

PAPER • OPEN ACCESS

The Contribution of Bioenergy in the Renewable Energy Technology Mix: Research Perspective

To cite this article: A.C Eloka-Eboka and R Chetty 2019 *J. Phys.: Conf. Ser.* **1378** 022053

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

The Contribution of Bioenergy in the Renewable Energy Technology Mix: Research Perspective

Eloka-Eboka, A.C. and Chetty, R.

Department of Construction Management and Quantity Surveying,
Mangosuthu University of Technology,
Umlazi, Durban, South Africa.
Email: eboka.andrew@mut.ac.za

Abstract

Renewable energy from biomass, biofuels and biodiesel encapsulated as bioenergy has become an interested aspect of clean energy technology and is currently receiving global attention. Bioenergy produced from renewable feedstocks and sustainable wastes using several technologies is the focus of this research and development presentation. In South Africa, bioenergy in the forms of solids, liquids and gaseous fuels have been characterised as first, second and third generations (1D, 2D and 3D) systems in order to solve myriads and most critical energy aspects of the sustainable development goals of Africa. The technologies evolved have been directed to specific bioenergy feedstocks and needs for optimal utilisation and application and they include: direct combustion (for power generation), anaerobic digestion (for methane-rich gas production), fermentation (of sugars for alcohols as fuels), oil extraction and transesterification (for biodiesel as fuels), pyrolysis (for biochar, gas and oils for fuel and chemicals), gasification (for carbon monoxide and hydrogen-rich syngas as fuels and value added products) and generalised thermo-chemical conversion. The technologies are further driven by arrays of secondary treatments (stabilization, dewatering, upgrading, refining) depending on specific final products. This presentation explored these and all such research and development (R and D) strategies and technological packages of bioenergy in South Africa. These have implications in the commercialisation, entrepreneurship, informing policy and direct impact in Africa's energy sustainability. The exploration of sugar-cane bagasse biomass for use as briquette/pellet fuels are also presented.

Keywords: Bioenergy, Biofuels, Biomass, Biodiesel, bio-product, bio-processing, bio-refineries.

1. Introduction

Bioenergy consists of solids, liquids, or gaseous fuels. Liquid fuels can be used directly in the existing roads, railroad, and aviation transportation network stock, as well as in engine and for power generations. Solid and gaseous fuels can be used for the production of power as well as for other purpose-driven direct or indirect turbine-equipped power plants. Chemical products can also be obtained from all organic matter produced. Additionally, power and chemicals can come from the use of plant-derived industrial, commercial, or urban wastes, or agricultural or forestry residues. Biomass resources include primary, secondary, and tertiary sources of biomass. Primary biomass resources are produced directly by photosynthesis and are taken directly from the land [1-3]. They include perennial short-rotation woody crops and herbaceous crops, the seeds of oil crops, and residues resulting from the harvesting of agricultural crops and forest trees (e.g., wheat straw, corn Stover, and the tops, limbs, and bark from trees). Secondary biomass resources result from the processing of primary biomass resources either physically (e.g., the production of sawdust in mills), chemically (e.g., black liquor from pulping processes), or biologically (e.g., manure production by animals). Tertiary biomass resources are post-consumer residue streams including animal fats and greases, used vegetable oils, packaging wastes, and construction and demolition debris. There are various conversion technologies that can convert biomass resources into power, heat, and fuels for potential use in UEMOA countries [1,2]. South Africa has huge potentials for bioenergy production with abundant untapped flora, recycled feedstocks, farm produce, biomasses, municipal wastes and so on.

