

# **Sustainable Waste Management through Waste to Energy Technologies in Saudi Arabia: Opportunities and Environmental Impacts**

**Tayeb Brahimi, Charles Rajesh Kumar J, Mohamed Abdulmajid, Nehal Alyamani**

Energy and Technology Research Center

Effat University

Jeddah, Saudi Arabia

[tbrahimi@effatuniversity.edu.sa](mailto:tbrahimi@effatuniversity.edu.sa), [moabdulmajid@effatuniversity.edu.sa](mailto:moabdulmajid@effatuniversity.edu.sa),

[nalymani@effat.edu.sa](mailto:nalymani@effat.edu.sa), [ckumar@effatuniversity.edu.sa](mailto:ckumar@effatuniversity.edu.sa)

## **Abstract**

The primary intent of this paper is to show the potential of the waste-to-energy (WTE) in Saudi Arabia that contributes to sustainable waste management strategies, environmental awareness, widespread of best practices in waste to energy including the possible technologies, job, and business opportunities and lastly the environmental influence. Also, the policies that need to be improved, evolved or modified to encourage WTE industry are suggested along with a few recommendations for the course of action in the WTE sector that can support the investors, WTE project developers, suppliers, decision-makers and the policymakers for further better management and planning.

## **Keywords (12 font)**

Vision 2030, Waste to Energy, Solid Waste Management, Environment, Incineration, WTE, Policy, Saudi Arabia.

## **1. Introduction**

The Kingdom of Saudi Arabia recently set ambitious targets in its national transformation program and Vision 2030 to move away from oil dependence and redirect oil and gas exploration to other higher-value uses to supply 10% of its energy demand from renewable sources. Saudi Arabia is seeking to have a sustainable future in all aspects by 2030, starting with having reliable, safe, efficient, and sustainable energy. Figure 1 shows the main strategic objectives of Vision 2030, namely: ensure sustainable use of water resources, reduce all types of pollution, improve the quality of services provided in Saudi cities, and improve the quality of services offered to citizens. Saudi Arabia is one of the 10th world largest consumers of total primary energy 266.5 million tons of oil equivalent due to population, urbanization, and an increase in living standards. The population of the kingdom is expected to reach 34 million at the end of 2019 and projected to increase by up to 45 million in 2030, with an annual growth rate of 3.4%. With a significant increase in population, industries, a fast-growing economy will contribute to the humongous volumes of waste generation. Chaotic landfilling, indiscriminate dumping of wastes, and mass burning may result in unacceptable environmental and health consequences.

The kingdom, through its vision 2030 plan, has, however, recognized the unfortunate consequences and the ill-effects of such techniques being practiced and has come forward to accommodate eco-friendly and affordable solutions for the dumping of wastes. Statistics by GaStat for the period 2010-2016 indicate that solid waste generation in Saudi Arabia averaged about 1.15 kg per person per day in 2010, with the average rising to 1.39 kg in 2016, Figure 2.

Today, there is an ever-increasing need for energy despite the increasing costs of oil with the depletion of fossil fuels. The energy demand, in particular, the electricity generation, has resulted in the creation of fossil fuel-based power

plants that let out abundant greenhouse gas/carbon emission into the environment, which has resulted in global warming and changes in climatic conditions. Like many developing nations, the Kingdom is working towards decreasing such undesirable impacts of global warming by making out policies conducive to encourage renewable energy generation with an ambitious target, by 2032, of 54 GW from renewable energy technologies such as Solar – 41 GW, wind – 9 GW, waste-to-energy - 3 GW, and geothermal – 1GW as evaluated by the King Abdullah City for Atomic and Renewable Energy K.A.CARE.

Several programs and initiatives have also been launched, such as the National program, to reduce food loss and waste and to prevent inadequate use of natural resources. However, the current policies, programs, and management structure do not sufficiently address the immediate hurdles of managing the projected waste due to a shortage of logistics and significant planning, inadequate funding, unsuitable technical attentiveness, and improper resource management. Saudi Arabia can undoubtedly benefit from the immense amount of solid waste generated to cover part of the increasing electricity demand. Using novel technologies to convert the waste to energy will positively affect environmental safety, reduce food loss and waste, and monitor best practices of waste mechanisms and procedures. As the global municipal solid waste (MSW) in the KSA mainly consists of 37% organic waste, the anaerobic digestion process is proposed as a practical solution to retrieve methane and convert it to energy. Plastic can be either recycled or converted into fuel oil using pyrolysis technology.

Accordingly, energy consumption and waste generation will be increased. Saudi Arabia is one of the 10th world's largest consumers of total primary energy, with 266.5 million tons of equivalent oil due to population, urbanization and an increase in living standards. The electric generating capacity of Saudi Arabia in 2016 reached 55 GW, and it is expected to reach 120 GW by 2032 (K.A.CARE, 2019a). With the increasing number of the Kingdom population, the huge amount of municipal solid waste (MSW) generated needs to be managed in a way to maximize benefit, raise the efficiency of food consumption, and minimize dumping in landfills. MSW generation and its management are being widely discussed over many events globally, from local forums to international conferences (K.A.CARE, 2019b).

