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Biodegradable waste to biogas: Renewable energy option for the Kingdom of Saudi Arabia

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ABSTRACT: Energy recovery from waste is not a new field of study, but its implementation continues to be a challenge in some Arab countries. Although there is abundance of useful waste in the urban markets, practices aiming at waste to energy conversion are still negligible. In the kingdom of Saudi Arabia, so-called green markets are abundant with renewable energy potential, but the practical implementation of this potential is missing. Therefore the objective of this paper is the evaluation of waste generation in KSA for the energy recovery purpose, and to show that the conversion of green waste into biofuel is not only environmentally friendly but also financially rewarding. Since the result illustrate that the major portion of the waste generated is organic waste, anaerobic digestion is proposed waste to energy technology because of its feasibility for biodegradation of moist organic wastes into biogas. Diversion of waste into biogas and bio-fertilizer will ensure that it is treated in such a way that it becomes a useful product instead of harmful one. Furthermore as the policy makers and planners in renewable energy sector have intended for kingdom of Saudi Arabia to be "kingdom of sustainable energy" as well, hence they are needed to give special attention toward the largest Saudi Arabia's green market and should invest more to implement this plan.

KEYWORDS: Waste management, Biodegradable waste, Renewable energy, Biogas, Anaerobic digestion.

1 INTRODUCTION

Arab countries are presently faced with problems such as increasing urbanization and demands for more food and shelter to sustain a standard life pattern. Organic waste primarily composed of food waste, especially in the major cities of these countries which are facing with solid waste problems because of an increasing population and urbanization. Solid waste mismanagement is one of the main reasons for environmental deprivation. [1]. Statistical data from the International Energy Agency [2] shows that conventional energy resources like oil continue to be the most important sources of energy, accounting for approximately 80% of the total primary energy supply (TPES); oil is followed by coal and gas as sources of energy. The second-most important contributor is combustible renewable energy (CRE), which accounts for 10% of the world's TPES share. CRE, or traditional biomass energy, constitutes 80% of the total renewable energy consumed mainly in developing countries. King Abdullah research centre for atomic and renewable energy (K.A.CARE) in Saudi Arabia is planning to get 16 GW from PV, 25 GW from ,17 GW nuclear,9 GW from wind, 3 GW from waste to energy and 1GW from geothermal by the year 2032 [3]. With fossil energy sources eventually dwindling and becoming increasingly more expensive, waste-to-energy routes are gaining future attraction [4]. Cities account for approximately two-thirds of the world's primary energy consumption and 71% of global fossil fuel related direct greenhouse gas emissions [5]. To ensure that cities maintain their vital social and economic functions, there is a need to develop urban energy systems that are more efficient and emit less carbon dioxide. One option is to switch from fossil fuels to renewable energy sources such as wind, solar or biomass. The average greenhouse gas emissions per capita in the WTET are much lower, representing 80% - 87% reductions over the gas boiler case [6]. Biomass is an interesting renewable energy source for several reasons. The main reason is that bio-energy can contribute to sustainable development [7]. The fruit and vegetable markets produce large amounts of waste each year, and the disposal of these wastes is costly, both financially and environmentally. Studies [5–11] have revealed that by utilizing the physiochemical properties of these wastes, they can be upgraded to products of higher value that have a place in the market. Vegetables, fruits, and flowers are sold in large quantities in markets, and wastes thereof are disposed of along with municipal solid wastes (MSW) in landfills or dump-sites; this creates a breeding ground for vector, pest, odor, and greenhouse gas (GHG) emissions into the atmosphere. Renewable waste materials from agriculture, industries, and domestic sources are converted to useful energy forms such as bio-hydrogen, biogas, and bio-alcohols through waste-to-energy routes for global sustainable growth. Biomass energy can play an important role in reducing green house gas emissions, the use of biomass for energy offsets fossil fuel greenhouse gas emissions. At present, biomass is mainly used as a traditional fuel, contributing to about 38±10 EJY^{1}, modern biomass to about 7 EJY^{-1} [8]. Many energy scenarios suggest large shares of biomass in the future energy system .The availability of this biomass are not always separately analyzed. Furthermore, large-scale utilization will have large consequences for land demand and biomass infrastructure, which should be assessed. Many studies have been undertaken to assess the future biomass energy potential [9- 12].

To produce renewable energy from green waste, there is great potential of waste in KSA. If the generated waste is properly utilized, it could add greatly to the energy needs of the kingdom. Therefore, the aim of this study is a preliminary but yet challenging step to conduct research on the green markets in KSA. The main purpose of this study is to review the prospective of producing biogas from the waste generated locally, and in order to point up that the conversion of waste-to energy is environmentally friendly. The study is divided into five section: the introduction; KSA's biomass energy potential, a case study of waste generation and management in KSA, a brief comparison of waste-to-energy technologies and selection of suitable one based on waste composition, cost analysis and yield prediction of biogas, and finally the concluding remarks. The study provides important information in order to enhance the development of this industry in KSA in the future.

2 BIOMASS ENERGY

Biomass energy is a renewable energy resource derived from the carbonaceous waste of various human and natural activities. It is derived from numerous sources, including the by-products from the timber industry, agricultural crops, raw material from the forest, and major parts of household waste. Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel. Biomass is the most important fuel worldwide after coal, oil and natural gas. Bio-energy, in the form of biogas, which is derived from biomass, is expected to become one of the key energy resources for global sustainable development. Biomass can be converted into three types of useful product namely, electrical energy, transport fuels and chemical feed stock.