Biomass derived energy currently accounts for about 3 quads of total primary energy use in the United States. Of this amount, about 0.8 quads are used for power generation [4] Several biomass energy production technologies exist today which contribute to this energy mix. Biomass combustion technologies have been the dominant source of biomass energy production, both historically and during the past two decades of expansion



of modern biomass energy in the U. S. and Europe [5]. As a research and development activity, biomass gasification has usually been the major emphasis as a method of more efficiently utilizing the energy potential of biomass, particularly wood. Gasification technology was first commercialized using coal, however biomass resources such as wood have a unique environmental advantage over traditional fossil fuels in that the gasification of biomass has a mitigating effect on global warming, when a renewable biomass fuel is used instead of a fossil fuel. Also, biomass feedstocks are typically lower in sulfur and nitrogen than most coals. Numerous biomass gasification technologies exist today in various stages of development. Some are simple systems, while others employ a high degree of integration for maximum energy utilization [6,7]. "Integration" refers in a general way to obtaining heat and multiple products, in addition to electricity from the fuel or feedstock used. In a specialized way in gasification power systems, "integration" refers to use of the heat and steam flows from the gasification and gas cleaning steps in the process, for enhancement of the other parts of the process. One important example of such integration is the use of steam raised in syngas cooling as part of the steam flow into the steam power section of an IGCC power plant. (IGCC is an integrated gasification combined cycle) [8-10]. Advanced biomass gasification offers the flexibility of producing a fuel gas with sufficient energy content to be utilized in advanced integrated combined cycle power systems [9]. The higher energy content of the advanced biomass gasification processes also improves the capability for the biomass-derived gas to be further processed for chemical production. The purpose of this short communication study is to explore the bioenergy potential of South Africa and their contributions in terms of the various research strategies being conducted in harnessing and tapping them for the direct socio-economic impact on the rural communities. Some economic comparisons of generations of bioenergy are presented, different biomass gasification technologies, including the carbon dioxide emissions reduction and potentials of each. To accomplish this, a literature search was first conducted to determine which technologies were most promising based on a specific set of criteria. The technical and economic performances of the selected processes were evaluated using computer models and available literature. Evaluation methods developed by EPRI (the Electric Power Research Institute) were then used to determine the carbon dioxide reduction potential of the technologies [11].

Renewable Energy Technologies

The renewable energy capabilities of South Africa employ the integration of one, two and more following technologies in different economic applications depending on provinces of abundance. The technologies developed and available for use in South Africa include the following: Bioenergy has been included as the last option as it is currently under development. The department of Energy have realised the huge potentials available and have made policies and legislations to advance and establish the bioenergy sector including research works on advanced and sustainable biofuels and biofuels from wastes biomasses:

- Wind turbines technologies
- Hydroelectric – SH, MH, PH
- Geothermal power
- Solar photovoltaics -Hybrids
- Solar thermal power -Hybrids
- Ocean current power technologies
- Tidal power technologies
- Hydrogen technologies
- Fuel Cells technologies
- Wave power technologies and
- Bioenergy – Biofuels, Biomass, Biodiesel

Bioenergy: Bioenergy consists of solids, liquids, and gaseous fuels. – These have been classed as first generation (1G), second generation (2G) and third generation (3G) bioenergy from diverse feedstocks.

- Biomass: bio-diesel, ethanol, bagasse, wood, bark, coconut fibre, straw, hemp, peat, willow, switch grass, charcoal etc.
- Waste: tires, landfill gas, food waste, forest residue, coffee refuse, Christmas trees, poultry litter, packaging waste, Algae etc.

First Generation bioenergy are primary resources produced directly by photosynthesis and are taken directly from the land: woody crops and herbaceous crops, the seeds of oil crops, and residues resulting from the harvesting of agricultural crops and forest trees.

Advanced and Sustainable Bioenergy are produced from recycled products, sustainable biomasses and from wastes while second generation bioenergy are products of processing of primary biomass resources or secondary products. Third generation bioenergy are post-consumer residue streams: They are also bioenergy produced from wastes, micro-algae, macro-algae and all such tertiary feedstocks and so on.

