Research and Development of Biomass Feedstocks for Non-Energy Multiple Uses

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Abstract

Biomass feedstocks have enjoyed a significant renaissance during the period since the first world oil crisis in 1973. While the initial focus was strictly on energy—heat, electricity or fuels such as ethanol—this has evolved to the concept of multiple uses, in which bioproducts with a higher value can be produced to improve the financial return on the crop. Strategies towards bioproducts include the development of crops that provide specialty chemicals, such as Jojoba, or towards crops in which the yield of biomass is maximized and then the feedstock is processed into a platform chemical. At this time there are essentially two platforms that are considered to be the leading avenues. The syngas platform is based on carbon monoxide and hydrogen produced by means of gasification of biomass. The sugars platform converts precursors such as cane sugar, starches (from corn and other crops), cellulose, and hemicellulose into monomeric sugar streams that can then be converted into a range of higher value chemicals and polymers by both thermal and biotechnological means. Along with the crops and process development, there is now a need to evaluate the life cycle impacts of the entire cycle, from crop to product, and to evaluate the bioproducts impact on the biosphere.

Introduction

The development of bioproducts other than traditional feed, food, fiber, and energy production has to face a series of hurdles as it moves from research, development, demonstration, through to deployment (RD3). The traditional emphasis on economics remains, however, indices of sustainability are becoming key to the acceptance of not only bioproducts, but also their processing and the suitability of the crops used as feedstocks. In this short note, some of these issues will be highlighted along with the major development thrusts that are currently in the RD3 cycle.

Feedstocks

Humanity's use of terrestrial biomass production is partitioned between energy (the dominant use of wood fiber), fiber, feed, and food production. Advances in agricultural and forest technology have increased the yields of many plant species, and this, coupled with the recognition of the role of the biosphere in the carbon and energy cycles, has resulted in increasing use of both bioenergy and biomaterials to displace fossil carbon in fuels and materials. The potential biomass feedstocks available for conversion into multiple products, including bioproducts, are both numerous and very diverse. The Australian New Crops group, operating out of the University of Queensland, has identified over 4200 species of crops that have been [1] *... associated somewhere in the world, at some time in history, with at least one useful product.* Table 1 is an alphabetical listing of the applications of these 4200 species (excluding energy use); the actual number of applications is greater than 4200 because many plants have multiple uses.

A more constrained listing primarily for bioenergy purposes has been produced by Bassam [2], which contains detailed descriptions of over 70 species that have been considered for energy and bioproducts production. This list includes established agricultural crops as well as commercial tree species. However, in the last three decades, much of the research into new bioenergy crops has focused on plant species for which the external inputs of nutrients, water, and pesticides are minimized. These include tree species such as eucalypts and pine in the

Table 1. Applications of 4200 Useful Plants of the World

Applications	Number of Plants	Applications	Number of Plants
Beverages	333	Oil crops	211
Cereals	72	Pesticide crops	32
Drugs	39	Pseudocereals	15
Dyes	27	Resin crops	31
Elastomers	47	Root crops	484
Forage grasses	53	Spices, herbs and condiments	367
Fibers	68	Starch crops	302
Forage legumes	62	Soil stabilizing crops	19
Fruits	1440	Sugar and sweetener crops	50
Green matter crops	22	Tanning agents	50
Gums	61	Vegetables	817
Legumes	89	Wax crops	10
Medicinal crops	196	Windbreak crops	44
Nuts	161		

tropics, and poplar and willow in the Northern hemisphere. Grasses have also been a high priority. In the USA, switch grass has been the model, while in Europe the model is Miscanthus. In the tropics, a well understood and established grass, sugar cane, is likely to be the choice for energy and biomaterials development. Though it is possible to consider a wide range of *New* crops as a source of phytomass, it is much more likely that those in which there has already been significant development will be more readily adopted, as there are a wide range of environmental, social and economic constraints that will severely limit the range of possibilities. One of these issues is the perennial question of food versus fuel (or non-food, non-energy) uses of land. This has been addressed in many studies of the future potential of the biosphere to provide bioenergy. The invariable answer is—there is unlikely to be a food versus fuel conflict, as the agricultural food system is more likely to intensify its production on the existing land base, thus liberating land that is currently in agricultural production, but marginal for food crops, as, for example, in India [3].