2.1 BIOMASS RESOURCES IN KSA

Huge amount of waste is generated in KSA mainly in the form Municipal Solid Waste (MSW), Industrial Organic waste, and sewage. It has been estimated that the total biomass energy potential of KSA is 3.0 (mtoe) [13] and it stands fourth in the Arab world after Morocco, Egypt and Sudan, Fig:1. Solid waste generation in Arab countries is increasing rapidly. Fig.2 shows [14] the solid waste generation comparison of some industrialized and emerging Arab countries; it is obvious that solid waste generation in KSA is much higher comparatively. This could be due to tourism to the Islam's holiest places in kingdom, rapid urbanization, construction, and/or population density. Thus for, KSA's per capita generation of waste per day (1.75Kg) is superior compared to other countries in the region that have less than one, Fig. 2.

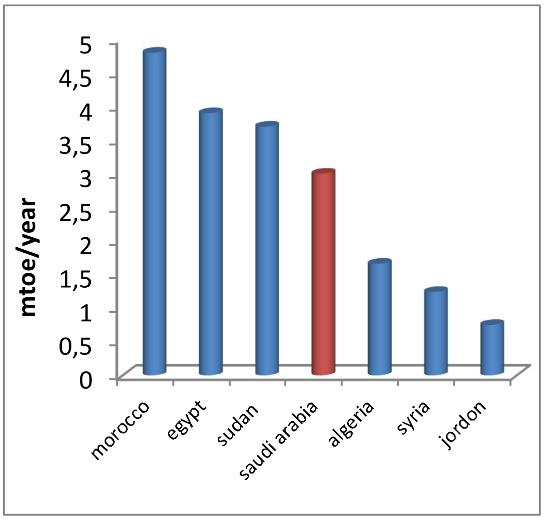

Fig. 1. Figure 1: Biomass energy potential (mtoe)

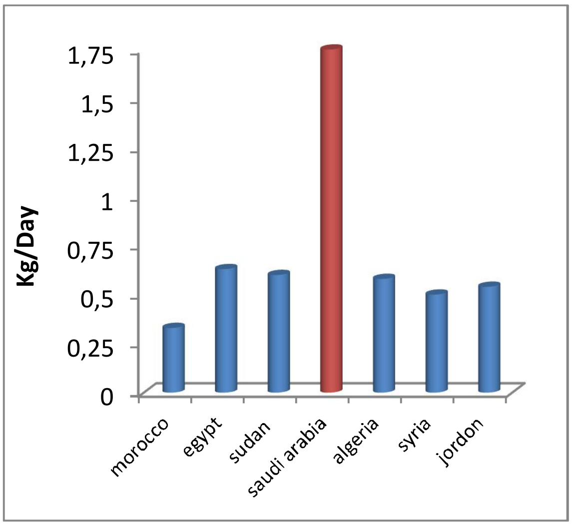

Fig. 2. Solid waste generation rate per capita

As per indicative levelized cost of renewable energy sources against gas-fired entrants in KSA [15] it is evident from figure:3 that the cost of energy produced from biomass is comparable to that of energy obtained from the other available resource (Solar thermal & PV, Tidal energy) in the kingdom, and if the biomass energy available is effectively utilized then it can provide energy at about $101/MWh which is 65.65% and 57.23% cheaper than solar and tidal energy respectively.

