Workshop 6
Agriculture Beyond Food: Science for a Bio-based Economy

Workshop Context

Plants play a crucial role in life and have been exploited by mankind to their benefit for thousands of years. Recently, exciting scientific developments in plant sciences have increased the potential of plants to meet the food, feed, fibre and energy needs of mankind in a way that does not jeopardize the ability of future generations to meet their needs.

The bio-based economy*:* The bio-based economy is a term which encapsulates a vision of a future society no longer wholly dependent on fossil resources for energy and industrial raw materials. The concept responds to a variety of global trends, such as growing global demand for healthy and sufficient food, produced according to ethically acceptable environmental standards, and growing risks of food-related diseases, posing a challenge to researchers from many disciplines to find solutions to make a bio-based economy possible. It is also a challenge for governments to design policies that enable adoption of techniques supporting developments toward such a future society. In the bio-based economy, the vision is that agriculture will expand widely beyond its main current function: the production of food. The challenge is to develop sustainable agricultural systems that can offer these new services. Within the bio-based economy, three topics attract specific attention: biofuels, bio-materials and the concept of the bio-refinery.

Biofuels*:* Discussion of the future of bio-based products, and competition between food and fuel, has generated considerable momentum in the global scientific community, and among politicians, policy makers and the media. New developments in the field of biofuels are considered both a threat in terms of sustainability, and an exciting new option for agricultural development. Many developing countries, well-suited for the production of biomass for the bio-based economy, face the challenge to sustainably profit from economic possibilities of the renewed interest in biomass. There are important implications of this major development in agriculture, which this workshop seeks to discuss.

Bio-materials: Much smaller in scale, but potentially large in economic impact, is the use of biomass for bio-materials. This application has a long history, in which biomass has been used for building, clothing, industrial products, paper and packaging (and indeed pharmaceuticals). Over the last century, materials based on petrochemistry became rapidly important and took over from bio-based products. However, increasing oil prices and diminishing stocks necessitate reconsidering the use of biomass for a wide range of materials. Where several alternatives for fossil energy are available, the only alternative for fossil based materials are materials originating from biomass. Inevitably, this development will grow in impact over the coming decades, supported by the many new options offered by sophisticated technologies.

Bio-refinery*:* Maybe the most exciting development of all is the multiple-use of biomass. By carefully fracturing biomass in components with different economic value, the over-all value of biomass can increase dramatically. In this concept, biomass is not used for one *or* the other application, but simultaneously serve several purposes. High-value components may be used for special chemicals, proteins and sugars may be used for food, and the remnants are still a suitable source for energy. This option relies on advanced technologies and carefully controlled and inter-reliant processes and production chains.

Agriculture Beyond Food in Developing countries*:* The bio-based economy has potentially much to offer developing countries. An increased demand for agricultural products may boost the development of agriculture, and consequently the economy of developing countries. However, these developments may back-fire if they are not sustainable. It is imperative, for example, that any application of 'agriculture beyond food' is only developed within the framework of food security and that it should not jeopardize food production. Furthermore, in the development of the bio-based economy, scientists, policymakers and civil society groups need to consider the broader consequences for issues such as biodiversity and access to land and water.

Economies of scale are a constraint for many aspects of the bio-based economy. However, small-scale applications can deliver a positive impact on local communities in some instances, to a greater extent than large-scale applications can. There are opportunities for communities to reap benefits at local level, and therefore it would be unwise to fail to consider them.

Research for a bio-based economy*:* New advances in science open new possibilities for the development of a bio-based economy. However, in order to reap the benefits, these developments would need to be tailored for the specific situations in developing countries. Furthermore, any technological innovation can only be successfully implemented in a conducive environment where institutions, policies, markets and education are in place. Technology alone is not sufficient. New arrangements between scientists and stake-holders are needed to formulate the research agenda and to implement research results. Networks are needed to capitalize on these scientific developments around the world. It is the challenge of the Science Forum 2009 to address these issues.