While there are no forecasts for future biomass supplies for non-energy purposes, there are a large number of scenarios that have been put together for both future bioenergy supplies and demand. The demand scenarios generally see the 11.1% biomass contribution of today holding or even gaining a little as the world's predicted energy consumption heads for between 1050 EJ (IIASA-WEC A3 scenario) [4], and more than 1500 EJ (Shell scenario). Thus today's 45 EJ of bioenergy would grow to between 110 to 160 EJ under these scenarios. As with descriptions of the future supply of fossil fuels, the estimation of future biomass supplies has three flavors: the theoretical potential, which is bounded by the estimate of total world photosynthetic biomass accumulation rate of 4000 EJ; the technical potential, which is a function of available technologies and thus changes with time; and finally, the economic potential, which is very variable, but much less than the technical potential.

The economic potential is clearly a function of the demand for all biosphere products, and is driven by population growth and growth in per capita incomes, as well as competition for land and other inputs. One detailed scenario for the technical potential for bionergy has been developed by Fischer and Schrattenholzer [5] in conjunction with estimations of the arable land and agricultural production in the IIASA world food system model. The results of this scenario are shown in Figure 1. This scenario and others presuppose a significant role for energy crops, even though, today, the bulk of bioenergy is derived from residue streams generated during harvest from the field, forest, and subsequent industrial processing.

Unlike the development of agriculture in both colonial times and the early part of the twentieth century, the introduction of new species into biomes where they were not present is now intensively regulated. Of major concern is the introduction of plants and plant pests into regions in which they were previously absent [6]. Thus, it is more than likely that it is

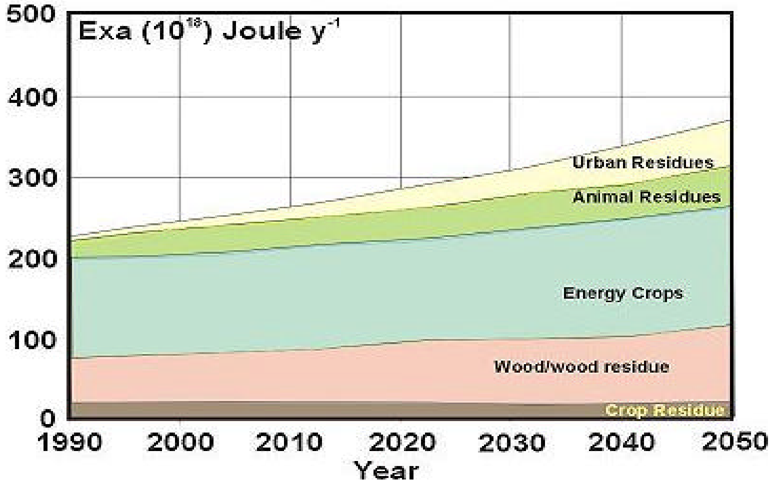

Figure 1. Future Biomass Resources

existing crops (both indigenous and introduced species) of economic importance that are going to be developed for bioproducts and multiple use. A similar issue is in the introduction of genetically modified organisms (GMO), which today have additional genes to express resistance to insect pests or commercial herbicides, but tomorrow may well include novel biochemical pathways to desired bioproducts. [7].

Bioproduct crops that have been evaluated since the energy crisis of 1973 also include microalgae. These photosynthetic prokaryotes are ancient species, such as blue-green algae as well as archae. They predate plants and are more akin to a bacteria than to vegetative plants that reproduce sexually. Indeed not all release oxygen, as some do not use water as an electron donor. The majority of these yield between 10% and 40% lipid content on a dry basis. Unlike terrestrial plants, microalgae are free floating in water and will require large areas of water and the development of harvesting technology; however, for specialty lipids and coloring materials there are existing industries.

Using the Life Cycle Approach to choose feedstocks, conversion processes and bioproducts

Sustainable development is more than a cachet to be applied to market a product. In the bioproducts area, it implies the use of sustainable production of both the raw material and its processing. In fact, the introduction of a sustainable bioproduct requires that a life cycle approach be taken—from the initial seedling, through its use as a bioproduct, and then its final return to the natural carbon cycle, as shown in Figure 2.

