THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Biorefinery and Biofuels

October 2017

University of Stellenbosch Business School

Table of Contents

1. Technology Overview and Detailed Description

The term "biorefinery" appeared in the 1990's in response to a least four industry trends. First, there was an increased awareness in industry of the need to use biomass resources in a more rational way both economically and environmentally. The environmental issue was both policy and consumer driven. Second, there was a growing interest in upgrading more low-quality lignocellulosic biomass to valuable products. Third, there was an increased attention to the production of starch for energy applications. Finally, there was a perceived need to develop more high-value products and diversify the product mix to meet global competition and, in some cases, utilise an excess of biomass (especially in the pulp and paper industry). In a biorefinery, biomass is upgraded to one or more valuable products such as transport fuels, materials, chemicals, electricity and, as by-product, heat. In principle, all types of biomass can be used, e.g. wood, straw, starch, sugars, waste and algae.

There exist several definitions of a biorefinery and biorefining. Two widely used definitions are formulated by The International Energy Agency Bioenergy Task 42 on Biorefineries (IEA) and NREL, respectively, namely:

i. "Biorefining is the sustainable processing of biomass into a spectrum of marketable bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat)"[1], and
ii. "A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass."[2]

Two definitions related specifically to biorefineries in the forest industry add the requirement of economic optimisation:

i. "Full utilization of the incoming biomass and other raw materials for simultaneous and economically optimized production of fibres, chemicals and energy."[3]
ii. "Maximising the economic value from trees," which requires "an improved business model and corporate transformation".[4]

Where does biorefining take place?

According to the NREL definition, a biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. This means that a biorefinery can be a facility, a process, a plant, or even a cluster of facilities.

By producing several different products, a biorefinery makes use of the various components in biomass as well as their intermediates therefore maximizing the value derived from the biomass feedstock through several bio-processes. A biorefinery could, for example, produce low-volume, but high-value, chemical or nutraceutical products, and a low-value, but high-volume liquid transportation fuel such as biodiesel or bioethanol through a conversion process.

During this conversion, electricity is generated, and heat is produced, both of which may be used in the biorefinery (a process called Combined Heat and Power (CHP)). At times, enough may be generated for sale of electricity to the local utility, such as Eskom or independent electricity suppliers as in the case of South Africa. As such, the high-value products increase profitability, the high-volume fuel helps meet energy needs, and the power production helps to lower energy costs and reduce greenhouse gas emissions from traditional power plant facilities[5].

The classification of biorefineries

The classification approach consists of four main features which can identify, classify, and describe the different biorefinery systems, viz.:

a. Platforms,
b. products (energy and bio-based materials and chemicals),
c. Feedstocks, and
d. Conversion processes or techniques

a. Platforms

The platforms (for example C5/C6 sugars, syngas, biogas) are intermediates which can connect different biorefinery systems and their processes. Platforms can also be already a final product. The number of involved platforms is an indication of the system complexity.

b. Products

The two biorefinery product groups are energy (e.g., bioethanol, biodiesel, synthetic biofuels) and products (e.g., chemicals, materials, food, and feed).

c. Feedstocks

The two main feedstock groups are "energy crops" from agriculture, or first-generation products are manufactured from edible biomass (e.g., starch crops, short rotation forestry) and "biomass residues" from agriculture, forestry, trade, and industry (e.g., straw, bark, wood chips from forest residues, used cooking oils, waste streams from biomass processing), also known as second-generation products utilize biomass consisting of the residual non-food parts of current crops or other non-food sources. Examples of these feedstock types are given below.

- *First-generation feedstocks*
    i. The most common type of biorefinery today uses **sugar- or starch-rich crops**. Sugar crops such as sugar cane, sugar beet or sweet sorghum store large

amounts of saccharose, which can easily be extracted from the plant material for subsequent fermentation to ethanol or bio-based chemicals. Sugar cane is currently the preferred feedstock from an economic and environmental perspective due to the relative ease of production. Starch-rich crops such as corn, wheat and cassava can be hydrolysed enzymatically to deliver a sugar solution, which can subsequently be fermented and processed into fuels and chemicals. The processing of many starch crops also delivers valuable animal feed rich in protein and energy as a side product (e.g. Distiller's Dried Grains with Solubles - DDGS)[6,7].

- *Second-generation feedstocks*
  - *i.* **Lignocellulosic biomass** is inedible plant material mainly composed of cellulose, hemicellulose and lignin (such as leaves, roots, stalks, bark, bagasse, straw residues, seeds, wood residues and animal residues). This type of second-generation feedstock will be used to produce biofuels and bio-based chemicals in the future using different conversion technologies. Cellulosic ethanol for example is ready for commercialization because of recent significant breakthroughs in enzymatic conversion process development[8].
  - *ii.* **Jatropha Oil: t**he Jatropha Curcas tree from Central and South America contains 27 to 40% inedible oil, which can be converted to biodiesel via transesterification[9].
  - *iii.* **Micro-algae** unicellular photo- and hetero-trophic organisms that have been evaluated extensively due to their potential value as a renewable energy source. Much research output has been on storage lipids in the form of triacylglycerols, which can be used to synthesize biodiesel via transesterification. The remaining carbohydrate content can also be converted to bioethanol via fermentation[10,11,12]. Algae-derived fuels can provide between 10 and 100 times more oil per acre than other second-generation biofuel feedstock. In some cases, the oil content of micro-algae exceeds 80% of the dry weight of the algal biomass, almost 20 times that of traditional feedstock. Furthermore, algae are safe, biodegradable and their use does not compete with arable land. Finally, algae, they are highly productive, are easily cultivated, and require readily-available substrates such as carbon-dioxide, sunlight and water for growth.
  - *iv.* **Animal waste** has potential as a fuel combustible and as an input to produce biogas, in particular methane biogas. Solid residues remaining from fermentation process are used as fertilizer. Laboratory studies of fermentative processes with organic residues proceeded from food and animal waste and sewage sludge have shown excellent energetic efficiency. It is possible to produce self-sufficient energy for biogas production, in closed circuit of water configuration, and synthesis of heat-integrated (HEN).

d. Conversion processes or techniques

Depending on the feedstock and the desired output, different conversion technologies may be applied in a biorefinery. There are four main conversion processes in the classification of biorefineries, namely, biochemical (e.g., fermentation, enzymatic conversion), thermochemical (e.g., gasification, pyrolysis), chemical (e.g., acid hydrolysis, synthesis, esterification), and mechanical processes (e.g., fractionation, pressing, size reduction). The technical explanation of these processes will not be elaborated upon, as it falls outside the scope of this report.

The details of the characteristics of biorefineries were elaborated upon[13,14] however, an overview is provided in Table 1 below.

Table 1: An overview of the main characteristics of the different types of biorefineries, with examples

Type of biorefinery	Type of feedstock	Technology	Phase of development	Products	Example
Conventional biorefineries	Starch (corn, wheat, cassava) and sugar crops (sugarcane, sugar beet), wood	Pre-treatment, chemical and enzymatic hydrolysis, catalysis, fermentation, fractionation, separation	Commercial	Sugar, starch, oil, dietary fibres, pulp and paper	Soybeans are used in many food products (margarines, butter, vegetarian burgers), as a source of vitamin E, in industrial products (oils, soap, cosmetics, inks, clothing), and—increasingly—as biodiesel feedstock[15].
Whole crop biorefineries	Whole crop (including straw) cereals such as rye, wheat and maize	Dry or wet milling, biochemical conversion	Pilot plant (and Demo)	Starch, ethanol, DDGS (Distiller's Dried Grains with Solubles)	DDGS can be used as cattle feed. Its nutritional characteristics and high vegetable fibre content make DDGS unsuited for other animal species.
Oleochemical biorefineries	Oil crops	Pre-treatment, chemical catalysis, fractionation, separation	Pilot plant, Demo, commercial	Oil, glycerin, cattle feed	The NExBTL process of Neste Oil[16,17]
Lignocellulosic feedstock biorefineries	Lignocellulosic-rich biomass: e.g., straw, chaff, reed, miscanthus, wood	Pre-treatment, chemical and enzymatic hydrolysis, catalysis, fermentation, separation	R&D/Pilot plant (EC), Demo (USA)	Cellulose, hemicelluloses, lignin	The European Forest-based Technology Platform[18]

Type of biorefinery	Type of feedstock	Technology	Phase of development	Products	Example
Green biorefineries	Wet biomass: green crops and leaves, such as grass, lucerne and clover, sugar beet leaf	Pre-treatment, pressing, fractionation, separation, digestion	Pilot plant (and R&D)	Proteins, amino acids, lactic acid, fibres	Austria, Germany, Ireland, and the Netherlands, most emphasis being put on grass refining[19],[20],[21]
Marine biorefineries	Aquatic biomass: microalgae and macroalgae (seaweed)	Cell disruption, product extraction and separation	R&D, pilot plant and Demo	Oils, carbohydrates, vitamins	Biofuel feedstocks[22].

