RESILIENT INFRASTRUCTURE
June 1–4, 2016
RESILIENT INFRASTRUCTURE LONDON 2016

WASTE-BASED BIOREFINERIES IN DEVELOPING COUNTRIES: AN IMPERATIVE NEED OF TIME

Iqbal Mohammad Ismail
King Abdulaziz University, Saudi Arabia

Abdul-Sattar Nizami
King Abdulaziz University, Saudi Arabia

ABSTRACT

The current world population of 7.2 billion is projected to reach up to 8.2 billion in 2025 with current annual growth rate of 1%. The Asia, Middle East, Africa and Latin America are the places, where most of this growth will occur due to rapidly growing industries and urbanization. As a consequence, the generation rate of municipal solid waste (MSW) will increase from 1.2 to 1.5 kg per capita per day in next 15 years. Globally, around 2.4 billion tons of MSW is generated every year that will reach up to 2.6 billion tons by 2025. Similarly, the energy demand will increase significantly in developing countries, especially in Asia with an increase of 46-58% at annual rate of 3.7% till 2025. Fossil fuels are the most relied source at the moment to meet the world's energy demands. The intensive and solely utilization of fossil resources are not only depleting our natural reserves but also causing global climate change. The municipal waste can be a cheap and valuable source of renewable energy, recycled materials, value-added products (VAP) and revenue, if properly and wisely managed. The possibilities for converting waste-to-energy (WTE) are plentiful and can include a wide range of waste sources, conversion technologies, and infrastructure and end-use applications. Several WTE technologies such as pyrolysis, anaerobic digestion (AD), incineration, transesterification, gasification, refused derived fuel (RDF) and plasma arc gasification are being utilized to generate energy and VAP in the form of electricity, transportation fuels, heat, fertilizer, animal feed, and useful materials and chemicals. However, there are certain limitations with each WTE technology, as an individual technology cannot achieve zero waste concept and competes with other renewable-energy sources like wind, solar, and geothermal. A conceptual and technological solution to these limitations is to integrate appropriate WTE technologies based on the country/or region specific waste characterization and available infrastructure, labor skill requirements, and end-use applications under a biorefinery concept. Such waste-based biorefinery should integrate several WTE technologies to produce multiple fuels and VAP from different waste sources, including agriculture, forestry, industry and municipal waste. This paper aims to assess the value of waste-based biorefinery in developing countries as a solution to waste-related environmental and human health problems with additional bonus of renewable energy and VAP.

Keywords: Waste-based biorefinery; Municipal solid waste (MSW); Waste-to-energy (WTE); Value-added products (VAP); Renewable energy; Fossil fuels

1. INTRODUCTION

The world population was about 7.2 billion in 2013 that is estimated to reach up to 8.2 billion by 2025 with the current annual growth rate of 1%. In coming decades, the population growth will mainly occur in developing world with more than half only in Africa (UN-DESA, 2012). The urban areas around the world accommodate about half of the world population (Gilbert and Wendell, 2008), which will increase by about 1.5% in next 15 years. Similarly like population, the growing urbanization will be mostly concentrated in the developing countries, particularly in Asia (GHO, 2014). As a result, the municipal solid waste (MSW) generation and energy demand have increased significantly in developing world (Sharholy et al. 2008). Globally, the generation of MSW is around 2.4 billion tons per year that is projected to reach up to 2.6 billion tons by the 2025 (World Bank, 2005). The per-capita generation of non-recyclable waste in the European Union (EU), and Asia ranges from 0.9 to 1.6 kg/day and 0.7 to 1.5 kg/day respectively (Themelis, 2006). The sustainable treatment of MSW is critical not only from sanitation, environmental and public health point of view (Sadaf et al., 2016), but also due to its economic values, including potential contribution to energy demands and reduction in landfill cost (Rathi, 2006).

The conventional fossil-based fuels and renewable (e.g. hydro, wind, solar, waste-to-energy (WTE), geothermal, etc.) energy sources have to suffice the ever growing energy demand-supply of the world (Nizami et al. 2015a). The energy demand in developing countries is expected to increase by 46-58% in 2025 in comparison to current energy needs (FAO, 2010). In Asia, particularly, the energy needs are projected to increase at an annual rate of 3.7% (US-EIA, 2007). Such trend will play a key role in future energy demand-supply in Asia; making the region of high interest for energy developments. At present, fossil fuels are the most relied source of energy supply to the world with electricity production of approximately 13,700 TWhr that is about 84% of the total electricity production worldwide (IEO, 2013). These resources are non-renewable and will eventually dry out with the ever increasing population, urbanization, living standards and energy demands (Demirbas et al. 2016).