Issues for the ScienceForum workshop Agriculture Beyond Food: The objective of this workshop to identify how developing countries can benefit from the bio-based economy, what role there is for science and technology, and what preconditions must be met for a successful implementation of new concepts and innovations. More specifically, we aim to consider the following questions:

- Which applications of the bio-based economy could feasibly achieve development impact through take-up into national systems of developing countries?
- Which developments have long-term potential for development impact, but lack an immediate development pathway and which developments can be implemented on a short term?

- How can science and technology deliver a positive impact on agriculture, the production of global public goods for development through progress in agriculture and the lives of the rural poor, especially the resource poor farmers and agricultural producers?
- What new arrangements, improved linkages and partnerships need to be developed to achieve the above?

TOWARDS A BIO-BASED ECONOMY: FOOD AND BEYOND

Background paper to the CGIAR 2009 Science Forum workshop on: "The future of food: developing more nutritious diets and safer food"

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1 General introduction

With the adoption of the Millennium Declaration, the realization of poverty alleviation and sustainable development received renewed attention and support of the Millennium Development Goals (MDGs) which were subsequently formulated, the most important of which for the CGIAR system is the halving of hunger and poverty by 2015, in developing countries strongly linked to agriculture. Modest progress towards MDGs is occurring in a dynamic context characterized by changes in demography, markets and prices, institutions and culture, policies, agricultural and environmental resources and technological development.

The discussion in this paper of agricultural futures in a bio-based economy is framed by the commitments underpinning the MDGs, assuming that agricultural production to meet the new demands which will emerge in a bio-based economy will be complementary to basic agricultural products and services required to meet the basic requirements of mankind echoed in the MDGs, especially those related to food, health and environment.

Even in the 21st Century, agriculture underpins key livelihoods for most people living in rural areas. In addition to the provision of food, fibre and energy, agriculture also contributes to poverty reduction and economic development by providing employment in and income from value chains. Diversification, defined as an increased number of activities generating farm output or added value for the farm household, can be defined at different levels of aggregation - e.g. field, farm, region or country (Langeveld et al., 2008). Much has been written on field and farm household level diversification, the former often being associated with the use of mixtures of varieties of one crop species or mixture of different crops or other useful plants, as practiced in agro-forestry or intercropping, while the latter includes activities generating off-farm income from business, wages and remittances. Economic and environmental developments in rural areas create opportunities with respect to diversification of farm household livelihoods; but can also threaten the fragile economic and ecological position of such households.

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The development of a bio-based economy will take place in a rapidly evolving and uncertain context, not least climate change, biofuels, fossil fuel price, global financial systems, trade and the nexus between food security and political stability. Between 1970 and 2004, greenhouse gas (GHG) emissions increased by 70%. By 2015 the world will need to provide extra food for an additional 750 million people; failure may jeopardize political stability. Food systems further need to accommodate impacts of demographic changes including urbanization and ageing of rural communities. Land use management, agronomy and livestock sciences, and technological development are key factors determining the net outcome of these processes. Good agricultural practices can contribute to increasing carbon soil sinks (Govaerts *et al*, 2008), reducing GHG emissions and providing feedstocks for bioenergy. Industrial production technologies will provide new uses for agricultural feedstocks. Developing countries require crops that are drought- and heat-resistant and can be grown on marginal land, show high water productivity while maintaining biodiversity. Strategic questions to be addressed include the use of water for food production, importing food as opposed to domestic production and the potential to grow high value crops for income generation (Annex, 2007).

The potential of the bio-economy extends well beyond bioenergy. Whilst a small share of fossil oil is used for chemical production and the remainder for fuel and energy, the economic value of the food and chemistry sectors is approximately equal. Future energy needs can be provided by a range of sources in addition to biomass but chemicals have no viable alternative source of carbon to non-renewable crude oil (which will diminish after peak oil) other than biomass. A long term and sustainable market can be envisaged for technologies that produce chemicals and pharmaceuticals from plant-based feedstocks, which will supplement the emerging demand for bioenergy feedstocks and the still growing demand for food and other agricultural products (Sanders *et al.*, 2007).

