Sustainability **2015**, *7*, 12209-12235; doi:10.3390/su70912209

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Review

Sustainability Issues and Opportunities in the Sugar and Sugar-Bioproduct Industries

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Academic Editors: Susan Krumdieck and Deepak Pant

Received: 10 July 2015 / Accepted: 25 August 2015 / Published: 3 September 2015

Abstract: Like many other industries, the sugar and sugar-bioproduct industries are facing important sustainability issues and opportunities. The relatively low and fluctuating profit for sugar, surpluses of sugar, world-wide trend to produce alternative, renewable bio-based fuels and chemicals to those derived from petroleum and reduce greenhouse gases, water- and energy-intensive factories and refineries, and increased consumer demands for sustainably manufactured products are putting pressure on the industries to diversify for sustainability. Sugar crops, including sugar and energy cane (*Saccharum officinarum*), sugar and energy beets (*Beta vulgaris*), and sweet sorghum (*Sorghum bicolor* L. Moench), are excellent, renewable biomass feedstocks because of their availability, their being amongst the plants that give the highest yields of carbohydrates per hectare, and high sugar contents. While much research has been focused on conversion technologies for advanced biofuels and bioproducts, attention is now focused on developing sustainable supply chains of sugar feedstocks for the new, flexible biorefineries, with customers wanting maximum feedstock reliability and quality, while minimizing cost. All biomass from sugar crops are potential feedstocks. The cogeneration of bioelectricity from bagasse and leaf residues is being increasingly manufactured in more countries and, due to the high carbon content of bagasse and leaves, can also be converted into value-added products such as biochar. Sugar crops are superior feedstocks for the production of platform chemicals for the manufacture of a range of end-products, e.g., bioplastics, chemicals, and biomaterials. In several countries and regions, green sustainability criteria are now in place and have to be met to count against national biofuel targets. Processes to convert high-fiber sugar crop biomass into biofuel have been developed but there has only been limited commercialization at the large-scale.

Keywords: renewable sugar crops; biomass; advanced biofuels; bioproducts; bagasse; extraneous matter

1. Introduction

Sucrose (α-D-glucopyranosyl-(1 → 2)-β-D-fructofuranose) is ubiquitously known as common table sugar, and crystalline sucrose is primarily produced industrially from sugarcane (*Saccharum officinarum*) and sugar beet (*Beta vulgaris*) (Figure 1). Like many other food and chemical industries, the sugar industry and related sugar-bioproduct industries are currently facing tough sustainability issues. Sustainability is the balancing of the three, interdependent, development pillars of the environment (ecology), society, and economy (Figure 2). For some industries the core principles for sustainable manufacture are renew, reuse, and recycle, which are applied to every production step and business practice [1]. Sustainable development should also ensure that the needs of the present are met without compromising the ability of future generations to meet their own needs [2].

Figure 1. Sugarcane harvested into billets (**top**) and sugar beets being delivered for processing (**bottom**).

Although the twentieth century saw enormous growth in chemicals manufacturing which fed the parallel growth in the developed world, it came at a cost. Inefficient processes reliant on fossil fuels leading to unacceptable levels of pollution, hazardous operations resulting in a number of well-publicized disasters, inadequate product testing causing often irrational public concerns over product safety, have all led to an exponential growth in chemicals legislation [3]. Chemical industries, including the sugar and associated industries, are now working towards achieving environmentally acceptable and economically viable manufacturing in a tough legislative framework while meeting the high demands of a growing population. Sustainable production of sugar, biofuels (for example, first generation ethanol in Brazil) and other bioproducts (such as chemicals and structural materials) from sugar crops, will only be realized through a re-assessment of the entire chemical product life-cycle from resources, to manufacturing and production, through to product use and ultimate fate [3,4]. Moreover, several critical changes are required both in mindset and practice that are listed in Table 1.

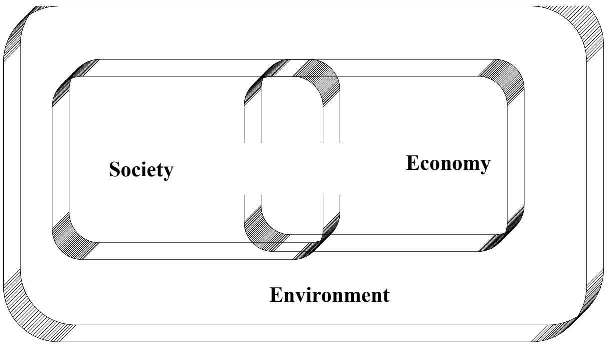

Figure 2. Sustainability focuses on the triple bottom line: (i) social responsibility; (ii) economic viability, which are both constrained by (iii) environmental limits that need protection. Sustainable development should recognize the well-being of human systems that is supported by a healthy, natural environment, and which future generations have an equal claim on our planets' resources.

Table 1. Unsustainable *versus* sustainable mindsets and practices in the current sugar industry. Adapted from [4].

Key Dimension	Unsustainable	Sustainable
Society/Policy Goals	Economic growth	Growth in well-being
Approach to Nature	Control over nature	Work with nature
Predominant Work Mode	Big is Better	Smart is Better
Focus on Business Activities	Goods	Services, needs
Energy Sources	Fossil fuels	Renewable energy (including biofuels and bioproducts)
Predominant Chemistry	Energy intensive	Low energy
Waste Production	High waste	No waste
Typical Materials	Iron, steel, and cement	Bio-based materials

Continued reliance on fossil fuel energy resources is unsustainable because of depleting world reserves and associated greenhouse gas (GHG), as well as energy security. This explains countries around the world legislating to curb GHG emissions. It also explains the currently vigorous initiatives of developing renewable and potentially carbon neutral, solid, liquid and gaseous biofuels as alternative energy resources as well as biobased alternatives to petroleum-derived chemicals and materials. Biomass, plant-derived organic matter, currently contributes to over 10% of primary energy to meet world annual demand [5] and is expected to grow further [6,7]. In the U.S., the Department of Energy (DOE), via the U.S. Biomass Roadmap, put forward the goal that by 2030 biomass will supply energy approximately equivalent to 30% of current petroleum consumption [8]. The European Commission (EC) has set mandatory targets for an overall share of 20% renewable energy and a 10% share of renewable energy in transport by 2020 [9]. The EC also reached an agreement in 2014 on an indirect land-use change (ILUC) directive [10], to minimize the impact of indirect changes of land use (for biofuel use), while at the same time protecting existing investments in biofuel production in Europe.

Two major challenges that need to be overcome for the creation of renewable biofuels and bioproducts from sugar crops are the need for: (i) net energy gain during feedstock production; and (ii) GHG emissions that are lower than those from fossil fuels [7]. This paper describes current trends, needs, and opportunities in the sugar and sugar-bioproduct industries that are expected to strongly contribute to their sustainability.

2. Background Information: Industrial Production of Sugar and Associated By-Products

2.1. Crystalline Sugar Manufacture

Commercially available sucrose has very high purity (>99.9%) making it one of the purest organic substances produced on an industrial scale. To obtain such a pure product from both sugarcane and sugar beet, complex isolation and purification process units are followed. Industrial sucrose production is essentially a series of separations of non-sucrose compounds (impurities) from sucrose (Figure 3). Sugarcane is grown in tropical and sub-tropical areas of the world and processing often occurs in two stages. Juice is first extracted from sugarcane (sucrose yields range between 10%–15% weight of sugarcane) by tandem milling or diffusion and converted to raw sugar (~97.5%–99.5% pure sucrose; golden yellow/brown crystals) at factories. Secondly, after raw sugar has been transported to a refinery, it is refined using similar unit processes used in raw sugar manufacture, as well as additional decolorization steps such as ion-exchange resins and activated carbon, to the familiar white, refined sugar (>99.9% sucrose) [11].