The advancement in energy recovery technologies with reduced process cost, and governmental subsidies have made renewable-energy sources more competitive in the energy market in the last two decades (Ouda et al. 2016). Kyoto Protocol has added extra momentum towards green energy, enforcing governments to move towards renewable energy (Ouda et al. 2015). The current dependence on renewable energy is significantly lower than conventional energy sources; however, their contribution is expected to rise dramatically in the future. So far, the wind and solar energy are the fastest growing energy resource in Asia, while hydro power achieved more than 200% increase. The WTE is next in developing countries with 150% potential increase that is more than the increase observed in the USA. The worldwide electricity generation through renewable resources is expected to achieve 3750 billion kWhr by the end of 2020 (US-EIA, 2007).

Biomass has been utilized for energy purposes since ancient times (Nizami et al. 2013). For instance, wood was used for cooking and heating. Ethanol was used to run the early automobiles and plant oils were used to run the diesel engines. The concept of biomass to energy has been re-emerged to produce eco-friendly and sustainable fuels and reduce the greenhouse gases (GHG) emissions (Murphy et al. 2010). The biomass to renewable energy is in solid, liquid and gaseous fuel forms (Rana and Roberto, 2008). Liquid fuels are used as transportation fuel and source of electricity generation through turbine and engine (Nizami and Ismail, 2014). The gaseous fuels are used to generate electric power in special designed direct and indirect turbine-equipped plants (IEA, 2014). The solid fuels are used in power plants as fuel briquettes or pellets (Ouda et al. 2016). Moreover, the value-added products (VAP) such as organic fertilizer, animal feed, and useful materials and chemicals are produced from organic biomass. Initially, most of the biomass for producing fuels were produced from fertile land. As a result, the issues of land-use and high food and animal feed price were linked with the fuels that were produced from fertile land resources (Sims et al. 2010). Therefore, the non-food biomass resources such as corn stover, cereal straw, sugar cane bagasses, perennial grasses, forest and agricultural residues, and municipal and industrial waste are given significant attention in recent years to generate single or multiple fuels under different conversion pathways (Naik et al. 2010).

Biorefinery is a sustainable concept of generating renewable-energy (IEA, 2014); similar to petroleum refinery with multi-processes and multi-products such as food, feed, materials and chemicals, and energy in the form of fuel, power and heat (Table 1). This new energy concept is very relevant for developing countries, where limited WTE and material recovery facilities exist, and waste-related environmental problems are prevailing (Ahmed et al. 2016). Therefore, developing non-food biomass or waste-based biorefineries in developing countries will not only solve the waste management problems, but also generate significant economic and environmental benefits in terms of renewable energy (Nizami et al. 2015b & c). This paper aims to assess the value of waste-based biorefineries in developing countries. A case study of Kingdom of Saudi Arabia (KSA) was presented under this concept.

2. WASTE-BASED BIOREFINERY

In the scientific literature, there is no standard classification of existing and emerging energy recovery technologies (Cherubini et al. 2009). Different pathways and platforms are used to classify these technologies based on their products, feedstock, and processes. Generally, conversion technologies are classified based on transportation fuels (Table 2). Other important classification criteria are biorefining (Table 3), which is based on biomass sources, type of fuel and VAP (Kamm and Kamm, 2005). However, the desired form of fuel determines the technology route, followed by the availability and quantities of biomass (Table 4). Biomass conversion to energy utilizes four conversion pathways such as thermal, biological, chemical and physical processes (Table 5). Thermochemical processes include pyrolysis, gasification, incineration and plasma arc gasification technologies that use high temperature to convert carbonaceous biomass into electricity, heat and VAP (Verma et al. 2012). Chemical and physical conversion processes include rendering and transesterification technologies that use chemical agents to convert biomass into liquid fuels and VAP (Brodeur et al. 2011). Biochemical processes include anaerobic digestion (AD) and fermentation technologies that use biological agents to convert biomass into liquid and gaseous fuels and VAP (Dobbelaere et al. 2014).

