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Solid waste as renewable source of energy: current and future possibility in Libya

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ABSTRACT

Solid waste holds the greatest potential as biomass source in Libya. The rapid expansion of industry has led to increased urbanization and growing population. These factors have dramatically increased the amount of MSW (municipal solid waste) generated in Libya. However, issues related to environmentally sound MSW management—including waste decrease and clearance—have not been addressed sufficiently. This study presents an overview on solid waste that can be used as a source of bioenergy in Libya including MSW, ISW (industrial solid waste), and HSW (health care wastes) as biomass sources. The management of solid waste and valorization is based on an understanding of MSW's composition and physicochemical characteristics. The results show that organic matter represents 59% of waste, followed by paper–cardboard 12%, plastic 8%, miscellaneous 8%, metals 7%, glass 4%, and wood 2%. The technology of WTE (waste-to-energy) incineration, which recovers energy from discarded MSW and produces electricity and/or steam for heating, is recognized as a renewable source of energy and is playing an increasingly important role in MSW management in Libya. This paper provides an overview of this technology, including both its conversion options and its useful products (e.g., electricity, heat, greenhouse gas emissions). The WTE benefits and the major challenges in expanding WTE incineration in Libya are discussed. It also demonstrates that Libya could become an exporter of hydrogen in lieu of oil and natural gas.

1. Introduction

Libya, located in North Africa between 26 latitude north and 17 longitudes east, extends over 1,759,540 km^2 [1]. It is bordered by the Mediterranean Sea to the north, Egypt to the east, Sudan to the southeast, Chad and Niger to the south, and Algeria and Tunisia to the west. Both the Mediterranean Sea and the desert affect Libya's weather. In the winter, the weather is cold, with some rain on the coast. The Sahara is very dry and hot in the summer and cold and dry in the winter [1]. Temperatures in the summer can reach 50 °C during the day; though they are typically closer to 40 °C. The average annual temperature is approximately 20.5 °C. The mean annual rainfall varies from 180 mm (in the east) to 90 mm (in the west). Libya's population has nearly doubled over the last 10 years. Libyan youth represent more than 50% of the current population. This situation places a great deal of pressure on energy demands, food supplies, and even the environment by increasing the generation of waste and residues. For the last two decades, Libya had depended on fossil fuels, petroleum,

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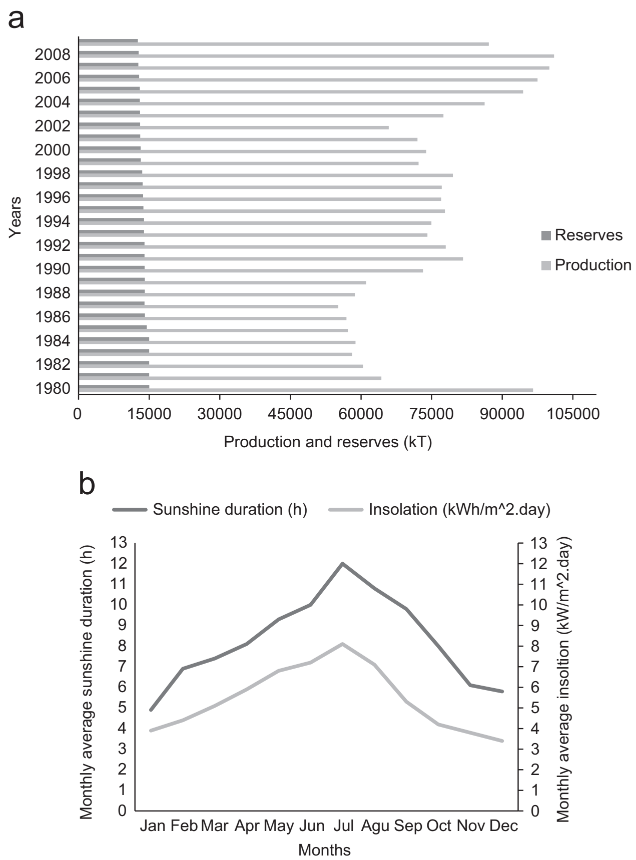