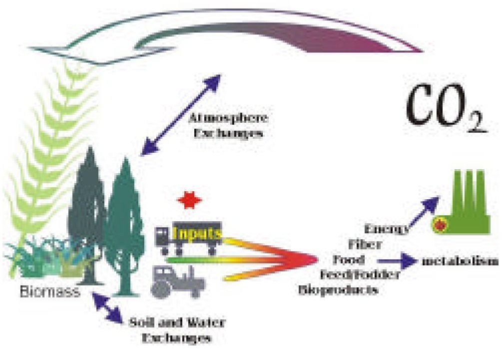

Figure 2. Closed Loop and Interchanges in the Biomass and Bioenergy Chain

Geiser identifies four categories of industrial materials groups according to their toxicity and persistence in the environment Figure 3 [8]. The first category includes cellulose and other biopolymers, which are indeed of low persistence in the environment and of relatively low toxicity. Hydrocarbon polymers are in a second category sharing the low toxicity, but of considerably greater persistence. The third category includes many of the industrial solvents that can be produced from biomass, having relatively low persistence ratings, though much higher toxicity values. The fourth category, with high values of persistence and toxicity, includes many halogenated polymers.

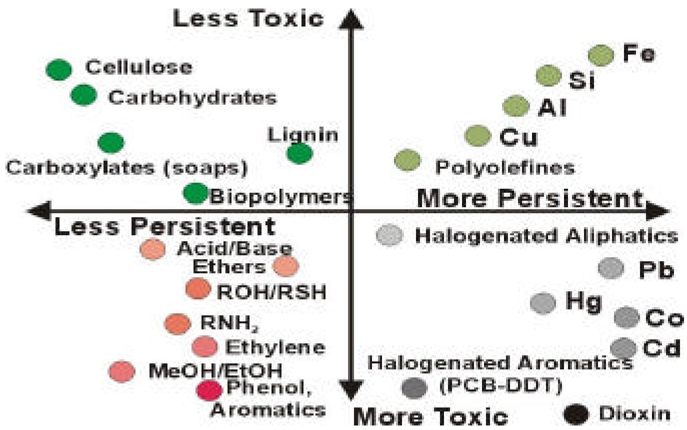

Figure 3. Chemical Impact Matrix

Clearly products in category one and two are the preferred sustainability goals. Table 2 shows the production volumes of plant-derived materials in the industrial material economy of the United States for 1992 and 1996, showing the growth in the application of categories one and two biomaterials in the economy.

Table 2. Bioproducts in the U.S.A.

Product	Production (Million tons) 1996	Production (Million tons) 1992	Share of Total (%) 1996
Solvent 95% Ethanol	0.42	0.37	>95
Surface cleaning agents	3.5	35.0	50
Adhesives	5.0	40.0	48
Plasticizers	0.8	15.0	32
Acetic Acid	2.3	17.5	28
Detergents	12.6	11.0	18
Inks	3.5	7.0	16
Dyes	4.5	6.0	15
Pigments	15.0	6.0	9
Wall paints	7.8	3.5	9
Specialty paints	2.4	2.0	4.5
Plastics	30.0	1.8	4.3

Another aspect of bioproducts and biomaterials, namely green processing, is going to drive the selection of a wide range of crop species so as to minimize the degree of processing and the contribution of that stage to the life cycle impacts. The extreme example of this would be for the plant (phytomass) to carry out all of the processing to the final product using the solar energy input, and the only manufacturing process involved would be extraction and packaging. In this respect the production of sucrose from sugar cane is close to the ideal, as is the production of palm oil. That is not to say that either of these is a perfectly green process as practiced today—both have significant emissions to both water and air that must be mitigated.

Forthcoming regulation of chemicals in Europe will be based on a comprehensive strategy according to the recent white paper [9]. This will result in standardizing chemical and materials risk assessments to reflect their role in the environment as shown in Figure 4. [10]