Such a development will need to be supported by processing steps that are energy efficient and cost-effective. Bio-refineries provide sufficient opportunities to allow such a development. While current bio-refinery practices do not always fully realise the potential of available biomass and market opportunities, further development of effective concepts may be expected in the near future. The development of the bioeconomy has often been portrayed as sustainable or environmentally friendly but there are key resource-related concerns that need to be addressed as bio-based economic systems evolve. These include: non-renewable energy use; renewable energy & land use efficiency; carbon emissions and sequestration; soil fertility and erosion; water quality and quantity; wildlife habitat; and invasive species and crop pests (Annex, 2007).

This paper has been prepared for the 2009 Science Forum workshop on the bio-based economy. It explores the possibilities of biomass application for development purposes, in particular biofuels, bio-products and bio-refinery. The paper is organized in the following manner. First, the paper provides an overview of non-fuel bio-products, including chemicals and pharmaceuticals, bio-plastics, and biopolymers (section 2). Next, we discuss options for future biofuel development (section 3). The key intermediaries between crop production and the advanced bio-based, applications are the bio-refineries, for which basic principles and applications are discussed in section 4. Development opportunities and impacts are discussed in section 5. Section 6 provides some conclusions and issues for discussion.

2 Bio-products

a. State of the art

Facing a future shortage of petrochemicals, biomass is expected to be the main future feedstock for chemicals. Resources like vegetable oils, cereal and root and tuber crop starch, residual proteins from biofuel production (Scott *et al.*, 2007) and cellulose from straw and wood are receiving more and more attention. These materials can be converted with physical, chemical and biochemical processes into polymers, lubricants, solvents, surfactants and specialty and bulk chemicals traditionally made from fossil feedstocks (Van Haveren *et al*., 2007). Currently only a tiny proportion of the huge variation of compounds produced by plants is tapped for commercial use. The challenge is to create viable business models for generating bio-products; and to tailor plants and plant systems to optimize available functionalities. To this purpose, dedicated policy programs have been implemented in the US, EU, and countries such as Canada, Japan and Malaysia. Their goal is development of industrial crops and/or the use of available biomass into high value products in advanced production chains. This section provides an overview of potential bio-products, their contribution to development, and their research requirements.

Bio-based products refer to non-food products derived from biomass (plants, algae, crops, trees, marine organisms and biological waste), ranging from high-value added (usually low volume) fine chemicals such as pharmaceuticals, cosmetics and food/feed additives to high volume materials such as enzymes, biopolymers, biofuels, fibres, etc. They may include existing products like paper and pulp, detergents, lubricants, construction materials, or new ones, such as vaccines made from plants or second generation biofuels. The main focus of this section paper is products and materials normally produced from fossil oil which could be produced from biomass.

Modern bio-materials excluding those materials exclusively indicated for medical use include: pharmaceuticals; chemicals; specialty products, industrial oils; biopolymers; and fibres (Ehrenberg, 2002; Thoen and Busch, 2006; Jonsson, 2009). They are discussed below.

<u>Pharmaceuticals</u>

Production of feedstocks for pharmaceuticals provides a major opportunity for agriculture, natural resources and household livelihoods. Their contribution is based in two elements, provision of genetic material and production of actual feedstocks. Both activities are related to highly specialist knowledge markets, and production volumes are not expected to arise above small levels. However, given their high added value, pharmaceuticals should be regarded as a potential avenue for development. Given the capital intensive character of the pharmaceutical industry, including high research and development costs, long term collaborative activities may provide the best way to link to their specialist research, production and marketing activities.

While the current industrial output is highly valuable, especially in India and other developing countries, it is likely to add value to agriculture worldwide in the near future.