2.1 Types of Waste-Based Biorefineries

There are different types of biorefineries that are under development such as agricultural biorefinery, forestry biorefinery, whole crop biorefinery, lignocellulosic feedstock biorefinery, green biorefinery, and municipal or industrial waste biorefinery (Börjesseon and Mattiasson, 2008). For instance, in green biorefinery, grass/grass silage is used for production of fibre-rich cake and the nutrient-rich juice (Kamm and Kamm, 2004). The cake is further processed into VAP such as dyes, pigments and crude drugs through different methods. The nutrient-rich juice is processed into feed pellets, raw material for chemical production such as levulinic acid and syngas and hydrocarbons. The wastes from all these processes are converted into biogas and organic fertilizer through AD technology (Kamm and Kamm, 2005). All the potential waste sources that can be used as feedstock for waste-based biorefineries include agricultural, forestry, animal, industrial and municipal waste (Table 6). Based on these waste sources, waste-based biorefinery is divided into following three main subtypes.

2.2.1 Agricultural Waste-based Biorefinery

Kaparaju et al. (2009) investigated the economic and energy-efficient processes utilizing agricultural residues in the biorefinery network. They examined various fuel productions such as bioethanol, biogas and biohydrogen using wheat straw as a feedstock. Half of wheat straw was used without pretreatment, while half of straw was hydrothermally pretreated. The pretreated wheat straw produced liquid and solid fractions that were rich in hemicellulose and cellulose respectively. Various treatments were studied under following six different scenarios:
(1) Energy production from incineration of untreated wheat straw
(2) Biogas production from AD of untreated wheat straw
(3) Conversion of pretreated wheat straw to biogas
(4) Fermentation of pretreated wheat straw to produce bioethanol
(5) Conversion of pretreated wheat straw to biogas, bioethanol and biohydrogen

The results showed that the most energy-efficient process was biogas production using AD alone or multiple fuel productions from wheat straw in comparison to bioethanol production alone from fermentation of hexose sugars. Moreover, they concluded that the biorefinery concept is more energy proficient than converting biomass into single fuel.

2.2.2 Forestry Waste-based Biorefinery

According to Klass, (1998) the earth surface covered by forest is about 32% of the entire available land. Moreover, forests are accounted for 89.3% and 42.9% of total standing biomass and annual biomass production respectively. In terms of energy generation, forest has the capacity to produce 1,030 quadrillion BTU/year that was more than double of the world’s total primary energy consumption of 460 quadrillions BTU in 2005. Therefore, for forestry-based biorefinery, forestry residues can be an imperative source of feedstock. From last few decades, energy productions from forests were lowered down due to cutting of forest for paper, timber and other products (Pande and Bhaskarwar, 2012). However, the significance of forests for energy production has regained its momentum due to the biorefinery concept. Currently, biorefinery is considered a promising alternative for paper and pulp mills effluents. Forest biomass is mainly composed of lignocellulosic material that contain lignin (16-31%), cellulose (40-47%), hemicellulose (25-35%) and other extractives (2-8%). Whereas, the structural rigidity by tightly cross-linkage of hemicellulose and polysaccharide's cellulose via ether and ester linkage require pretreatments, in order to convert forestry feedstock into a suitable digestive feedtsock for biorefineries (Pande and Bhaskarwar, 2012).

2.2.3 Industrial and Municipal Waste based-Biorefinery

Municipal waste is a combination of wastes generated by commercial, domestic and construction activities (Iyer et al. 2002). There are various municipal waste management techniques such as recycling, material recovery and WTE (Ouda et al. 2016). A promising waste management technique under organic waste-based biorefinery is the separation and utilization of green components in AD and composting for energy and organic fertilizer production. Nowadays, industrial and waste-based biorefineries are given significant attention due to load reduction of waste on landfills, and higher net GHG emissions saving and energy balances in comparison to other biomass-based fuels (Posada et al. 2013).