Fig. 1. a Fossil fuel reserves and production of Libya vs. time. b – Sunshine duration and insolation for Libya.

and natural gas for its income, energy, industrialization, and development. Although some efforts have been made to diversify the sources of income, to a large extent, fossil fuels have continued to play a major role in the country's economy. Unfortunately, the fossil fuels available in this area are becoming depleted (Fig. 1a). A total dependence on oil and gas can lead to serious consequences [2]. Out of the renewable energy sources, such as solar, wind, and wastes, conversion of waste feedstocks to H_2 and its useful products such as electricity, heat, reduce fossil fuel usage, and greenhouse gas emissions at the Libya, solar energy stands out as the most promising. Libya experiences 3400 h of sunshine per year; it maintains an average insulation of approximately 2200 kWh/m^2 annually (Fig. 1b) [2,3]. More than 80% of the land is unused. This land might not be used for either agriculture or any other foreseeable purpose than solar energy collection. Solid waste is one of the most important sources of biomass potential in Libya. Biomass is a by-product from human activities that is characterized by negative impacts that may affect man and the environment when disposed of in an inappropriate way. This paper investigates whether or not solid waste can be used as a source of bioenergy in Libya.

2. Solid waste generation in Libya

Classifications of solid wastes are proposed here according to the origin wastes: municipal solid waste (MSW), industrial solid waste (ISW), and healthcare solid waste (HSW) [4,5]. The quantity of MSW generated in Libya is estimated at 3.2 million tons/year (household and similar waste) [6,7]. The overall generation of ISW, including non-hazardous wastes, industrial wastes, demolition, and construction, is 1,248,000 tons/year [6,7]. The hazardous waste generated is 106,200 tons/year; HSW reaches 87,000 tons/year [6]. The increase in solid waste production has been attributed to the population growth, the expansion of trade, and the increased number of industries in Libya.

2.1. Municipal solid waste

Municipal solid waste, more commonly known as either trash or garbage, consists of everyday items (e.g., product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries) that are collected by municipalities or other local authorities [8]. These wastes are generally in either a solid or a semi-solid form. They can be classified as biodegradable wastes that include the following: food and kitchen waste, green waste, and paper

Table 1
Waste composition category [4].

Waste category	Waste components
Organic matter	Waste from foodstuff (e.g., food and vegetable refuse, fruit skins, stem of green, corncob, leaves, grass, and manure)
Paper/carboard	Paper, paper bags, cardboard, corrugated board, box board, newsprint, magazines, tissue, office paper, and mixed paper (e.g., all papers that do not fit into other categories)
Plastic	Wrapping film, plastic bags, polythene, plastic bottles, plastic hoses, plastic strings, and so on
Glass	Bottles, glassware, light bulbs, ceramics, and so on
Metal	Both ferrous and non-ferrous metals including cans, wire, fence, knives, bottle covers, aluminum cans and other aluminum materials (e.g., foil, ware, and bimetal)
Wood	Products comprised of wood (e.g., tabels and charis)
Miscellaneous	Materials comprised of leather, rubber, fiber, textiles, soils, and more (e.g., yard waste, tires, batteries, large appliances, nappies/sanitary products, medical waste, and so on)