The integration of biorefining

Biorefining would benefit from being integrated with a processing industry, and the benefits of such integration will be seen in energy efficiency and economy. Integrated biorefineries in process industries are very rare, except in some cases where specialty chemicals were produced in pulp mills. The pulp and paper industry therefore lends itself to biorefinery integration, and an example is the extraction of hemicelluloses and lignin in the pulping process, black liquor gasification, biomass gasification and ethanol production from the pulping process.

Oil refineries also lend themselves to integration into biorefinery systems. Biofuels can be upgraded to meet existing fuel standards by using catalytic cracking to reduce oxygen content and molecular size and improve thermal stability. The catalytic cracking process is however still under development. A driving force for this technology is that no hydrogen is needed, which is beneficial for the energy economy of the oil refinery. Another opportunity is hydro-treating of liquids, e.g. pyrolysis oil. In this way bio-based diesel can be produced.

Transesterification is a process for converting vegetable oils into biodiesel. This process is applicable to industries in which oil residues that can be converted into a biodiesel, such as raw tall oil in the pulp and paper industry, or for industries interested in using biodiesel to blend into petroleum products, such as the oil refining industry. Applicable technologies are the Fischer Tropsch process and gasification with several downstream processes which further convert fractions (naphtha, diesel, wax) of these processes into gasoline.

2. Application Examples and Case Studies

In this section an example is used to illustrate the application of biorefinery technologies.

Production of Cellulose Nanowhiskers (CNW) from wheat straw

CNW are defined as fibrous, high-purity, single crystals with nanometric dimensions[23]. Dispersion of CNW in a polymer matrix, such as latex, enhances the physical properties of the material [24]. The bio-based composites developed from the cellulose nanofibers could have widespread applications, replacing fiberglass and similar materials (CNW have several advantages over fiberglass components, such as a superior strength to weight ratio (greater strength at the same weight), are biodegradable, recyclable, carbon dioxide neutral, and potentially cost less to produce[25].MBI International has begun analyzing the potential of CNW applications in the automotive industry, focusing on components such as interior elements, exterior panels, and suspension parts.

An overview of the commercial, demo, pilot-scale biorefining facilities and concepts in global territories was developed, and is recommended as a resourceful reference for the reader of other examples and case studies[26].

3. Technology or Application Life Cycle: Current Status and Expected Development in 2020 and 2025

Table 2: Heading

Technology Area	Current application in agriculture	Expected applications in agriculture by 2020	Expected applications in agriculture by 2025
Biorefinery	Starch Based Biorefineries: Wet & Dry Mills; Increase ethanol production by access to residual starch & increased protein in co-products; Fractionation of the feedstock to access the high value products prior ethanol production; Fractionation of residues in Dry Mills for new co-products from lignin; Fractionation of grain and residues, introduction of energy crops in dry mills	Integrated Industrial Biorefinery: multiple feedstocks fractionated to high value products for economics and fuel production drive scale. Products are chemical intermediates, solvents, plastics, bio-plastics, building blocks for construction, adhesives, paints, dyes, pigments, identification of new microorganisms, new genes and enzymes from the microbial biodiversity for carbon flux manipulation, increase in substrate uptake, tolerance of toxic substances, and generation of new compounds[27]	Use of algae to produce fuel; refining of water; refining of waste water and manure into high-value products

4. Business Eco-System View

The biorefineries industry has made demands for microbial strains able to produce fuels and chemicals from different renewable resources in high yields and productivity. In response, researchers have been constructing and genetically improving microbial strains. The focus of these improvements can be grouped in four main categories: i) driving carbon flux towards the desired pathway, ii) increasing tolerance to toxic compounds, iii) increasing substrate uptake range (increasing substrate variation), and iv) the generation of new products of economic value. Advances in genomic and molecular analysis techniques, and systemic analysis tools, have resulted in microorganisms able to produce a variety of biofuels and chemicals from lignocellulose and other substrates, with production capacities (yields) in magnitudes orders higher than native (wild-type) ones, and this is currently available in the literature[28]. The possibilities of enhanced or improved biorefinery processes by similarly improved micro-organisms using advanced technologies such as bioinformatics intervention is shown in Figure 1 below.

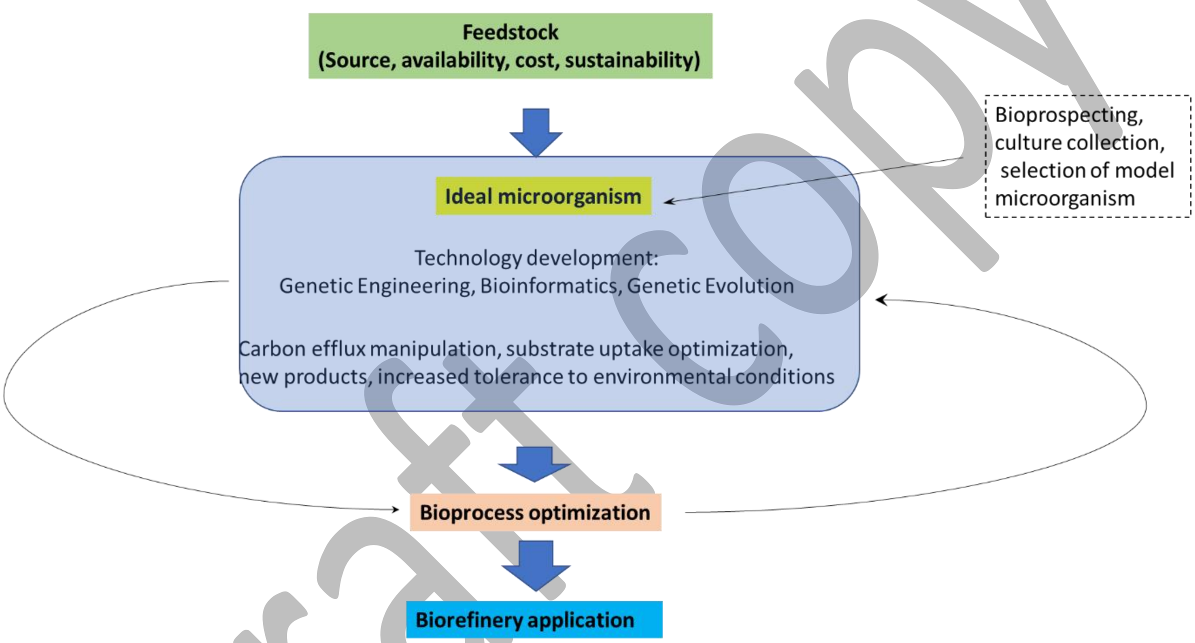

Figure 1: A role for improved microorganisms in biorefinery efficiency and versatility (adapted)29

Biorefinery overlaps with:

- Genetics
- Bioinformatics
- Waste management and recycling
- Synthetic biology

5. Benefits and Risks

A SWOT analysis of biorefineries was conducted by[30], and is presented below in Table 3.

Table 3: A SWOT analysis of biorefineries

Strengths	Weaknesses
• Add value to the sustainable use of biomass.	• Broad undefined and unclassified area.

Strengths	Weaknesses
• Maximize biomass conversion efficiency - minimizing raw material requirements. • Production of a spectrum of bio-based products (food, feed, materials, chemicals) and bioenergy (fuels, power, and/or heat) • Strong knowledge infrastructure available to tackle both nontechnical and technical issues • Long-established discipline	• Involvement of stakeholders of different market sectors (agriculture and agroprocessing, energy, chemical) over the entire biomass value chain is necessary. • The most promising biorefinery processes/concepts not clear. • The most promising biomass value chains, including current/future market volumes/prices, not clear. • Concept development is prioritized over real market implementation. • Variability of quality and energy density of biomass brings uncertainty
Opportunities	**Threats**
• Makes a significant contribution to sustainable development. • International consensus on biomass availability is limited, and so raw materials should be used as efficiently as possible through the development of multipurpose biorefineries • The development of a portfolio of biorefinery concepts, including composing technical processes is global. • Strengthening of the economic position of various market sectors (e.g., agriculture, forestry, chemical, and energy)	• Economic change and drop in fossil fuel prices. • Fast implementation of other renewable energy technologies feeding the market requests. • Global, national, and regional availability and supply of raw materials is threatened, due to climate change, policies, logistics). • (High) investment capital for pilot and demo initiatives difficult to find, and existing industrial infrastructure is not depreciated yet. • Fluctuating (long-term) governmental policies. • Food/feed/fuels (land use competition) and sustainability of biomass production debates. • Goals of end users often focused upon single product.