Energy from biomass and biogas

Biomass is produced in nature through photosynthesis achieved by solar energy conversion. Biomass means organic matter. In simplest form the reaction is the process of photosynthesis in the presence of solar radiation, can be represented as follows: $H_2O + CO_2 \xrightarrow{\text{Solar energy}} CH_2O + O_2$ Biomass can be converted into fuels through a number of different processes, including solid fuel combustion, digestion, pyrolysis, and fermentation and catalysed reactions. Electricity is generated in many places through solid fuel combustion [12]. Biomass resources fall into three categories: • Biomass in its traditional solid mass (Wood and agricultural residue: It can burn directly and get the energy) • Biomass in non-traditional form (converted into liquid fuels: the biomass can be converted into ethanol and methanol to be used as liquid fuels in engines.) • To ferment the biomass anaerobically to obtain a gaseous fuel called biogas (In biogas = 55 to 65 % Methane, 30 to 40% CO_2 and rest impurities i.e. H_2 , H_2S and some N_2) The main source for production of biogas is wet cow dung or wet livestock (and even human) waste, to produce biogas. Biogas can be captured from marshes, from landfill or wastes such as sewage, and burned to produce electricity. It can also be generated intentionally through anaerobic composting. When refined, it can be used to power vehicles directly. Biogas can be produced from the decomposition of animal, plant and human waste. It is a clean but slow burning gas and usually has a calorific value between 5000 to 5500 kcal/kg. It can be used directly in cooking, reducing the demand for firewood. Moreover, the material from which the biogas is produced retains its value as a fertilizer and can be returned to the soil. Biogas has been popular on the name, "Gobar Gas" mainly because cow dung has been the material for its production, hitherto. It is not only the excreta of the cattle, but also the piggery waste as well as poultry droppings are very effectively used for biogas generation [13]. A few other materials through which biogas can be generated are algae, crop residues (agro-wastes), garbage kitchen wastes, paper wastes, sea wood, human waste, waste 160 Energy Resources: Development, Harvesting and Management from sugarcane refinery, water hyacinth etc. Any cellulosic organic material of animal or plant origin, which is easily biodegradable, is a potential raw material suitable for biogas production [14].

Table 1: First Generation Vs Second Generation Bioenergy - Biofuels

	1 st Gen.	2 nd Gen.
Biofuels readily usable in existing petroleum infrastructure	Yes	Yes
Proven commercial technology available today	Yes	No
Relatively simple conversion processes	Yes	No
Markets for by-products of fuel production needed	Yes	Yes/No
Capital investment per unit of production	Lower	Higher
Feedstock cost per unit of production	Higher	Lower
Total cost of production	High*	Lower
Minimum scale for optimum economics	Modest	Large
Land-use efficiency	Low	High
Direct food vs. fuel competition	Yes	No
Feasibility of using marginal lands for feedstock production	Poor	Good
Ability to optimize feedstock choice for local conditions	Limited	High
Potential for net reduction in petroleum use	Good*	Better
Potential for net reduction in fossil fuel use	Modest*	High
Potential for net reduction in greenhouse gas emissions	Modest*	High

* Except for first-generation Brazilian sugar cane ethanol, which would get a more favourable mark.

Industry standard tests for characterizing biomass

Several of the industry standard tests for characterizing biomass are described:

Total Solids: A way to determine the moisture content within the sample.

Ash Determination: The amount of inorganic or mineral material present in the sample.

Exhaustive Ethanol and Water Extractable: The removal of non-structural material from the biomass sample to prevent interferences during other analyses, as well as free sugar determination.

Structural Carbohydrates: The determination of glucose, xylose, galactose, arabinose and mannose concentrations in the sample; used to determine cellulose and hemicellulose concentrations in the biomass.

Acetyl Content: Acetic acid concentration in the sample, may also include formic and levulinic acid content depending on the feedstock.

Lignin: Determination of the structural plant material that does not contribute to the sugar content in the sample.

Starch Content: Represents the readily available source of sugar within some feedstock.

Ethanol Content: Analysis of fermentation broths using gas chromatography.