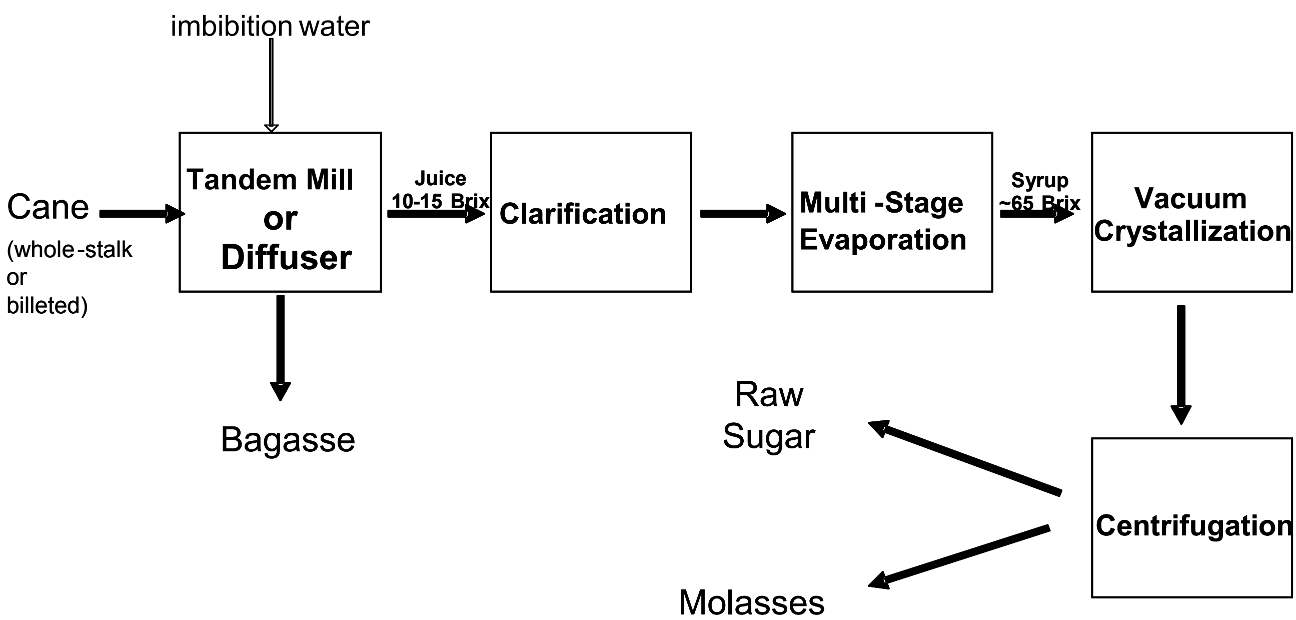

Figure 3. Basic scheme of the raw sugar manufacturing process in a sugarcane factory [11]. Brix is % dissolved refractometric solids.

Sugar beets are grown in more temperate areas and processed directly into white sugar (>99.9% sucrose) at nearby factories. Production of refined sugar from sugar beets has some similarities to refined cane sugar production, but dissimilarities exist because sugar beet is a tuberous root and sugarcane a grass. Sugar beets are introduced to the factory, washed, and sliced into "V" shaped cossettes. Sucrose and impurities are extracted from cossettes with hot water in a diffuser. Diffusion juice contains ~12% sucrose and 2% soluble impurities on sugar beet weight, and is heated to ~85 °C before it is clarified. The resulting "thin" juice is then concentrated from ~14 to 60–65 Brix (% dissolved refractometric solids) syrup or "thick juice" across multiple-effect evaporators, then triple-crystallized and centrifuged to produce white, refined sugar (>99.7% purity). As in sugarcane refineries, some sugar beet factories employ additional purification steps. For more detailed information on the industrial production of sucrose from sugarcane and sugar beet, the reader is referred to other comprehensive texts [11–15].

2.2. By-Products of Sugar Manufacture

The major by-products of crystalline sucrose manufacture are sugarcane bagasse, beet pulp, and sugarcane/beet molasses. The major agricultural residue is sugarcane extraneous leafy material. Minor by-products include fly ash, filter cake, lime and calcium carbonate residues. By volume, fibrous bagasse is the most important by-product and is the primary source of fuel for the generation of steam and electricity to operate sugarcane factories (see Section 4.1). Wet and dry beet pulp as well as pressed pulp silage, with or without added molasses, are sources of animal feed. Molasses is a valuable by-product of sugar manufacture and exists in a range of grades: edible molasses, cane and beet molasses, and refinery molasses. It is used as an animal feed additive, in the industrial production of rum and other beverage alcohols, bakers' yeast, citric acid, and other fermentation processes [4].

3. Sustainable Supply Chains of Sugar Biomass Feedstocks for the Manufacture of Advanced Biofuels and Bioproducts

3.1. Sugar Crops as Biomass Feedstocks

A major trend in the U.S. and world-wide is to manufacture advanced biofuels and bioproducts from sugar crops, including sweet sorghum (*Sorghum bicolor* L. Moench), energy cane (*Saccharum officinarum*) and energy beets (*Beta vulgaris*). Sugar crops and their associated by-products and residues make good renewable carbohydrate feedstocks because they are readily available, can be grown in a much larger area of the world than grain crops [4], and are amongst the plants giving the highest yields of carbohydrates per hectare. A unique advantage sugar crops have over grain and cellulosic crops, are that they require less processing as their juice sugars are directly fermentable. Moreover, concerns of conversion efficiency, high production costs, and increased prices for whole corn grain and dried distiller's grain in the USA have provided a real opportunity for alternative feedstock sources from sugar crops [16]. Sugarcane and sugar beet industries, furthermore, have well-established agricultural production systems with a well-developed logistics and processing structure.

At present, approximately 40% of the world's fuel ethanol production is already from sugar crops (mostly the fermentation of either sugarcane juice or molasses in Brazil, Thailand, and India) with the remaining 60% from grain crops [17]. Thus, as of 2014 most fuel ethanol manufactured around the world is first generation ethanol. Also, since 2011, world fuel ethanol production has been steadily rising, with the latest reported figures for current production of 24,570 million gallons in 2014 [18]. The Environmental Protection Agency of the U.S. government designated Brazilian sugarcane ethanol as an advanced biofuel in 2010 due to its estimation that 61% reduction of life cycle GHG emissions, including direct and indirect land-use change emissions [19]. It has been acknowledged, however, that first-generation fuels have technical issues, such as their oxygen contents, that limit their use because they cannot completely replace fossil fuels on their own. For example, 2-carbon ethanol has lower energy per volume than petroleum fuels, and is not fully compatible with existing vehicles and the current fuel-distribution infrastructure [20]. Biofuels with high carbon contents, e.g., 15-carbon alkene β-farnesene that is converted from sugar by engineered yeasts by Amyris in California, offer more sustainable substitution of fossil fuels in the future. Moreover, β-farnesene addresses reduction in GHGs while also delivering improved engine performance [20]. Very recently, Balakrishnan *et al.* [21] went even further and showed that sugars from sugarcane can be converted in >95% yields to a new class of cycloalkane compounds used for aviation fuels and also achieved net life cycle GHG savings of up to 80%.