An active informal sector drives waste sorting and recycling. Recycling activities are mostly manual and labor-intensive. Responding to this growing issue, the Public Investment Fund (PIF) was planning to create the Saudi Recycling Company (SRC), a waste management body that will be empowered to set up and support domestic recycling projects across the country. Currently, Saudi Arabia only recycles around 10% of its waste; the government aims through the SRC to increase this ratio to hit 85% (Elattari, 2018).

Municipalities are making the increased investment in municipal solid-waste components and the establishment of sorting and urgent facilities after the approval of the competent authority in the ministry on the terms and specifications of the technical contract. Companies and institutions wishing to establish municipal waste sorting, treatment, and recycling solid wastage facilities are recommended to follow terms and conditions. Six points should be concerned about it: First, obtaining a license, as well as the presence of the investment contract in one of the components of municipal solid waste with the competent authority within the contract area. Second, obtaining the approval of the competent authorities on the location of the establishment of sorting and recycling facilities and processing. Third, meet the requirements of the environmental assessment and the regulatory approvals on the site of the establishment of the sorting facilities recycling and treatment of related parties. Fourth, presenting and approving the drawings and technical specifications of the establishments and designing the sorting lines and methods. Fifth, treatment and reuse to be followed by the investor. Sixth, comply with the terms and conditions of investment in the components of municipal waste prepared municipality previously.

Moreover, there are four conditions to be obeyed: First, provide an operational plan for sorting facilities. Second, identify the types of waste to be invested. Third, Compliance with security and safety requirements. Fourth, submit periodic reports on the confidentiality of work (MMRA, 2016). Recently the Saudi Government approved new laws to confirm Associate in an integrated framework for the management of municipal wastes. The Ministry of Municipal and Rural Affairs are liable for overseeing the tasks and responsibilities of the solid-waste management system (Zafar, 2015).

The primary intent of this paper is to show the potential of the waste-to-energy (WTE) in the Kingdom that contributes to sustainable waste management strategies, environmental awareness, widespread of best practices in waste to energy including the possible technologies, job, and business opportunities and lastly the environmental influence. Also, the policies that need to be improved, evolved or modified to encourage WTE industry are suggested along with a few

recommendations for the course of action in the WTE sector that can support the investors, WTE project developers, suppliers, decision-makers and the policymakers for further better management and planning.