Bomb Calorimetry: The determination of the sample's calorific value

Biomass processing Technologies

There are six generic biomass processing technologies based on:

- direct combustion (for power)
- anaerobic digestion (for methane-rich gas)
- fermentation (of sugars for alcohols)
- oil exaction (for biodiesel)
- pyrolysis (for biochar, gas and oils)
- gasification (for carbon monoxide and hydrogen-rich syngas).

These technologies can then be followed by an array of secondary treatments (stabilization, dewatering, upgrading, refining) depending on specific final products. They are encapsulated on the following schematics in Figure 1

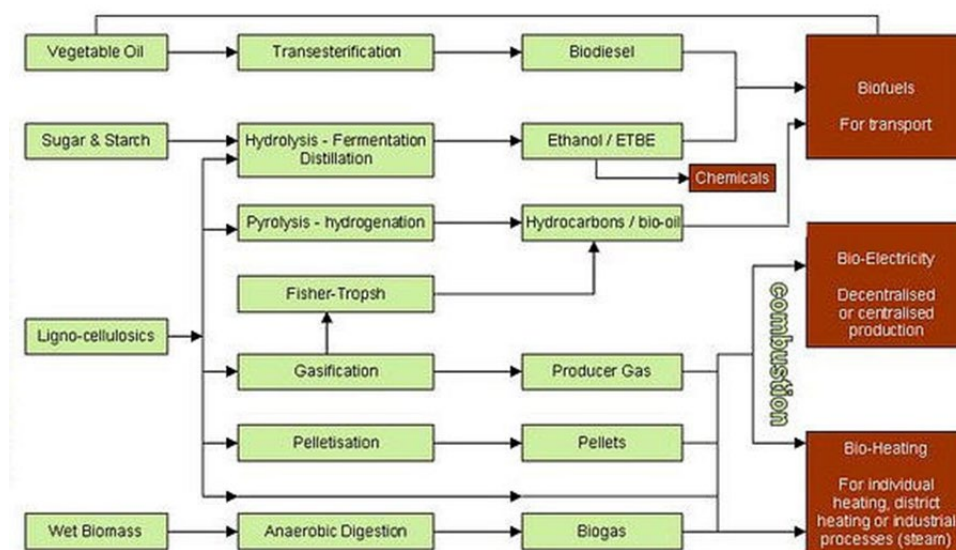


Figure 1: Schematics of Bioenergy Processing Technology – an overview

Availability of biomass (Sources of Biomass)

Biomass resources fall into three categories: (i) Biomass in its traditional solid mass (wood and agriculture residue) In this, it is to burn directly and gets the energy. (ii) Biomass in non-traditional form (converted into liquid fuels) The biomass is converted into ethanol (ethyl alcohol) and methanol (methyl alcohol) (iii) It is to ferment the biomass anaerobically to obtain a gaseous fuel called biogas. Terrestrial crops include (1) sugar crops such as sugarcane and sweet sorghum; (2) herbaceous crops, which are non-woody plants that are easily converted into liquid or gaseous fuels; and (3) silviculture (forestry) plants such as cultured hybrid poplar, sycamore, sweet gum, alder, eucalyptus, and other hard woods. Animal and human waste are indirect crops from which methane for combustion and ethylene (used in the plastic industry) can be produced while training the fertilizer value of the manure. Aquatic crops are grown in fresh, sea and brackish waters. E.g. Sea weeds, marine algae.

Available Quantity of Energy

Calorific value the heat of combustion (calorific value) is the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions. It is measured in units of energy per unit of the substance, usually mass, such as: kJ/kg, kJ/mol, kcal/kg, Btu/lb. Heating value is commonly determined by use of a bomb calorimeter.

High calorific value the quantity known as higher calorific value (HCV) is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced. Such measurements often use a standard temperature of 15°C. This is the same as the thermodynamic heat of combustion since the enthalpy change for the reaction assumes a common temperature of the compounds before and after combustion, in which case the water produced by combustion is liquid. The higher heating value takes into account the latent heat of vaporization of water in the combustion products, and is useful in calculating heating values for fuels where condensation of the reaction products is practical (e.g., in a gas-fired boiler used for space heat). In other words, HCV assumes the entire water component is in liquid state at the end of combustion and that heat below 150°C can be put to use.