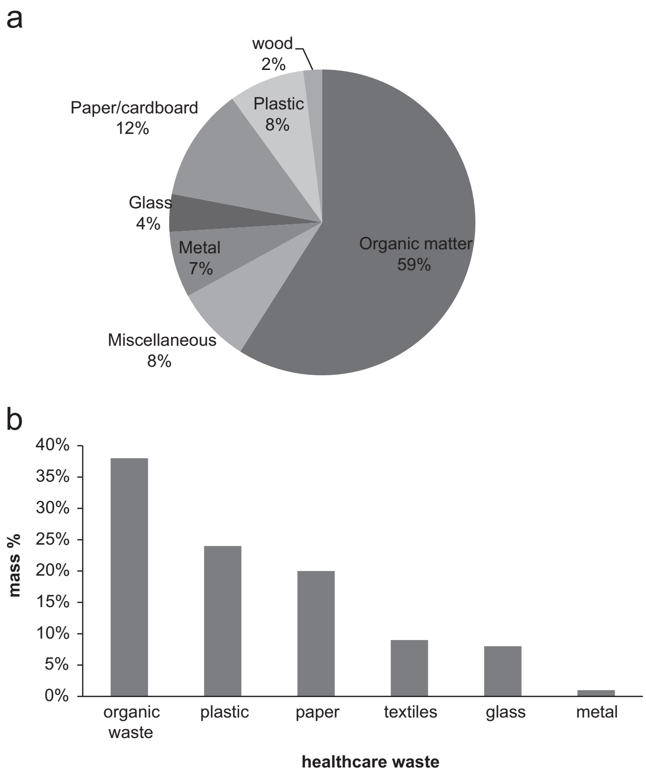

Fig. 2. a – MSW composition survey in Libya. b – Classification of general healthcare waste in Libya vs mass%.

(recycled); recyclable materials (e.g., paper, glass, bottles, cans, metals, and certain plastics); inert waste (e.g., construction wastes, demolition wastes, dirt, rocks, and debris); composite wastes (e.g., clothing and tetra packs); waste plastics (e.g., toys); domestic hazardous wastes (also referred to as household hazardous wastes); and toxic wastes (e.g., medication, e-waste, paints, chemicals, light bulbs, fluorescent tubes, spray cans, fertilizer, pesticide containers, and shoe polish). Libya produces 6,301 tons per day or an average rate of 1.12 kg/capita/day of waste. The composition of MSW is closely related to the residents' level of economic development and lifestyle. The composition of MSW will be different across districts. In general, the composition of MSW in Libya consists of six major categories of waste: organic matter, paper–cardboard, plastics, glass, metals, and miscellaneous (Table 1)

Organic matter was considered as primary category as it represented 59% of the waste collected. The remaining (see Fig. 2-a) were as follows:

- 12% paper–cardboard
- 8% plastic
- 4% glass

Table 2
Quantities of industrial waste and composition category.

Industrial waste	Quantity (Tons/year)
Steel, metallurgical, mechanical, and electrical industries	16×10^4
Building material, ceramic, and glass industries	89×10^3
Chemical, rubber, and plastic industries	34×10^2
Food processing, tobacco, and match industries	65×10^3
Textile, hosiery, and confection industries	68×10^2
Leather and shoe industries	17×10^2
Wood, paper, and printing industries	10×10^3
Total	34×10^4

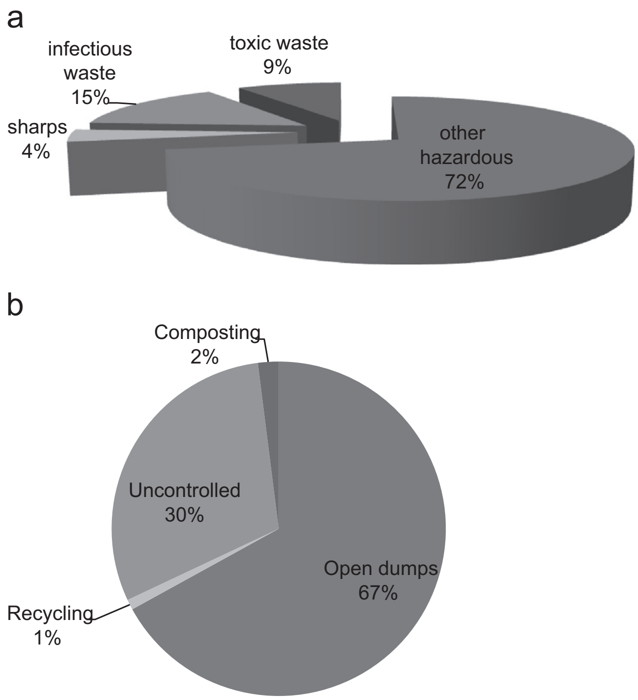

Fig. 3. a – Classification of hazardous healthcare waste in Libya vs mass%. b – Methods of waste disposal in Libya.