While much research has been focused on conversion technologies for advanced biofuels and bioproducts, attention is now focused on developing sustainable supply chains of sugar feedstocks for the new, flexible biorefineries [22]. This includes improved feedstock quality and cost-effective approaches for minimizing feedstock sugar losses during storage [22]. Kenney *et al.* [23] similarly reported that while "much progress has been made in improving biomass collection and pre-processing machinery performance and efficiencies, reducing material losses throughout the supply chain, and expanding harvesting and storage operational windows" and "emphasis on feedstock quality is still lacking." The quality of the feedstock supply chain from the field to the processed end-product is impacted by crop genotype variability, production conditions, harvest method, collection and storage practices, season date, and environmental conditions. These relationships and their integration are illustrated in Figure 4 using the examples of sweet sorghum and energy beets, but other sugar crops such as energy cane could be included as well as by-products and residues. Furthermore, as the current pioneer biorefineries move from technology development and deployment to operations, the quality and specifications of the feedstock will become even more important [23]. Overall, customers of sugar feedstocks want maximum feedstock reliability and quality, while minimizing variability and cost.

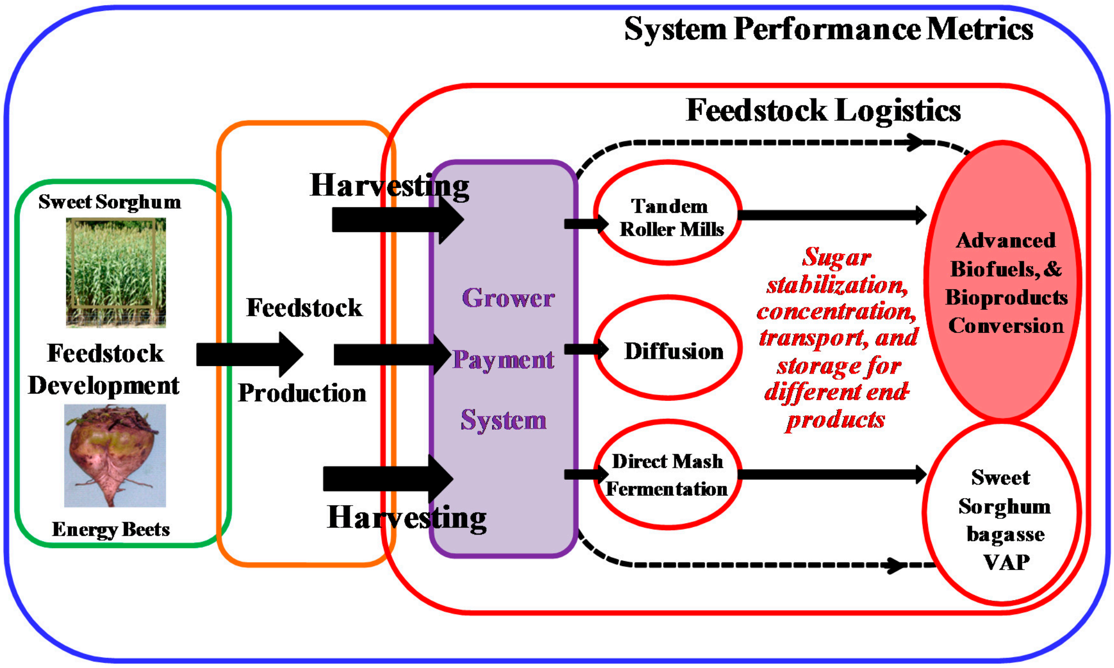

Figure 4. The manufacture of advanced biofuels and bio-products supply chain components for sweet sorghum and energy beets. VAP = value added products. This schematic is also applicable to energy canes, bagasse, and extraneous leafy matter.

3.2. Sweet Sorghum as a Biomass Feedstock

Sweet sorghum is a type of sorghum that, like sugarcane, contains juice rich in soluble sugars as well as fiber but, unlike sugarcane, also contains starchy grain that could be used for food, animal feed, or non-food products. Sweet sorghum is an attractive biomass feedstock because it can overcome many of the shortcomings of other sugar crops, due to its efficient C4 photosynthetic pathway, easy cultivation from seed, low fertilizer and water requirements, growth on marginal lands, short growth cycle (90 to 150 days after planting, depending on cultivar and environment) that allows the possibility of multiple crops per season or rotation with other food or non-food crops, wide geographical suitability, and huge breeding potential [24]. It must be noted, however, that due to its low juice purity (sucrose/Brix × 100) of only ~75%, which is markedly lower than for sugarcane (~85%) and sugar beets (~87%) as well as high reducing sugar content, it cannot be used to manufacture crystalline sucrose [25]. Although many current global applications of sweet sorghum are still for small-scale edible syrup and forage production, there has been a recent dramatic increase in interest for large-scale biofuel and bioproduct manufacture [24,26,27]. Several private-sector groups in the U.S. and world-wide have been pursuing development of new domestic industrial sugar feedstocks from sweet sorghum to supply the bioprocessing demand, and new biorefineries are now becoming a reality. For example, Heckemeyer Mill in rural Sikeston, Missouri, recently built the largest, operational sweet sorghum biorefinery in the U.S., which is capable of crushing up to 82 tonnes/h (equivalent to ~49 ha/day) and producing 24,000 gal of syrup (80% solids)/day [28]. Moreover, as sugarcane factories can sit idle for up to 9 months of the year, processing of sweet sorghum to syrup in factories before the sugarcane harvest would allow the use of under-utilized capital equipment. This is currently being explored and tested in numerous sugarcane factories/distilleries in Brazil and by Okeelanta, Florida [29].

4. Bagasse from Sugar Crops: Large-Scale Cogeneration of Electricity and Other Energy Products

4.1. Cogeneration of Electricity from Bagasse

Bagasse, the fibrous fraction remaining after juice extraction from sugarcane and sweet sorghum, varies in composition depending on intrinsic and extrinsic factors such as genotype, maturity (lignifications), and environment [30]. Sweet sorghum bagasse is available to a much lesser extent than sugarcane, and its higher amounts of protein can make it more valuable as an animal feed [24]. Most sugarcane processors burn bagasse to cogenerate steam and electricity for running the factory [31]. The recovery of energy from bagasse is also a major reason that sugarcane has a higher net energy ratio (output/input) than many other crops [7]. Furthermore, cogeneration contributes to sustainability as the negative environmental impact of GHGs from traditional thermal power stations are reduced [32]. Presently, some countries' sugar industries, e.g., Brazil, Mauritius, India, Australia, El Salvador, Nicaragua, Guatemala, Columbia, and The Philippines, also operate large-scale cogeneration of electricity and sell the surplus to the local or national grid, and there is great potential for many other countries to follow. Currently, bagasse-based cogeneration is the most profitable sector in the large Brazilian sugar industry, with underperforming sugar and ethanol sectors being bailed out and/or supported recently by cogeneration units [33].