Key strategic and operational benefits

It is recognized that biorefineries should contribute to the body of knowledge and application of sustainable innovation, provided they are appropriately designed and operated. Renewability is feature of biorefineries, since they transform renewable resources in a clean and efficient way into a variety of products that can in turn be recycled or reused as a material or energy.

A biorefinery should produce a spectrum of marketable products and energy. As described earlier in this report, the products of a biorefinery process can be both intermediates and final products, (and include food, feed, materials, and chemicals). Energy outputs include fuels, power, and heat.

The future of biorefineries is in the production of transportation biofuels, especially those that can be blended petroleum, kerosene, diesel, and natural gas, so that the already existing infrastructure in the transportation sector can be utilized. Of course, for this blending to be economically attractive, the volume and prices of present and forecasted products should be market competitive.

Biorefineries are also expected to contribute to an increased competitiveness and wealth of the implementing countries by supplying a variety of bio-based products and energy in an economically, socially, and environmentally sustainable manner. Biorefineries show promises both for industrialized and developing countries. As a result, new competences, new job opportunities, and new markets are also expected to be created.[31].

Key strategic and operational risks

Even with the promise of biorefineries, there remain technical, commercial and strategic challenges to the commercialization of biorefinery processes and products. Some of these are dealt with below.

i. Feedstock yield and composition of biomass.

Feedstock yield and composition of biomass need to be improved if mankind is to benefit from optimal conversion efficiency. This improvement calls on the development and application of technologies in plant genomics, breeding programmes and the chemical engineering of economically favourable characteristics such as drought resistance, photo-cycle insensitivity, cold-tolerance, and sugar composition (the appropriate C5/C6 configuration). The clear benefits of such an approach are improvements to the economics and security of feedstock availability throughout the year, which is still elusive.

ii. Efficient enzymes manufacturing and incorporation.

Another technical challenge is the requirement for efficient and robust enzymes for application in biorefineries, particularly for the conversion of lignocellulosic material from a variety of feedstock like corn cobs, stover, wheat straw, bagasse, rice, woody biomass.

iii. Microbial cell factory development.

Microbial cell factories, i.e. production hosts that produce a desired product in high yields and with high productivity have not yet been developed an applied sufficiently to control and manipulate biorefinery performance.

iv. Processing and logistics.

The optimization of feedstock processing and logistics in the face of the seasonal availability feedstock presents with challenges to the economics of biorefineries. Investments in the required infrastructure is not only costly, but exploiting the value of the related IP (intellectual property) is difficult. Similarly, setting up a bio-based product distribution network is another necessity, not yet realized, which makes use of existing infrastructure, e.g. using oil pipelines, or upgrading petrol stations to allow for the distribution of a significant volume of biofuels.

v. Integration into existing value chains.

One of the main commercial challenges is to integrate biorefinery output into existing value chains. There are two different classes of products which require integration into existing value chains. These are bio-based products that directly replace molecules in existing value chains, and bio-based products that are novel and that cannot easily be integrated into existing value chains. The investment quantum required to accommodate these kinds of products is also inhibitory.

vi. Funding challenges.

Venture capital and private equity funding have become tougher to access, making it difficult to finance pilot and full-scale commercial plants and infrastructure, and to obtain follow-up lending rounds, due to different priorities, or market forces, or the realization that to fully realize commercialization, very large capital infrastructure is required, or the uncertainty surrounding the profitability of a biorefinery.

vii. Uncertainty in adopting a new, unconventional field.

Another commercial hurdle is the hesitance of first-to-market movers, the inability to obtain a premium price for the product in competition with conventional petroleum products

viii. Reputational risks to cooperatives.

The practices of biorefineries may threaten biodiversity, damage rural communities, promote the excessive use of water resources or damage the food supply chain. These factors represent reputational and commercial risks for corporations investing in biorefineries, and place them at risk of lawsuits.

Despite advances made, the major challenges still to be tackled are:

- The development of develop industry legitimacy
- Lack of multi-sectorial stakeholder involvement in the deployment of sustainable value chains;
- technology development and deployment, and biorefinery scale-up using best practices;
- the slow pace in unlocking available expertise develop the necessary human capital by training students and other stakeholders to become the biorefinery experts

6. Potential Economic, Social, Ecological (Environmental) and Political Developments and Impacts

Bio-based products and processes may produce (intended or unintended) impacts on human society and the environment. These impacts may occur anywhere along the value chain of bio-based products. One single product or process can have several impacts, which are in turn influenced by factors that are not related to the product or process[32].

Economic Developments and Impacts

Bioeconomy-related innovations provide the opportunity for new production processes. The ever-changing demand for products leads to several impacts. For example, a growing bioeconomy leads to a rising demand for bioeconomy-related feedstock (input) and products, while the demand for fossil fuel based products might decrease.

An increasing demand for bioeconomy-related feedstock and products can lead to changes of the respective commodity prices (such as food, fibre etc.). At the same time, new bioeconomy processes also potentially alter production methods, biomass productivity and processing.

An increased demand for feedstock and input for the bioeconomy potentially in new sources of income for the producers of these inputs. At the same time, increasing commodity prices results in price pressures on the consumer. Changing demand and prices for bioeconomy-related products and processes could also have a significant influence on regional and national trade balances. New markets and changing trade balances then influence the overall gross domestic product (GDP) and gross national income (GNI). This relationship is shown in Figure 3, and Table 4 is a summary of the possible economic effects of the bioeconomy in greater detail.

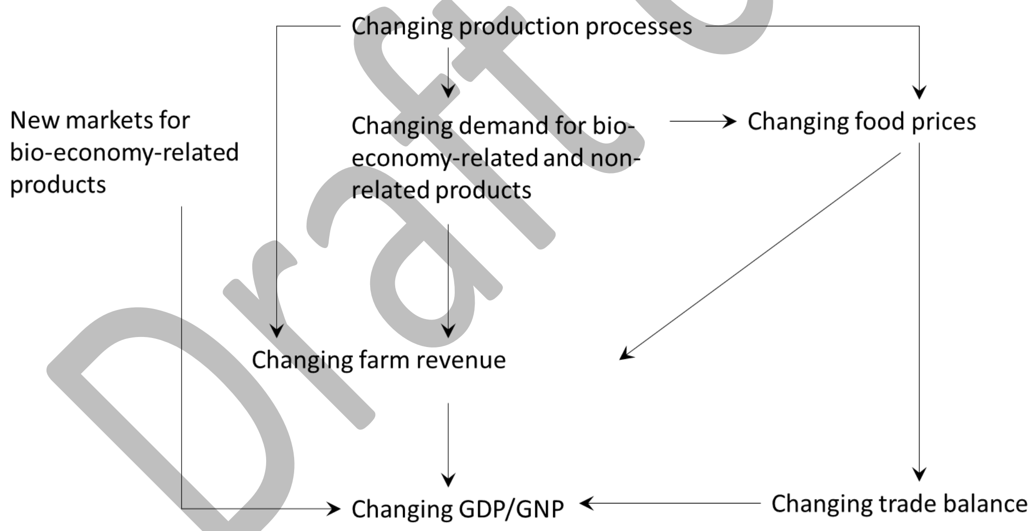

Figure 3: An overview of the economic impacts of biorefineries[33]

Table 4 shows other possible economic impacts of biorefineries.

Table 4: possible economic effects of biorefineries[34]

Impact	Possible indicator
Change in GDP/GNI	▪ Change in GDP/GNI ▪ Rural development perspectives
New market for innovative bio-based products	▪ Change in turnover of bio-based sectors ▪ Business opportunities/challenges

Impact	Possible indicator
Change in trade balance	▪ Change in trade (biomass (incl. wood) & animal-based products (incl. Fish) ▪ Energy diversification
Change in commodity prices	▪ Change in food process ▪ Real wood & forest product prices
Change in demand for biomass products	▪ Change in cropland-based demand for products/energy ▪ Change in wood/wood fibre demand for forest products ▪ Change of biomass demand for energy use
Change in public cost	▪ Dependence on subsidies
Change in farmers' revenue	▪ Yield/hectare ▪ Costs for agrochemicals/year

The potential for generating revenues

Biofuels markets are estimated to more than triple by 2020. The combined sales of biodiesel and ethanol will surge to around US$ 95 billion in 2020 due to government mandates alone. The resulting combined US and EU demand for biomass in the fields of heat and power is also expected to more than double by 2020.