Low calorific value the quantity known as lower calorific value (LCV) is determined by subtracting the heat of vaporization of the water vapour from the higher heating value. This treats any H₂O formed as a vapour. The energy required to vaporize the water therefore is not released as heat [8]. The LCV assumes that the latent heat of vaporization of water in the fuel and the reaction products is not recovered. It is useful in comparing fuels where condensation of the combustion products is impractical, or heat at a temperature below 150°C cannot be put to use.

Biomass characteristics

Ultimate & Proximate analysis

Proximate analysis is used for calculation of chemical composition of the residue including Moisture content, Ash content, volatile matter & fixed carbon. Moisture content is one of the important property of biomass, over which its heating value depends. The moisture content is determined by drying the weighed amount of sample in an open crucible kept at 110°C in an oven for one hour by using standard oven dry method. The biomass sample is first ground to form fine powder, then this powdered sample is kept for determination of proximate analysis. Energy Resources: Development, Harvesting and Management 165 Standard method for moisture determination involves heating of 1 gm biomass sample in a hot air oven to 110°C using the following equation. Moisture (% M) = $(W_1 - W_2) / W_3 \times 100$ W₁ = Weight of the crucible & the air dried sample (g), W₂ = Weight of the crucible & oven dried sample (g), W₃ = Weight of the air dried sample taken (g) The experimentation of moisture content determination is extended for measurement of ash content of biomass. The sample, so obtained after determination of moisture content, is then heated to 750°C in a muffle furnace and is kept there for two hours or more till constant weight is recorded.

The weight of residue represents the ash content of the biomass. Ash is defined as the weight of the residue remained after complete burning of 1gm of the biomass at 750°C. Ash (% A) = $(W_4 - W_5) / W_6 \times 100$ W₄ = Weight of the crucible & the oven dried sample (g), W₅ = Weight of the crucible & residue (g), W₆ = Weight of oven dried sample taken (g) Volatile matter (% VM) is determined by keeping the dried sample in a closed crucible at 600°C for 6 minute and then at 900°C for another 6 minute. The difference in the weight due to the loss of volatiles is taken as the total volatile matter present in the biomass. It is termed as the weight loss due to heating of 1gm of biomass at 900°C in furnace for 6 minutes. Weight loss due to VM = Total loss of

weight- loss due to moisture. Fixed carbon (FC) content is found by applying the mass balance for the biomass sample. The carbon content determined through this method is not the actual carbon content present in biomass but only the non-volatile part of carbon content, as some of carbon present in biomass also escape along with the volatiles. The content of fixed carbon is determined by subtracting the sum of A %, VM & % M from total of 100 % composition. $FC = 100 - (\% A + \% VM + \% M)$ Ultimate Analysis This analysis is important for determining the elemental composition (C, N₂, H₂, S, O₂ etc.) of the biomass fuels & is also useful for calculating their heating value. The carbon and H₂ contents are determined by C-H-O analyser by standard method.

Energy Resources

Development, Harvesting and Management: Further, knowing the ash content, O₂ is determined by difference. However, the samples must be dried prior to analysis. Nitrogen and sulphur are normally negligible. C-H-O analyser is consisting of an electric furnace, a sample column and absorbent column. The dry matter is powdered and weighed (w₁) before putting it in the sample column. The absorbent column is filled with a weighed quantity (w₂) of calcium hydroxide [9]. Subsequently the furnace is started and O₂ from a separate O₂ cylinder is supplied to the sample column at a pressure of 4 PSL. A temperature of more than 1400°C is maintained for about 20 min. Then furnace is switched off and the fused sample is taken out and weighed (w₃). The calcium hydroxide from the absorbent column is also taken out and reweighed (w₄). From these observations the carbon content of the sample can be determined using the following relationship. The difference (w₄ – w₂) will give carbon dioxide formed. Carbon in absorbent (w₅) = $(w_4 - w_2) \times 12 / w_3$ % carbon in the sample = $w_5 \times 100 / w_1$