Chemicals

Chemicals and their feedstocks provide markets and specifications that are more predictable in comparison to pharmaceutical products. Chemical markets refer to bulk chemicals (or chemical building blocks), with high volumes but low values and fine chemicals with smaller market size but higher added value. The potential list of chemicals to be produced from biomass is considerable. 1,3-Propanediol (1,3 PDO), a building block for polymers applied as composites, adhesives, coatings, etc. It is mostly made from maize syrup by modified *E. coli* bacteria. Annual production is approximately 120,000 tons. Succinic acid, another chemical building block, is generated by fermentation of glucose. It has many applications in food, industry and pharmaceutics, world market amounting to 25,000 tonnes (Sijbesma, 2009). Efforts are made to improve bio-based production routes and reduce production costs (Carole *et al.*; 2004; Koutinas *et al*., 2008). Chemicals produced via fermentation (like 1,3 PDO and succinic acid) are made from sugar or starch crops including sugar cane, maize, rice, barley and potato (Thoen and Busch, 2006).

Specialty products

Specialty chemicals serve as adhesives, solvents and surfactants (an important group of products applied in detergents, cosmetics and manufacturing processes). Surfactants, still mainly petroleum-derived, are increasingly made from renewable feedstocks. Production exceeds two million tonnes. They provide a large market for renewable feedstock, mostly tropical vegetable oils (Ehrenberg, 2002; Turley, 2008). Coconut and oil palm are preferred feedstocks because of shorter length of their fatty acids. Longer chained oils from temperate crops (rapeseed, sunflower) are more suited for use in polymers and lubricants.

Fossil solvents, applied in manufacturing of pharmaceuticals, paints and inks, are increasingly replaced by bio-based alternatives like ethyl lactate, a lactic acid derivative (Carole et al., 2004). Lactate esters are produced from alcohols and fatty acids, which both can be obtained via fermentation of carbohydrates (cereals, potato, and sugar beets). Vegetable oil derived fatty acids used predominantly come from rapeseed and sunflower oil. Soy is the most common oil used for vegetable resins (Johansson, 2000).

Industrial oils

Applications of industrial oil products offer considerable scope for bio-based market development. End-uses include high quality lubricants, hydraulic oils. Biolubricants constitute an innovative area for agriculture and industry, realizing performance levels required for high tech applications. Bio-based hydraulic fluids comply with European quality labels, while soy based colour inks dominate the market due to its superior performance (Nowicki *et al*., 2008). Oils high in oleic oils (sunflower, safflower) have high oxidation resistance. Oils high in erucis oils (crambe, carinata) have high lubricant qualities (Lazerri, 2009). Triglycerides used as starting points are typically derived from oil palm, rapeseed, sunflower or coconut (Johansson, 2000).

Biopolymers

Plastics are the most widely used materials worldwide and the introduction of bio-plastics offers huge opportunities (Carole et al., 2004). The use of starch in plastic(s) production began in the 1970s. Some bio-products are now commercially produced, offering a major end use for cassava (Nigeria, Brazil), maize and wheat. Ideal starch properties relate to the amylose/amylopectin ratio and size of starch granules. Amylose ethers have mechanical properties similar to those of high-density polyethylene. They offer biodegradable alternatives for polyethylene and polystyrene, offering major economic perspectives for agriculture (Somerville and Bonetta, 2001).

Commercially interesting polyesters are made from starch or sugar via fermentation systems, e.g. polylactic acid – PLA and polyhydroxyalkanoate – PHA; Turley, 2008; Vaca-Garcia, 2008). Starch polymers are dominant, and will probably remain so in the future. Starch based bio-plastics are biodegradable, applications including packaging materials, kitchenware as well as car interiors, horticulture devices and diapers (Johansson, 2000). PLA competes economically with fossil polymers and shows equal or superior performance to fossil polymers like PET. The main markets are packaging and fibre/fibrefill applications. Feedstocks is glucose syrup made from maize, cane, potato or wheat (Vaca-Garcia, 2008). In the future, PLA might be produced from lignocellulosic feedstocks (Carole et al., 2004; Dornburg et al., 2006).