A waste-based biorefinery can be an energy or VAP oriented. However, the hybrid or integrated waste-based biorefinery can produce more efficiently the both energy and VAP and is capable of switch towards alternative feedstocks, if required. Such integrated waste-based biorefinery should use different combination of WTE or conversion technologies and feedstocks for numerous fuel productions. Therefore, in order to get utmost energy and economic benefits from waste-based biorefinery, integration of all three types of waste-based biorefineries such as agricultural, forestry and industrial and municipal waste-based biorefineries should be required (Pande and Bhaskarwar, 2012). The USA's National Renewable Energy Laboratory (NREL) and Du Pont in October 2003 launched the World's first integrated biorefinery project. Afterwards, a large number of integrated biorefineries have been successfully developed in different parts of the world utilizing different feedstock for different products (Pande and Bhaskarwar, 2012). However careful planning is critical for the availability, generation and utilization of waste sources as feedstock for integrated waste-based biorefinery (Ouda et al. 2016). Moreover, a focus on the conversion process should be given to analyse, whether it is technically and economically feasible and environment friendly (Pande and Bhaskarwar, 2012).

3. CASE STUDY OF SAUDI ARABIA

KSA is facing a chronic challenge of sustainable waste management. There is no energy or VAP recovery facility exits in KSA; all the collected municipal waste is disposed to landfill or dump sites untreated. As a result, the problems of GHG emissions, and groundwater and soil contamination along with public health issues are occurring in the waste-disposal vicinities (Ahmed et al. 2016). Every year, around 15 million tons of MSW is generated in KSA with an average rate of 1.4 kg per capita per day (Nizami et al. 2016). This municipal waste can be a valuable source of recycled materials and energy and VAP, if properly and wisely managed (Ouda et al. 2016). The food and the plastic waste are the two largest waste streams that collectively add up to 70% of total MSW. Nizami et al. (2015a) and Ouda et al. (2016) very recently examined the appropriate WTE technologies for KSA according to the local waste composition and energy contents. They suggested the following three WTE technologies along with recycling to divert the MSW from landfills to material recovery and WTE facilities.
(1) AD technology for food waste that accounts for 50.6% of total MSW
(2) Pyrolysis for plastic waste that is 17.4% of total MSW
(3) RDF for paper, cardboard, wood, textile and leather waste that are collectively 26.3% of total MSW
(4) Recycling for glass and metals that collectively account for 5.6% of total MSW

An estimated potential of 2.99 TWh electricity can be generated from AD plants every year in KSA, if all of the produced food waste is utilized in AD facilities. Similarly, from pyrolysis and RDF plants, an electricity potential of 1.03 and 1.55 TWh electricity can be achieved annually in KSA, if all of the plastic waste and RDF related wastes are utilized in their respective processes (Nizami et al. 2015a). An integrated waste-based biorefinery with multiple processes and products is proposed for KSA based on the country's waste composition and generation rates and energy contents (Figure 1). However, according to Nizami et al. (2015a, c & d) and Ouda et al. (2016) recommendations, the real decision of developing and commissioning WTE technologies for integrated waste-based biorefinery in KSA requires in-depth socio-economic, technical and environmental evaluations using the life cycle assessment (LCA) tools.

4. CONCLUSIONS

Increasing energy consumption has exerted great pressure on natural resources and results in significant GHG emissions, especially in developing countries. This has led to a move towards sustainable energy production, mainly from the non-food biomass, including cereal straw, sugar cane bagasse, perennial grasses, forest and agricultural residues and industrial and municipal waste, in order to improve the energy supply, rural economies and agricultural industries. The full commercialization of WTE technologies are expected in near future due to continuous improvement in process technologies with reduced process costs, governmental subsidizes and generation of variety of energy in the form of fuel, heat, power and VAP such as chemicals, materials, animal feed, organic fertilizer under a biorefinery concept. The LCA-based studies on the integrated waste-based biorefinery will provide a knowledge base platform for academics and industries about technical, economic and environmental benefits and limitations of the conversion technologies. Moreover, the findings of the LCA studies will help the municipalities to optimize the different waste management practices and develop new sustainable and environment-friendly waste collection, handling and disposal methods. A case study of KSA showed potential economic and environmental benefits of developing integrated waste-based biorefinery in the country that include reduction in GHG emissions, and waste landfill cost, improvements in public health, protection of land resources, and generation of renewable electricity.