Biomass Conversion

Biomass can either be utilized directly as a fuel, or can be converted into liquid or gaseous fuels, which can also be as feedstock for industries. Most biomass in dry state can be burned directly to produce heat, steam or electricity. On the other hand, biological conversion technologies utilize natural anaerobic decay processes to produce high quality fuels from biomass [10, 11]. Various possible conversion technologies for getting different products from biomass is broadly classified into three groups, viz. (i) thermo-chemical conversion, (ii) bio-chemical conversion and (iii) oil extraction. These alternative technologies for biomass conversion offer sound and alternative options for meeting the future fuels, chemicals, food and feed requirements [12-16]. Three main approaches can be adopted for generation and utilization of biomass: (i) Collection of urban and industrial wastes as supplementary fuel in boilers and as a feed stock for producing methane and some liquid fuels. (ii) Collection of agricultural and forest residues to produce fuels, organic manures and chemical feed stock. (iii) Growth of some specific energy plants for use as energy feedstock and cultivation of commercial forestry, aquatic and marine plants for different products. Energy Resources: Development, Harvesting and Management [17]

Thermo-chemical conversion includes processes like combustion, gasification and pyrolysis. Combustion refers to the conversion of biomass to heat and power by directly burning it, as occurs in boilers. Gasification is the process of converting solid biomass with a limited quantity of air into producer gas, while pyrolysis is the thermal decomposition of biomass in the absence of oxygen. The products of pyrolysis are charcoal, condensable liquid and gaseous products. Biochemical conversion includes anaerobic digestion to produce biogas and fermentation to obtain alcohol fuels, the third approach is oil extraction. Edible and non-edible oils can be extracted from a variety of grains and seeds [19-20]. They can be directly used as fuels by transesterification process to produce bio-diesel, which is a good substitute for conventional diesel oil. Thermal conversion processes for biomass involve some or all of the following processes: Pyrolysis: Biomass + heat + charcoal, gas and oil. Gasification: Biomass + limited oxygen + fuel gas and Combustion: Biomass + stoichiometric O₂ + hot combustion products [20].

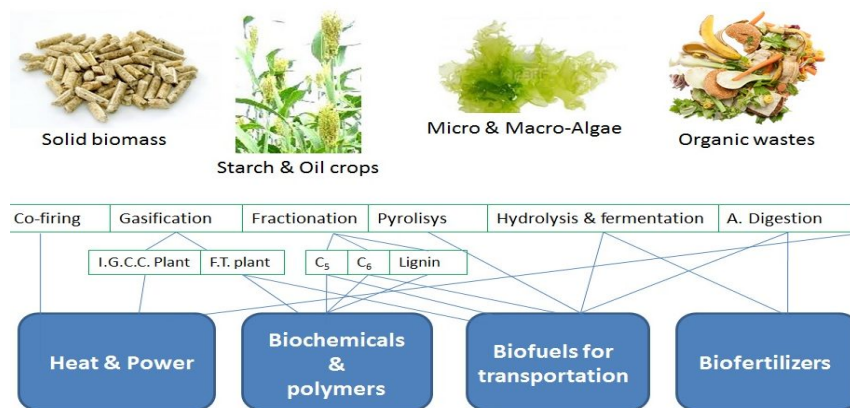


Figure 2; Feedstocks of Bioenergy and by-products and processes

R&D Strategy and Technology Packages

In our institutions in South Africa, the following are our research strategies in exploring the contribution of research and development in Bioenergy:

- Enhancements to existing biomass resource assessment and management strategies to cover wider biomass resources and period of analysis.
- Advanced research addressing thermo-chemical conversion of biomass — combustion and gasification, with an emphasis on efficiencies and environmental compliance.
- Establishing of standards, best practices and monitoring protocols in the biomass-based projects.
- Development of technology packages for replacing fossil fuels in industries.
- Evolving of specifications and standards for biomass energy devices and providing technical support in establishing test centers.
- Engine research with special reference to Producer Gas Applications and adoption of Natural Gas engines for this.
- Exploring extent of potential for replacement of fossil fuel by biomass in sector-wise industrial and commercial usage.