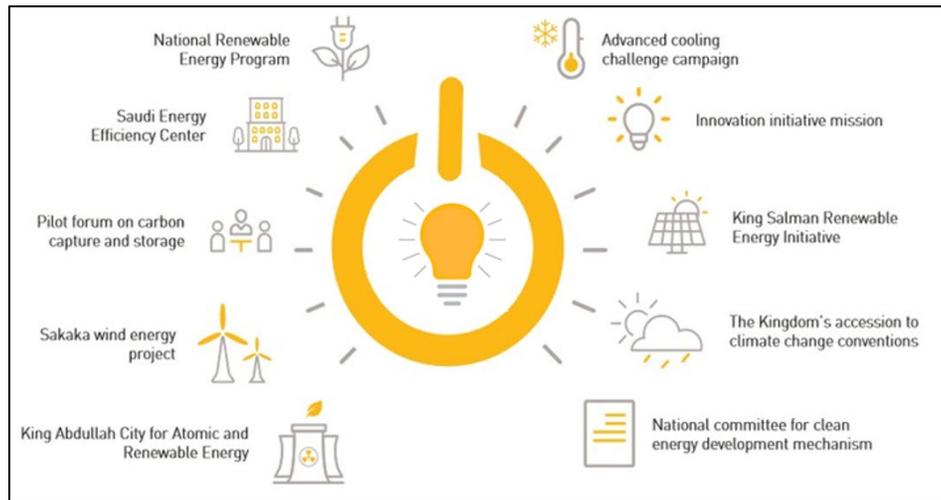


Figure 1. Vision 2030 strategic objectives in renewable energy

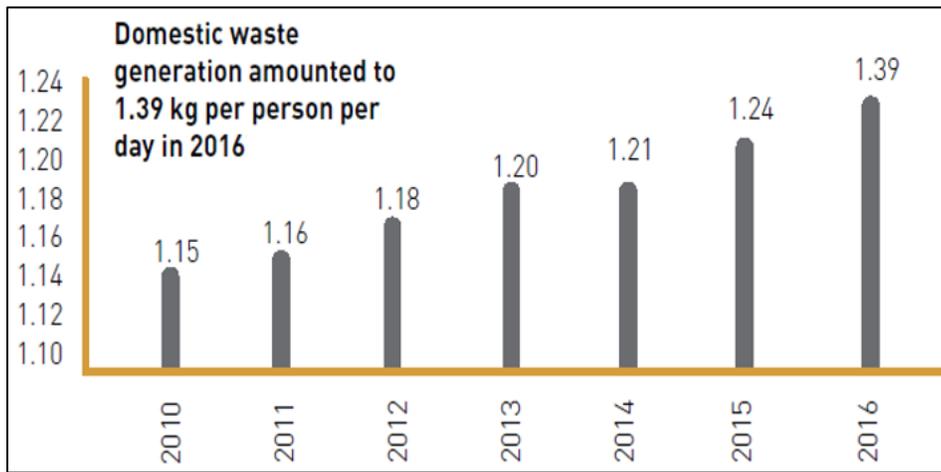


Figure 2. Solid waste generation in Saudi Arabia for the period 2010-2016

## 2. Waste to Energy Technologies in Saudi Arabia

Saudi Arabia's WTE prospects were pursued in two scenarios: (1) incineration and (2) refuse based fuel (RDF) in combination with biomethanation between 2012 and 2035. Biomethanation technology can be shown as being the most effective WTE technology for Saudi Arabia because the (i) presence of large quantities of food waste that can be used as a feedstock (37% of overall MSW) (ii) improved productivity (25%-30%) and (iii) the lowest annual investment (USD 0.1-0.14/ton) and operating costs. A need for a large area for continuous operation, however, could raise operating costs (Ouda et al., 2017; Rafat Al-Waked et al., 2014). The RDF has a benefit over incineration because of (i) the lowest annual investment (USD 7.5-11.3/ton) (ii) operating costs (USD 0.3-0.55/ton), yet high demands for labor skills will most likely be a constraint if appropriate education and associated facilities are not designed as a prerequisite.

The incineration system also demonstrates to be relatively higher in performance (25 percent) and lower in operating costs (USD 1.5-2.5/ton). Moreover, the need within the incineration facility to handle air and waterborne contaminants and ash may be the limiting factor for the implementation of this technology in KSA. In 2012, KSA's power generation

capacity from incineration was measured at 671 MW, and RDF with biomethanation scenarios was estimated at 319.4 MW. It is projected to reach up to 1447 MW and 69976 MW, respectively, by 2035 for both scenarios.

WTE technologies could, therefore, make a significant contribution to KSA's renewable energy generation as well as mitigate the cost of landfilling and its related adverse effects on the ecosystem. The decision to choose between the two scenarios involves further in-depth economic, technological, and environmental analysis. According to recent estimates, if all of the Saudi Arabia food waste is used in biogas plants, an electricity capacity of 3 TWh per year can be produced. Similarly, electricity can be generated at 1 TWh and 1.6 TWh per year if all of Saudi Arabia's plastics and other mixed waste (i.e., paper, carton, wood, cloth, leather, etc.) are treated in pyrolysis and RDF technologies respectively.

### 3. Saudi Arabia's Recycling Prospects

Metal and cardboard recycling is Saudi Arabia's primary waste recycling activity, representing 10-15% of total waste. The informal sector mostly does the practice of recycling. Waste pickers and waste scavengers are taking recyclables throughout the cities from the waste bins and containers. The rate of waste recycling in some areas of the same cities is often high (up to 30 percent of total waste) by waste scavengers. Recycling is also carried out at some landfill sites, and includes formal and informal industries, covering up to 40 percent of total waste. According to the region, the recycled items are glass bottles, aluminum cans, steel cans, plastic bottles, paper, cardboard, waste tires, etc. It is estimated that by recycling only glass and metals from MSW flow, 45,000 TJ of energy can be saved. This calculation is based on the concept of energy conservation, which assumes that the same amount of recyclable material would be generated using xyz amount of energy. Based on literature review such as (Ouda et al., 2017; Rafat Al-Waked et al., 2014) WTE forecasts in major cities of Saudi Arabia is shown in Figure 3.

Waste to the energy content of different types of wastes is shown in Table 1 (Ouda et al., 2017; Rafat Al-Waked et al., 2014). Riyadh, Jeddah, Dammam accounts for 44% of KSA waste. According to Saudi Gazette (13th March 2018 report), of the total annual waste generated by 169 cities, towns, and villages in the Kingdom of Riyadh, Jeddah, and Dammam of 13.6 million tons. According to the national census, 65.6% of the Kingdom's population is concentrated in Riyadh, Jeddah, and Dammam. The national per capita waste production is estimated at 1.1 kg per day, while it is estimated at 0.7 kg per day in small towns and villages. Municipal waste per capita is measured at 14 kg per day, equivalent to the amount of waste per capita in other GCC countries.