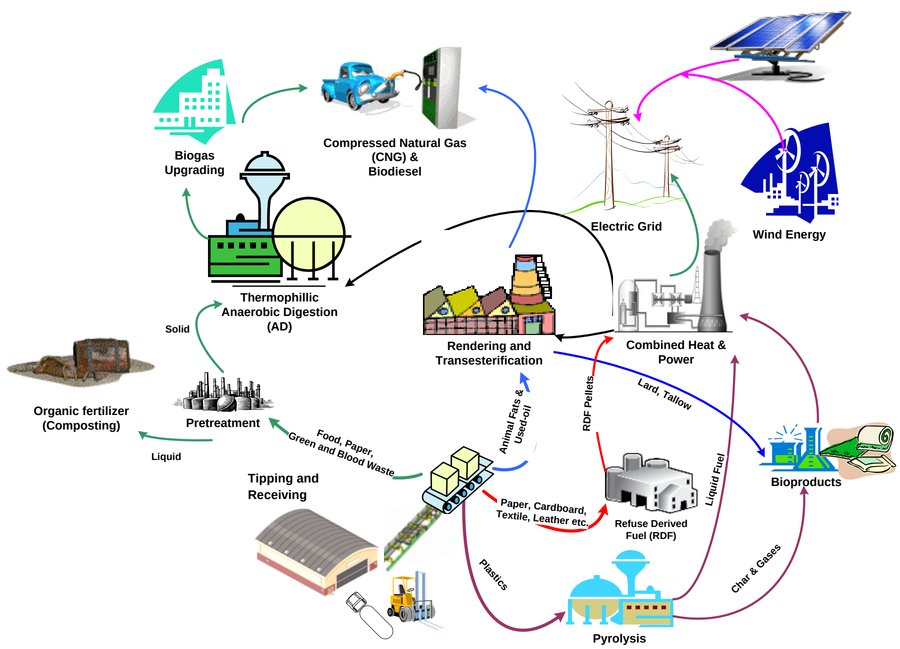

Figure 1: A Conceptual model of integrated waste biorefinery in KSA

Table 1: Salient features of integrated waste biorefinery (Sims et al., 2010; Jose and Bhaskar, 2015)

- Lesser amount of carbon and hydrogen comparable to petroleum feedstock and rich in oxygen
- Oxygen presence increase the porosity and decrease heat of molecules
- Difficult to combine with fossil fuel due to high polarity
- Reduce transportation cost due to biorefinery setup close to feedstock
- Variable feedstock composition
- Capability of processing raw materials of different composition
- Various products formation facility
- Require large array processing technologies
- Different industrial complexes can be developed
- Contributing to economic uplifts of rural areas due set up in these areas
- Increase carbon credits
- Carbon negative fuels can be develop
- Variability in products nature and yield due to seasonal changes in composition and availability of feedstock
- Require long term feedstock storage
- Different from oil refinery due to product range

Table 2: Biorefinery classification based on transportation based fuels (Jose and Bhaskar, 2015; Pande and Bhaskarwar, 2012)

1st generation biofuels	2nd generation biofuels	3rd generation biofuels	4th generation biofuels
Fuels produced from raw materials in competition with food and feed industry. Examples include, bioethanol from sugarcane, sugar beet and starch (corn and wheat), biodiesel from oil based crop like rape seed, sunflower, soybean, palm oil and waste edible oils and starch derived biogas	Fuels produced from non-food crops (energy crops) or raw materials based on waste residues. Examples include, biogas from waste and residues, fuels from lignocelluloses materials like residues from agriculture, forestry and industry and fuels from energy crops such as sorghum	Fuels produced using aquatic microorganisms like algae Examples include, biodiesel produced using algae and algal hydrogen	Fuels based on high solar efficiency cultivation Examples include, carbon-negative technologies and technologies of the future

Table 3: Biorefinery classification based on biorefining (Naik et al., 2010; Pande and Bhaskarwar, 2012)