Bio-based chemicals are also expected to grow significantly and increase their share in overall chemicals production to some 9% of all chemicals[35]. However, at current oil prices, a biofuels industry would not be commercially viable, as seen in the USA.

The Figure 4 below summarizes the estimated revenue incomes from the different value-chain stages of an established biorefinery by 2020[36].

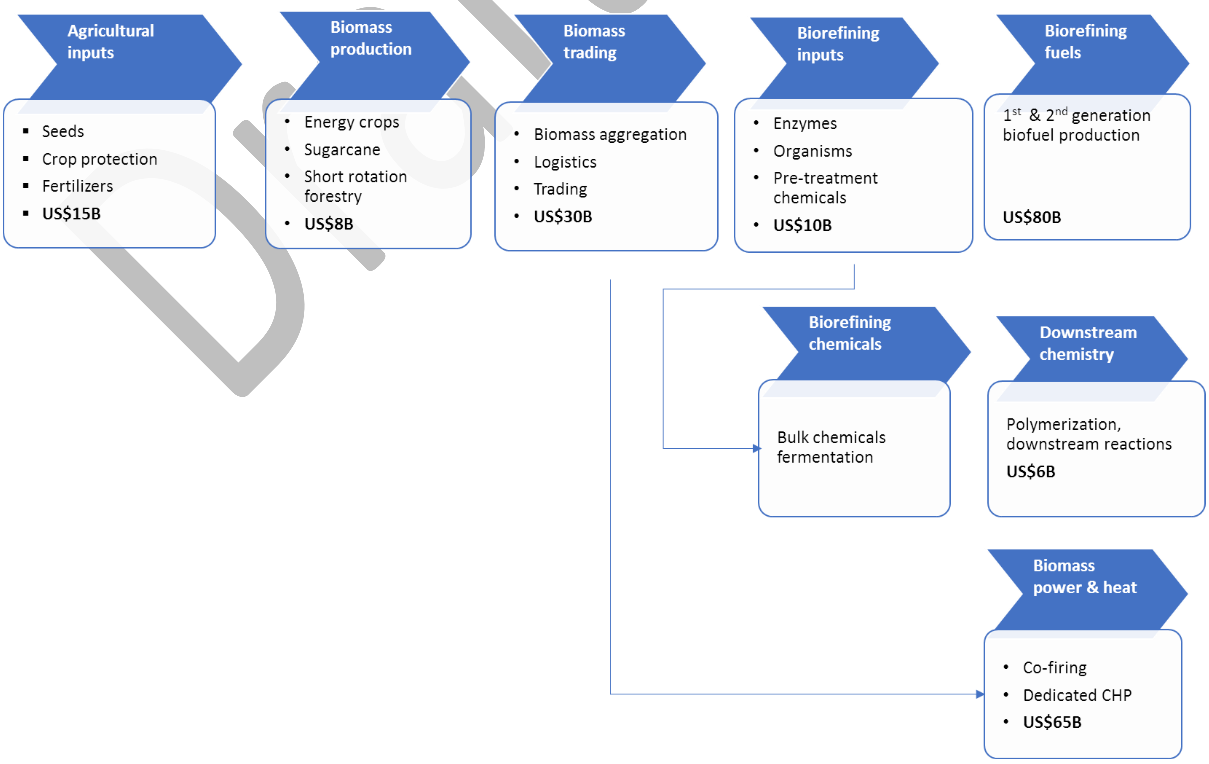

Figure 4: The biorefinery biomass value chain and projected income streams per stage by 2020[37].

Social Developments and Impacts

The drivers of social impacts have economic impact influence. Changing income levels, new markets and production processes, for example, have potentially positive effects on employment, health and food security. Equally so, concerns about the distribution of income and economic possibilities are relevant to the assessment of social impacts. These concerns are very much linked to access to land, markets, seed capital and technology. Limitations in access can potentially indicate which communities or individuals are not benefitting from the bioeconomy.

Changing prices on bioeconomy-related commodities can directly or indirectly affect food security. All these changes, like changing household income, consumer prices, health, and access issues have an impact on people's quality of life. This relationship is shown in Figure 5, and the possible social effects of biorefineries are summarized in Table 5.

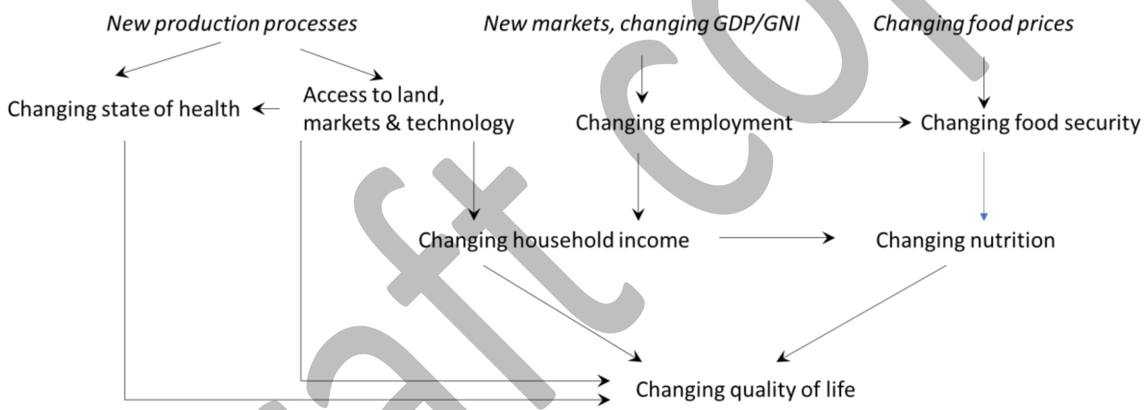

Figure 5: An overview of the social impacts of biorefineries38

Table 5: possible social effects of biorefineries[39]

Impact	**Possible indicator**
Food security (including GMO crops)	▪ Use of agrochemicals (incl. fertilisers) and GMO crops ▪ Change in food prices (and its volatility) ▪ Malnutrition ▪ Risk of hunger ▪ Macronutrient intake/availability
Land access (incl. gender issues & tenure)	▪ Land prices ▪ Land tenure ▪ Property rights (incl. gender equality) ▪ Access to land (incl. gender equality)
Employment	▪ Change in employment rate ▪ Full time equivalent jobs ▪ Job quality ▪ Need for/lack of highly specialised workforce
Household income	▪ Income of employees in bio-economy sector (total) ▪ Distribution of income

Impact	Possible indicator
Quality of life	▪ Change in quality of life ▪ Equality (of gender for example)
Health	▪ Exposure to agrochemicals ▪ Numbers of multi-resistant organisms ▪ Toxicity of ‘green’ vs. ‘grey’ industrial products

Ecological (Environmental) Developments and Impacts

An important reason for promoting bio-based products is to realize benefits of the possible environmental impacts, including the desire to replace oil and oil-based products. The motivation of this replacement ranges from moving away from finite natural resources and import dependency, to lowering the carbon footprint of the production. Other environmental impacts are to be realized, such as land use change/intensity and soil and water quality. These have an impact on biodiversity and ecosystem services. Figure 6 and Table 6 elaborate this further.