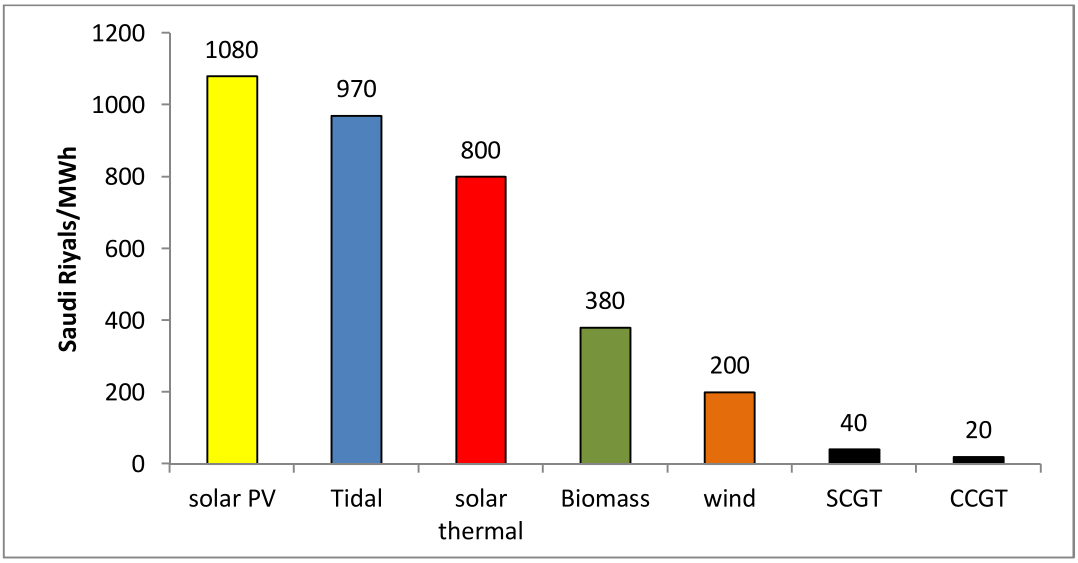

Fig. 3. Comparison of Renewable Energy costs in KSA

2.1.1 ORGANIC WASTE GENERATING INDUSTRIES IN KSA

Industries in the kingdom produce a large amount of organic residues and by-products whose disposal is a major problem to the municipal authorities, and also affect the environmental standards. There are many technologically-advanced dairy products, bakery and oil processing plants in the kingdom that produces a huge amount of organic waste [16-17]. In recent decades, the fast-growing food and beverage processing industry has remarkably increased the organic waste generation. Since the early 2008, the increased agricultural output stimulated an increase in fruit and vegetable canning as well as juice, beverage, and oil processing in the country. Over 30 types of industry have been identified as having organic waste production in KSA [18] that is amenable to anaerobic digestion treatment, including food e.g Dairies ,beverages, meat processing, olive oil, pulp and paper, pharmaceutics, cosmetics fish oil and fish processing plants.

Dairy industrial production began in Saudi Arabia since 1970s and there are now 17 dairies in KSA [19]. Each plant produces waste of a distinctive composition, depending on the kind of product that is produced e.g milk, cheese, butter, milk-powder, condensate etc. Total of 1039 MT of milk is produced daily in KSA with proportional amount of other dairy products. An average of about 2400 kg waste is generated per ton of the dairy products [20]. The main solid waste produced by the dairy industry is the sludge resulting from waste-water purification [19].

Olive oil production in KSA increased from 1000MT in 2001 up to 3000 MT by the year 2013 [21] and hence there is proportional increase in the waste produced. The nature of solid waste produced depends mostly on the processing method of olive oil, and consists of about 25%- 33% organic matters. The average yield of waste olive cake is about 50% of the total waste, but varies greatly [22].

Beef and veal meat production started in KSA with 8000 MT in the year 1975 and continuously increased up to 25000 MT by 2013 [21], and this industry contributes to the highest loads of organic waste in the food sector.

2.1.2 AGRICULTURAL WASTES

Saudi Arabia's agricultural produce may offer a potential for biomass energy. KSA produces, in order of importance, wheat, barley, tomatoes, melons, dates, and citrus fruits; the main livestock are mutton and chickens. Various crop/vegetable production (2.5 million tons in 2004) and animal waste could be used as feedstock to generate electricity. However wheat production gradually reduced, requiring reliance on other sources for biomass [15].

2.1.3 MUNICIPAL SOLID WASTE GENERATION IN KSA

In Saudi Arabia, MSW is collected from individual or community bins and disposed off in landfills or dumpsites. MSW consists mainly of food waste, yard waste, plastic bags, furniture scrap, used tires, home appliances, and waste paper. In KSA, currently only 10-15% of this waste is recycled while the remaining goes to landfill [17]. Organic materials represent the huge amount of MSW including food waste, paper and wood waste. Fruit and vegetable waste is generated in large quantities with their high biodegradability, in the main cities of the kingdom. Solid waste generation from food e.g meat, fruit, and vegetables etc, in the central sharing market of three largest cities – Riyadh, Jeddah and Dammam, exceeds 6 million tons per annum [18]. During the Ramadan and Hajj season about 600,000 kg, or 4,500 cubic meters, of waste is generated each day, which puts a heavy burden on those responsible for collecting the waste [23]. MSW generation has increased from 12.1 million ton per year to 15.2 million ton in five years since 2007. From the table.1 it is cleared that compared to increase in population the amount of waste generated is much higher, and hence the per capita rate per day raised from 1.4 in the year 2007, to 1.75 by the year 2012.

Table 1. MSW Generation in KSA

Year	Population(approximately) million	Average rate of generated MSW kg/per capita/day	Estimated gross quantity of MSW million ton/year
2007	23.67	1.4	12.1
2012	29.40	1.75	15.20

The percentage of different types of items in food waste sample of KSA is 38.72 (rice), 18.74 (bakery products), 25.15 (meat), 13.03 (fat), 2.19 (bones) and 2.16 (fruits and vegetables) [24]. Waste related to Construction materials and hazardous wastes is not considered in the division here. More than 75% of the population of KSA is concentrated in urban areas and urban population increase by 3% annually [16], which make it necessary for the government to initiate measures to improve recycling and the waste management scenario in the country.