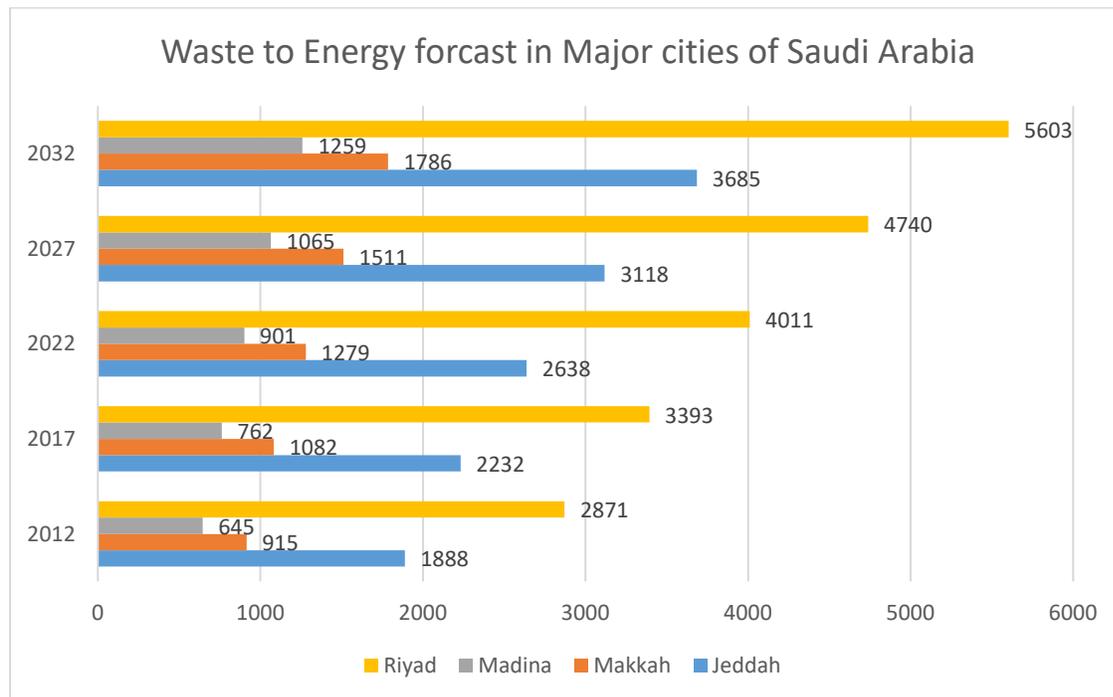


Figure 3. Waste to Energy Forecast in Major cities of Saudi Arabia

Table 1 Waste to the energy content of different types of wastes according to GAMEP report of the Ministry of Municipal and Rural Affairs

Component/material	Composition of waste (%)	KWh/kilogram in component/material	Content of Energy	KWh/kilogram in waste low heating value
Paper	28.5%	4.39	68000	1.21
Textiles	6.4%	5.2	8100	0.22
Glass	4.6%	0	0	0
Plastic	5.2%	9.05	14000	0.46
Organic	37%	1.55	2400	0.1
Wood	8%	4.73	7300	0.24
Others	10.3%	3.36		0.28
Total energy with recycling scenario for mass burning (KWh/kilogram)				0.377
Total energy mass-burn contents scenario (KWh/kilogram)				2.512

Equations (1), (2), (3) (Ouda et al., 2017, Rafat et al., 2014) show the potential of energy recovery calculation, which depend on the low heating value of waste and dry waste. The power generation potential (MW) and Net generation potential (MW) are given by equations (2)-(4).

$$\text{Potential of energy recovery} \left( \frac{GWh}{\text{day}} \right) = \frac{\text{Low heating value of waste} \left( \frac{KWh}{\text{kilogram}} \right) * \text{Dry waste} \left( \frac{Tons}{\text{day}} \right)}{1000} \quad (1)$$

$$\text{Potential of power generation} (MW) = \frac{\text{Low heating value of waste} \left( \frac{KW}{\text{kilogram}} \right) * \text{Dry waste} \left( \frac{\text{kilogram}}{s} \right)}{1000} \quad (2)$$

$$\text{Potential of net power generation} (MW) = \text{Potential of power generation} (MW) * \text{efficiency of the process} \quad (3)$$

#### 4. Environmental and Health Impact

In recent years, the country has been struggling with the problem of solid waste. With an average per capita of 1.4 kg per day, about 15 million tons of MSW are produced in the country annually. With the existing rising population (3.4 percent annual rate), urbanization (1.5 percent annual rate), and economic growth (3.5 percent annual rate of GDP), MSW's generation rate will double by 2033 (30 million tons annually). Saudi Arabian garbage's main ingredients are food waste (40-51 percent), paper (12-28 percent), cardboard (7 percent), plastics (5-17 percent), glass (3-5 percent), wood (2-8 percent), textile (2-6 percent), metals (2-8 percent), etc., based on the population size and urbanization of the region.

Issues of waste management in Saudi Arabia are related not only to water but also to land, air, and sea. In the oil-rich kingdom, solid waste management is still in its infancy. In Saudi Arabia, after partial separation and recycling, MSW is collected and then sent to landfills or dumpsites. The majority of the waste collected ends up in untreated landfills. The demand for landfill is very high, nearly 28 million m<sup>3</sup> per year. The issues of wastewater, waste sludge, methane, and odor emissions arise in landfills and surrounding areas. Most of the landfills are non-sanitary or un-engineered.

Moreover, the plans for future sanitary landfills are in effect in many cities and towns with methane capture and leachate facilities. Various forms of wastes are shown in Figure 4. The Al-Hayat Arabic daily study concludes that as a result of an increase in healthcare services, medical waste in the Kingdom is growing, adding that these medical wastes cause human health problems. It showed the risk of unloading medical waste without handling it in public dumps. According to the Health Ministry's latest statistics, the total solid medical waste produced by government hospitals and health centers in the Kingdom exceeded 39,419 tons per year. Simultaneously, liquid medical waste was 34,888 tons.