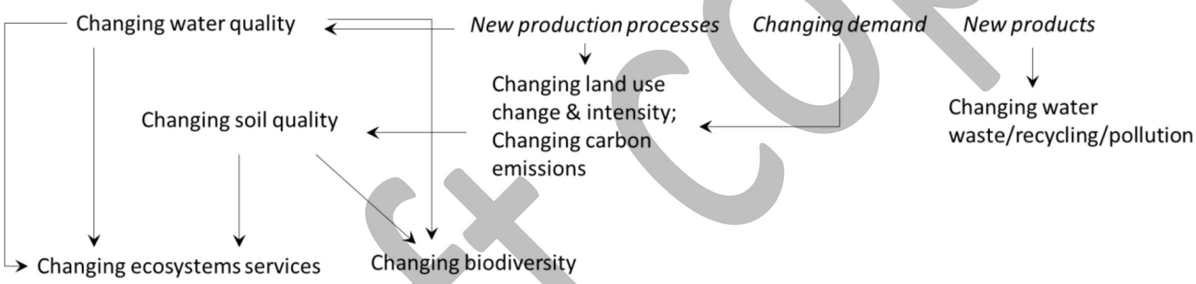

Figure 6: An overview of the environmental impacts of biorefineries[40]

Table 6: Possible environmental effects of biorefineries[41]

Impact	Possible indicator
Land use change	▪ Change in cropland / grassland / forest area, non-arable land use ▪ Short rotation plantations
Land use intensity	▪ Change in land use intensity ▪ Forest carbon content
Soil quality depletion	▪ Acidification ▪ Salinization ▪ Bulk density ▪ Soil carbon content
Biodiversity loss & threats (including invasive species)	▪ Rate of biodiversity loss ▪ Habitat loss ▪ Forest fragmentation
Decline in ecosystem services provision	▪ Change in ecosystem service provisioning
Water depletion	▪ Water scarcity, ▪ Consumptive water use ▪ Water exploitation index ▪ Water use for agriculture ▪ Forestry ▪ Manufacturing

Impact	Possible indicator
	▪ Recycling
Water pollution	▪ Eutrophication ▪ Toxicity level of water pollution
Reduced consumption of fossil resources	▪ Change in consumption level of fossil resources
Increased consumption of biomass	▪ Change in wood resource balance ▪ Consumption level of biomass
Increased re-use of biomass	▪ Organic waste diverted from landfills
Increased consumption of fish	▪ Change in fish stocks
GHG emissions	▪ Change in GHG emissions ▪ LULUCF carbon baseline
Atmospheric pollution	▪ Level of emission ▪ Concentration of air pollutants
Material carbon pools	▪ Change in carbon stocks
Products characteristics	▪ Degree of the products biodegradable parts ▪ Level of the products toxicity

Economic and environmental factors have been pushing the chemical industry to invest in new means to get the same products in a more sustainable and economical way. It is estimated that by 2025, 15% of global chemical sales will be bioderived[42].

7. Political Developments and Impacts

The political and legislative environment in South Africa

Several policies and strategies exist in South Africa to support the production of biofuels. These are underpinned by the following:

- New Growth Path

The New Growth Path framework sets an ambitious goal of creating five million jobs by 2020. One of the sectors expected to contribute to job creation is the "green" industry sector, of which renewable energy forms part. The targets in the renewable sector that can stimulate job creation include a 33% target for power generation from renewable energy sources by 2020.

- Industrial Policy Action Plan (IPAP) and the South African Renewables Initiative (SARi)

South Africa has developed and implemented several IPAP versions. These plans are aimed mainly at developing competitive local manufacturing for renewable energy technologies, including biofuels. IPAP2 supports the recently launched South African Renewables Initiative (SARi), of the Department of Trade and Industry and the Department of Public Enterprises. SARi, pursues the following objectives

  - to design, establish and secure appropriate funding to catalyse the generation of power from renewables, and associated industrial development

- to effectively implement industrial and renewable energy policy, planning and procurement programmes to mitigate climate change consequences in achieving economic development goals domestically
- to demonstrate and share learning from innovative large-scale collaboration to mobilise investment in climate change-compatible infrastructure and green growth
- to enable public partnerships to leverage funding, including private sector investment, in a manner that supports South Africa's efforts to move towards a greener economy that offers sustainable social development and economic upliftment.

- National Development Plan (NDP)

A key deliverable in the NDP is for South Africa to move away from the unsustainable use of natural resources and to transition to a resilient, low-carbon economy. The NDP proposes:

- supporting a carbon-budgeting approach, and carbon emission reduction targets
- introducing an economy-wide price for carbon, and programmes and incentives to raise energy efficiency and to manage waste in a more efficient manner
- simplifying regulation to encourage renewable energy use.

Annexure 1 illustrates the alignment of Biorefineries and Biofuels with the key policy mandates of DAFF, articulated in the NDP, and APAP, and illustrates where Biorefineries and Biofuels, and possibly technologies of the future may be used to support the delivery of the South African government's proposed interventions as articulated in the APAP.

The impact of biorefineries on rural development, employment and the environment

For a selection of biorefineries interviewed in developed countries (Chemrec biorefinery in Piteå, Sweden, British Sugar, Wissington, Norfolk, UK, Greenmills/Amsterdam, The Netherlands, BioMCN, The Netherlands, Domsjö Fabriker in Örnsköldsvik, Sweden, Biowert, Brensbach, Germany, Nedalco, The Netherlands, and Cargill/Cerestar Trafford Park, Manchester, UK), the following were given as the impacts of biorefineries on rural development, employment and the environment, and are similarly applicable to South Africa:

- Transition of existing plants to biorefineries usually helps in the maintenance of current jobs.
- New labour-saving technologies in biorefineries change the manufacturing processes and may cause job redundancies, which can be offset by the more jobs in the nonmanufacturing sectors i.e. supply-chain or business services
- Effects on employment in agriculture are mostly positive but also depend on the geographic supply chain structure.

- Biorefineries are catalysts for innovation in the economy: they strengthen job creation effects in the industry and especially R&D area.
- Biorefineries constitute a more environment friendly proposition for various industries because of their lower carbon footprint, enhanced energy efficiency and mostly zero-waste production processes
- Biorefineries help in the economic utilization of previously unwanted or low-value feedstocks[43].

A biorefinery approach to improve the sustainability of the South African sugar industry

Several economic and environmental drivers such as global warming, energy conservation, security of supply, and agricultural policies have also directed those industries to further improve their operations in a biorefinery manner. This should result in improved integration and optimization aspects of all the biorefinery subsystems.

A main driver for the establishment of biorefineries is the sustainability aspect. Ideally, all biorefinery projects should be assessed over the entire value chain on their environmental, economic, and social sustainability, from construction, to operation, to shut down. This assessment should also consider issues of competition for food and biomass resources, the impact on water use and quality, changes in land-use, soil carbon stock balance and fertility, net balance of GHGs, impact on biodiversity, potential toxicological risks, and energy efficiency, to name a few. Possible impacts on international and local dynamics, end user/consumer needs, as well as investment feasibility should also be looked at. It is important that the sustainability assessment is made parallel to conventional systems providing the same products and services, where possible[44].

The Department of Environmental Affairs of South Africa, has set up the Green Fund, essentially to support the country's transition to a low-carbon, resource-efficient and pro-employment economy. The impacts of diversification in the sugar industry through the development of sugarcane biorefineries, in terms of economic viability, environmental benefits and social benefits were assessed and reported. Furthermore, the potential benefits of establishing a biorefinery for sugar mills in South Africa was investigated. The aim was to determine if sugarcane biorefineries could improve the viability of the sugar industry in South Africa, while at the same time contributing to the development of a sustainable green economy and job creation[45]. The general conclusions of this report are listed below:

- Biorefineries using residues from industrial biomass processing can provide substantial environmental benefits. The economics would improve because the energy source is cheaper and more biomass would be available, thus increasing the size of the biorefinery and benefitting from economies of scale.

- Biorefineries can provide significant job creation, especially in the supply of feedstocks, such as the harvesting residues to the sugar mills. "Green cane harvesting," (instead of burning of cane before harvesting) would double the number of jobs created for harvesting, including collection and transport for delivery to sugar mills. Of course, with more jobs, the salary bill becomes higher, but this could be off-set by better/premium prices as the product is processed in a biorefinery. The risk with green cane harvesting is the increased use of mechanization, which aspect is also to be studied.
- To attract investment, the economic viability of biorefineries needs to be proven, alongside environmental and social benefits.

As anticipated, such an approach to the sugar industry in South Africa would have policy implications, also listed below[46].

- Feedstock-process-product-market scenarios must provide sufficient economic returns. Government policies in the green economy, bio-economy, waste economy, renewable electricity and biofuels production should be considered during decision-making to establish biorefineries.
- The small number of biorefinery scenarios analysed[47] did not demonstrate sufficient economic returns for private investment to participate. Financial support from government will therefore be required to enable the development of economically-viable biorefineries. A national biorefinery strategy should carry greater priority than the Industrial Biofuels Strategy and the production of renewable electricity and high-value products through co-generation, should receive sufficient financial support from government, through price premiums on products, grants or subsidisation of producers.
- Investments in technology development and commercialisation will be required to improve economic returns and environmental footprint, which will include (i) adaptation of global technologies to local feedstocks, possibly through in-licensing of these technologies, (ii) development, scale-up and industrialisation of new technologies.