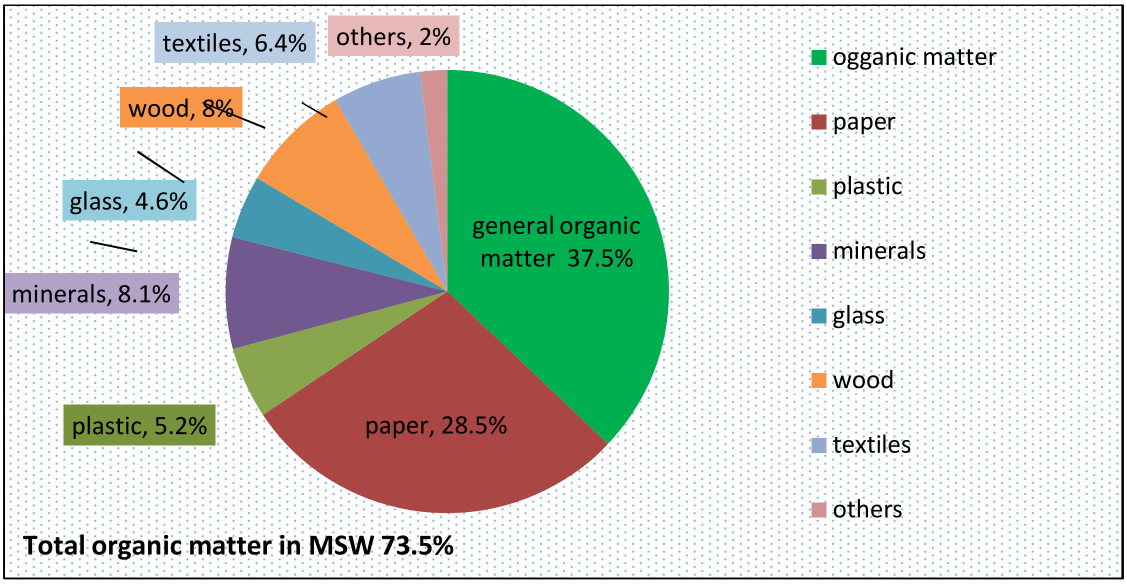

Fig. 4. Components of MSW in Saudi Arabia

Fig.4 shows that most of the MSW consists of the organic matter and it is 37.5 % of the total MSW generation.

According to the current report by [25] the composition of the overall waste produced in KSA consists about 75% of organic wastes, including paper, food and wood waste. The individual food waste percentage is contributing for the 50.57% of the total organic waste, the paper waste is 11.97%, and plastic waste production on overall basis comprise of 17.39%. Other components produced on minor scale in the waste included glass of about 3.5% and cardboard that 6.64%, while textiles, metals, leather and aluminum are less than 4-5% as shown below in the figure 5.

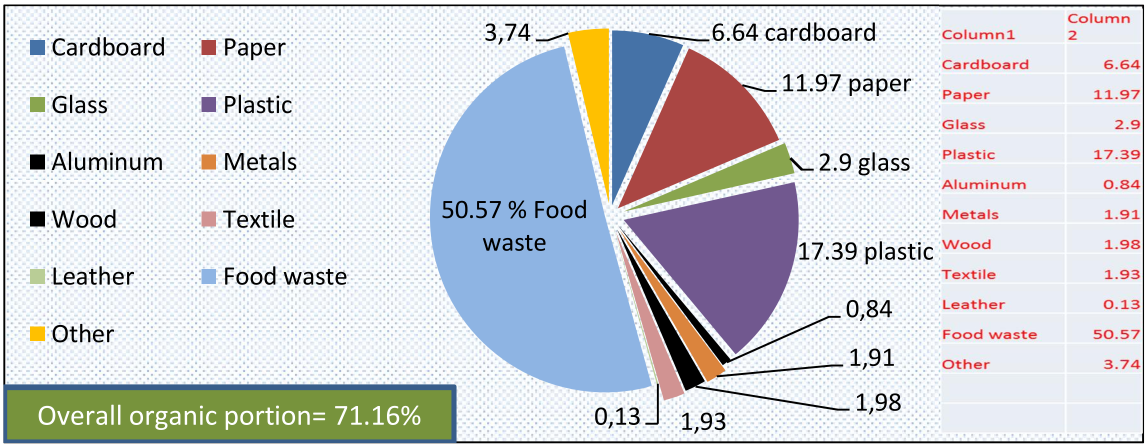

Fig. 5. Composition of overall waste produced in (mass %) KSA

The Chemical composition of food waste sample in KSA analyzed by [24] is moisture (38.4%), carbohydrates (25.56%), crude protein (17.26%), crude fat (15.27%), fiber (0.3%) and ash (3.21%). The results shows that food waste samples is rich in carbohydrates, crude protein and fat contents while fiber and ash are in small amounts shown as in the Fig. 6.