- 7% metals
- 2% wood
- 8% miscellaneous

Demolition and construction wastes were not considered because they are disposed of in uncontrolled open-air sites [8]. The high consumption of fruits and vegetables could explain the preponderance of organic matter in Libya's waste.

2.2. Industrial solid waste

The overall generation of industrial waste, including non-hazardous and inert industrial wastes in Libya, is 1,248,000 t per year with a stock quantity of 2,196,480 t [8]. Quantities of industrial waste and composition category are shown in Table 2.

2.3. Healthcare solid waste

Healthcare wastes (HSW) include plastic syringes, animal tissues, bandages, cloths, and so on. This type of waste is produced by the treatment, diagnosis, and immunization of humans and/or animals at hospitals, veterinary and health-related research facilities, and medical laboratories. These HSWs contain infectious waste, toxic chemicals, and heavy metals. Several may contain substances that are radioactive. Libya contains 193 hospitals [6,7] (99 governmental hospitals and 94 private hospitals) with a total of 23,353 beds. It also contains 1484 primary healthcare facilities (Libyan Ministry of Health, 2010). HSWs reach 87,000 tons/year, of which 72% is general waste and 28% is hazardous waste [6,7].

2.3.1. Generation and classification of both hospital and clinical waste in Libya

Solid waste generated by each hospital in Libya was weighed, and the average quantity of waste was determined. The highest generation rate of 1.6 kg/patient/day occurred at the Tripoli Medical Center. The lowest rates 0.9 kg/patient/day occurred at the clinics and rural health centers [6,7].

The hospital waste analyzed was comprised of 28% hazardous waste and 72% general waste. The qualitative analysis of general waste (Fig. 2-b) revealed that organics were the primary component (38%), with plastic in second place (24%). The high plastic content is the result of a widespread use of disposable, rather than reusable, products (e.g., bottles, packaging materials, and bags used for food) intended for various purposes. Paper had the third highest percentage (20%). A classification of hazardous wastes indicates that sharps, infectious pathological wastes, and toxic wastes comprised nearly 28% of all hazardous wastes measured as illustrated in Fig. 3-a [6,7].

3. Solid waste management

Elimination is the solution applied to 95% of waste produced in Libya. These wastes are either thrown into open dumps (67%) or burned in the open air in either public dumps or municipal, uncontrolled dump (30%). Quantities destined for recovery are quite low: only 1% for recycling and 2% for composting, as illustrated in Fig. 3-b [6,7]

3.1. The open dump method

In Libya, the elimination of household and similar wastes through the implementation of open and uncontrolled dumps is the most common method of waste disposal used. Approximately 90% of wastes end up in open dumps. More than 2,300 open dumps have been identified in the country with an area of approximately 3,500 ha [6]. Most of these dumps are nearly saturated.

3.2. Landfill mode

The Libyan government has chosen to use the landfill technique to eliminate municipal solid waste. Unlike the traditional mode in which waste is disposed of in open dumps, the landfill technique stores waste underground. The primary advantages of this technology include the following: (i) this technique offers a universal solution that provides ultimate waste disposal; (ii) it is relatively inexpensive and easy to implement; (iii) landfill biogas can be used as a by-product for both household and industrial uses. Unfortunately, this technology also has several disadvantages. For example, landfills require a large surface area. They also pose serious pollution hazards, including ground water pollution, air pollution, and soil contamination.

3.3. Composting mode

Composting is a biological method that is used to recover organic material from solid waste. Composting represents only 2% of all waste produced in Libya [6]. The primary benefit of this technology is that it converts decomposable organic materials into organic fertilizers.

3.4. Recovery and recycling mode

Solid waste clean and reuse process contribute to the recovery of part of the economic value of solid wastes. They contribute to the provision of work opportunities and financial revenue for the community [7]. Preliminary estimates for Libyan cities revealed that 25% of the waste generated in Libya can be recycled [7]. These recyclable materials include paper, textile materials, metals, plastics, and glass. Unfortunately, only 2% of these are in fact recycled, as presented in Table 3.