Further Some Research Insights

We have expanded our research scope and competencies to include wilder research and development needs of the country. The most isolated case is the exploration of the use of sugar cane fibres and pith for producing briquettes and fuels pellets for various industrial, commercial and domestic purposes. They are also to be explored as hybrids briquettes and pellets in mix with existing charcoal briquettes which are so much in need for the braaiing industry, a huge industry in South Africa. This isolated case of waste to energy from sugar cane bagasse is presented in Figure 3.

- Large Scale algae biomass Integrated Bio-refineries
- Prospects of biofuels and biodiesels from Micro-algal Technologies
- Production of Value-added products from Micro-algal Cultivation
- Modelling and simulation of integrated algal biomass bio-refineries
- Energy Requirement/Exergy of algal biomass integrated bio-refineries
- Integration of Flue gases/effluents for carbon sequestration: Algal biomass production
- Techno-economics of Renewable Energy Technologies
- Bio-Nanotechnology for Thermal/Energy Application
- Energy Efficiency for the South African Power Generating Industry
- Exploring the effectiveness of pith-fibre fractions separation: Sugarcane bagasse briquetting
- Photovoltaic Applications for Rural Electrification
- Integrating Technology and design Research in Policy Framework
- Thermo-chemical conversions and valorisation of various biomass in Africa



Figure 3: Bioenergy from Waste: Charcoal and Sugar bagasse in South Africa – isolated examples
Conclusion

Bioenergy and its technologies have become an interested aspect of clean energy technology and is currently receiving global attention. South Africa has also woken up to this need and have laid out several research and development strategies to institute this technology. Bioenergy from renewable feedstocks and sustainable wastes research and development were presented. The approach in the forms of solids, liquids and gaseous fuels have been characterised as first, second and third generations (1D, 2D and 3D) feedstocks have been to solve the sustainable development goals of Africa. The technologies evolved have been directed to specific bioenergy feedstocks and there is the needs for optimal utilisation and application. This short communication explored these and all such research and development (R and D) strategies and technological packages of bioenergy in South Africa. These have implications in the commercialisation, entrepreneurship, informing policy and direct impact in Africa's energy sustainability. The exploration of sugar-cane bagasse biomass for use as briquette/pellet fuels are also presented and they held huge potentials for one of the world's producers of sugar as second and third generations bioproduct as renewable fuels.

REFERENCES

- [1] Anjos, M., Fernandes, B. D., Vicente, A. A., Teixeira, J. A., & Dragone, G. (2013). Optimization of CO₂ bio-mitigation by *Chlorella vulgaris*. *Bioresource technology*, 139, 149-154.
- [2] Arts, R., Chadwick, R., Eiken, O., Trani, M., & Dortland, S. (2007). *Synthetic versus real time-lapse seismic data at the Sleipner CO₂ injection site*. Paper presented at the 2007 SEG Annual Meeting.
- [3] Barbanera, M., Lascaro, E., Stanzione, V., Esposito, A., Altieri, R., & Bufacchi, M. (2016). Characterization of pellets from mixing olive pomace and olive tree pruning. *Renewable Energy*, 88, 185-191.
- [4] Chadwick, R., Holloway, S., Kirby, G., Gregersen, U., & Johannessen, P. (2000). *The Utsira Sand, Central North Sea—an assessment of its potential for regional CO₂ disposal*. Paper presented at the Proceedings of the 5th
- [5] Cheng, J., Huang, Y., Feng, J., Sun, J., Zhou, J., & Cen, K. (2013). Improving CO₂ fixation efficiency by optimizing *Chlorella* PY-ZU1 culture conditions in sequential bioreactors. *Bioresource technology*, 144, 321-327.
- [6] De Lary, L., Loschetter, A., Bouc, O., Rohmer, J., & Oldenburg, C. (2012). Assessing health impacts of CO₂ leakage from a geological storage site into buildings: role of attenuation in the unsaturated zone and building foundation. *International Journal of Greenhouse Gas Control*, 9, 322-333.
- [7] Eloka-Eboka, A. C., & Inambao, F. L. (2017). Effects of CO₂ sequestration on lipid and biomass productivity in microalgal biomass production. *Applied Energy*, 195, 1100-1111.
- [8] Hu, Q., Zeng, R., Zhang, S.-X., Yang, Z.-H., & Huang, H. (2014). Production of microalgal lipids as biodiesel feedstock with fixation of CO₂ by *Chlorella vulgaris*. *Food Technology and Biotechnology*, 52(3), 285-291.