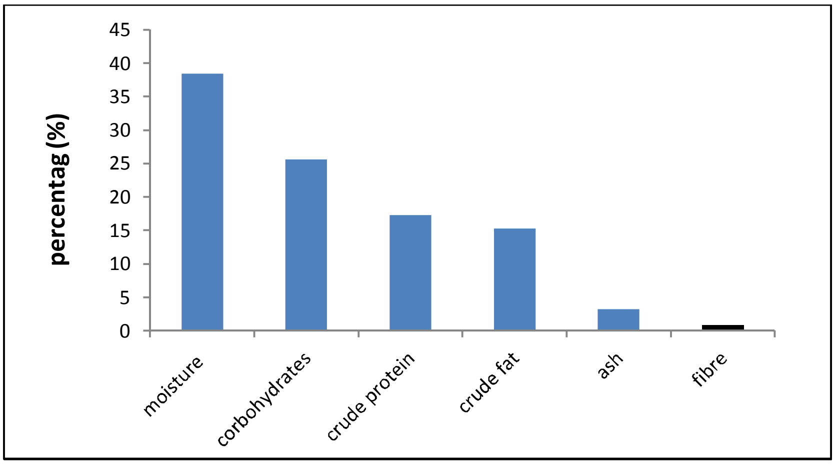

Fig. 6. Chemical composition of KSA's market organic waste

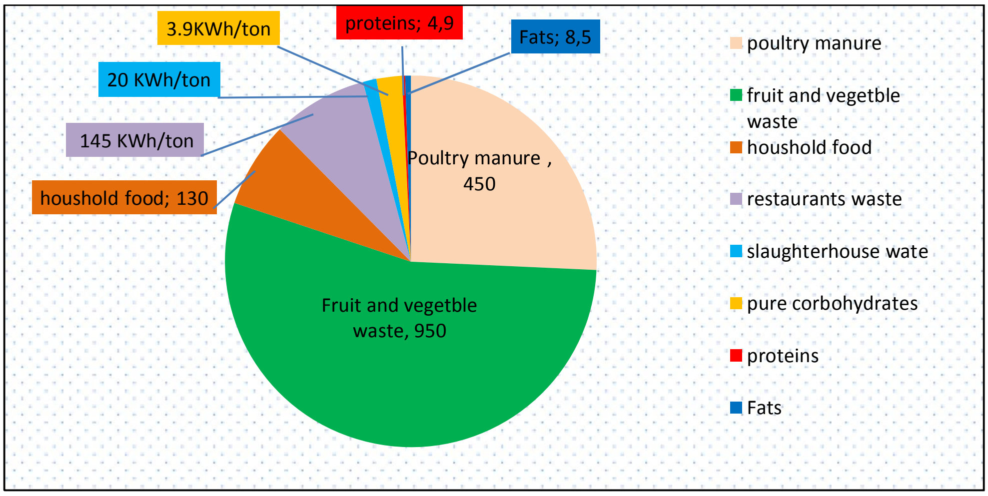

Fig. 7. Energy contents of different substrates (KWh/ton)

3 WASTE MANAGEMENT IN THE KSA

KSA is one of the promising economies of Arab world and its population is almost 29.4 million according by 2012 [28]. According to world bank report estimation of hazardous waste quantity on GDP basis, KSA has been marked as "High" in classification, with waste hazard coefficient of over 2000 ton/$billion [29]. Conventionally, the municipal authorities and waste collection companies are responsible for waste management in KSA. But, due to the urbanization, waste management problem has become severe, especially in main cities i.e Riyadh, Dammam and Jeddah, and it is one of the significant challenges for the municipal authorities. Recycling, reuse and energy recovery is still at an early stage, although they are getting increased attention. Waste sorting and recycling rate ranges from 10-15%, driven by an active informal sector which extracts paper, metals and plastics from the waste. Currently the organizations for the waste management in the kingdom are working for the safe disposal of the waste only, and not for the energy recovery from it. The Saudi government is aware of the critical demand for waste management solutions, and is investing heavily in solving this problem and efforts are underway to deploy waste-to-energy technologies in the Kingdom. The 2011 national budget allocated SR 29 billion for the municipal services sector [16-18], which includes water drainage and waste disposal. But if the same amount of money is spent on installing waste to energy production plants, profits would increase and equivalently the GHG emissions will also reduce. KSA is the 3rd highest per capita consumer of water in the world, behind the U.S. and Canada [17]. Handling huge quantity of sewage sludge is one of the most significant challenges for municipal authorities in the Saudi Arabia due to high treatment costs and risk to environment as well as human health. According to JETRO (Japan org) survey report [16], an average, wastewater generation is 80-200 liters per person each day in KSA. According to an estimate from the Drainage and Municipality Department of kingdom, sewage generation has increased from 50,000 m^3 per day in 1981 to 450,000 m^3 per day in 2012. Sewage generation across the country is rising by an astonishing rate of 25 percent every year. The dried municipal sewage sludge has organic material content (40 – 45 wt. %) [27], that contributes to the total organic waste produced.

4 WASTES-TO-ENERGY TECHNOLOGIES (WTET)

Waste-to-energy technologies convert waste materials into different types of fuels. Advanced WTET produces biogas, syngas, liquid bio-fuels or pure hydrogen; and these fuels can then be used directly or to generate electricity. WTET is the use of, physical thermochemical and biological technologies to recover energy from the wastes Fig. 8.