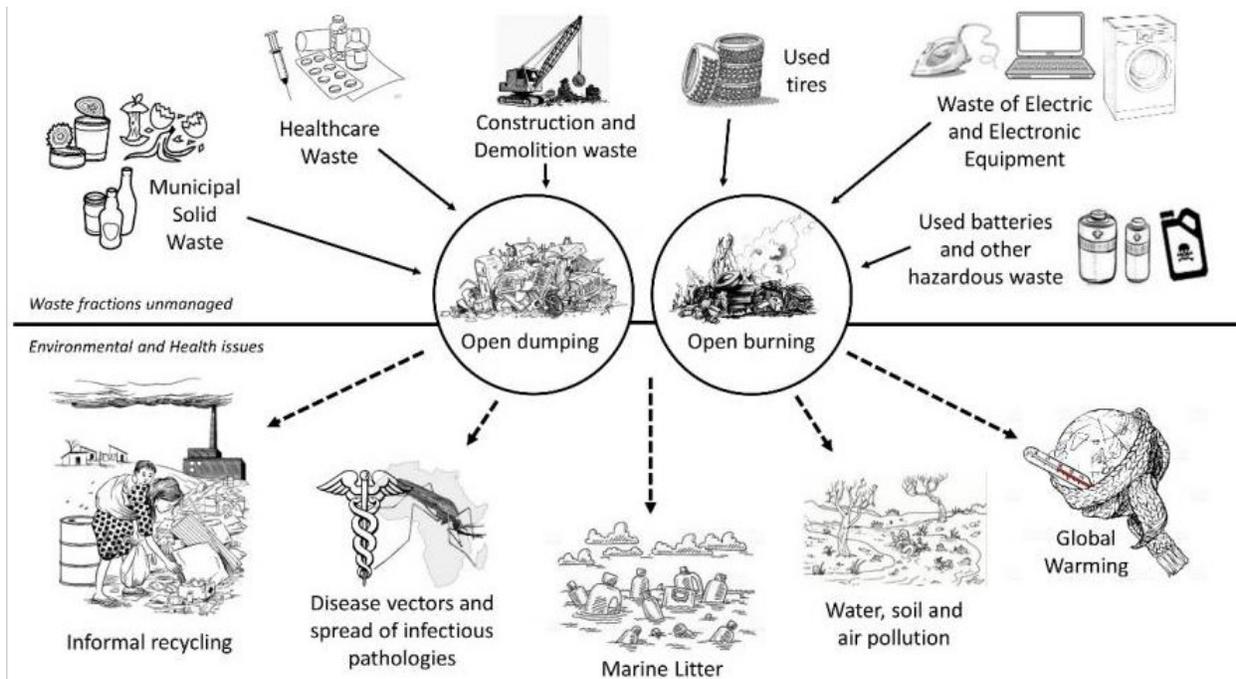


Figure 4. Various forms of wastes and their impacts

#### 4.1 Incineration

In the absence of effective regulations, toxic contaminants from WTE can be released into the air, soil, and water that can affect human health and the environment. Though municipal waste incineration combined with energy recovery may be an important part of an integrated waste management program, strict controls are needed to prevent its harmful impact on people and the environment. The method of incineration generates two kinds of ash. Bottom ash comes from the furnace, mixed with slag, while fly ash comes from the stack containing more dangerous components. Incinerator pollutants may include heavy metals, dioxins, and furans that may be found in waste gases, air, or ash. Plastic and metals are the primary sources of waste's calorific value. Such highly toxic contaminants are produced by the combustion of plastics, such as polyvinyl chloride (PVC). Toxics are generated at different stages of such thermal technologies, not just at the stack's edge. These can be produced as residues in ash, scrubber water, and filters during the process, in the stack tubes, and in reality, even in air plumes that exit the stack. There are no safe ways to avoid or destroy their production, and they can be caught in sophisticated filters or ash at the best possible cost. The final release is inevitable, and if they are stuck in ash or pipes, they become hazardous waste.

The contaminants that are produced, even if they are trapped, remain in filters and ash that require disposal in special landfills. While trying to recover fuel, it needs heat exchangers working at temperatures that maximize the output of dioxin. If the gasses are quenched, energy recovery will be reversed. Throughout the environment, these works spread incinerator ash that eventually reaches our food chain. Waste incineration systems contain a wide range of contaminants that affect human health. These devices are costly and do not remove or monitor chemically complex MSW toxic emissions adequately. Also, modern incinerators release toxic gases such as metals, dioxins, and acids. Far from removing landfill requirements, waste incinerator systems produce significant toxic ash as well as other contaminants.

Dioxins seem to be the most toxic persistent organic contaminants with irreparable health effects for the environment. The population impacted includes those who live near the incinerator as well as those who live in the wider region. There are several ways in which people are exposed to toxic compounds: Through breathing the air that affects both plant workers and those living in the vicinity, through eating local foods and water polluted by the incinerator's air pollutants; and; through eating fish and animals polluted with pollution pollutants. Dioxin is a

highly poisonous substance that can lead to cancer and neurological damage, affecting reproductive systems, thyroid systems, respiratory systems, and so on.