Fibres

Fibre and fibrefills constitute a large polymer market, with applications include apparel, car parts, construction, electronic, furniture, and machinery. Key fibres like polyester, nylon, cellulosic and acrylic offer large opportunities for bio-based feedstocks (Carole et al., 2004). Natural fibres can be applied in high value added composite materials, using cellulosic feedstocks from wood and straw plus classical crops like kenaf, sisal, jute, flax and hemp. Additionally, Eucalyptus may be used to replace synthetics like rayon (Nowicki et al., 2008). Composite materials based on cellulosics offer special advantages (reduced weight, improved safety and good acoustic properties) and natural fibres should reinforce traditional synthetic materials (polypropylene, polyester), rather than replace them (Vaca-Garcia, 2008).

b. Potential for development impact

The size of existing (fossil-dominated) markets and potential bio-based shares shows large variations. Highest market volumes are reported for polymers, solvents and surfactants. Best perspectives are projected for pharmaceutical ingredients, enzymes and specialties (e.g. solvents, surfactants, Carole *et al.*, 2004; Ehrenberg, 2002), followed by bulk chemicals and biopolymers (Nowicki et al.; 2008). Bio-based market developments are supported by ambitious policies in the EU and the US (the latter targeting at 12% replacement of chemical feedstocks in

2010 and 25% in 2030; Thoen and Busch, 2006). At present fossil oil prices, however, production is not competitive (e.g. Lazerri, 2009).

Impacts of enhanced biomaterial production and application include:

- reduced demand for fossil fuels;
- increased added value generation for biomass producers and traders;
- reduced GHG emissions; industrial development;
- development opportunities for rural areas, including employment;
- reduced toxicity and enhanced health implications. ´

While not all these impacts offer options for developing countries, it is difficult to evaluate bio-based product groups in terms of development perspectives they offer. These will probably be a combination of market size, price plus potential share for bio-based feedstocks, and the opportunities this offers for farmers in developing countries or local labourers. Prospects for various bio-materials are summarized in Table 1.

Table 1. Main characteristics of biomaterial production types

Product	Feedstocks	Market size	Price	Bio-based share	Bio-based produc-tion	Impact for local producers	Local employ-ment	Perspec-tive for develop-ment
Pharma-ceuticals	Selective crops	X	XXXXX	XXXX	X	X	-	X
Bulk chemicals	Starch, sugar crops, proteins	XXXX	XX	XXX	X	X	-	XXX
Fine chemicals	Oil, starch, sugar crops, straw	X	XXX	XX	XX	XXX	X	XXX
Solvents	Oil, starch, sugar crops, straw	XX	XX	X	X	X	X	X
Surfac-tants	Various	XX	XX	XXX	XX	XX	X	XX
Lubri-cants	Oil crops	X	XX	XXX	XX	XX	XXX	XXX
Polymers	Mostly starch & sugar crops	XXXX	X	XX	XXX	X	X	X
Fibres	Lignocellu-losic crops, residues, grasses	XXX	XX	XX	XXX	XX	XXX	XXX