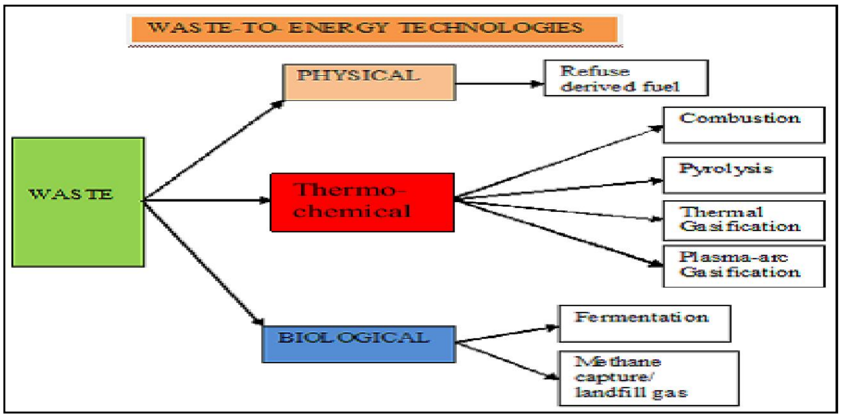

Fig. 8. Waste-to-energy pathways

4.1 PHYSICAL CONVERSION

Physical WTET treats the waste physically to convert it in to fuel pellets/refuse-derived fuel (RDF). The fuel pellets consists largely of organic materials taken from solid waste streams, such as plastics and biodegradable waste. The waste is first processed to remove glass, metals, and other materials that are not combustible and then treated with high-pressure steam to kills viruses and other potential pathogens. This process reduces the volume of the waste by up to 60%. The combustion of fuel pellets is clean and efficient than incinerating MSW or other solid waste directly, but the processing is additional cost [31-36].

4.2 THERMOCHEMICAL CONVERSION

The principal methods of thermochemical conversion are, combustion in excess air, gasification in reduced air, and pyrolysis in the absence of air and all these are recommended for waste with moisture content less than 20%. Plasma gasification, which takes place at extremely high temperature, is also hogging limelight and is in the early stages yet can produces up to 13,000 °F temperature. This high temperature breaks down the wastes into syngas. All type of waste, including even concrete, steel, and toxic chemicals can be converted to heat energy using plasma converters, but the technology need large energy inputs at the start and that is the only disadvantage [31-36].

4.3 BIOLOGICAL CONVERSION

Biochemical processes, like anaerobic digestion and fermentation, produces clean energy in the form of biogas and ethanol respectively. AD is the natural biological process which biochemically degrades the organic waste in a controlled, oxygen-free environment resulting in the production of bio fuels, it is a reliable technology for the treatment of wet, organic waste. Advance digester systems can now produce biogas with pure methane content higher than 95%. Fermentation uses yeast to generate liquid ethanol from biomass waste [31-36].

From the comparative study of the above mentioned techniques in table.2 it is noted that AD is the most applicable WTET for the organic waste.

Table 2. Comparative study of WTET

Waste type	Incineration	Anaerobic Digestion	Gasification	Use in power plant
Food	Yes (mixed with high C.value waste)	Yes	No	No
Paper	Yes	Yes	Yes	Yes
Wood	Yes	No	Yes	Yes
Garden	Yes (mixed with high C.value waste)	Yes	No	No
RDF	Yes	Yes	Yes	Yes

5 PROPOSED WASTE TO ENERGY TECHNOLOGY FOR KSA

WTET is selected based on standard criteria i.e considering the amount of substrates, kind of substrates, the composition, the quality, and its energy contents. It is found from Fig: 5 that waste produced in KSA consists of 70.16% organic portion by mass, and its moisture content is 38.45% Fig: 6. From the comparative study of different WTET earlier, we found that biological conversion is the most suitable for converting waste with high moisture content such as organic waste, hence in our study, "high-solids anaerobic digestion with the thermophilic range" is recommended for KSA. According to NREL report 2001, it (high-solids AD with the thermophilic range) is an established technology and many plants are using it. The main benefits provided by this system for the scenario of waste generation in KSA will be e.g hygenizaion of mixed MSW waste, minimum retention time and higher biogas yield. Mixed MSW as well as biowaste can be processed by high-solids AD systems and it is an added advantage. The main benefit of AD is that, it is favorable for the waste with the high moisture contents, and this high moisture content is the main problem for other WTET to treat with. AD of organic wastes is fast gaining popularity worldwide as a means to protect the environment and to recycle biodegradable materials efficiently.

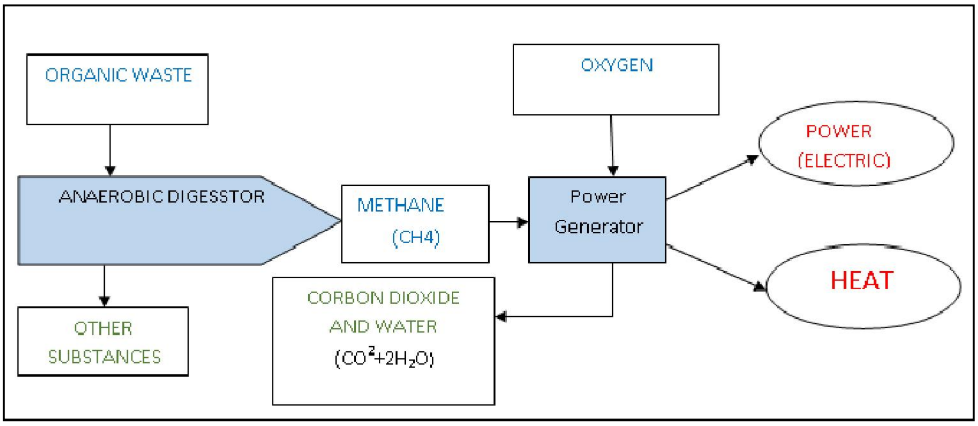

Fig. 9. Schematic diagram of Proposed Biogas production process from organic waste