- [9] Lam, M. K., & Lee, K. T. (2011). Renewable and sustainable bioenergies production from palm oil mill effluent (POME): win-win strategies toward better environmental protection. *Biotechnology Advances*, 29(1), 124-141.
- [10] Ponnuswamy, I., Madhavan, S., Shabudeen, S., & Shoba, U. (2014). Resolution of lipid content from algal growth in carbon sequestration studies. *Int. j. Sci. adv. technol*, 67, 23-32.
- [11] Protocol, K. (1997). United Nations framework convention on climate change. *Kyoto Protocol*, Kyoto, 19.
- [12] Rahaman, M. S. A., Cheng, L.-H., Xu, X.-H., Zhang, L., & Chen, H.-L. (2011). A review of carbon dioxide capture and utilization by membrane integrated microalgal cultivation processes. *Renewable and Sustainable Energy Reviews*, 15(8), 4002-4012.
- [13] Rogner, H.-H. (1997). An assessment of world hydrocarbon resources. *Annual review of energy and the environment*, 22(1), 217-262.
- [14] Shabani, M. (2016). CO₂ bio-sequestration by *Chlorella vulgaris* and *Spirulina platensis* in response to different levels of salinity and CO₂. *Proceedings of the International Academy of Ecology and Environmental Sciences*, 6(2), 53.
- [15] Singh, S., & Singh, P. (2014). Effect of CO₂ concentration on algal growth: a review. *Renewable and Sustainable Energy Reviews*, 38, 172-179.
- [16] Van Den Hende, S., Vervaeren, H., & Boon, N. (2012). Flue gas compounds and microalgae: (Bio-) chemical interactions leading to biotechnological opportunities. *Biotechnology Advances*, 30(6), 1405-1424.
- [17] Vassilev, S. V., Baxter, D., Andersen, L. K., & Vassileva, C. G. (2013a). An overview of the composition and application of biomass ash. Part 1. Phase-mineral and chemical composition and classification. *Fuel*, 105, 40-76.
- [18] Xie, Y.-P., Ho, S.-H., Chen, C.-Y., Chen, C.-N. N., Liu, C.-C., Ng, I.-S., . . . Chang, J.-S. (2014). Simultaneous enhancement of CO₂ fixation and lutein production with thermo-tolerant *Desmodesmus* sp. F51 using a repeated fed-batch cultivation strategy. *Biochemical engineering journal*, 86, 33-40.
- Yoo, H. M., Al-Attiyah, H.M., .. (2013). *United Nations Framework Convention on Climate Change*. Retrieved from
- [19] Zhao, B., & Su, Y. (2014). Process effect of microalgal-carbon dioxide fixation and biomass production: a review. *Renewable and Sustainable Energy Reviews*, 31, 121-132.
- [20] Zheng, H., Gao, Z., Yin, F., Ji, X., & Huang, H. (2012). Effect of CO₂ supply conditions on lipid production of *Chlorella vulgaris* from enzymatic hydrolysates of lipid-extracted microalgal biomass residues. *Bioresource technology*, 126, 24-30.