Source: authors

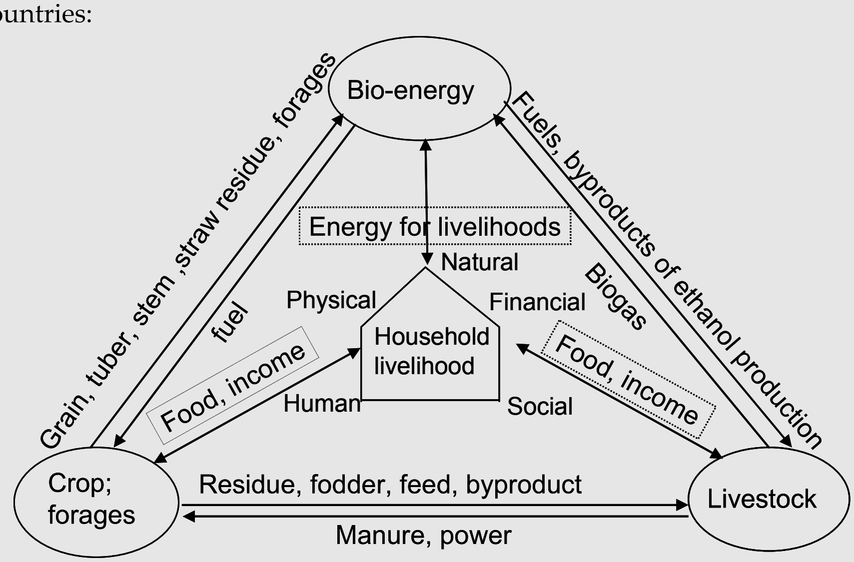
Bio-product markets offer potentials for crop producers around the world, following the principle that highest added value is found in the smallest markets. In this respect, one should compare high value but low volume markets with low value, high volume markets. Crucial is the combination of opportunities (feedstock added value, employment, import replacement, export) offered by the entire production chain, rather than considering biomass feedstock market values alone. Further, one needs to consider investment requirements vis-à-vis impacts for capital, labour and land productivity. In this perspective, fine chemicals, lubricants and fibres may offer best perspectives for developing countries.

Potential impact on developing countries is discussed in Box 1.

Box 1 Impact on developing countries

Many developing countries are tropical and have high biodiversity, efficient photosynthesis and high biomass productivity because of ample solar radiation, moisture and growing temperatures. Where political and economic circumstances are favourable, there is a tendency for agricultural production to shift from temperate zones to the sub-tropics and tropics, e.g., induced by higher productivity and fewer climate-related resource constraints, the centres of rice, legume, sugarcane and cotton production may shift from southern Australia to Queensland and the Northern Territory. Many developing countries may also benefit from lower labour costs. However, this natural advantage of the tropical developing countries may be eroded by the specificity of plant species for particular chemicals – and even more so if specific cultivars are bred for biomaterial production. However, three caveats must be mentioned. First, agricultural production takes place in extremely heterogeneous, complex and dynamic local systems: thus it is foolhardy to attempt to predict system changes with any precision. Second, it is likely that in the early stages of biomaterial industry development low cost by-products (sometimes viewed as wastes) may be utilized in preference to purpose-specific cropping. Third, as purpose-specific biomaterial farms are developed, both cultivars, rotations and production practices are likely to be optimized for different products, e.g., in Laos different practices are used for Eucalyptus plantations, depending on whether the fibre is intended for paper or rayon.

The following diagram illustrates an approach to the characterization of impacts on smallholder farmers in developing countries:



Source: Dixon et al. (2009)

The direct contribution to GHG emissions reduction is modest, but indirect reductions (preventing energy intensive processing steps) can be many times higher. This is especially the case for some chemicals, production of which can require considerable amounts of fuels for heating. Some products offer the advantage of biodegradability, thus reducing emissions of waste fossil products to soil and water. Reduced health risks are expected mostly for specific groups currently at risk (i.e. working mostly with fossil chemical products or living nearby dumpsites).

c. Research priorities

Research initiatives are mainly focusing on plant breeding, product development and more effective and competitive production processes. Theoretically, a range of crops can be used as feedstock for different bio-materials, with exception of many pharmaceuticals, oil products and (fine) chemicals. In practice, production chains often are based on a single crop, such as Dow's PLA which made from maize. Aspects of bio-refining and input and output replacement are discussed in section 4.

Perspectives of plant breeding are reviewed by Ranalli (2007). Van Beilen et al. (2007) explored the use of sugar beet, tobacco and *Miscanthus* for production of industrial bio-based products (chemicals, biopolymers, fuels). These crops are currently not generally cultivated by smallholders in developing countries (with exception of local production of tobacco in Africa, e.g., Zimbabwe and Malawi and Asia, e.g., China and Laos). It is often assumed that genetic modification needs to play an important role in tailoring plants for bio-materials. Depending on possible restrictive policies on genetic modification, this may limit the development of suitable plant varieties.