AD is four-stage process i.e hydrolysis, acidification, cytogenesis and methanogenesis all these process takes place in the digester tank simultaneously. AD may be at low temperature or under the thermophilic conditions. KSA is a tropical country, where the average ambient temperature is higher than 27 C^o during a period of more than 8 months of the year, so thermophilic AD is readily applicable here. Performance comparison of organic waste anaerobic digestion in the thermophilic (55C^o) , psychrophilic (20 C^o) and mesophilic (35 C^o) conditions experimentally verified that average biogas production from thermophilic digester is higher than from psychrophilic and mesophilic digesters by 14.4% and 41%, respectively. Similarly the net energy production in the thermophilic digester is 196.7 and 48.07 kJ/day higher than that for the psychrophilic and mesophilic digesters, respectively. The relation between the daily production of biogas and the temperature indicated that for the same produced quantity of biogas, the size of the thermophilic digester is small [32-37]. This huge amount of organic wastes produced locally in KSA's largest market is a recommended substrate for the proposed process. The potential of AD for energy production showed that, from organic waste containing organic fraction about 74.50% in the form of biodegradable material with 9.1% cellulose, and 5.4% lignin , AD converts 70–95% of organic matter to methane [33]. AD of food-market waste resulted in a production of 640 m^3 biogas/ton waste added [34]. The biogas yield from canteen wastes, which is a mixture of fruit and vegetable waste, when subjected to AD varies from 820 up to 900 m^3/ton [35]. The biogas yield of the organic feedstock from MSW, correspond to 80.4-100 m^3 methane production per ton feed-stock [31]. Comparison of typical reported biogas yield from different substrate in literature is shown in Fig. 10 [38-39]. It is noted that food waste has a superior yield of biogas/dry tone, compare to other substrates. It shows that biogas yield from food waste is 15 times more than yields from cow manure.

Hence the diversion of generated organic waste in KSA into biogas and bio fertilizer will ensure that it is treated in such a way that it becomes a useful product instead of a harmful one to the environment and can add to the revenue of the kingdom in the form clean energy.

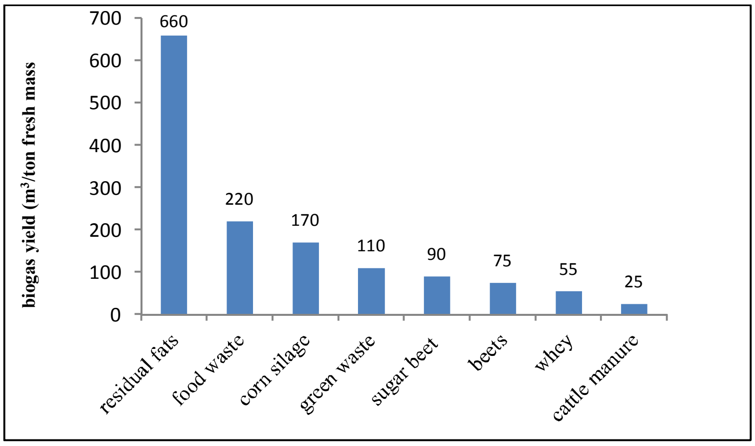

Fig. 10. Biogas from various substrates in m^3/tone VS

6 Biogas yield prediction and cost analysis based on KSA's organic waste potential

For the KSA to achieve the objectives of the proposed WTEC system, it is necessary to predict the biogas yield and to perform cost analysis in order to investigate whether the waste conversion into biogas is financially feasible or not.

Many techniques are available in literature to predict biogas yield from organic waste e.g ultimate analysis, molecular formula based estimation, and literature review of experimentally determined biogas yields. It's very difficult to find out the percentage of carbohydrates, proteins, and lipids in a heterogeneous market substrate. So for simplicity the literature available, based on experimental results for biogas production from organic waste is used in the study to predict the biogas yield. For example,

(1). Ultimate analysis of food waste for biogas prediction used by [39] gives the result as, for about 40-65% of the organic material conversion, yield up to 402-653 m^3 biogas per ton of various substrate (VS).

(2). Biogas yield prediction from organic waste based on estimation from molecular formula by [39] gives an amount of 490 - 754 m^3/t VS, this value is assuming that all of the volatile solids are destroyed.

(3). Using a tool for biogas prediction in matlab simulink by [39] the biogas yield was 316 m^3/t VS, with a 14% difference compared to the experimental yield of 367 m^3/t VS. **(4).** The experimental biogas yield based on the estimated annual food waste of 216.5 ton/year is 374.25-408.5 m^3/ton food waste, and the corresponding useable energy in the form of heat is 172561.94 KWh and in the form of electricity is 86280.97 KWh annually with calorific value 258843 KWh [24].

Hence with reference to the above mentioned experimental based literature, taking average 450 m^3/tone yield value, the approximate biogas yield from organic waste generated in KSA is about 3420.50 million m^3 per annum when 50% of the organic waste out of 70% in overall composition is converted and only 20% of it is dumped per day.

To analyze the financial feasibility of the proposed technology, the net saving is calculated. For simplicity, the cost analysis is explained from the viewpoint of current budget spends on the waste management by the KSA's government, and its comparison with the proposed scenario. The input costs e.g labor, machinery, capital, etc. are in accordance to the current market prices in KSA. The following formula is used

Gross savings = Total benefit -Total costs

Currently the municipal service sector spend about 29 billion SR per annum [18] on sewage and solid waste management, however, they get nothing in return, The proposed technology will be useful as instead of spending money they will get revenue back in the form of useful energy. Table: 3 explains firsthand benefit of the current scenario and the benefits obtained by reducing/stopping the dumping of green/organic waste. The typical costs of a biogas plant, including all essential installations but not including land, is between 50-75 US Dollar per m^3 capacity [39]. Two assumptions are made here

(1). The cost of SWM is assumed to be 30% of the total annual budget.