In a similar report[48] which sought to:

- establish the status quo of the policy regime to promote and create a biofuels market in South Africa
- examine the possible impacts of biofuels on food prices and availability in the global context
- examine and quantify the extent of the possible or anticipated impacts of the production of biofuels on water resources
- examine whether the current investments and planned investments in biofuels and the biofuels production chain can benefit upstream agricultural development
- examine if new technologies can overcome food security and resource issues,

a comparable conclusion was drawn, namely that biofuels, present with few sustainability risks for related food production in terms of land and water resources.

Agrarian transformation with clear benefits to rural communities would increase the availability of biomass in general, since biomass resources are available to varying degrees to establish a local bioenergy industry[49]. Next-generation technologies would then be deployed in the non-food components of the available biomass, to produce biofuels and high-value chemicals, via a biorefinery approach. Despite this opportunity, the biofuels sector faces several sustainability challenges in the **South African** context, specifically competition for land (with potential implications for food security and food prices, and the availability of water resources.

The integration of small-scale and large-scale bioenergy systems to rural livelihoods

The benefits of small-scale and large-scale bioenergy systems to rural livelihoods should also be evaluated, looking at food-security and energy-security where increase in food productivity, access to modern energy, and broader rural development are the major sustainability indicators. A key aspect of this approach is the use of. Bioenergy has the potential for using advanced technologies to contribute to socio-economic development and sustainable environmental practices, provided that the correct combination of feedstock (type and supply volumes), processing technologies, end-uses and community-ownership is crafted. In terms of global supply chains, innovative business models have been called for to maximise the small-scale opportunities that bioenergy offers. This is illustrated in Figure 7 below.

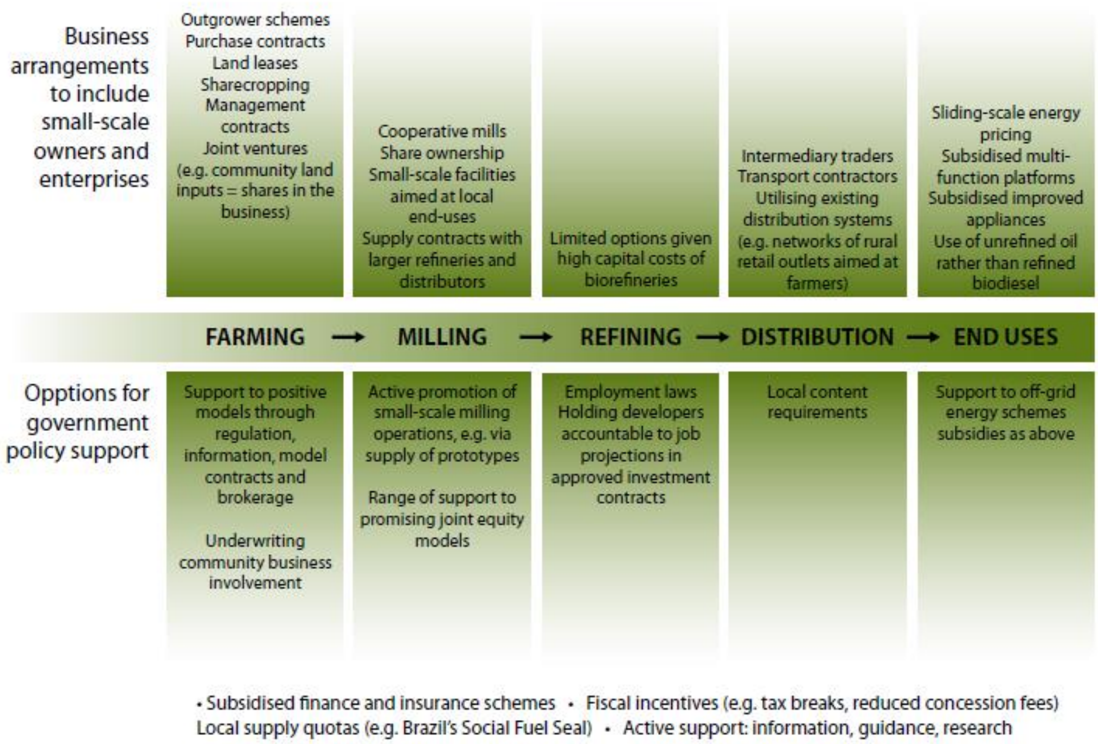

Figure 7: Business model innovations that provide small-scale opportunities in bioenergy supply chains[50]

The social, economic and environmental impacts of biorefinery products are summarized in Table 7 below.

Table 7: Summary of social, economic and environmental impacts of biorefinery products[51]

	IMPACTS		
	Social	Environmental	Economic
Conventional biofuels	No threat to food supplies Rising food costs; shortage of food in developing countries	GHG emissions More land and water necessary Feedstocks require more fertilizer	Use of food crops Higher food prices Dependent on subsidies; not cost competitive
Advanced biofuels	Municipal waste as feedstock does not compete with food security Energy crops prioritized over food crops Aquatic biomass prioritized over algae use for protein foods	GHG reduced by 70-90% Soil degradation Negative impacts on soil biodiversity and water	More yields per ha than conventional biofuels Potential to increase job numbers Residue collection is costly Costs not competitive to conventional biofuels
Bioplastics	Limited understanding of production processes Competition for feedstock with food consumption	Recyclable	Less price variations Higher production costs
Industrial, aircraft & automotive parts	Employment in rural areas where feedstock can be produced	Weight and fuel savings Reduced CO_2 emissions Less energy consumed	Cost efficient
Green chemicals	Lower toxicity	Biodegradable Lower volatile oxides release Lower energy consumption	Waste disposal costs reduced Processing is cost intensive
Lubricants	Job creation Limited public awareness Possible contribution to food security	Biodegradable Less use of fossil fuel resources Negative effects on the environment due to over-use of fertilizers and agrochemicals	Cleaner than petroleum motor oil Small market Competes with biodegradable oil-based products Higher prices
Personal & homecare products	Employment in rural areas (especially developing countries) where feedstock can be produced Limited public awareness Increasing number of multi-drug resistant microorganisms	Cleaning at lower temperatures means less GHG emitted Chemical processes are replaced Biodegradable	Large global market (US$B) Downstream processing is complicated and costly Consumers will not pay high prices
Fibre products	Reduced human & marine toxici Food vs fuel debate Public opposition to GMOs	Recyclable Reduced GHG emissions The process impacts on air & water	Large global market (US$B) Competes with food & bioenergy industry Competes with energetic & material use of biomass
Food & feed additives	Recent innovation	Microalgae cultivation results in sustainability	Competitive price-wise with oil-based products High-value markets Small firms in niche markets Total production volumes & market size are small

Legend	
(blue)	Negative impact
(green)	Positive impact
(yellow)	Neutral impact

Biofuels the Western Cape Province

Known examples of significant biofuels operations in South Africa are those shown in Table 8 below, guided primarily by the cultivation potential of economically significant levels of renewable feedstocks, such as sugar beet. This presents an opportunity for the deliberate cultivation of biomass feedstocks, provided their effects on water reserves can be controlled (note the current water shortage crisis in the Western Cape).

Table 8: Biofuels operations in South Africa

Name	Plant type (bioethanol/biodiesel)	Capacity (million L per annum)	Location	License status
Arengo 316 Pty ltd	Sorghum/bioethanol	90	EC	Granted
Mabele Fuels	Sorghum/bioethanol	158	FS	Issued
Ubuhle Renewable energy	Sugarcane/bioethanol	50	KZN	Granted
Rainbow Nation Renewables Fuels Ltd	Soybean/biodiesel	288	EC	Issued
Exol Oil Refinery	Waste vegetable oil/biodiesel	12	GP	Granted
Phyto Energy	Canola/biodiesel	>500	EC	Application
Basfour 3528 Pty Ltd	Waste vegetable oil/biodiesel	50	EC	Granted
E10 Petroleum Africa CC	Bioethanol	4-2	GP	Granted

The most recent works about sub-products such as bio-products of resins, of polymers and film barriers, biodegradable plastic, dispersers, flocculants, as well as other more traditional uses such as cellulose, paper and textile fibres, resulting from fermentation of lignocellulosic residues are shown in Table 9 below.

Table 9: Feedstocks and raw material for production of value added products[52]

Feedstocks	Bioproducts
Sugarcane, beets, corn sorghum juice	Bioethanol, Ethanol production
Forest wastes	Ethanol production
Agricultural wastes	Cellulolytic enzyme
Eucalyptus kraft pulp	Xylanase
White-rot fungi	Animal feed
Lignocellulose	Biochemicals, biopesticides, biopromoters
Olive stone	Bioactive compounds
Sisal stems waste	Lactic acid

An opportunity is therefore presented for the Western Cape province of South Africa to consider biorefinery investment using lignocellulose as feedstock.