The success of the cogeneration of bagasse depends on the availability of adequate technology as well as a profitable price structure [34]. In recent years, there have been major technological improvements leading to higher efficiency cogeneration of electricity from bagasse, in particular the use of new high-pressure boilers, *i.e.*, up to 82–100 bar (producing superheated steam at 525 °C) [35]. Efficiency gains leading to a surplus of electricity generation for export to the grid have also been accomplished through the retro-fitting of turbo-alternators with high steam pressure and temperature [31], and the optimization of other process parameters, including steam consumption, increasing fiber content of sugarcane through breeding, lower moisture content of bagasse, and reducing the consumption of electricity in the factory tandem mill and power plant [32]. In Brazil, during the 2009/2010 harvesting season the total electricity produced from sugarcane bagasse was 20,031 GWh and this value may rise up to 68,730 GWh over the next 9 years, as long as all factories install 99 bar boilers and 1.04 billion tons of sugarcane is produced [35].

4.2. Second Generation Biofuels from Bagasse

The sustainable trend towards electricity generation from bagasse has been accompanied by progress in developing other large-scale uses for the material, e.g., second-generation ethanol and other biofuels [30] and syngas from Fischer-Tropsch (FT) processes [36,37]. Lignocellulosic ethanol involves the conversion of cellulose and hemicelluloses, which is much more difficult than the conversion of starch and simple sugars. On the other hand, ethanol produced from lignocellulosic feedstocks is seen as a viable option to decrease any perceived competition between the production of foods and bioenergy [30], although energy will always be needed for food production. Other advantages over first generation ethanol are: (i) lignocellulose and cellulose are abundant and less expensive than agricultural food feedstocks; (ii) growth potential is huge; and (iii) some cellulosic crops can be grown in marginal lands that often require less fertilizer and water inputs but grow better on good quality land with optimal imputs.

There are five key-steps for the production of lignocellulosic ethanol from bagasse: (i) milling; (ii) chemical or physical pre-treatment; (iii) enzymatic hydrolysis or saccharification; (iv) fermentation of hexose (C6) and pentose (C5) sugars; and (v) distillation-dehydration of the ethanol. However, the processing technology for conversion in the most part has only reached very limited commercial scales. Dedini S/A Indústrias de Base, was the first company to build a bagasse-based pilot-scale ethanol facility in Brazil, but commercialization has yet to take place [38]. Gran Bio established the first second generation ethanol facility in Brazil in 2014 in Alagoas. Raizen now has a second generation ethanol facility in Piracicaba, Brazil, that started operating from July 2105. The commercialization of second generation bioethanol depends mostly on economic factors such as values for agricultural feedstocks that have been estimated to range between 50%–80% of the total ethanol's cost [39], government tax incentives for ethanol production, and mandatory ethanol/gas blends [40]. Dantas *et al.* [41] in their assessment of the productivity and cost of different technological routes, determined that, when compared to ethanol production, burning bagasse to generate electricity provided the most benefits from an investor perspective, although this may not be applicable to every country. For more information on this lengthy topic see [41].

4.3. Biochar

Biochars (Figure 5) can be produced via the thermo-chemical conversion of organic feedstocks. Thermo-chemical conversion reactions encompass processes such as: (1) gasification; (2) slow pyrolysis; (3) fast pyrolysis; (4) hydrocarbonization; and (5) combustion, and distinctions among these different options are related to the relative availability of oxygen, residence time, temperature and pressure. Slow pyrolysis (residence time is minutes or hours), in particular, is feedstock-flexible, and this has resulted in the research of a multitude of biomass materials as possible precursors due to their lower cost and availability. Yaman [42] published a review of pyrolysis of various biomass types which includes pyrolysis conditions. Sugarcane bagasse, due to its high carbon content, can serve as an excellent biochar feedstock. Within the thermo-chemical platform, pyrolysis generates biochar as the main product, synthesis gas and bio-oil from the non-condensable fraction of the gas with the split between liquid, char and gas being governed to a certain degree by variation in process conditions. During thermal decomposition of the organic material under limited supply of oxygen and a regime of high temperature (300–700 °C), the material undergoes a series of cleavage reactions, as volatile matter evolves, resulting in a porous high carbon product (Figure 6), mainly composed of aromatic compounds characterized by rings of 6-C atoms linked together. Biochar is part of the black carbon continuum with variable properties due to the net result of production (e.g., feedstock and pyrolysis conditions) and post-production factors (storage or activation). Therefore, biochars are not a single entity but rather span a wide range of black carbon forms [43].

Figure 5. Biochar in various forms (pelletized, granular [18 × 40 mesh] and powdered [less than 100 mesh]).

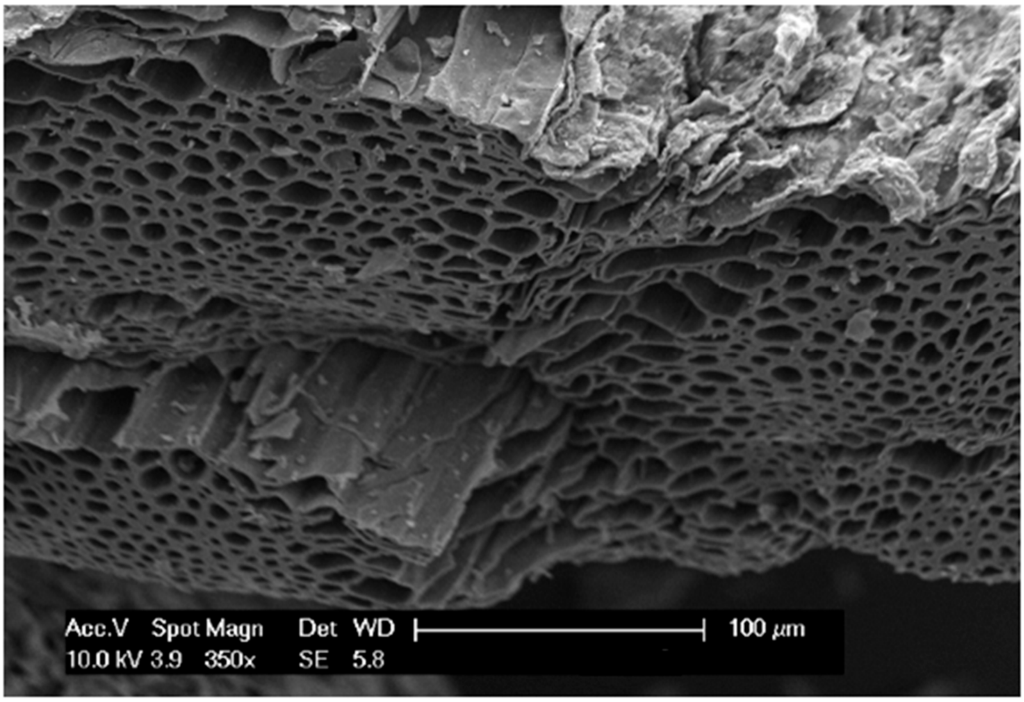

Figure 6. Scanning Electron Micrograph of a sugarcane bagasse biochar (magnification of 350×), showing its highly porous nature.

The terminology of biochar is commonly associated to its use in soil applications, and is unlike charcoal, which traditionally was manufactured from coal, and used as a fuel. The first use of the term biochar was around 1998 for the solid residual of biomass pyrolysis [44]. Biochar can be further upgraded or converted into activated carbon through either physical or chemical activation to produce a highly porous material that can be used in adsorption applications.

