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ASSESSMENT OF THE ENVIRONMENTAL PERFORMANCE OF FACTORIES IN THE TREATMENT OF EMISSIONS AND RESIDUES OF PRODUCTION IN SAUDI ARABIA

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Abstract: Millions of tons of waste are generated in the Kingdom every year from residential, commercial, and industrial sectors. Rapid industrialization in Saudi Arabia has resulted in the creation of an ecosystem that is far away from the conceptualized "green ecosystem". The resultant production of industrial wastes and the continuous burning of fossil fuels have generated pollutants in the solid, liquid, and gaseous forms, which are proving as a prominent burden on the environment leading to pollution in all forms. An intelligent approach to recycle, reuse, follow the "waste to wealth" approach for producing energy, and educate the human resources to follow green approach may be a probable solution to curb the problem in the present scenario. Therefore, the review provides insights related to the type of industrial wastes produced, the potential approaches for mitigating the emissions, and residues of production in Saudi Arabia along with the involvement of human resources employed in the industrial sectors to achieve a greener ecosystem.

Keywords – Industrialization; emissions; human resources; fossil fuels.

INTRODUCTION

Millions of tons of waste are generated every year, most of which are either dumped into landfills or piled near industrial facilities and cause environmental threat and economic loss. In order to sustain development and protect the environment, an integrated concept on waste reduction, recovery of usable materials, and recycling and reuse of waste should be developed. Serious and prevalent environmental issues pertaining to industrial wastes have become a debatable question in the present scenario [27]. The wastes produced by activities pertaining to industries during the manufacturing process in factories, industries, mills, and mining operations are termed as industrial wastes. These mostly include scrap metal, oil, dirt, gravel, gaseous emissions, chemicals/solvents, etc. Industrial waste may be in solid, liquid, or gaseous form and it can be categorized as hazardous or non-hazardous. The generated industrial wastes can have a deleterious effect on the environment causing pollution of air, water, and soil.

According to EPA, solid waste can be termed as hazardous if it falls into one of the following categories:

- Waste specific to the source: It covers waste generated from specific industries like secondary lead smelting, petroleum refining, and wood preserving. It also covers sludge produced from production processes from the above-said industries.
- Generic waste: This category includes waste produced by widespread manufacturing practices and industrial processes. Some of them include spent solvents, wastes from ink formulation, degreasing operations and leachates resulting from landfills.
- Commercial chemical products: This list covers some insecticides/pesticides, toxic/harmful spent chemicals produced from processes, and creosote.

Additionally, the waste can be termed as hazardous if it has one or more of the following characteristics, including corrosiveness, inflammability, toxicity, or reactivity [1]. The various types of hazardous wastes produced by industries are described below in Table 1.

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Table 1. List of hazardous wastes generated by different industries.

Type of industry	**Generated waste**
Petroleum refining industry	Sludge resulting from the refining process, wastewater containing hydrocarbons.
Chemical manufacturers	Acids, bases, spent solvents
Printing industry	Ink sludges containing heavy metals, discarded solvents, and heavy metal solutions.
Metal manufacturing	Waste containing cyanide and heavy metals.
Construction company	Strong acids and bases, waste from paint solutions which are ignitable, solvents obtained after chemical processes
Leather manufacturing company	Chemicals such as toluene and benzene

The wastes, which do not fall in the category of EPA's definition of hazardous waste, are termed as non-hazardous industrial waste [2]. The classification of non-hazardous wastes follows the under mentioned classification

a. Class 1 waste:

- Liquids that are known to be ignitable at temperatures above 150 of, or are solids and semi-solids and include chemicals considered ignitable under certain conditions that are related to storage, disposal, or treatment;
- Material containing asbestos;
- Empty containers containing hazardous substances or a Class 1 waste, unless the residue has been completely removed through certain processes.
- Materials enclosing specific toxic chemical constituents, which are above the permissible concentration levels, although not enough to be considered hazardous.
- Semi-solids and solids that displays corrosive characteristics after combined with water.
- Waste having more than 50 parts-per million of total polychlorinated biphenyls (PCBs);
- Waste generated after processing, development as well as the production of geothermal energy, crude oil or natural gas which includes greater than 1,500 parts-per million total petroleum hydrocarbon.