8. Conclusions

The role of government, business and Research & Development (R&D)[53]

The roles of these players may be summarised in bullet points as shown below:

The role of government

- Provide seed funding

- Set tough regulations to drive innovation to comply with this regulation
- Encourage local energy security for rural community development
- Create markets
- Respond to climate change by enacting GHG emissions regulations
- Invest in technological developments, R&D and encourage exchange of information
- Development of biomass supply chains
- Invest in environmental sustainability
- Subsidies and incentives should be given to entrepreneurs or businesses considering low-carbon petroleum replacement strategies to encourage investment in new technology and infrastructure and reduce the reliance on public funding.
- Set up public-private partnerships to initiate private sector investments and reduce the delay between product development and commercialization

The role of business

- Support the development of global biomass supply chain
- Develop and support a reliable upstream supply chain able to mobilize a sufficient level of feedstock available for conversion, but not at the expense of food/land use
- Grow larger quantities of energy crops than is currently under cultivation
- Organize feedstock storage facilities to ensure a continuous supply of feedstock throughout the conversion process
- Ensure growth of a global industry through transportation and trading infrastructure

The role of R&D

- Research into conversion techniques and feedstock processing, new enzyme and catalyst technology, densification techniques and metabolic pathways
- Research into agriculture and crops should be supported to gain a better understanding of crop rotation, land management, land-use change issues, the food versus fuel trade-off, cultivation and harvesting techniques, natural resources (water, sun, fertilizer) management, and the genetic engineering of energy crops and microorganisms
- Research into the optimization of biorefineries which will be capable of larger-scale and more commercially viable, reduced carbon footprint bio-based production

Scaling considerations

The ability to scale biorefineries to meet market demand presents with its own challenges.

- larger plants demand larger feedstock volumes, which will need to be transported over long distances, all year round. This adds substantial costs to the process. Transporting large volumes of feedstock over long distances is deleterious to feedstocks with high concentrations of water (which cannot be stored over long periods), minerals, or organic components. Year-round biomass availability also requires expensive storage facilities.

- Biorefinery systems should be designed in such a way that capital intensive operations can continue year-round so that collection, separation, and storage can be decentralized. Certain fractions could then be transported to alternative biorefineries, for further processing of crops-derived intermediates [54]

9. Synthesis and key trends from the literature

Key trends speak to the following[55]:

Agriculture

As has been alluded to elsewhere in this report, with the establishment of biorefineries, there will be increased demand for plant-based feedstocks, and this may escalate the debate on the use of land for food versus fuel. Agricultural commodity prices may also be influenced by the increased production of bio-based materials in biorefineries. The up-side is that this demand may open new economic opportunities for famers in developing countries, as well as other suppliers into the value chain, leading ultimately to increased agricultural productivity across the globe, particularly in Africa, where opportunities to participate in a new agricultural revolution will be realized. New plants with novel traits will make it possible to use less fertile land (as is currently the case), however, a substantial increase in fertilizer use is foreseen, especially in Africa.

The automotive industry

The replacement of conventional gasoline and diesel by biofuels is technologically is a reality of the foreseeable future, and is supported by policy, declining fossil fuel reserves and incentives to drive innovation in that direction. Similarly, the aviation industry is looking for alternative fuels suitable for jet propulsion to the industry's carbon footprint, given the challenging goal of reducing its carbon dioxide emissions by 50% by 2050.

The chemical industry

The use of bio-based chemicals (green alternatives) as substitutes to traditional petroleum-based chemicals with equivalent functionality and performance is a growing priority for the chemical industry.

Transportation

The transportation industry is dependent on oil. As with the aviation and automotive industries, the transportation industry is looking at biofuels to reduce the carbon footprint caused by its oil consumption.

The need for multi-disciplinary collaborations

Collaborations should be encouraged by bringing together key stakeholders from separate backgrounds (agriculture/forestry, transportation fuels, chemicals, energy, for example), to discuss common processing topics, craft necessary R&D projects multi-disciplinary partnerships, for biorefinery integration[56].

End Notes

[1] International Energy Agency (IEA). 2008. *Bioenergy Task 42 on Biorefineries: Minutes of the third task meeting.* Copenhagen: IEA.
[2] NREL Biomass Research
[3] Berntsson, T., Axegård, P., Backlund, B., Samuelsson, Å., Berglin, N. & Lindgren, K. 2008. *Swedish pulp mill Biorefineries: A vision of future possibilities.* Stockholm: Swedish Energy Agency.
[4] Stuart, P. 2010. *Biorefinery 101: Maximizing benefits and minimizing risks associated with implementing the forest biorefinery.* [Online] Available: http://egon.cheme.cmu.edu/esi/docs/pdf/Paul%20Stuart04-2010_Biorefinery%20101_Carnegie%20Mellon.pdf [Accessed: 23 October 2017].
[5] Wikipedia definition.
[6] The Royal Society. 2008. *Sustainable biofuels: prospects and challenges.* [Online] Available: https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2008/7980.pdf [Accessed: 23 October 2017].
[7] International Energy Agency (IEA). 2008. *Bioenergy Task 42 on Biorefineries: Minutes of the third task meeting.* Copenhagen: IEA.
[8] Naik, S.N., Goud, V.V., Rout, P.K. & Dalai, A.K. 2010. Production of first and second-generation biofuels: A comprehensive review. *Renewable and Sustainable Energy Reviews,* **14**(2), 578-597.
[9] Van Eijck, J. 2008. Prospects for Jatropha biofuels in Tanzania: An analysis with strategic niche management. *Energy Policy,* **36**(1), 311.
[10] Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances,* **25**(3), 294.
[11] Greenwell, H.C., Laurens, L.M.L., Shields, R.J., Lovitt, R.W. & Flynn, K.J. 2009. Placing microalgae on the biofuels priority list: A review of the technological challenges. *Journal of the Royal Society Interface,* **7**(46), 703-726.
[12] Smith, V.H., Sturm, B.S.M., deNoyelles, F.J. & Billings, S.A. 2010. The ecology of algal biodiesel production. *Trends in Ecology & Evolution,* **25**(5), 301-309.
[13] de Jong, E. & Jungmeier, G. 2015. *Biorefinernery concepts in comparison to petrochemical refineries.* [Online] Available: http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/3/7/5/cf7aa6b6-2140-46f2-b4ca-455f5c3eb547_de%20Jong%202015%20Biorefinery%20Concepts%20in%20Comparison%20to%20Petrochemical%20Refineries%20Book%20Chapter.pdf [Accessed: 1 November 2017].
[14] King, D. 2010. *The future of industrial biorefineries.* [Online] Available: http://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/WEF_Biorefineries_Report_2010.pdf [Accessed: 23 October 2017].
[15] de Jong, E., van Ree, R., Sanders, J.P.M. & Langeveld, H. 2010. Biorefineries: Giving value to sustainable biomass use. In Langeveld, H., Meeusen, M. & Sanders, J. (eds.), *The biobased economy: Biofuels, materials and chemicals in the post-oil era*, 111-130. London: Earthscan Publishers.
[16] Dinjus, E., Arnold, U., Dahmen, N., Höfer, R. & Wach, W. 2009. Green fuels: Sustainable solutions for transportation. In Höfer, R. (ed.), *Sustainable solutions for modern economies,* 125-163. Cambridge: RSC Green Chem.

[17] Egeberg, R.G., Michaelsen, N.H. & Skyum, L.H.T. 2009. *Novel hydrotreating technology for production of green diesel.* [Online] Available: http://www.topsoe.com/file/novel-hydrotreating-technologyproduction-green-diesel [Accessed: 1 November 2017].

[18] Axegård, P., Karlsson, M., McKeogh, P., Westenbroek, A., Petit-Conil, M., Eltrop, N., *et al*. 2007. *A bio-solution to climate change: Final report of the biorefinery taskforce to the forest-based sector technology platform.* [Online] Available: http://www. forestplatform.org/ [Accessed: 1 November 2017].

[19] de Jong, E., van Ree, R., Sanders, J.P.M. & Langeveld, H. 2010. Biorefineries: Giving value to sustainable biomass use. In Langeveld, H., Meeusen, M. & Sanders, J. (eds.), *The biobased economy: Biofuels, materials and chemicals in the post-oil era*, 111-130. London: Earthscan Publishers.