4.3.1. Biochar as a Soil Amendment

Biochar has been applied to soils virtually from the dawn of civilization, since fire pits were built on soil [43]. The current application of biochar to soil has been modeled after the Amazonian Terra Preta soils, which have higher soil fertility believed to result from intentional additions of biochar from "slash and char" agricultural practices [45–47]. Resulting biochars' nutrient contents are variable because they are based on feedstock and production conditions, however, differences have been noted in the chemistries of various biochars despite the similarity in production conditions [48]. Biochar consists mostly of carbon, hydrogen, and oxygen, but also contains the majority of the inorganic micronutrients that were native to the original feedstock. Thus, for biochars made from sugarcane bagasse, the mineral content is transferred to the biochar and concentrated due to burn-off of carbon moieties.

Inorganic material located at the surface of the biochar contributes to surface functional groups and charge that can advantageously enhance microbial relationships in soil as well as contribute to soil's nutrition [49]. Microbial biomass appears to increase in the presence of biochars, however, there is still little insight into the mechanisms by which biochar influences soil microorganisms, fauna, and plant roots [50]. When applied to soil, biochars have also been shown to suppress GHGs such as methane and nitrous oxide from soil [51]. In a recent greenhouse study, Lima *et al.* [52] observed that, by adding 4% *v*/*v* sugarcane bagasse biochar to soil, the sugar yield of sugarcane improved by 25% over the control. Furthermore, significant increases in sugarcane crop yield were also observed.

4.3.2. Biochar as Fuel

Pyrolysis of biomass including both agricultural and processing residues, as well as forestry products, has been traditionally used to make fuel or charcoal. When considering fuel production, densification technologies such as pelletization and agglomeration can improve the properties of the biomass feedstocks while generating a harder, less abrasive, and higher quality denser fuel. Zandersons *et al.* [53] produced charred fuel briquettes from sugarcane bagasse and determined that volatile matter given off during pyrolysis was sufficient to provide drying heat as well as sustain the pyrolysis process. Molasses is commonly used as a binder and conveniently available at the factory, making co-location of biochar manufacturing facilities in proximity to the factory even more efficient. Because sugarcane bagasse is considered a softer biomass material when compared to other biomass materials such as wood, Pendyal *et al.* [54] used sugarcane and corn syrup molasses as binders to create briquettes before pyrolysis. The suitability of bagasse biochar as a fuel, either by itself or blended with other by-products (e.g., leafy material) depends, among other parameters, on its heating value. A high carbon content, reported as 47% on a moisture and ash free basis, is also desirable and directly affects the fuel value [55], while ash content negatively impacts fuel value. Several empirical correlations have been established to calculate heating value from either proximate analysis (volatile matter, fixed carbon and ash content) [56] or from the elemental composition (e.g., C, H, N, O) [57]. Based on several available reports in literature, dry bagasse contains 82%–87% volatile matter, 1%–7% ash, and 10%–17% fixed carbon [58–61].

4.3.3. Biochar as an Adsorbent

Extensive literature exists on the use of biochars and their activated counterparts in remediation applications. Biochars produced from biomass such as sugarcane bagasse have low surface area when compared to commercial activated carbons, but their surface functionality can make them an attractive alternative particularly in adsorption of charged species. Additionally, they have a relatively lower cost of production, due to higher yield and more simple manufacture. When studying various agricultural by-products blended with various types of molasses, Ahmedna *et al.* [62] found that sugarcane bagasse was a better choice than rice straw or rice hulls as a precursor for activated carbons with desirable sugar decolorization properties, especially when combined with corn syrup. In another study, Ahmedna *et al.* [63] found that bagasse activated carbons performed as well as commercial carbons commonly used in sugarcane refineries, despite the fact of having half as much surface area. Because color removal both at the sugarcane factory and particularly refinery is such an integral part of the process, it is logical from a sustainability viewpoint to utilize biochars from sugarcane bagasse and/or trash as alternate color removal adsorbents. Feasibility studies for producing activated carbons from sugarcane bagasse and molasses revealed the cost to be $3.12/kg of carbon for a 2000 kg daily output [64,65]. In heavy metal ion adsorption applications, a sugarcane bagasse activated carbon outperformed a commercial carbon in the adsorption of nickel, copper, zinc, and lead, despite having much lower surface area [66]. This was most likely because of the presence of surface oxides such as carbonyls, lactones, phenols, and carbonyls giving biochars a negative surface charge [63]. Binder choice can also play a significant role in the biochar properties although properties of the base material will ultimately determine the properties of the biochar and the activated carbon [54].

4.3.4. Biochar for Carbon Sequestration

The process of biochar production has the potential of being carbon negative and, therefore, a carbon sinking technology by which a large percentage of the carbon in the biochars is in the fixed form. As sugarcane grows, it takes in carbon dioxide and converts it into plant building blocks such as cellulose and lignin, which will be again turned back into carbon dioxide through combustion. This process can be altered if carbon in sugarcane bagasse is instead converted into fixed carbon form as happens with pyrolysis. Pyrolysis temperature and residence time are directly proportional to the percent of fixed carbon generated. To effectively reverse climate change it may be necessary to return some of the atmosphere's carbon dioxide to the soil [67]. One way of achieving this, is by pyrolyzing biomass such as sugarcane bagasse to produce gas or oil for energy and using the remaining chars as soil amendments. Benefits of biochars use as climate change mitigation tool was recognized and reported to the U.S. Congress [68].

4.4. Storage of Large Piles of Bagasse

Challenges still exist with respect to the prolonged storage of very large quantities (can be >900,000 tonnes) of bagasse (~50% moisture content), particularly for off-season electricity generation. These include microbial decomposition and loss of fuel value, self-heating leading to spontaneous combustion, bagasse handling, and a variety of health issues, and environmental impacts [37]. An important health issue is bagassosis—A respiratory disease resulting from exposure to fungal spores from moldy bagasse dust. Environmental impacts include: (i) water pollution due to run-off from bagasse piles; (ii) bagasse dust that is a major problem in windy areas and at bagasse transfer points; (iii) noise and lights that have caused problems at storage sites close to residential areas; and (iv) off-odors.

Studies have been undertaken in various countries to overcome storage challenges, and in the case of Australia, guidelines for storage have even been established with cooperation of the Environment Protection Agency [37]. Options to solve bagasse storage problems have been reported and include the patented "Bagatex-20" process developed in Brazil [69], which depends on a biochemical catalyst to accelerate and control fermentation in the piles. Other options are forced drying before storage [70], special stacking, covering of piles [37], and densification processes. The latter includes pelletizing, which is known to significantly reduce final volume with bulk densities in the range of 1030 to 1260 kg/m^3, depending on pellet diameter [55]. Furthermore, pelletizing sugarcane bagasse is a way of improving fuel handling, transportation, conversion and also allowing for storage for off-season utilization [55]. Recent initial results from a sugarcane bagasse storage study in the U.S. [71], indicated that dramatic gains in fuel value can be achieved just by covering stored bagasse piles with tarpaulin (Table 2). Covering the bagasse also reduced the rate of deterioration [71].

Table 2. Proximate Analysis and estimated fuel value of sugarcane bagasse samples as a function of storage conditions across two factories *.