(2). The operational and maintenance cost of the biogas plant is assumed 20% of the total net annual benefit.

Table 3. Benefit/cost analysis of proposed technology

<table>
<tr><td colspan="7">Current SWM cost</td></tr>
<tr><td colspan="2">KSA , SWM budget/annum</td><td>Total benefit</td><td colspan="4">Direct saving by discontinuing the waste dumping</td></tr>
<tr><td colspan="2" rowspan="4">8.7 billion SR</td><td rowspan="4">Nil---Nil---Nil</td><td colspan="2">Cost/tone of waste</td><td colspan="2">572.36 SR</td></tr>
<tr><td colspan="2">Total quantity/day</td><td colspan="2">21111.67 (tone)</td></tr>
<tr><td colspan="2">Total cost</td><td colspan="2">12.0850 million SR</td></tr>
<tr><td colspan="2">Annual direct saving</td><td colspan="2">4.2105 billion SR</td></tr>
<tr><td colspan="7">Proposed biogas technology revenue</td></tr>
<tr><td>Organic waste</td><td>Annual Biogas yield</td><td>Equivalent energy in term of Electricity</td><td>Total energy output</td><td>Electricity Cost/KWh (domestic)</td><td>Total benefit</td><td>Waste collection/ plant Operational and maintenance cost</td></tr>
<tr><td>7.6million tone/annum</td><td>3420.00 (million m^3)</td><td>398.528 KWh/ tone</td><td>3028.89 million KWh</td><td>0.22 SR</td><td>666.34 million SR</td><td>133.26 million SR</td></tr>
</table>

Gross benefit from direct saving and revenue from biogas plants

= (Annual direct saving) **+** (annual revenue from biogas production)

= 4743.58 million SR/annum

7 POSSIBLE USES OF BIOGAS IN KSA TO REDUCE ITS DEPENDENCE ON FOSSIL FUELS

1. There is extreme demand for air-conditioning in the KSA as a result of the high ambient temperatures. Of the total electricity production (45 GW by 2012) in Saudi Arabia, 52.12% is consumed in residential purpose, 17.9% industrial, 11.50% governmental, 2.2% agricultural and 12.20% in commercial areas, and 30% of the total domestic use of electricity, is consumed for refrigeration in Riyadh and Jeddah, each, and 18% in Dammam [39]. Possible option to reduce the amount of electricity consumption for refrigeration purpose is to use biogas-powered novel absorption-refrigeration cycle. It can be used in absorption refrigeration system as heat source for regeneration of refrigerant. For a Refrigerator of 230 KW capacity, the biogas consumption will be approximately 0.044 m^3 [39]. Such systems will significantly share the load of electrical energy generated by burning fossil fuel; hence it will reduce the global warming effects equivalently. Its use can be an interesting alternative for solving problems of electrical over-consumption by conventional vapor compression refrigeration used in KSA.

2. The biogas has high octane rating and calorific value ranges between 4700-6000 Kcal. It has ignition temperature of 640–840 C^0. If it is generated on small scale from the locally generated waste then it is highly recommended for domestic use, e.g cooking etc. It can be used in lamps, as per studies 1 KWh of electricity can be generated from 0.7m^3 of biogas, which can light electric bulbs of 60 watt rating for 1 hour [38-39].

3. The useful products from AD are high purity methane gas and pure CO_2 gas suitable for use in the soft-drink industry, high purity liquid fertilizer, and high purity solid fertilizer for use in small scale plantation inside the cities.

8 CONCLUSIONS AND FUTURE PERSPECTIVES

Preliminary efforts have been made in the study to review the overall waste energy potential of KSA's largest markets. For KSA the task was difficult due to the non availability of the sufficient literature. It was very difficult to compare the study's results with literature, but it can be assured that this study could serve as a point of reference and open up avenues for future research work in this field. The results of this study showed that the KSA market has immense potential of waste, and production of biogas is a better solution instead of dumping waste into landfills. The proposed WTET for the production of biogas can play a pivotal role in KSA to reduce its dependendence on the fossil fuels and thus reduces the environmental impact. Huge amount of organic waste generation make it evenhanded to convert it into useful energy instead of being harmful to the environment as well as human health. Biogas plants will help to reduce the financial burdens on SWM, apart from being an environmentally friendly way to manage the waste, and this makes it the ultimate solution. Cost analysis of the predicted biogas yield showed that the instead of spending money to dispose the waste we can get revenue back. It can also solve the challenges faced by Saudi government in treating waste, because of the enormous increase in the population of the kingdom in urban areas. Foremost is the fact that current anaerobic digestion technologies are not sufficiently efficient .If we are to utilize renewable waste as a bio-energy resource, substantial improvements in the efficiency of energy recovery will have to be made to make these processes more economically viable. Another key factor for the future research is the waste collection in KSA due to its dispersed nature; hence to recover energy from waste its collection and transport is also a significant challenge and this section needs further improvement.

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