follows from above, NPOSW in Egypt is approximately 32×10^6 tonnes and it is not well suited for incineration. This amount of waste can be processed in two options of biological treatment as follows:

5.1 The first option is represented by aerobic digestion, taking into consideration 1 ton of waste produces 0.4 tonne of compost according to section 4, this route of processing will lead to production of compost that equals $= 32\times10^6 \times 40\% = 12.8\times10^6$ ton/year.

5.2 The second option is represented by anaerobic digestion. If used to treat the total organic waste in Egypt, there will be a production of both compost and biogas. Considering the fact that 1 ton of NPOSW produces 0.35 ton of compost plus 417 m^3 biogas, this second route of treatment will lead to production of the following:
Compost production = $32\times10^6 \times 35\% = 11.2\times10^6$ ton
Biogas production = $32\times10^6 \times 417 = 13.34\times10^9\ m^3$
Natural gas equivalent = $13.34\times10^9\ m^3 \times 97\% = 12.94\times10^9\ m^3$
From the above layout and analysis of the data the authors concluded that by the biological treatment of organic waste in Egypt there will be an outcome (Table 6) will add more than 20% of the total annual Egyptian natural gas production for the last year and more than 50% of the total annual soil fertilizers produced in Egypt.

Table 6: Analysis results of the **o**utcome of biological treatment of organic waste in Egypt

Category	Annual production	Annual outcome of organic waste	Annual % that will be added
Compost	20.7×10^6 ton	11.2×10^6 ton	~ 54%
Nat. Gas	$61\times10^9\ m^3$	$12.94\times10^9\ m^3$	~ 21%

Conclusions

We have demonstrated that applying biological treatment technologies on Egyptian MOSW leads to the following:

1. Compost

An amount of around 11.2×10^6 – 12.8×10^6 ton/year of compost can be produced and this amount of compost increases the compost production in Egypt with around 54% and contributes in compensating the shortage of compost demand in Egypt with an annual increasing by the increase of waste generation.

2. Biogas

Generating of approximately 13.34×10^9 m^3 of biogas (equivalent to 12.94×10^9 m^3 of natural gas) which is up to 21% of the total natural gas production in Egypt annually, and it will contribute in solving energy problem and lowering the usage of fossil fuel in Egypt. This excess of gas will compensate the shortage of gas which is needed for consumption and export.

3. Environmental sustainability and work opportunities

Processing the Egyptian Organic solid waste in a proper way (bio-degradation) will decrease the negative impact on the environment and public health and in consequence to production of both compost and biogas there will be job opportunities that will be created for many people.

We recommend that additional to the efforts that have been done by the Egyptian government, an establishment of a management system in an integrated and economic manner has to be done. Improvement of the institutional and administrative systems, and in addition a monitoring and control operations, financial resources to achieve the required services, technical capacity at various levels, efficient waste collection and transportation systems, sanitary landfills that meet environmental requirements and public awareness in waste handling and its implication on health and environment.

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