Storage Conditions	Sample	Moisture	Ash Content	Fixed Carbon	VOC	Fuel Value, KJ/kg	Moisture
		%	%	%	%	HHV [59]	LHV [72]
Covered	Fresh	38.5	6.0	15.7	78.3	17,712	10,890
	3 months	49.9	8.3	13.6	77.7	16,980	8504
	4 months	43.1	9.0	13.9	77.1	16,857	9590
	5 months	33.6	7.6	15.3	77.1	17,371	11,535
	6 months	56.9	9.9	14.0	76.1	16,738	7213
Uncovered	Fresh	-	-	-	-	-	-
	3 months	81.0	15.7	8.9	75.5	14,779	2805
	4 months	73.7	10.9	11.2	77.9	16,021	4203
	5 months	73.1	17.5	8.8	73.7	14,472	3889
	6 months	68.1	15.2	11.1	73.8	15,289	4875

* Data presented at the 45th Annual Joint ASSCT Meeting in New Orleans, LA 2015 [71].

5. New Sustainable Uses for Sugar Crop Extraneous Matter (Leaves and Tops)—Agricultural Biomass Residue

5.1. New Uses for Sugarcane Extraneous Matter

Although sugarcane extraneous matter (E.M. also known as trash or leaves and tops) is an agricultural biomass residue that is widely available in many countries, but is still under-used or improperly utilized. There is, however, a growing reality that E.M. represents a rich source of renewable biomass. Sweet sorghum E.M. is also available but to a much lesser extent than for sugarcane, and the higher amounts of protein in sweet sorghum can make it more valuable as an animal feed [24]. For sugarcane, the continuing global reduction in pre-harvest burning of cane leaves as well as the increased use of green mechanical harvesting have considerably increased the availability of E.M. that can be collected either in the field or at the factory [35]. It should be noted, however, that some sugarcane E.M. must be left on the fields to protect the soil and recycle nutrients [73,74], nevertheless there is still plenty left to serve as a biomass feedstock.

Like other sustainable biomass sources, E.M. can be converted through a wide range of biochemical or thermal platform technologies into a multitude of chemicals, bioenergy, and biomaterials including cellulosic ethanol, electricity, and biochar [75]. E.M. also represents a real opportunity for rural communities to access local energy supplies and bring economic opportunities to many developing countries that grow sugarcane [5]. Sugarcane E.M. has already contributed to greater cogeneration of electricity [31,35]. In 2007 a study in Brazil showed that the utilization of sugarcane E.M. with bagasse can double the MWh production of electricity compared to bagasse alone [76]. E.M. can also be combined with bagasse to produce biochar, either with or without pelletizing, and the presence of certain minerals in the E.M. such as calcium, potassium, phosphorous, can be beneficial when using the biochar as soil amendment in sugarcane.

Considerable amounts of E.M. are still delivered to factories and processed to the detriment of the quantity and quality of raw sugar produced [77]. Thus, the development of large-scale industries utilizing E.M. as a biomass feedstock could additionally improve the sustainability and profitability of the sugar industry by indirectly improving the quality of raw sugar. The use of sugarcane E.M. as a biomass feedstock is greatly dependent on the amount of dry mass available after collection. It is known that genotype and environmental variation occurs for sugarcane E.M. Sugarcane in the U.S., has ~34% total dry E.M. biomass [78] compared to 41% for some sugarcane varieties in South Africa [77]. Dried leaf residue contains approximately 36% cellulose, 21% hemicelluloses, and 16% lignin [79] and is similar to the composition of bagasse. The quantity and quality of leaves can also vary across the harvesting season in different countries. Donaldson *et al.* [80] in South Africa and Eggleston *et al.* [81] in Louisiana, U.S., both reported that the amounts of green leaves varied with season date while dried, brown leaves changed little with season.

5.2. Biochar from Extraneous Matter

Along with sugarcane bagasse, E.M. is another feasible feedstock for the manufacture of biochar. Varying amounts of soil, leaves, *etc.*, present in E.M. will, however, produce heterogenous biochars of equally varying physico-chemical properties, which could present a challenge to their usability. Because E.M. is mainly composed of leaves, it is significantly less heavy than sugarcane bagasse, with approximately 4 to 5 times lower densities. This can become an issue during the field application of biochars due to wind losses, as well as during storage. Densification technologies can potentially address these challenges, although the moisture content would have to be reduced prior to pelletization to <20%. As with sugarcane bagasse, sugarcane molasses can be used as a binder in biochar manufacture from E.M. [62,63,66].

5.3. Collection and Storage of Sugarcane Extraneous Matter

If E.M. is to work as a reliable, sustainable, and economical biomass feedstock to the new biorefineries, then collection of excess E.M. in the field needs to be optimized, preferably after some solar drying to create greater dry mass [82]. Collection could include baling to increase the material's bulk density for transportation to the biorefinery. As an alternative, E.M. could be separated from the stalks at the biorefinery site if economical and effective separation technologies are in place such as dry cleaning before the sugarcane is shredded [83]. Alta Mogiana sugarcane factory in Sao Paulo State, Brazil has an E.M. dry cleaning system and the separated E.M. is burnt in the boilers. In 2014, NFR BioEnergy LLC, initiated an E.M. dry cleaning system of their own design in the USA, which is co-located with the Cora Texas sugarcane factory in White Castle, Louisiana [84]. NFR BioEnergy already has the technology to produce biochars from sugarcane bagasse and plan to also use separated E.M. as a feedstock. Their dry cleaning system incorporates a large drying tumbler that effectively removes E.M. from the cane. The collected E.M, together with excess bagasse, will be fed into a torrefaction or pyrolysis unit for the manufacture of biochars, although currently the unit is only pilot-plant size. In their process, synthesis gas will also be recovered and used to supply energy to the torrefier/pyrolysis unit. The objective is to create a new source of sustainable energy from using the pelleted biochar as fuel, but to also remove E.M. and allow for cleaner sugarcane to be processed at the factory. The removal of leaves and soil before it enters the factory will allow more sugar to be produced at a higher quality than was previously possible [85]. Energy generated from syngas released during torrefaction can be used to make the whole system "energy negative" and to help run additional equipment such as a pellet mill upstream from the torrefier [86]. However, questions still remain on how efficiently E.M. separation technologies perform while not removing valuable sucrose in stalks [74,87]. Moreover, in some cases separation at the biorefinery could also create excessively large piles that would have to be stored or rapidly utilized [74].

Just as for bagasse, if E.M. is to be a stable and sustainable biomass feedstock it will most likely be stored in piles at the biorefinery or near the harvest site. Unlike bagasse, however, very little is known on how piles of E.M. store and for how long. Eggleston *et al.* [88] reported on the deterioration of brown, dry (BL) and green leaves (GL), stripped from sugarcane whole-stalks, stored under simulated wet and dry conditions. The worst deterioration for both BL and GL, generally, occurred in the watered samples and when the humidity was highest. On deterioration, more soluble impurities were extracted from GL than BL. Only prolonged deterioration of BL caused a reduction of fiber biomass, and the fiber content of GL usually increased on deterioration because of loss of moisture. Because its shredded state created more surface area to absorb water, moisture was highest in deteriorated BL; this also allowed for more *Leuconostoc mesenteroides* bacteria to grow and form dextran and mannitol [88].

6. Dedicated Energy Feedstocks from Sugar Crops

The manufacture of second generation biofuels is expected to utilize a much more diverse set of feedstocks compared to first generation biofuels [89], and dedicated energy crops represent one option. Dedicated energy crops offer high output per hectare with low inputs. They are also expected to grow on land less suitable for food production. Often, the new energy crops yield well under various stress conditions and have even been developed with advantageous processing characteristics [90]. Energy cane, beet and sorghum crops can be converted to second generation cellulosic fuel ethanol as well as power and bioelectricity. Processes to convert high fiber energy canes and beets into fuel ethanol are still under investigation as discussed in Section 4.2. The challenge is to develop energy crops with a suite of desirable physical and chemical traits while increasing biomass yields by a factor of two or more [91].