b. Class 2 waste:

- Empty containers containing hazardous substances or a Class 1 waste, unless the residue has been completely removed through certain processes and the container made unusable.
- Containers of capacity < 5 gallons which had previously held Class 1 waste;
- Depleted aerosol cans;
- Non-surgical and non-radioactive medical waste;
- Wrappings, Paper, cardboard, linings, and paper packaging materials or absorbents, which do not meet the specifications of hazardous, radioactive or industrial Class 1 criteria;
- Wastes resulting from food products, plastics, glass, aluminum foil, and food packaging that result from plant production, manufacturing, or laboratory operations.

c. Class 3 waste

- This group includes wastes that do not meet the criteria of Class 1 or 2 waste. It includes chemically inert and insoluble substances, samples without detectable levels of PCBs or hydrocarbons, and waste that reflects no risk to human wellbeing and the ecosystem;
- Insoluble and inert solid waste materials, including plastics, rock, brick, glass, dirt, and rubbers.

A SYSTEMATIC APPROACH FOR THE TREATMENT OF EMISSIONS AND RESIDUES OF PRODUCTION IN SAUDI ARABIA

The Kingdom of Saudi Arabia (KSA) is now the main energy-consuming countries worldwide due to mounting population, rapid urbanization along with rising living standards [3]. With a total energy consumption of nine quadrillion British thermal units back in the year 2013, the country was placed among the world's 12 largest primary energy producer countries [4]. It is estimated that the demand for electricity to be doubled by 2032 and fossil fuels remain as the prime basis to encounter the energy necessities of the country. The fossil fuel used that dominates the category includes natural gas, coal, and crude oil, which upon continuous usage causes serious environmental pollution, especially emission of greenhouse gases (GHG). The concept of waste to energy (WTE) is gaining huge attention in the present day, which is a doable option for both disposals of municipal solid waste (MSW) and production of renewable energy [5]. A detailed description of the different approaches for WTE is presented in Table 2. It is estimated that the amount of MSW to be produced in KSA to reach approximately 30 million tons by the year 2033. Currently, the accumulated MSW is disposed to landfills or dump yards followed

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by partial recycling of products like paper and cardboard, which constitutes 10–15% of the over-all MSW. This procedure often culminates in environmental and community health is-sues. Hence, the Government of KSA is adopting suitable solutions for MSW management with an aim to quench the increasing energy demand-supply gap [6].

