# Investing in green and white biotech

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**A substantial increase in political and financial investment that aligns plant and industrial biotech will pay dividends for sustainable energy and materials production.**

Plants use the energy of sunlight to fix atmospheric $CO_2$ into a vast biomass, yet we currently use only a small proportion of this fixed carbon for fuel, fiber and building materials. At least three major factors—rapidly increasing atmospheric $CO_2$ levels, dwindling fossil fuel reserves and their rising costs—suggest that we now need to accelerate research plans to make greater use of plant-based biomass for energy production and as a chemical feedstock as part of a sustainable energy economy.

## The potential

Plants can convert up to 34% of solar energy of the appropriate wavelengths to fixed carbon in photosynthesis, and highly efficient converters of fixed carbon to biomass, such as sugarcane, can store about 1% of incident light as biomass over a year[1]. This energy conversion compares favorably with that achieved by photovoltaic cells. The conversion of plant-based products to make industrial feedstocks, such as ethanol, is an increasingly important process in many countries. Brazil is the largest producer of alcohol from biomass by fermentation of sucrose[2], producing 14.4 billion liters of ethanol annually as a petrol supplement that has saved $27 billion in oil imports since the program started.

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The development of new products from sugar cane, including biomass for electricity generation and industrial precursors derived by fermentation, illustrate the potential of biomass for industrial production. In the United States, which is the second largest bioethanol producer, corn starch is the principal feedstock for ethanol production by fermentation. The industrial-scale production of lactic acid by fermentation of milled corn starch for the synthesis of polylactic acid (PLA)-derived polymers is one of the most advanced biomass conversion projects. The NatureWorks manufacturing plant in Blair, Nebraska, can produce 140,000 tons of PLA per annum for biodegradable packaging[3]. In Europe, oilseed rape is esterified to form biodiesel, and by 2020, 20% of the EU's petrol and diesel will be bio-based, according to ambitious new targets[4]. In southeast Asia, palm oil has also been proposed as an efficient source of biodiesel[5].

Three main factors determine the economic viability of biomass conversion in addition to the costs of fossil fuels: the efficiency of carbon capture into an amenable storage form by plants, the energy intensity of conversion processes and the value of by-products from biomass. Sugarcane is a relatively efficient source of bioenergy as it uses efficient C4 photosynthesis to produce sucrose as a storage molecule, which can be directly fermented. Corn's main storage carbohydrate is starch, which has to be

The NatureWorks plant in Blair, Nebraska, which produces PLA, sales of which more than doubled in the past year, with particularly strong uptake in the European market.

converted by milling and enzymatic digestion to produce sugars for fermentation. The energy intensive distillation required for the conversion of agricultural carbohydrate to fuel is currently an economic barrier to the widespread use of ethanol as an alternative fuel, even when byproducts, such as sugarcane bagasse, are used as a fuel source. Some of the costs of distillation can be saved using steam reforming—an endothermic reaction whereby steam and heat is applied to a feedstock to form a hydrogen-rich stream—to convert carbohydrates to hydrogen, but this is not widely used, again because of energy costs. The value of by-products contributes significantly to the economic viability of all these biomass-conversion processes. There are two aspects of biomass production for biofuels and bioenergy where improvement may be tractable: developing novel enzymes and catalytic processes for degrading complex plant polymers, and creating new plant crops based on improved knowledge of biomass structure and accumulation and developing coproduction of valuable products, such as proteins for animal feed or other uses.



## Plant growth and metabolism

Most plant products have been used for biomass production in their near-natural state, with limited chemical modification. The vast proportion of plant energy and chemical reservoirs are locked up in the form of cell wall material comprising cellulose, complex polysaccharides and phenolic polymers such as lignin. Until now, most research on complex carbohydrates has focused on starch as it is one of the most important raw materials for sustainable use. It can be fermented and chemically modified to make a wide variety of chemical feedstocks and low amylopectin starch is used for biodegradable films and packaging. Pathways that produce lignin, a phenolic polymer that is a by-product of paper manufacture, can be downregulated to increase the proportion of cellulosic materials derived from pulping, and reduce the energy and chemical-intensive processes involved in paper-making[6]. Future progress in increasing the efficiency of cell-wall biomass degradation requires a greater understanding of the structure, synthesis and assembly of cell wall materials, especially in members of the grass family that have more efficient C4 photosynthesis.

Plant metabolism can produce an enormous variety of molecules and storage polymers. Nutritional supplements, such as ±α-tocopherol and vegetable sterols, are already produced in large amounts in plants. Although much has been learned about enzymes, pathways and their regulation, adding additional steps to pathways, redirecting metabolism and accumulating high levels of products has proven to be exceptionally difficult[7]. For example, although direct synthesis in plants of polymers, such as polyhydroxybutyrate (PHB) and polyhydroxyalkanoates (PHAs), is feasible, their accumulation tends to reduce growth[8]. Very little is known about the mechanisms that partition photosynthate to growth and storage, and to the accumulation of lipid, carbohydrate and protein storage molecules. By understanding these regulatory mechanisms, it may be possible to engineer current crop plants to produce efficiently a wider range of designer storage products for varying end uses such as biofuels and industrial feedstocks.