6.1. Energy Canes

Energy cane varieties are high-fiber and biomass clones of conventional sugarcane [92], and often have extended ratooning abilities. The goals of achieving energy cane with attributes for a biomass-based economy are readily achievable through existing sugarcane breeding programs [7]. In sugarcane breeding, more rapid genetic gain can occur for total biomass than sugar yield because growth does not have to be intentionally restricted during the life cycle of the crop, and a wider array of germplasm of potential value is available to the breeder once stringent standards for sucrose and fiber levels are relaxed. Breeding strategies for energy cane are classified as Type I and Type II. Type I are energy cane varieties close to conventional sugarcane but have lower sucrose content and thus higher fiber contents. Type II are energy cane varieties that have marginal sugar content and high fiber at such high levels (typically >16%) that raw sugar manufacturers consider unacceptable for processing [7]. Furthermore, the Type II energy canes would be utilized as biomass feedstock for the production of electricity and cellulosic biofuels [92]. For more information about Type I and Type II energy canes the reader is referred to Botha and Moore [7].

A few energy cane varieties have already been developed and released, for example in Louisiana, U.S. [93]. Three Type I high fiber sugarcane varieties (L 79-1002, HoCP 91-552, and Ho 00-961) released for commercial planting in 2007 produce dry biomass yields in excess of 25 tonnes/ha [93]. As marginal land to grow energy canes in Louisiana are mostly north and, therefore, colder during the winter, a major emphasis of the breeding program is to breed for cold tolerance.

6.2. Energy Beets

Many biofuel/bioproduct sugar feedstock producers, including U.S. large-scale sweet sorghum producers, are considering energy beets as a co-rotation crop to allow the year round production of sugar feedstocks. Energy beet is a non-edible, water efficient, selected hybrid of commercial sugar beet that has not been bred for sugar but for dry matter. The creation of higher biomass yields for energy beets have been made possible by using fodder beet germplasm as a parent in hybrids with sugar beet [94,95]. Biomass yield potential is dependent upon interception of solar radiation which gives beets grown in areas with long growing seasons a decided advantage. Energy beets are typically grown as winter crops (winter beets in the U.S. have a longer growing season and, therefore, a much higher yield potential), can grow on marginal lands, and also have higher fiber, glucose and fructose concentrations [96]. However, the glucose and fructose concentrations are still lower than in sweet sorghum, and the sucrose considerably higher. Overall, energy beets hybrids are comparatively new compared to conventional sugar beets, and very little processing research has been reported.

7. Sugar and Sugar-Bioproduct Industries: Platform Chemicals from Sugar Feedstocks and Other Value Added Products from Sucrose

7.1. Platform Chemicals from Sugar Feedstocks

Several years ago, Novozymes CEO Steen Riisgaard said "in a few years sugar will be the new oil" as sugar is a superb feedstock for the production of platform chemicals for the manufacture of a range of end-products, e.g., bioplastics, industrial solvents, and chemicals [97]. This statement still holds true today and structural bio-based materials, such as artificial spider silk "Spiber™ (Stockholm, Sweden)" which is stronger than steel and lighter than carbon fiber [98], can now be added to the portfolio of possible end-products. Furthermore, Koch *et al.* [99] recently stated that "a promising option for intermediates of sugar production, including syrup, is to ferment them and this is less expensive than pure sucrose". Scientists are also currently taking a closer look at natural sweeteners such as honey, maple syrup, molasses, and sweet sorghum syrup, as sugar replacements. This is because they contain, beyond sucrose, glucose, and fructose, other classes of bioactive compounds including complex carbohydrates, amino acids, and polyphenols that might impart health benefits [20].

Efforts in "green chemistry" have been ramped up to transform renewable crop biomass, e.g., from sugar crops, into the basic chemical ingredients that go into many everyday products [99,100]. Thanks to numerous years of work on engineered microbes and new catalysts, the reach of biobased chemicals into consumer items is expanding [101]. A host of biobased intermediates are at or near commercialization, and include raw materials for common polymers such as polyester, spandex, synthetic rubber, and nylon [101]. Such products are being manufactured by both start-up firms and industrial giants, with announcements of progress gaining in frequency and substance [101]. A large-scale shift to bio-based polymers, however, will depend on the availability and reliability of large quantities of sugar feedstock at competitive prices. Moreover, as Bomgardner [101] stated that commercializing a biobased polymer "requires sustained, parallel progress on several fronts including technology development, end-product verification, market demand, and robust business acumen." In 2004, DOE identified a set of biomass-derived compounds best suited to replace petroleum-derived chemicals [102], and Table 3 lists the current and projected commercialization of these products [101]. Only succinic acid, sorbitol, and xylitol productions are established on a large, commercial scale (Table 3). For example, DSM and Myriant are now manufacturing succinic acid in Italy [103] and the USA, respectively. It must be noted that some of the new, start-up companies that started out aiming for commodity biofuels and bioproducts have ended up manufacturing specialty compounds instead [104]. This is because selling in expensive markets helps pay the company bills when the start-up scale is small and its products are still costly to manufacture. Moreover, this strategy can allow companies to work their way into commodities [104].

Although there is no current, effective one-step method or multi-step methods for converting raw lignocellulose to finished products, progress is being made. Furthermore, increasing investments in the sugar-ethanol industry could facilitate the construction of the physical infrastructure, and associated technologies that could also be used for the production of bioproducts [97]. Biotechnology processes are particularly suited for the transformation of natural feedstock from sugar crops into the necessary sugars and building blocks of secondary bioproducts, and bioethanol itself can also be used as a platform chemical [97].

Table 3. Current and Projected Commercialization of Biobased Products from Sugar Feedstocks that were Identified in 2004 by the U.S. Department of Energy (DOE) and the most likely compounds to replace petroleum-derived chemicals. Adapted from Bomgardner [101].

Biobased Compound	Number of Carbon Atoms	Method of Manufacture	Key Uses and End-Products	Commercialization in 2014	Projected Commercialization in 2024
Succinic acid	4	Bacterial fermentation of glucose, chemical oxidation of 1,4-butanediol	Solvents, polyesters, poly-urethanes, nylon, food and beverage acid control, surfactants, adhesives, fabrics, inks, paints	Yes	Yes
2,5-Furanedicarboxylic acid	6	Chemical dehydration of glucose, oxidation of 5-HMF	Polymers such as nylon, plastic bottles/containers, carpet fiber	Soon	Yes
3-Hydroxypropionic acid	3	Bacterial fermentation of glucose	Polymers, carpet fiber, paints and adhesives, superabsorbent, contact lenses	No	Yes
Sorbitol	6	Hydrogenation of glucose from corn syrup, bacterial fermentation under development	Sweeteners, fuel ingredients, anti-freeze, water treatment	Yes	Yes
Xylitol	5	Hydrogenation of xylose, extraction from lingo-celluloses, bacterial fermentation under development	Sweeteners, cough drops and medicines, anti-freeze, new polyesters	Yes	Yes
Levulinic acid	5	Acid-catalyzed dehydration of sugars	Fuel ingredients, solvents, plastic bottles, polyesters, polyamides, pharmaceuticals, herbicides	No	Maybe
Itaconic acid	5	Fungal fermentation of glucose	Styrene-butadiene copolymers, rubber, plastics, paper	No	Maybe
3-Hydroxybutyrolactone	4	Multi-step chemical synthesis from starch	Solvents, synthetic intermediates for pharmaceuticals, new polymers	No	Maybe
Glutamic acid	5	Bacterial fermentation of glucose	Polyesters, nylon analogs, flavor enhancers, fabrics, plastics	No	Maybe