There is need for a knowledge platform for industrial oil crop research to develop engineering of oil-producing plants to produce higher yields of existing and designer oils, and to identify molecular markers for fast-track breeding (Graham, 2007). EPOBIO, a research consortium in Europe, considers three crops: rapeseed, oat, and crambe (*Crambe abyssinica*) (Carlsson, 2007).

Commercial exploitation of less common fatty acids from oil plants such as *Calenda officanalis* is hindered by low yield, small seeds and limited geographical distribution. There is a need to understand the metabolic pathways, molecular interactions and factors that are linked to a certain fatty acid. Many genes have been identified that could be used to alter seed oil fatty acid composition, and transgenic plants have been created based on these candidate genes. However, yields in these transgenics remain low and a number of questions remain to be answered (Graham, 2007).

With respect to research funding, it is expected that an increasing proportion of research will be funded by the private sector (Pardey *et al.*, 2007), as is already evident in tobacco, vegetables and other high value crops.

3 Biofuels

a. State of the art

While many government policies are based on the principle that biofuels should not compete directly with food security, the reality is that biofuel production, whether first or second generation, may compete indirectly for scarce natural resources (soil, water, nutrients) (Dixon *et al.* 2006). Naturally, as agricultural productivity increases resources can be freed from food production for the production of energy, chemicals and other bio-products. This section explores some options for a sustainable and balanced development of an agriculture providing food and fuel, and the scientific and technological needs for the next generation of biofuels produced in a bio-based economy, recognizing that the ultimate limitation on the production of biomass lies with photosynthesis.

Plant biomass has long been used to generate energy through thermo-combustion. First and second generation biofuel production which uses starch, oil, ligno-cellulose and other plant biomass materials is well described. A considerable use of first or second generation biofuel will impact biomass demand, may threaten biodiversity and interfere (in)directly with food production. Sustainable biofuels will ask technologies that do not jeopardize food production or availability.

First generation biofuel is partly based on cereals. They constitute the majority of all crops cultivated in industrialized, emerging and developing countries. In terms of harvested area, they make up 70 to 90% of reported arable annual crops with exception of Latin America. The potential of cereal bio-refinery for bio-based production (e.g. biofuels) in developing countries is however restricted by public perceptions of cereals as food – although a large and growing proportion of cereal grains is used for animal feed. For example, a large majority of the projected yield increase in maize will occur in Asia and approximately 90% of that increase will be fed to animals. Social tensions caused by the food versus fuel debate have put serious limits on this development pathway, sometimes leading to exclusion of specific crops, and defining detailed environmental, economic and social criteria to be met by producers in other situations.

Sugar and oil crops, two other major sources of first generation fuels are less common, but may play an important role in specific regions. Research and development have been much less spectacular than those reported for cereals, but still large efforts for improvement have been made often in close collaboration with industry.

Availability of lignocellulosic crop residues, a major feedstock of second generation biofuels is determined by crop area, yield, harvest index and demand for other purposes, e.g. livestock fodder. The greatest biomass productivity is expected for sugar cane in Brazil, followed by maize in the US. Second generation technology could, however, threaten soil fertility as soil cover is removed, and in a similar fashion soil erosion and soil health including the depletion of soil nutrients, structure and organic matter which underpins agricultural productivity and food security.

While the impact of large-scale cultivation of biomass for first or second generation biofuels is debated, more consensus appears to exist about small-scale biomass for biofuels applications in developing countries. Local production of biomass, or local use of residues, may help local communities to improve access to (renewable) energy sources and hence reduce workloads, pressure on wood resources and gain independence from often expensive fossil fuels sources. This holds especially for less endowed small scale farmers in isolated inland areas.