#### **4.2 Biomethanation**

The extent of health and environmental consequences due to biomethanation may vary considerably depending on the feedstock, mode of operation, digester volume, slurry handling system, and position of the digester. Unwanted environmental changes can vary from local, national, and up to global levels. Biomethanation gas-related major air pollutants include: (a) gas-methane (CH<sub>4</sub>), carbon dioxide (CO<sub>2</sub>), ammonia (NH<sub>3</sub>), hydrogen sulfide (H<sub>2</sub>S), (b) volatile organic compounds, and (c) odor. Due to different levels of exposure, air quality near anaerobic digesters impacts the health of animals and farmers to various degrees. The air quality can affect the health of farm neighbors in the case of community size plants. Usually, air quality close to anaerobic digesters is a problem because the rates of air pollution can surpass the safety threshold.

Biomethanation gas contains a variety of gasses that are unintentionally and unwittingly released into the atmosphere. These gasses can be identified as irritants or asphyxiants. Irritants cause respiratory system inflammation and irritation. Asphyxiants are gasses that strip oxygen (O<sub>2</sub>) from the atmosphere (simple asphyxiants) and mix with hemoglobin (chemical asphyxiants) from the blood. The problems associated with soil and water are largely due to inadequate biomass treatment and processing pre and post anaerobic digestion. Biogas consists primarily of CO<sub>2</sub> (45%) and CH<sub>4</sub> (65%), and these gases displace oxygen.

The main danger of CO<sub>2</sub> is that it can cause a lack of oxygen and can lead to suffocation and asphyxiation. Displacing the O<sub>2</sub> in a sealed digester renders the atmosphere unsafe for humans without an adequate source of oxygen. High levels of CO<sub>2</sub> affect the rate of breathing, and higher levels often displace oxygen. The most harmful of biogas gaseous components is hydrogen sulfide. This interacts chemically with the hemoglobin of the blood to prevent oxygen from being transferred to the vital organs of the body. In addition to the biotic effect, if biogas is used as fuel, H<sub>2</sub>S induces corrosion of internal combustion engines. Dry desulphurization, using ferrous substances, is the only practical way to remove the H<sub>2</sub>S, but it is not technically and economically feasible. At levels of 30-50 ppm, ammonia irritates the eyes. High levels of ammonia in workers and livestock can also cause eye irritation, respiratory problems, and illness. Ammonia released to the atmosphere in its oxidized form leads to acid rain. Ammonia may also react to nitrate in the environment to form particles of ammonium nitrate that lead to problems with pollution and safety.

### **5. Business and Employment Opportunities in Waste-to-Energy technologies in Saudi Arabia**

WTE could move many people in all communities to job opportunities, reducing unemployment rates. The employment opportunities include primary collection and transportation, secondary collection and transportation, the transfer station and processing site, and disposal site, which is shown in fig.3. Today, collecting, transporting, and disposing of MSW are the country's most pressing issues. Such tasks include an extremely complex collection of procedures on a vast scale. Most companies in the private sector have seen an economic opportunity in waste management in recent years. The emphasis is on creating a more effective end-to-end waste management supply chain. It begins by segregating waste collection and ends with waste disposal and treatment. Several private players in waste management are already making a mark, for example, transforming plastic waste into 3D printing filaments and the establishment of compact waste-to-energy plants to convert waste from the kitchen to biogas.



### Figure 5. Waste management supply chain

In the last decade, waste-to-energy professions have grown steadily from year to year. Advances in technology in materials processing and consumer preferences trends continue to influence waste management practices, generating efficiencies and creativity within the industry. With the growing demand for WTE needs and the advancement of WTE systems in the years to come, WTE job opportunities will increase. With this steady increase in demand, and there is ample room for the WTE industry to grow, and it means that the WTE labor market is full of job opportunities. Some of the possible jobs that are available in the Waste to the Energy sector are in Engineering (Infrastructure Engineer, Resource Conservation Engineer, Power Systems Engineer, Engineering Analyst, Engineering and Design Supervisor, Engineering Development Director). In Research and Development (Hydro Geologist, Environmental Waste Consultant, Energy Analyst, Greenhouse Gas Assessor, Carbon Consultant, Energy Manager, Program Analyst, Waste Reduction Consultant). In Construction (Industrial Waste Manager, Construction Project Manager, Distribution Standards Manager, Design Engineer, Industrial Energy Manager). Technology (Geo Exchange Designer, Electrical Engineer, Intelligent Building Specialist, Performance Assurance Coordinator, Geothermal Designer, Lighting and Design Specialist, Grid Designer). It only scratches the surface of possible job openings in the WTE market.