Table 3
Recycling capacity.

Waste	Quantity produced (Tons/year)	Quantity recycled (Tons/year)
Paper	75,000	1,080
Textile materials	19,000	420
Metal	20,000	360
Plastics	26,000	660
Glass	9,800	480
Total	149,800	3,000

4. Waste-to-energy (WTE) conversions

The production of energy from waste is not a new concept, thought it is a field that requires serious attention. Various energy conversion technologies are available. The selection, however, is based on the physicochemical properties of the waste, both the type and quantity of the available waste feedstock, and the form of energy desired. The conversion of solid waste to energy can be undertaken with three main process technologies: biochemical extraction, thermochemical extraction, and mechanical extraction [9].

4.1. Biochemical conversion

Biochemical conversion processes make use of the enzymes in bacteria and other microorganisms to breakdown biomass. This process is one of the few processes that provide environmentally friendly direction for obtaining energy fuel from MSWs [10,11]. In most cases, microorganisms are used to perform the conversion process by using anaerobic digestion with combined heat, hydrogen, and power system (CHHP) and fermentation. Digester and biogas production are shown in Fig. 4-a [12–15]. Fermentation is used commercially, on a large scale, in various countries, to produce ethanol from sugar crops. This method produces diluted alcohols that must be distilled.

4.2. Thermochemical conversion

Thermal conversion is one component in a number of integrated waste management solutions proposed in various strategies. Four main conversion technologies have emerged for the treatment of both dry and solid wastes: combustion, gasification, pyrolysis, and liquefaction (to produce an intermediate liquid or gaseous energy carrier) and are as follows:

- Combustion is the burning of biomass in air. It is used over a wide range of commercial and industrial combustion plant outputs to convert the chemical energy stored in the solid waste into either heat or electricity. Combustion uses various items of process equipment, such as boilers and turbines. In theory, any type of biomass can be burned in practice; however, combustion is feasible only for biomass with a moisture content $<50\%$ unless the biomass has been pre-dried [16].
- The gasification process involves treating a carbon-based material with either oxygen or steam to produce a gaseous fuel. Gas produced can be either cleaned and burned in a gas engine or transformed chemically into methanol that can be used as a synthetic compound.
- Pyrolysis is the heating of biomass in the absence of oxygen to produce liquid (termed bio-oil or bio-crude), solid, and gaseous fractions in varying yield. Pyrolysis depends on a range of parameters such as heating rate, temperature level, particle size, and retention time.
- Liquefaction is the low-temperature cracking of biomass molecules as a result of high pressure to produce a liquid-diluted fuel. Liquefaction employs only low temperatures of around 200 °C to 400 °C.

4.3. Mechanical extraction

Mechanical extraction can be used to produce oil from the seeds of solid waste. Rapeseed oil can be processed further by reacting it with alcohol, a process known as esterification, to obtain biodiesel. The type of energy produced from biogas depends directly on the buyer's needs. These needs can be broken down into three categories: electricity generation, heat and steam generation, and transportation of fuel.

4.3.1. Electricity generation

The most common form of energy production today is through well-designed facilities and are as follows:

- Combined heat and power (CHP) generation, also known as cogeneration, is an efficient, clean, and reliable approach to generating both power and thermal energy from solid waste. When a CHP system designed to meet the thermal and electrical base loads is installed, it can greatly increase a facility's operational efficiency while decreasing its energy costs, and CHP can also reduce greenhouse gasses, which contribute to global climate change [12–15, 17].
- The conversion of biogas to electricity via fuel cell technology offers significant increases in efficiency and, hence, is highly sought after technology. Several biogas installations utilize molten carbonate fuel cell technology. However, solid oxide fuel cell technology is thought to be the most promising technology due to its higher power density and its applicability to a wide range of scales [18,19].
- Biogas can be used as a motive power for the production of electricity using engines. A biogas-fueled engine generator will typically convert between 18% and 25% of biogas to electricity. Biogas engine depends on engine design and load factor.