Biorefinery type	Features	Products
Agriculture biorefinery	Uses all types of waste generated from agricultural activities	Methane, hydrogen, biofuels, energy, chemicals and materials
Cereal biorefinery	Uses dedicated starch crops, sugar crops and grains	Bioethanol
Oil seed biorefinery	Uses oil seed crops and oil plants	Vegetable oil and biodiesel
Green biorefinery	Uses grass and green plants	Bioethanol
Lignocellulosic biorefinery	Uses agricultural wastes and crop residues	Bioethanol (Lignocellulosic)
Forest biorefinery	Uses forest residues, barks, saw dust, pulping liquors and fibers	Fuels, energy, chemicals and materials
Industry and municipal waste biorefinery	Uses all types of waste including forest generated waste, industrial waste and municipal solid and liquid waste	Methane, hydrogen, fuels, energy, chemicals and materials

Table 4: Process used to produce energy and value added products (Awang et al. 1988; Antizar-Ladislao and Turrion-Gomez, 2008)

Technologies	Products	Potential utilization	Application
Anaerobic digestion (AD)	Fuel gas	Boiler, gas engine, gas turbine, fuel cell	Heat power, heat
Fermentation, extraction	Liquids	Oil burners, liquids motor fuels, fuel cells	Power, heat, transport
Combustion	Hot exhaust gas	Boiler, steam engine	Space heating, process heat, hot water, power, heat
Gasification	Fuel gas,	Boiler, gas engine, gas turbine, fuel cells,	Heat power, heat
	Synthesis gas	Synthetic natural gas, liquid motor fuels, chemicals, heat	Heat, transport
Pyrolysis	Gas fuel,	Engine boiler engine	Power, heat
	Liquid (fuel oil), char (solid fuel),	Engine boiler engine	Power, heat
Enzyme	Ethanol, amino acid (protein based chemicals)	Oil burners, liquids motor fuels, fuel cells	Power, heat, transport
Hydrolysis	Cellulose, hemicelluloses and lignin		Chemicals, Additives, VAP
Solvent extraction	Primary and secondary metabolites		Chemicals, Additives, VAP
Supercritical conversion of biomass (greener route)	Cellulose, hemicelluloses and lignin		Chemicals, Additives, VAP
Liquefaction	Heavy oil	Engine boiler engine	Power, heat
Refuse Derived Fuel (RDF)	RDF pellets	Power plants	Power, heat

Table 5: Waste to energy and VAP processes

Thermochemical conversion	Biological conversion	Chemical conversion	Physical conversion
• Liquefaction • Pyrolysis • Gasification • Combustion	• AD • Fermentation • Enzyme • Aerobic digestion /composting	• Hydrolysis • Solvent extraction • Supercritical conversion of biomass (greener route) • Transesterification • RDF	• Mechanical extraction • Briquetting of biomass • Distillation

Table 6: Sources of waste for waste biorefineries (Antizar-Ladislao and Turrion-Gomez, 2008; Jose and Bhaskar, 2015)

Forestry waste	Agricultural waste	Animal waste	Industrial waste	Municipal waste
• Bark • Sawdust • Pulping liquors • Fibers • Dead trees • Culling and logging waste • Leaves • Straws	• Crop waste • Citrus waste • Green waste • What and rice straw waste • Wood chips • Sawdust	• Fats • Tallow • Blood • Meat processing waste • Manure • Swine waste	• Olive pulp • Wastewater from pulp and paper industry • Wastewater from sugar or toffee industry	• Food waste • Used cooking oil • Sewage • Plastics • Paper and card boards • Textile • Leather • Construction and demolition waste

REFERENCES

Ahmad, I., Rehan, M., Balkhyour, M.A., Abbas, M., Basahi, J.M., Almeelbi, T., Ismail, I.M.I. 2016. Review of environmental pollution and health risks at motor vehicle repair workshops: challenges and perspectives for Saudi Arabia. *Int. J. Agric. Environ. Res*., 2(1):1-23.

Antizar-Ladislao, B. and Turrion-Gomez, J.L. 2008. Second-generation biofuels and local bioenergy systems. *Biofuels, Bioprod. Bioref*., 2:455–469.

Awang, G.M., Jones, G.A., Ingledew, W.M. 1988. The acetone-butanol-ethanol fermentation. *Crit Rev Microbiol*., 15:33–67.

Börjesseon, P. and Mattiasson, B. 2008. Biogas as a resource-efficient vehicle fuel. *Trends Biotechnol.*, 26(1):7-13.