## 6. Obstacles in Implementation of Waste-to-Energy technologies in Saudi Arabia

- The greatest obstacle to Waste-to-Energy adoption lies not in the technology itself, but citizens' acceptance. Citizens who are eco-friendly but lack knowledge of the current waste-to-energy status pose environmental justice issues. WTE lacks community awareness and understanding.
- Most regulations are underdeveloped, and there is no systematic or robust application of the regulatory framework.
- So far, in municipal waste management, there is no idea of outcome-based funding. Projects involving significant upfront investment are, therefore, also poorly executed.
- The government does not have the state-of-the-art engineering resources needed to create innovative solutions for waste management. In terms of technically viable waste management approaches, private-public collaborations are a much better approach.
- Urban regional bodies' technological ability is severely limited, making it more difficult for them to pursue long-term projects.
- Solid waste management's current status in Saudi Arabia is low because there is no use of the latest and most suitable methods from waste collection to disposal.
- There is a lack of training in Solid waste management, and there is limited availability of qualified professionals in waste management and WTE.
- There is a lack of accountability across the country in the current WTE programs.
- Municipal authorities in the country are responsible for managing municipal solid wastes, but they have budgets that are inadequate to cover the costs of implementing adequate waste collection, storage, treatment, and disposal.
- The lack of strategic urban solid wastes and proposals for WTE, waste collection/segregation, and a regulatory framework for government funding are major obstacles to achieving successful WTE in the country.
- Innovation and the adoption of new technologies that could change waste management in the country have been hampered by limited environmental awareness combined with low motivation.
- As compared to wind and solar renewable energy technologies, energy generation from waste and WTE technology is still a new idea to develop WTE technology.
- Equipment required for WTE technologies is imported from abroad. For example, biomethanation-based projects are very expensive, and the components are being imported.
- WTE plants do not have, most of the time, segregated waste.
- There is a lack of favorable policy guidelines on land allocation for the construction of WTE plants and the supply of waste from sources of waste generation.
- Employees have a learning gap, and fewer experts are trained in waste management engineering.

- WTE plants often obtain low waste content in which it is not possible to generate energy, and the result is unsatisfactory.
- The cost of capital to build the WTE plant is very large, and the cost of operation and maintenance is also significantly high.
- Few failed WTE ventures give investors and the general public low encouragement.
- There is no WTE Research Center devoted to R&D.

## **7. Policy and recommendations for waste to energy technologies in Saudi Arabia**

- The path forward in urban waste management through WTE can only come through deep government-private partnerships. The government needs to concentrate heavily on organizational efforts, specifically comprehensive policies and campaigns for awareness. Much innovation in the supply chain will come from the private sector, particularly in waste collection and disposal. All sides should make a strong effort to create successful public-private partnerships.
- Solid waste generation and WTE can be regarded as a source of opportunities: renewable energy production, new jobs, new economic benefits, private investment, and increased understanding of environmental issues among the population. Suitable policies should be put in place to facilitate these practices, such as raising public awareness, enacting new laws and regulations, and introducing infrastructures for solid waste management and WTE.
- WTE technology should comply with standards and agreements accepted internationally.
- Taking into account the international understanding of tendering, tracking, and reinforcing processes.
- Waste quantities, waste efficiency, accessibility of waste, waste characteristics, and data related to technology choices should be readily available for WTE for proper waste management.
- Municipal Corporation plays an important role in working with WTE plants, and they should be financially healthy and supported by the government concerned to routinely collect waste and supply to the WTE plant without delay or problems.
- Agreements and coordination between the municipality and the WTE plants should be evident and involved in the efficient transport and disposal of ash etc.
- Comprehensive investment plans, strategic plans, and realistic estimates are essential for the successful operation of WTE plants.
- It is important to hire skilled and trained staff and to provide regular training related to technical and managerial responsibilities for the successful operation of the plant. Outsourcing can be undertaken for certain projects to reduce the pressure on existing employees.
- The highest priority should be proper planning for a backup and emergency power.
- Legal protection for the WTE plant should be assured, and the WTE plant's vision should be transparency, confidence in providing people with clean energy through eco-friendly WTE technologies and public safety.
- Rather than importing all equipment from overseas, consider using WTE's domestic equipment before deciding to add content from anywhere else. To save capital investments, try combining with local equipment with few imported equipment.
- Enhance the isolation of waste and use appropriate WTE technology. Most of the time, the amount of moisture in the waste reduces the technology's performance and creates dioxins.
- Promotion of waste separation, recycle and reuse through promotional strategies to companies and residents.
- For their long-term waste management policies/strategies, policymakers need to consider the long-term effect of the WTE policy. The policy must be related to the goals of sustainable development and vision 2030 of Saudi Arabia.
- Offer a WTE-related undergraduate course for university students in the country. The Ministry of Education can frame the syllabus, curriculum, and begin a WTE undergraduate course and provide the students with the scholarship to complete their studies.
- To have an excellent future for the WTE market, the government should consider and fund R&D in WTE.
- Research cooperation between the WTE plant and the research institutions should be formed. Research centers can be built on the campus of the WTE plant. Scientists and researchers should be allowed to research the WTE

plant following environmental impact studies; the inquiry should include effective waste management methods and technologies. Research scholars will focus on WTE and developments in WTE technology to receive a Ph.D. degree.

- To have steady growth in this field, the relationship and MoU between the WTE market, businesses, and educational institutions should be healthy.
- An efficient method should be available to explore the potential of WTE.
- The government can encourage and provide business opportunities in the WTE sector for citizens and private companies.