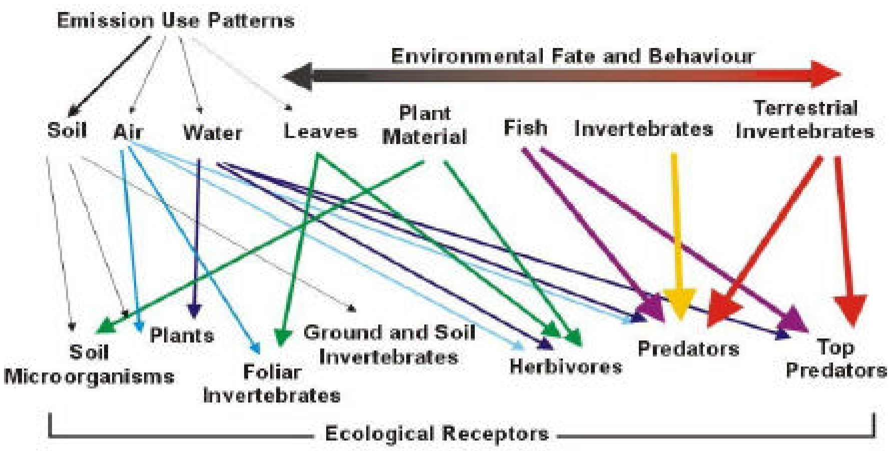

Figure 4. Hazard Identification and Conceptual Model

Examples of biproduct pathways - existing and under development

The future of bioproducts is bound up with the other plant material applications, as it is not possible to only make a single product - at a minimum there will be heat production, and residue or co-product streams that can be utilized as feedstocks for biofuels, as with today's corn industry. In other words, the biorefinery concept will apply - whether at a small scale (babassu) or a large scale in either the C-1 or the sugar platforms that have been proposed. In the case of the small scale, the applications and the technology will be so-called appropriate technologies. At the large scale, the technology choices are much broader. One strategy could be entirely thermochemical, involving the production of syn-gas and then following catalytic routes—especially C-1 chemistry to Fischer Tropsch liquids, methanol, higher alcohols or ammonia, as an intermediate in nitrogen chemistry. The advantage of the thermochemical routes is that all of the feedstock polymers can be converted to syngas. In fact this flexibility opens up co-feedstocks such as natural gas, so that the C-1 platform could gain significant advantages from the economies of scale. The sugar platform could utilize a range of sugar resources including sucrose (cane sugar), corn starch, cellulose, and hemicellulose.

Today's corn wet mill industry produces multiple coproducts, with corn oil extraction, corn gluten feed, and meal, followed by corn starch production. Though starch has direct markets, these are less than 20% of the production and the remainder is used as the foundation of a sugar platform that has two major products, high fructose corn syrups (HFCS), and ethanol. The former is produced by enzymatic hydrolysis, and the latter through hydrolysis and fermentation with the co-production of food grade carbon dioxide. The economics of this coproduct system have been described recently by Schenk [11], who observes that, as would be expected in such a biorefinery, the price of corn is the largest single variable manufacturing cost of the corn wet milling industry. Corn starch and HFCS prices are directly proportional to corn price, and the profitability improves with the corn price. Fuel ethanol has a price which is independent of corn—due to the various subsidies—and as a result, the ethanol profit is highest with low corn prices and high gasoline prices.

A new polymer system, based on the sugar platform to produce lactic acid, is moving towards deployment. Lactic acid (2-hydroxypropionic acid) has applications in the production of biodegradeable polymers, oxygenated chemicals, green solvents, plant growth regulators, and specialty chemicals [12]. Cargill Dow polymers is developing a polylactic polymer trademarked as NatureWorks™, using sugars derived from the carbohydrate portion of lignocellulosic resources. Coproducts for this platform would include ethanol fuel and electricity generated from the lignin component.

Conclusions

Bioproducts can potentially meet many of the sustainability criteria of future chemicals and bioderived materials. The natural resource base can be managed for sustainability if special attention is paid to land and water use issues, and the quantities and types of inputs are carefully managed in the production of biomass feedstocks. The conversion of these biomass feedstocks into bioproducts will proceed through thermal, chemical, and biochemical processes, along with traditional and novel separations technologies in what are known as platforms. At this time there are two basic industrial platforms; one is based on C-1 chemistry following the production of syngas from biomass, and the other is based on fermentation chemistry following the production of sugars from the biomass. Both of these are capable of industrial-scale production in the very near future. At a much smaller scale, the use of specialized plant species to produce many products will probably be based on lipid and latex resources, such as the babassu palm and the jojoba plant. These yield products that are relatively easy to extract and modify into higher value materials. Ultimately much of the conversion that is proposed to take place in the various industrial process platforms could be undertaken in the living plant, such that solar energypowered biochemical pathways lead to useful products that can be isolated by relatively simple extraction techniques.

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