Brodeur, G., Yau, E., Badal, K., Collier, J., Ramachandran, K.B., Ramakrishnan, S. 2011. Chemical and physicochemical pretreatment of lignocellulosic biomass: a review. *Enzyme Research*, 2011:17.

Demirbas, A., Bafail, A., Nizami, A.S. 2015. Heavy oil upgrading: unlocking the future fuel supply. *Petroleum Science and Technology,* 34(4):303-308.

Dobbelaere, S., Anthonis, T., Soetaert, W. 2014. *Conversion technologies for the production of liquid fuels and biochemicals, in cellulosic energy cropping systems* (Ed D. L. Karlen), John Wiley & Sons, Ltd, Chichester, UK. doi: 10.1002/9781118676332.ch2

FAO: Food and Agriculture Organization. 2010. Energy supply and demand: trends and prospects. Available from: ftp://ftp.fao.org/docrep/fao/010/i0139e/i0139e03.pdf

GHO: Global Health Observatory. 2014. World Health Organization. Available from: http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

Gilbert, M.M., Wendell, P.E. 2008. *Introduction to Environmental Engineering and Science*, Chapter 9: *Solid Waste Management and Resource Recovery*, Third Edition, Pearson Education Inc., ISBN-13: 978-0-13-233934-6.

IEA: International Energy Agency. 2014. Sustainable and synergetic processing of biomass into marketable food & feed ingredients, products (chemicals, materials) and energy (fuels, power, heat). IEA Task 42: BIOREFINING. Wageningen, the Netherlands.

IEO: International Energy Outlook 2013, Available from: http://www.eia.gov/forecasts/ieo/world.cfm

Iyer, P.V.R., Rao, T.R., Grover, P.D. 2002. *Biomass: thermo-chemical characterization*. Indian Institute of Technology, New Delhi

Jose, S. and Bhaskar, T. eds., 2015. *Biomass and Biofuels: Advanced Biorefineries for Sustainable Production and Distribution*. CRC Press.

Kamm, B. and Kamm, M. 2004. Biorefinery – Systems. *Chemical & Biochemical Engineering Quarterly,* 18:1-6.

Kamm, B. and Kamm, M. Principles of biorefineries. 2005. *Appl Microbiol Biotechnol.,* 64: 137–145.

Kaparaju, P., Serrano, M., Thomsen, A.B., Kongjan, P., Angelidaki, I. 2009. Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept. *Bioresour Technol.,* 100:2562–2568.

Klass, D.L. 1998. Biomass for renewable energy, fuels and chemicals. *Academic Press*, San Diego

Murphy, J.D., Korres. N.E., Singh. A., Smyth. B., Nizami. A.S., Thamsiriroj. T. 2010. Grass Biomethane. Environmental Protection Agency (EPA), Ireland. EPA Climate Change Research Programme 2007-2013. (2007-CCRP-1.7), Johnstown Castle, Co. Wexford, Ireland. Available from: http://www.epa.ie/downloads/pubs/research/climate/

Naik, S.N., Goud, V.V., Rout, P.K., Dalai, A.K. 2010. Production of first and second generation bioenergy: a comprehensive review. *Renewable Sustain. Energy Rev*., 14:578-597.

Nizami, A.S., Saville BA, MacLean HL. 2013. *Anaerobic Digesters: challenges and perspectives*. Chapter in 'Bioenergy Production by Anaerobic Digestion Using Agricultural Biomass and Organic Waste'. Pp 139-152, ISBN 13: 978-0-415-69840-5, Routledge, Taylor and Francis, US.

Nizami, A.S., Ismail IMI. 2013. *Life cycle assessment of biomethane from lignocellulosic biomass*. Chapter in 'Life cycle assessment of renewable energy sources'. Green Energy and Technology book series. 2013, XVI, 293 p. 100 illus., 24 illus. in color. Springer-Verlag London Ltd.

Nizami, A.S., Rehan, M., Ouda, O.K.M., Shahzad, K., Sadef, Y., Iqbal, T. 2015a. An argument for developing waste-to-energy technologies in Saudi Arabia. *Chemical Engineering Transactions*, 45:337-342. doi:10.3303/CET1545057.