## 8. Conclusion

Saudi Arabia's current solid waste management activities require a safe and integrated approach to the recovery of waste at source separation, waste recycling, waste to energy, and value-added product. WTE is the solution for waste that cannot be recycled. The alternative to landfill (methane gas to coal) is to generate energy from the incineration. The cost of incineration in roughly Saudi Riyal 400 per ton is about 40 times more expensive than the current landfill price. Incinerating waste in Saudi Arabia is still a less attractive choice than recycling, but it will be used as a last resort for certain waste sources in the future. The findings of the study show that the incineration scenario has the greatest capacity to generate power over the RDF and recycling biomethnation and incineration with recycling. The waste management industry may generate a range of opportunities to include the private sector, invest in companies and find investment opportunities.

The enormous quantity of waste should be properly managed; otherwise a significant long-term environmental impact can be expected. Saudi Arabia has recognized the potential of WTE technologies for successful municipal solid waste management (MSWM) and WTE as a potential renewable energy source that will partially meet the demand for energy and ensure productive MSWM. WTE services, however, lack adequate infrastructure, pollution control systems, and maintenance in the country. The country puts greater emphasis on enhancing the policy of process efficiency recycling/recovery and regulation of emissions. Developing WTE facilities in compliance with that country's requirements and regulations is important. In the country, WTE plants need to be installed on a smaller scale. The WTE facilities scenario will be enhanced by government policies and regulations, financial support, improved technology. This paper will help readers and strategic decision-makers identify Saudi Arabia and the rest of the world with the best WTE technology

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## **Biographies**

**Dr. Tayeb Brahimi**, Assistant Professor at the Department of Electrical and Computer Engineering (ECE), at Effat University, Jeddah, KSA, received his Ph.D. (1992) and Master Degree (1987) from University of Montreal, Canada. He has worked as Research Scientist under Bombardier Chair/Canadair from 1992-1998. In 1998, he joined Jeppesen DataPlan in California, then Peregrine System as a Technical Support Analyst, Quality Assurance Engineer, and Consultant for Electronic data interchange (EDI) in Dallas, Texas. Dr. Tayeb Brahimi has been a consultant at IONPARA Inc. for wind energy and aeronautics. He published more than 80 articles in scientific journals, international conferences, on novel methodologies of teaching and learning, renewable energy, sustainability, and machine learning. Among other activities, he is a reviewer for many international journals, invited speaker by the Japan Society of Mechanical Engineering, the Gulf Educational Conference as well as the Int. Conference on Eng. Education & Research. He also participated in Public Debate on Energy organized by the Government of Quebec, Canada. Current research interest relates to renewable energy (solar, wind, wave, and waste to energy), sustainability, machine learning, use of technology to support learning, engineering education, MOOCs, and Makerspace. Other areas of interest include integrating innovative Islamic heritage into the STEM.

**Dr. Mohammed Abdul Majid** received an M.Sc. degree in Electrical Engineering from King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia, in 2002. In 2011, he was awarded his Ph.D. degree in Electronic and Electrical Engineering from the University of Sheffield in the U.K. From 2002-2008, he was a Lecturer at KFUPM, where he was involved in modeling and simulation of anti-resonant reflecting optical waveguides. He was an EPSRC Prize Postdoctoral Fellow (2011-2012) at The University of Sheffield and Postdoctoral Research Fellow (2012-2015) at the King Abdullah University of Science and Technology (KAUST). He is currently in the Electrical and Computer Engineering department at Effat University, where he is engaged in applying semiconductor quantum dot/quantum well devices to applications such as renewable energy, biomedical imaging, optical communications to solid-state lighting.

**Charles Rajesh Kumar. J** received the Bachelor of Engineering degree in Electronics and Instrumentation Engineering from the Madurai Kamaraj University, India, the Master of Engineering degree in Electronics & Communication Engineering from Anna University, India, and Master of Business Administration degree in Financial Management from the Indira Gandhi National University, India. He has been bestowed the Gold medal for excellence in Master of Engineering degree by the Anna University, India. He has been Faculty member of Engineering at various Universities of repute in India and abroad. He has published numerous research articles in refereed impact factor journals and conference proceedings, which are indexed in Thomson Reuter's Journal Citation Report (JCR) and Scopus. His current research involves VLSI system design, System on Chip (SoC), Network on Chip (NoC), Embedded Systems, Wireless Sensor Networks, Video coding, and Image processing

**Nehal Alyamani** is currently conducting a Master in Energy Engineering at Effat University. She received her Bachelor's degree from Effat University, in 2017, in Electrical and Computer Engineering with a concentration in digital systems, she also holds a Professional diploma in cyber security from King Abdulaziz University and spent a 4-credit hours in Design Thinking at Lingman University in Hong Kong, in 2019. Nehal is interested in Smart Building, Electrical plans, Renewable Energy, and Embedded Systems. In 2016 she participated in 5th International Conference on Electronic Devices, Systems, and Applications (ICEDSA). She has learned about solar energy systems design, wind energy, and waste to energy technologies. Currently, Nehal is conducting research on wind energy development, renewable energy in Saudi Arabia, and designing electrical and mechanical plans on AutoCAD for Effat University College of business building