In addition to these gene-based strategies, breeding strategies using molecular markers and other genomics strategies to optimize biomass production from existing crops with minimal input of fertilizers and to increase harvestable yield also show promise. In Europe, short-rotation coppice poplar is a promising source of biomass that can be produced in an environmentally sustainable way. Breeding and genome programs targeted at potential new crops—for example, switchgrass (*Panicum virgatum*) and the fast-growing grass *Miscanthus x giganteus*[9], which both have low input requirements, low nitrogen and lignin, and high cellulosic biomass—are also likely to provide a wider range of alternative crops for biomass and biofuels production. A roadmap for research toward these goals has recently been published in the Strategic Research Agenda of the European Plant Science Organization's (Ghent, Belgium) Technology Platform 'Plants for the Future'[10].

## Fermentation and processing challenges

Perhaps the greatest challenge to the widespread use of plant biomass in fermentation is the complexity of the lignocellulosic cell wall components that form the bulk of biomass. Novel hydrolysis and enzymatic methods are needed for more efficient fermentation, and current research aims to improve hydrolysis methods and fermentation systems for the efficient direct fermentation of lignocellulose and other complex polysaccharides. The Fischer-Tropsch reaction uses synthetic gas (mainly carbon monoxide and hydrogen) produced by gasification of biomass to produce liquid fuel. Coupled to steam reformation, this process can produce hydrogen from biomass. It has been used on an industrial scale to produce liquid fuel from coal, but it is energy intensive and may not be economically viable at current oil prices. Recent forecasts predict that improvements can reduce its energy demand by 50% (ref. 11), suggesting its use will become widespread once again. A recent report of the conversion of biomass-derived carbohydrates to useful hydrocarbons is encouraging[12]. The process involves sequential catalytic dehydration, aldol condensation and hydrogenation, and direct removal of hydrophobic alkanes from the reaction mixture. This technology captures 90% of the energy of the input biomass and hydrogen, and promises to play a key role in energy generation and carriage.

There is a strong need for better and more diverse catalysts (chemical and biological) to convert biopolymers into the plethora of chemical products that we are used to today. It will not be easy to produce current bulk chemicals from bio-derived starting materials, but it will be an even bigger challenge to produce them at the same price as current processes. Some examples are promising, such as the chemoenzymatic formation of phenol from glucose[13], but this process remains too costly. Research should also aim to produce novel materials and compounds, with a different structure than the current fossil-derived materials, but with the same performance. The roadmap to achieve these objectives has recently been published in the Strategic Research Agenda of the Technology Platform on Sustainable Chemistry[14] initiated by EuropaBIO (Brussels) and the European Chemical Industry Council (Cefic; Brussels).

## Replacing fossil fuels

Can biomass production ever start to replace oil supplies over time—is there enough land and can it be converted to useful products efficiently? The US National Security and Bioenergy Investment Act of 2005 (ref. 15) proposes the widespread commercialization of bio-based fuels and products by providing R&D, demonstration and market-led incentives to supplant national dependence on oil. A policy paper[16] from the Rocky Mountain Institute, an influential think-tank based in Snowmass, Colorado, suggests that a quarter of current US oil needs could be met from the conversion of agricultural biomass by 2025, with the benefits of rejuvenated rural economies and increased sustainability and national security. The US Department of Energy 'Genomes to Life' Program[17] aims to follow a roadmap to clean energy production through genomics of microbes and plants, carbon sequestration and clean energy production.

A positive message is also conveyed in by European Commission's (Brussels, Belgium) 'Technology Platform' reports[10,14], which indicate that the technical skills and knowledge needed for producing bio-materials is now available. Even so, significant increases in the funding of R&D are required to establish viable and sustainable industrial processes based on plant biomass in Europe. Moreover, this funding should emphasize interdisciplinary research—research that would take a systems-level approach, harnessing diverse disciplines from economics and ecology to plant and microbial biology and chemistry—to meet the sustainable energy and biomaterials challenges.

Although there is a broad consensus recognizing the need to develop more sustainable resources to supplant oil and gas, it is paradoxical that the growth rate of R&D expenditure as a proportion of gross domestic product (GDP) has been declining in Europe since 2000, and is now essentially zero[18]. This trend also opposes the political intention of developing a European 'knowledge-based economy' (under the 'Lisbon Agenda') that can use the talents and educational capacity of European citizens. Other economic indicators, such as labor productivity, which is driven by innovation, also show the effect of reduced R&D growth. The persistently negative attitude of some national policy makers towards plant biotech also limits progress and has arguably led to reduced engagement of key industrial sectors in Europe. These trends suggest there will simply not be enough research funding or appropriate political support to transform European manufacturing to a more sustainable basis. A lack of a coherent framework for applying the creative potential of scientists is currently the main obstacle to developing a sustainable bio-based economy in Europe.

## Reinvigorating rural economies

Rural communities would be the principle beneficiaries of any new biomass production and conversion technologies. The production of new materials from crops and their local processing will help underpin future competitiveness and development of the rural sector. The range of measures currently used by the European Agricultural Fund for Rural Development[19] to support the rural sector does not include R&D aimed at developing sustainable bio-based industries, such as those described above. A realignment of even a small proportion of these funds would be sufficient to spark the needed R&D. This would provide rural economies with capabilities for future growth beyond food production and reorient this key sector toward a more central role in future economies, as it always had in the past. Together with a coherent and stable funding program with a true European scope, the exceptional promise of plant productivity and industrial biotech can make major contributions to sustainable economic growth. The Technology Platforms have identified the scientific research needed, their implementation and the barriers that need to be removed to make a real bio-based economy feasible. It is now up to the European politicians, industrialists and scientists to work together and bring these plans to life.


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