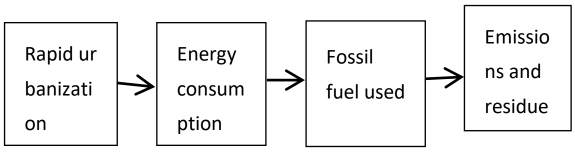

Figure 1. Factors affecting emission of residues

Table 2. List of WTE technologies

Name of WTE technology	Characteristics	Advantages	Disadvantages	Reference
Landfilling	1. Dumping of MSW in planned areas of a manufacturing facility. 2. The mixture of gases is produced such as CH_4, CO_2 and other trace components which are utilized as energy for gas turbines or steam boilers for production of heat or electricity.	1. Low cost and no requirement for skilled labor. 2. Formed gas, if captured can be a source of heat and energy. 3. Unused land can be converted into useful land.	1. The requirement of a large area 2. Chances of groundwater pollution 3. High transportation cost.	[7]
Incineration	Burning at high temperatures (between 750 to 1100 ^{o}C)	1. Reduction of volume of waste up to 80% 2. Reduction of a mass of waste up to 70%	1. High investment in terms of operation and maintenance cost. 2. Production of harmful chemicals leading to air and water pollution and the incidence of cancer.	[8]
Pyrolysis	Thermal decomposition takes place in the absence of oxygen at a temperature range of 300–1300 ^{o}C	1. Volume reduction of wastes up to 50-90%. 2. Capability up to 80% energy recovery from waste.	1. High operating, maintenance and capital cost 2. Low yield of liquid products	[9]
Biomethanation	Anaerobic conversion of organic materials into organic fertilizers and energy.	1. Cost-effective technology 2. Production of nutrient-rich product which is used as biofertilizer.	1. Huge space requirement. 2. May not be applicable on large scale.	[10]
Plasma arc gasification	Conversion of waste and organic materials into syngas or synthesis gas and solid slag using plasma generated by an electrically powered plasma torch.	1. No emission of greenhouse gas, so less pollution. 2. Easy scaling up of technology. 3. Proper utilization of produced waste substrate.	High operating and capital costs due to high energy requirements.	[11]
Refuse derived fuel (RDF)	Involves different phases such as size reduction followed by its separation, crushing, drying and pelletization.	1. Produced pellets have a high calorific value 2. Proper sterilization of waste	1. Incidence of air pollution and the production of ash. 2. High net unit cost per ton	[12]
Dark fermentation	Decomposition of organic substrates by anaerobic bacteria in the absence of oxygen and light to produce biohydrogen by conversion of complex organic compounds such as carbohydrate-rich materials	Applicable for mass production of H_2		[13]

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Microbial fuel cells	Use of aerobic and anaerobic treatments using s electrochemically active microorganisms for the fabrication of biohydrogen.	Negligible contribution to GHG emission	Does not work at low temperatures	[14]
Anaerobic digestion	Decomposition of organic matter for biogas generation (composed of methane and carbon dioxide) in the absence of oxygen.	Applicable for biomass with high water content	1. Unsuitable for wastes containing less of organic matter 2. Degradation of lignin takes extended time period	[15]
Microbial electrolysis cells	Use of electrochemically energetic bacteria to change MSW into H_2 and chemicals, such as CH_4, acetate, hydrogen peroxide, ethanol, and formic acid.	1. Low energy requirement 2. High product recovery and hydrogen translation efficiency.	1.Involvement of high cost 2. Yield effects by the composition of the substrate	[16]

A report was published examining the prospects of power generation using WTE technologies for the KSA from the year 2012 until 2035 employing WTE technologies, including incineration, RDF, and biomethanation. Biomethanation technology showed to be one of the best economical options as compared with the other technologies, and RDF yielded lesser environmental pollution [17].

The major factors contributing to global warming entails burning fossil fuels like coal, oil and natural gas, and releasing carbon dioxide and other greenhouse gases into the atmosphere. Typical approaches to addressing the issue of greenhouse gas emissions include the adoption of policies to reduce greenhouse gas (GHG) emissions. Saudi Arabia is known to be the leading producer and exporter of total petroleum liquids worldwide, which continues to rely exclusively on oil and petroleum industries, including petrochemicals and petroleum refining. Approximately 90% of total Saudi export earnings are obtained from oil export revenues and owing to the lack of availability of non-fossil energy sources, the demand for oil is foreseen to be hugely rising. Hence, Saudi Arabia is the major sufferer of greenhouse gas emissions as its economy is oil-based and the whole energy sector is reliant on fossil fuels and the cheap availability of fossil fuels further discourages investment in renewable energy sources. It is evidenced that the emission of GHG is solely dependent on industrialization, population growth, and increased transportation. Electricity generation, solid waste disposal, and agriculture account for the highest proportion of CO2, CH4, and N2O emissions, respectively [18]. It was elsewhere reported that in the year 1990, the energy sector was the major contributor (90%) of CO2 emissions followed by the industrial processes and product use sector. The waste sector was primarily responsible for emissions of CH4 followed by the energy sector and agriculture while the agricultural sector was majorly responsible for the N2O emissions. From the outlined figures, it is quite evident that the energy sector has the highest potential for reducing greenhouse gas emissions [19]. This prompted the government to take on certain initiates to curb the emission of greenhouse gases in the said region. The Ministry of Water and Electricity has established Energy Conservation and Awareness Department which is responsible for putting restrictions to the maximum power that can be transported to electricity consumers, organizes workshops to inculcate a sense of awareness promoting conservation of energy. It is anticipated that by catching the waste heat produced by the diesel power plant, absorption chillers can be used to produce refrigeration, which will reduce about 10,000 tons/year of CO2 emissions. Additionally, the adoption of solar energy, geothermal energy, and wind energy conversion initiatives was found to be an alternative way of con-serving energy and reducing gas emissions.