- Small gas turbines that are specifically designed to use biogas are also available. An advantage to this technology is lower NOx emissions and lower maintenance costs. These turbines, however, are not as efficient as IC engines. Additionally, they cost more than IC engines.

4.3.2. Heat and steam generation

Producing and selling both heat and steam require the existence of available industrial customers. They should be matching the supply with their needs. Steam can also be used at institutional domestic complexes.

4.3.3. Transportation fuel

Biogas is used as a transportation fuel in a number of countries. It can be upgraded to natural gas quality for use in normal vehicles designed to use natural gas [12–15, 17, 20].

5. Results and discussion

5.1. WTE benefits in Libya

Interest in converting waste to energy has recently in Libya because this technology will reduce fossil fuel usage, greenhouse gas emissions, pollution, and landfill dumping. Advanced technologies can be used to generate fuel from waste, reducing the country's dependence on increasingly scarce and expensive non-renewable fossil-fuel resources. Using waste as a feedstock for energy production reduces the pollution caused by burning fossil fuels. Traditional incineration produces CO_2 and pollutants. We can observe that biogas from waste landfill contains 55% CH_4 that has a calorific value of 21.5 MJ/Nm^3, while pure CH_4 has a calorific value of 35.8 MJ/Nm^3; this is the reason to remove CO_2 from raw biogas. The energy balance of biogas is highly important, which can replace many other form of combustible gas, and (Fig. 4-b) illustrates the calorific value that can be replaced by methane. Advanced methods (e.g., gasification, pyrolysis, and liquefaction) have the potential to provide a double benefit: reduced CO_2 emissions as compared to incineration and coal plants and reduced methane emissions from landfills. Landfills require large amounts of land that could be used for other purposes; the incineration of solid waste can generate energy while reducing the volume of waste by up to 80%.

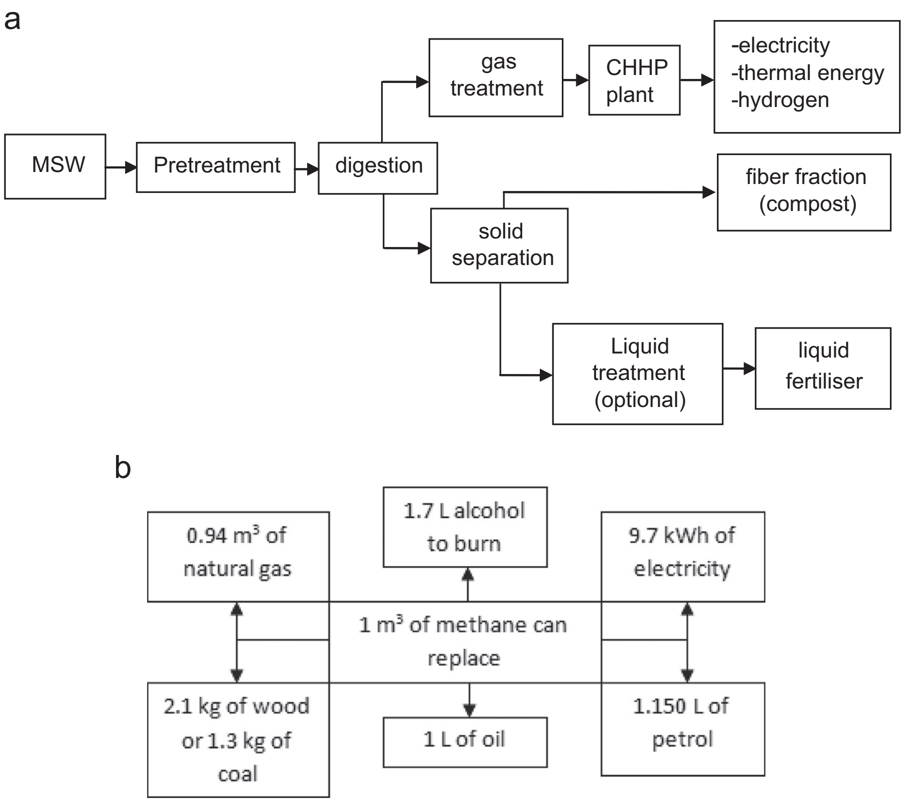

Fig. 4. a – Simplified flow diagram of a general anaerobic digestion plant based of MSW. b – Energy equivalence of methane.