[20] Mandl, M.G. 2010. Status of green biorefining in Europe. *Biofuels, Bioproducts and Biorefining,* **4**(3), 268-274

[21] Schaffenberger, M.E., Koschuh, J., Essl, W., Mandl, R., Boechzelt, M., *et al.* 2012. Green biorefinery-production of amino acids from grass silage juice using an ion exchanger device at pilot scale. *Chemical Engineering Transactions,* **29**, 505-510.

[22] de Jong, E., van Ree, R., Sanders, J.P.M. & Langeveld, H. 2010. Biorefineries: Giving value to sustainable biomass use. In Langeveld, H., Meeusen, M. & Sanders, J. (eds.), *The biobased economy: Biofuels, materials and chemicals in the post-oil era*, 111-130. London: Earthscan Publishers.

[23] Liu, R.G., Yu, H. & Huang, Y. 2005. Structure and morphology of cellulose in wheat straw. *Cellulose,* **12**(1), 25-34.

[24] Helbert, W., Cavaille, J.Y. & Dufresne, A. 1996. Thermoplastic nanocomposites filled with wheat straw cellulose whiskers. Part 1: Processing and mechanical behavior. *Polymer Composites,* **17**(4), 604-611.

[25] Leistritz, F.L., Hodur, N.M., Senechal, D.M., Stowers, M.D., McCalla, D. & Saffron, C.M. 2007. Biorefineries using agricultural residue feedstock in the Great Plains. Paper presented at the Western Regional Science Association 2007 Annual Meeting, Newport Beach, CA, 21-24 February.

[26] IEA Bioenergy. 2014. *Task42 biorefining: Sustainable and synergetic processing of biomass into marketable food & feed ingredients, chemicals, materials and energy (fuels, power, heat).* [Online] Available: http://www.ieabioenergy.com/wp-content/uploads/2014/09/IEA-Bioenergy-Task42-Biorefining-Brochure-SEP2014_LR.pdf [Accessed: 31 October 2017].

[27] Paes, B.G. & Almeida, J.R.M. 2014. Genetic improvement of microorganisms for applications in biorefineries. *Chemical and Biological Technologies in Agriculture,* **1**, 21.

[28] Paes, B.G. & Almeida, J.R.M. 2014. Genetic improvement of microorganisms for applications in biorefineries. *Chemical and Biological Technologies in Agriculture,* **1**, 21.

[29] Paes, B.G. & Almeida, J.R.M. 2014. Genetic improvement of microorganisms for applications in biorefineries. *Chemical and Biological Technologies in Agriculture,* **1**, 21.

[30] de Jong, E. & Jungmeier, G. 2015. *Biorefinernery concepts in comparison to petrochemical refineries.* [Online] Available: http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/3/7/5/cf7aa6b6-2140-46f2-b4ca-455f5c3eb547_de%20Jong%202015%20Biorefinery%20Concepts%20in%20Comparison%20to%20Petrochemical%20Refineries%20Book%20Chapter.pdf [Accessed: 1 November 2017].

[31] de Jong, E. & Jungmeier, G. 2015. *Biorefinernery concepts in comparison to petrochemical refineries.* [Online] Available: http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/3/7/5/cf7aa6b6-2140-46f2-b4ca-455f5c3eb547_de%20Jong%202015%20Biorefinery%20Concepts%20in%20Comparison%20to%20Petrochemical%20Refineries%20Book%20Chapter.pdf [Accessed: 1 November 2017].

[32] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].

[33] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].

[34] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].

[35] International Energy Agency. 2008. *From 1st to 2nd generation biofuel technologies: An overview of current industry and RD&D activities.* [Online] Available: https://www.iea.org/publications/freepublications/publication/2nd_Biofuel_Gen.pdf [Accessed: 1 November 2017].

[36] King, D. 2010. *The future of industrial biorefineries.* [Online] Available: http://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/WEF_Biorefineries_Report_2010.pdf [Accessed: 23 October 2017].
[37] King, D. 2010. *The future of industrial biorefineries.* [Online] Available: http://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/WEF_Biorefineries_Report_2010.pdf [Accessed: 23 October 2017].
[38] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].
[39] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].
[40] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].
[41] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].
[42] Vijayendran, B. 2010. Bio products from bio refineries-trends, challenges and opportunities. *Journal of Business Chemistry,* **7**, 109-115.
[43] BIOPOL. 2009. D 2.2.3: *Report with the assessment results concerning the impact of biorefineries on rural development, employment and environment.* [Online] Available: http://www.biorefinery.nl/fileadmin/biopol/user/documents/PublicDeliverables/BIOPOL_D_2_2_3_-_Final_120609.pdf [Accessed: 3 November 2017].
[44] de Jong, E. & Jungmeier, G. 2015. *Biorefinernery concepts in comparison to petrochemical refineries.* [Online] Available: http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/3/7/5/cf7aa6b6-2140-46f2-b4ca-455f5c3eb547_de%20Jong%202015%20Biorefinery%20Concepts%20in%20Comparison%20to%20Petrochemical%20Refineries%20Book%20Chapter.pdf [Accessed: 1 November 2017].
[45] Gorgens, J.F., Mandegari, M.A., Farzad, S., Daful, A.G. & Haigh, K.F. 2015. *A biorefinery approach to improve the sustainability of the South African sugar industry: Assessment of selected scenarios.* [Online] Available: http://www.sagreenfund.org.za/wordpress/wp-content/uploads/2016/04/SU-Biorefinery-Research-Report.pdf [Accessed: 1 November 2017].
[46] Gorgens, J.F., Mandegari, M.A., Farzad, S., Daful, A.G. & Haigh, K.F. 2015. *A biorefinery approach to improve the sustainability of the South African sugar industry: Assessment of selected scenarios.* [Online] Available: http://www.sagreenfund.org.za/wordpress/wp-content/uploads/2016/04/SU-Biorefinery-Research-Report.pdf [Accessed: 1 November 2017].
[47] Gorgens, J.F., Mandegari, M.A., Farzad, S., Daful, A.G. & Haigh, K.F. 2015. *A biorefinery approach to improve the sustainability of the South African sugar industry: Assessment of selected scenarios.* [Online] Available: http://www.sagreenfund.org.za/wordpress/wp-content/uploads/2016/04/SU-Biorefinery-Research-Report.pdf [Accessed: 1 November 2017].
[48] Brent, A. 2014. *The agricultural sector as a biofuels producer in South Africa: Understanding the food energy water nexus.* Cape Town: WWF-SA.
[49] Department of Minerals and Energy (DME). 2007. *Biofuels Industrial Strategy of the Republic of South Africa.* [Online] Available: http://www.info.gov.za/view/DownloadFileAction?id=77830 [Accessed: 31 October 2017].
[50] Vermeulen, S., Sulle, E. & Fauveaud. S. 2009. *Biofuels in Africa: Growing small-scale opportunities.* [Online] Available: http://www.iied.org/pubs/display.php?o=17059IIED [Accessed: 4 November 2017].
[51] Hasenheit, M., Gerdes, H., Kiresiewa, Z. & Beekman, V. 2016. *Summary report on the social, economic and environmental impacts of the bioeconomy.* [Online] Available: http://ecologic.eu/sites/files/publication/2016/2801-social-economic-environmental-impacts-bioeconomy-del2-2.pdf [Accessed: 2 November 2017].
[52] Forster-Carneiro, T., Berni, M.D., Dorileo, I.L. & Rostagno, M.A. 2013. Biorefinery study of availability of agriculture residues and wastes for integrated biorefineries in Brazil. *Resources, Conservation and Recycling*, **77**, 78-88.

[53] King, D. 2010. *The future of industrial biorefineries.* [Online] Available: http://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/WEF_Biorefineries_Report_2010.pdf [Accessed: 23 October 2017].

[54] de Jong, E., van Ree, R., Sanders, J.P.M. & Langeveld, H. 2010. Biorefineries: Giving value to sustainable biomass use. In Langeveld, H., Meeusen, M. & Sanders, J. (eds.), *The biobased economy: Biofuels, materials and chemicals in the post-oil era*, 111-130. London: Earthscan Publishers.

[55] King, D. 2010. *The future of industrial biorefineries.* [Online] Available: http://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/WEF_Biorefineries_Report_2010.pdf [Accessed: 23 October 2017].

[56] de Jong, E. & Jungmeier, G. 2015. *Biorefinernery concepts in comparison to petrochemical refineries.* [Online] Available: http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/3/7/5/cf7aa6b6-2140-46f2-b4ca-455f5c3eb547_de%20Jong%202015%20Biorefinery%20Concepts%20in%20Comparison%20to%20Petrochemical%20Refineries%20Book%20Chapter.pdf [Accessed: 1 November 2017].