Nizami, A.S., Ouda, O.K.M., Rehan, M., El-Maghraby, A.M.O., Gardy, J., Hassanpour, A. 2015b. The potential of Saudi Arabian natural zeolites in energy recovery technologies. *Energy, doi*:10.1016/j.energy.2015.07.030.

Nizami, A.S., Rehan, M., Ismail, I.M.I., Almeelbi, T., Ouda, O.K.M. Waste biorefinery in Makkah: a solution to convert waste produced during Hajj and Umrah Seasons into wealth. Conference: *15th Scientific Symposium for Hajj, Umrah and Madinah visit*. Held in May 2015c in Medina, Saudi Arabia, doi: 10.13140/RG.2.1.4303.6560.

Nizami, A.S. Waste-to-energy potential in Saudi Arabia. Article published in Blog Magazine 'EcoMENA; Echoing Sustainability'. December 23, 2015d. Available from: http://www.ecomena.org/wastetoenergy-saudiarabia/

Nizami, A.S. Recycling prospects in Saudi Arabia. Published in Blog, 'EcoMENA: Echoing Sustainability', on 26 January 2016. Available from: http://www.ecomena.org/recycling-in-saudi-arabia/

Ouda, O.K.M., Raza, S.A., Al-Waked, R., Al-Asad, J.F., Nizami, A.S. 2015. Waste-to-energy potential in the Western Province of Saudi Arabia. *J King Saud University-Engineering Sciences*, doi:10.1016/j.jksues.2015.02.002.

Ouda, O.K.M., Raza, S.A., Nizami, A.S., Rehan, M., Al-Waked, R., Korres, N.E. 2016. Waste to energy potential: a case study of Saudi Arabia. *Renewable & Sustainable Energy Reviews*, doi: 10.1016/j.rser.2016.04.005.

Pande, M. and Bhaskarwar, A.N. 2012. *Biomass conversion to energy,* Chapter 1. Published in C Baskar et al. (eds.), *Biomass Conversion*. DOI: 10.1007/978-3-642-28418-2_1, Springer-Verlag Berlin Heidelberg.

Posada, J.A., Patel, A.D., Roes, L., Blok, K., Faaij, A.P., Patel, M.K. 2013. Potential of bioethanol as a chemical building block for biorefineries: preliminary sustain- ability assessment of 12 bioethanol-based products. *Bioresource Technology*, 135:490–499.

Rana, M.C. and Roberto, R. 2008. Renewable Energy from Biomass: Solid Biofuels and Bioenergy Technologies. *Sustainable Development and Environmental Management*, 5 (3): 221-235.

Rathi, S. 2006. Alternative approaches for better municipal solid waste management in Mumbai, India. *Journal of Waste Management*, 26 (10):1192–1200.

Sadaf, Y., Nizami, A.S., Batool, S.A., Chaudhary, M.N., Ouda, O.K.M., Asam, Z.Z., Habib, K., Rehan, M., Demibras, A. 2016. Waste-to-energy and recycling value for developing integrated solid waste management plan in Lahore. *Energy Sources, Part B: Economics, Planning, and Policy*, doi: 10.1080/1556249.2015.105295.

Sharholy, M., Ahmad, K., Mahmood, G., Trivedi, R.C. 2008. Municipal solid waste management in Indian cities – A review. *Waste Management*, 28:459–467.

Sims, R., Mabee, W., Saddler J., Taylor M. 2010. An overview of second generation biofuel technologies. *Bioresource Technology*, 101:1570-1580.

Themelis, N. 2006. Energy recovery from global waste to energy, Waste to energy Research and Technological Council.

US-EIA: Unites States Energy Information Administration. 2007. Available from: http://www.eia.gov/forecasts/aeo/archive.cfm

UN-DESA: United Nations. 2012. *World Population Prospects: The 2012 Revision.* Department of Economic and Social Affairs, Population Division. ST/ESA/SER.A/345, United Nations, New York.

Verma, M., Godbout, S., Brar, S.K., Solomatnikova, O., Lemay, S.P., Larouche, J.P. 2012. Biofuels production from biomass by thermochemical conversion technologies. *International Journal of Chemical Engineering*, 2012:18.

World Bank. 2005. Urban Development Series-Knowledge Papers, A Global Review of Solid Waste Management, Available from: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap3.pdf