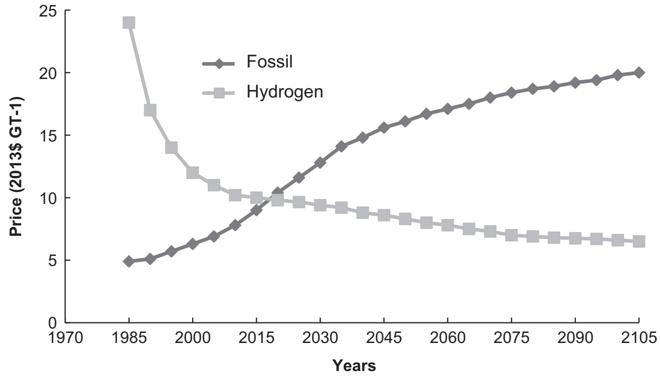

Fig. 5. Fossil fuel and hydrogen price predictions vs. time.

5.2. WTE challenges

Many WTE technologies are designed to handle only a few types of waste (biomass, solid waste, and so forth). Completely separating different types of waste can be tremendously difficult. Determining the exact composition of a waste source can be nearly impossible. WTE technologies must either become more versatile or be supplemented by material handling and sorting systems if they are to be successful. They are many WTE challenges (e.g., waste-gas cleanup, conversion efficiency, regulatory hurdles, and high capital costs). The gas generated by various processes (e.g., pyrolysis and thermal gasification) must be cleaned of tars and particulates before clean, efficient fuel can be produced. A number of WTE pilot plants, particularly those using energy-intensive techniques (e.g., plasma), have functioned with low efficiency. Toxic materials include both trace metals (e.g., lead, cadmium, and mercury) and trace organics (e.g., dioxins and furans). Such toxins pose an environmental problem if they are released into the air, dispersed into the soil, allowed to migrate into ground water supplies, or make their way into the food chain. The control of such toxins and air pollution is a key feature of environmental regulations governing MSW-fueled electric generation. The regulatory climate for WTE technologies can be extremely complex. These regulations may prohibit a particular method (typically incineration) due to air-quality concerns. Although changes in the power industry have allowed small producers to compete with established power utilities in many areas, the electrical grid is still protected by yet more regulations. These regulations pose as obstacles to would-be waste-energy producers. WTE systems are often quite expensive to install. Despite the financial benefits they promise, the high installation cost is a major hurdle, particularly for new technologies that are not widely established in the market. Fig. 5 illustrates possible fossil fuel and hydrogen prices up to the year 2015. This image suggests that although fossil fuel prices are predicted to increase, hydrogen prices are predicted to decrease. By 2018 these price will cross each other at the $10 GJ-1 range. However, because hydrogen has a higher utilization efficiency ($\eta = 1.35$), hydrogen prices will be competitive with those of fossil fuels by approximately 2015.

6. Conclusion

This paper presents an overview on solid waste that can be used as a source of bioenergy in Libya including MSW, ISW, and HSW as biomass sources. The management of solid waste and valorization is based on an understanding of MSW's composition and physicochemical characteristics. Energy from waste is not a new concept, but it is a field that requires serious attention. Various energy conversion technologies (thermochemical extraction, biochemical extraction, and mechanical extraction) can produce useful products (e.g., electricity, heat, and transportation fuel). The dependence of Libya on fossil fuels will be reduced thereby significantly reducing both pollution and greenhouse gas emissions. Solid waste can be used as an energy source in Libya. The implementation of landfill disposal techniques should be encouraged for the valorization of biogas.

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