7.2. Value Added Products from Sucrose

For the sugar industry, value-added products from sucrose can increase the demand, value, and consumption of sucrose, as well as improve the industry's competitiveness. However, only a small percentage of the sugar produced in the world is used in non-food applications [105], which is unfortunate as much research effort and funds have been expanded on the identification and development of value-added products from sucrose. Part of the reason for such little impact of this research is that the scientists inventing the products have not fully considered the market, and do not have the business acumen to sell such products to industry [11]. More involvement by industry, particularly at the conception phase, would help to gain more impact [11]. Another explanation is that, historically, fossil-based oil has been a less expensive feedstock than sugars.

Sucrose is a good source for many value-added products because of its chemical and enzymatic reactivity. The basis for the reactivity of sucrose is the eight hydroxyl groups present on the molecule. Generally, the three primary hydroxyls have greater reactivity but they often prove a hindrance as they are difficult to react exclusively [106]. The synthesis of an enormous number of sucrose derivatives is possible; substitution with just one group type could theoretically give two hundred and fifty five different compounds. Moreover, the alcohol group can be derivatized to form esters, ethers, and substitution derivatives [106]. Sucrose can be readily degraded by acids, oxidizing agents, alkalis, and catalytic hydrogen to compounds of lower molecular weight. Sucrose is also an exceptional molecule for enzymatic synthesis reactions [105,107] to form, for example, oligosaccharides and polysaccharides [108].

8. VHP (Very High Pol) and VLC (Very Low Color) Sugar Production—A Sustainable Trend

In recent times there has been a world-wide trend to manufacture VHP and VLC raw sugars for supply to refineries, *i.e.*, a trend of vertical integration from the field to the white sugar output. Furthermore, a concomitant trend exists to build refineries of the VHP/VLC cane raw sugar close to the consumption areas to satisfy the needs of the food industry. There is also a growing demand for exports of VHP and VVHP (very, very high pol) raw sugars, particularly from Brazil, mainly for overseas markets. Some refineries also want lower ash concentrations in the VHP/VLC sugar because: (a) some of the refined sugar will be manufactured into liquid sugar, which requires low ash; and (b) lower ash is needed for short, medium, and long term refinery strategies [4]. The supply of higher quality raw sugars is expected to create additional efficiencies at the new refineries, particularly at the early, energy-intensive affination stage. Some refineries such as Al Khalij Sugar in Dubai and Dangoto in Lagos are even eliminating the affination stage altogether. The higher quality raw sugars will also allow factory processors to gain premiums from the new refineries. Furthermore, manufacture of higher quality raw sugars at the factory where the energy source is renewable bagasse, will save fossil energy utilization by the refiners.

9. Sustainability Metrics

Traditionally, chemical/food process and product development has focused on the assessment of economic criteria, but additional criteria for sustainability have become increasingly important and integrated into decision making processes [109]. Assessment tools, standards, and enhanced metrics to measure "green, greener, or greenest" have been and are continuing to be developed [110]. Many countries and regions have introduced policies or adopted standards to promote sustainable manufacture of biofuels and bioproducts and use, most prominently in the U.S. and European Union. Ecological or environmental sustainability, one of the three pillars of sustainability (Figure 2) can be examined using Life Cycle Assessment (LCA) [110]. LCA is an internationally recognized methodology for evaluating environmental performance of a product, process, or pathway along its partial or whole life cycle, which can be applied to new processes for converting sugar biomass [7]. Late in 2014, the World Business Council for Sustainable Development (WBCSD) in Geneva, Switzerland, published a guide titled "Life Cycle Metrics for Chemical Products" to help the chemical industry and associated stakeholders compare, on a common sense basis, the environmental footprint of chemical products [111]. This should allow chemical sector companies, including those using sugar feedstocks, to communicate with a common language to companies downstream, and help scaling up solutions [111]. Current operating chemical companies such as BASF, Amcor, and Dow Chemical are benefiting from using sustainability metrics to meet the challenge of improving processes and products, and have already provided insights on opportunities and progress [112].

Rein [113] specifically reported on measuring and monitoring sustainability in the sugar and sugar-ethanol industries. The Better Sugarcane Initiative (BSI) is a collaboration of sugar retailers, investors, traders, producers, and NGOs who are committed to sustainable sugar production by establishing principles and criteria that can be applied to sugarcane [113]. In the sugarcane industry, Brazil has been the most active in embracing and reporting sustainability performance, mostly because they export to other countries [113], although broader sustainability reporting relating to social and other environmental issues have been less of a focus in Brazil. For the future sustainability of the sugar and sugar-bioproduct industries, there is also a need for new analytical methods in biofuels and bioproducts manufacture as well as for grower payment systems with the new feedstock crops [4].

10. Overall Outlook

Biomass from sugar crops is expected to become a significant part of the world-wide shift from a fossil-fuel based economy to one that is biobased [7]. This shift, however, is still mostly in the early pioneering stage. Key criteria in the establishment of commercial biobased plants are cost of the facility, availability of reliable quality feedstocks at low cost, financing, and the policy environment [103]. Concomitantly, in many areas of the world, there is a progressive diversification of the sugar industry into "sugar and sugar-bioproduct industries" that are deeply involved in the maximization of the sugar crop biomass. This includes Europe where many beet factories have diversified to produce ethanol as well as sugar from sugar beets. An excellent example of a sugar company diversifying into biobased chemicals while obtaining social, environmental, and financial sustainability gains, is Godavari in India [114]. Starting with sugarcane, Godavari manufactures refined sugar, ethanol, and chemicals including ethyl acetate, crotonaldehyde, 1,3-butanediol, and even flavor and fragrance ingredients [114]. From bagasse, electricity is cogenerated and used to power the sugar and chemicals factories and plants. Godavari's biobased chemical are produced so efficiently that they are able to compete pricewise against the same chemical produced from fossil sources [114]. It is expected that more "sugar" and "sugar-bioproduct" companies like Godavari, will become more and more eager to become greener [110] as they realize that they can reduce pollution and increase profits simultaneously [115]. Moreover, such companies will want to be able to select greener starting materials and use cleaner chemical processes to make environmentally preferred products [110], and to appease consumers who are becoming increasingly aware of sustainability issues [116]. Consumers are, in fact, holding companies to higher standards and asking them to demonstrate the wider impact of their operations [116].

Overall, the sustainability of the sugar and sugar-bioproduct industries should be viewed as a continuous improvement journey [1], and behavior change and education will also be linchpins in effective sustainability programs.

Acknowledgments

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

Author Contributions

Gillian Eggleston led the research on sugar processing, the effect of sugarcane extraneous mass on processing and how it deteriorates on storage. She also conducted the review of literature on sugar processing, use of sugar crops as a biomass source. Isabel Lima led and conducted the research on biochar production from bagasse and extraneous matter, and also conducted the review of literature on these topics.

Conflicts of Interest

The authors declare no conflict of interest.

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