Technologies focused on recycling play a key role in mitigating greenhouse gas emissions, which can entail waste collection as well as energy recovery from waste. Thermal recycling can be advocated in situations where recycling seems impossible due to eco-nomic constraints. In corroboration to the outlined ideation, Komatsu et al. explored Re-fuse Derived Fuel (RDF) power generation for the reduction of greenhouse gas (CO2) emissions and concluded that it was possible to produce significant electrical output by large-area waste treatment [20].
The introduction of solid waste management techniques can also help in reducing CH4 emission to a large extent. Biogasification technique involving the simultaneous ap-plication of high-temperature and the use of dry-type methane fermentation system with gas engine power generation conferred lesser emission of greenhouse gases when com-pared with direct combustion with steam power generation and direct combustion with composting [21]. In addition, the utilization of GHG in the industrial sectors for chemical synthesis can also be an appropriate option

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to reduce the proportion of these gases in the ecosystem. In such a pursuit, CO_2 is being utilized in the production of carboxylates, polymers, and methanol. [22] reported regarding a technology involving lower temperatures than the presently used thermal processes to use CO_2 as mild oxidant, which would be eco-friendly in terms of greenhouse gas emissions.

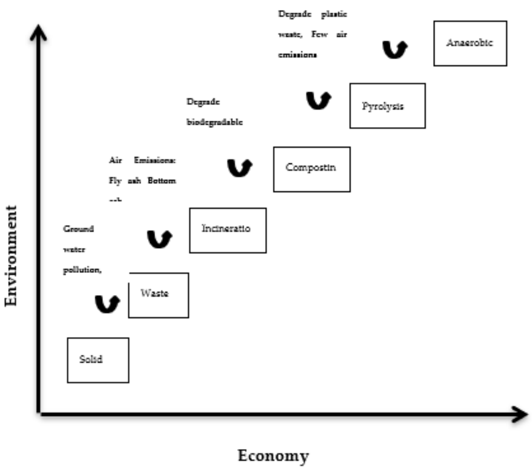

Figure 2. Solid waste management hierarchy for various technologies. [28]

An intelligent and systematic approach needs to be garnered by the industrial man-agers to conserve the natural ecosystem, which will ultimately lead to less pollution. The amount of industrial waste generated primarily depends on the type of raw material used in generating a certain product. Hence, choosing the suppliers of raw material according to environmental criteria is of prime importance. Additionally, environmental awareness seminars and training need to be imparted to the workers in the industrial sectors and a regular in-house audit must be organized to assess the environmental performance of the workers. Hence, it becomes imperative on the part of industrial managers to put substantial effort and time towards training the employees towards adopting "green technology" [23].

A concrete knowledge of environmental protection and substantial awareness is known to have a positive influence on green behavior. Taking into consideration the deficiency of expertise as an obstacle to green initiatives, regular training courses are suggest-ed to improve environmental knowledge and awareness of employees and managers [24]. It is the prime responsibility of the organization to convert its current operations to be more environment-friendly. Therefore, employees must be properly trained to deal with green concepts and practices. Educating staff members about knowledge and awareness of the environment allows them to understand how their activities and actions can affect the environment. Industries must enlighten managers and employees about the significance and influence of their activities on the environment and should issue regular writ-ten reports on their environmental impact management actions. One of the management practices to improve the dedication of workers to green actions is to create a system of encouragement and reward [25].
New industrial set-ups with a probability of having a deterring impact on the environment should organize research on Environmental Impact Assessment along with Agenda 21 requirements [26]. These studies are required to be organized, filed (along with any necessary mitigation plans), and permitted to get environmental licenses to activate business in a particular area.

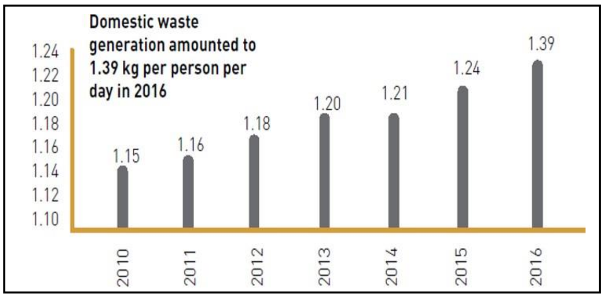

Figure 3. Solid waste generation in Saudi Arabia for the period 2010-2016 [29]

It is also imperative to establish a central waste data management database, which will make a high degree of accuracy in the quantification of waste information. It will thereby support the Kingdom in decisions making by giving precise data as well as indicators, measure the act of waste producers, and assist them in waste management by comparing with others, screen progress towards achieving sector aims that are in line with the Kingdom's vision and international conventions. Moreover, it will enhance public awareness of waste management matters and maintain waste reduction initiatives, helping in the supply and demand planning and the necessary infrastructure and offer the sector with this information, and ultimately attract investment opportunities.

In view of the current scenario, there are certain initiatives taken by KSA to achieve a greener ecosystem:

- The establishment of a master gas collection system has resulted in dramatically lowering CH_4 emissions from the oil and gas fields in the stated region.
- Continuous attempts are being placed for trapping emissions and enhancing oil recovery from the field. Carbon management technology roadmap was

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suitably developed which aims for leveraging petroleum industry resources.

- National Energy Efficiency Program was launched with an aim to educate the huge masses to have a strong knowledge relating to the significance of energy conservation and proper procedures to execute the same.
- Suitable steps are taken to improve renewable and nuclear energy re-sources for substituting the use of crude oil and natural gas for producing electricity. In agreement with it, the Kingdom has signed an agreement with France for generous cooperation in improving nuclear energy with the use of geothermal, wind and solar energy.
- The Kingdom has also adopted the "Cogeneration" approach for sequentially producing two or more forms of energy from a common source of fuel, which targets to be used under different modes and technologies established on the type of application.
- Various programs, treaties, and centers are established in the region with an aim to encourage research and development in preserving the natural ecosystem. Center of Research Excellence in Renewable Energy was established with an aim of carrying out scientific/technological development in all main spheres of renewable energy with a core emphasis on developing public awareness and finally catering to the renewable energy industry in the Kingdom.

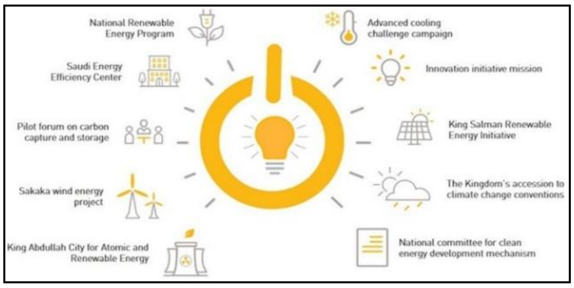

Figure 4. Vision 2030 strategic objectives in renewable energy

CONCLUSION

In this review, we have summarized the rigorous efforts placed by the researchers hold a preliminary proof-of-concept relating to the use of renewable sources of energy like solar and wind energy conversion for preserving the ecosystem. Huge investments in increasing the use of renewable sources for reducing GHG emissions hold a concrete background indicating strong commitments for environment conservation. In addition, the exploitation of microalgae for biodiesel production, biological sequestration of CO2, and wastewater treatment seems promising as a future endeavor. Therefore, structured efforts must be initiated between the public and private sectors along with the common people to acknowledge the necessity for genuine commitment and action to address GHG emissions with a view to guarantee a sustainable ecosystem for current and future generations.

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