Still, developments that take advantage of new technologies are needed in order to avoid the food vs. fuel controversy, sometimes referred to as 'next generation biofuels'. A specific scientific development is focusing on photosynthesis, production of sugars by plants (and some bacteria), using chlorophyll to harvest solar energy. Photosynthesis is a two stage process. The Light Dependent Process (light reaction) uses the energy of light to make energy carrier molecules which are used in the Light Independent Process (or dark reaction) to form carbohydrates. These carbohydrates can be utilized for plant growth or harvested for food and feed or bioenergy. As photosynthetic efficiency fundamentally limits potential biomass production, it is important to examine ways to increase the current efficiency.

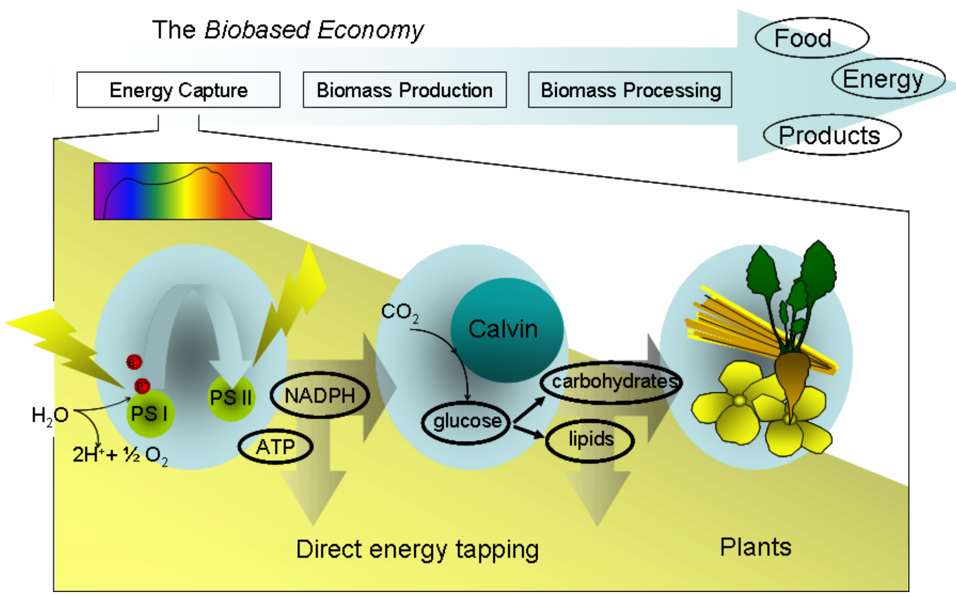


Figure 3. Options to improve energy capture by plants for enhanced production of food, fuels and products

Although a higher photosynthetic efficiency may result in a higher production of biomass, energy delivered from this biomass still could not avoid competition with food. In theory future biofuel systems can be envisaged in which plant fuel cells tap photosynthetic products directly, bypassing the development of plant structural elements (stems, root and reproductive elements) and thus potentially realizing productivity and efficiency gains while by-passing food applications. Innovative applications of biotechnology, nanotechnology and genomics provide tools to improve photosynthetic energy conversion. These tools enable us to study and understand the fundamental processes of photosynthesis, starting from the molecular building blocks via the thylakoid membrane to the leaf. This knowledge is the key to improving the energy efficiency of photosynthesis either by direct energy tapping or by the production of energy-efficient biomass (Figure 3).

b. Potential for development

The potential contribution of crops or plant systems with enhanced photosynthetic capacity can not easily be overestimated. Improving existing light use efficiency rates by a tenth of the current values can lead to considerable yield potential increases. The potential for development related improvement will depend on the application of an enhanced production system. Artificial leaves and bio-solar cells are most likely to be implemented in high tech environments and will, for the time being, not be directly linked to vulnerable groups in developing countries.

Algal production may be implemented in a less sophisticated setting, offering potential for resource-poor farmers in the tropics, in ways similar to the complex and integrated crop-fish production systems of Southeast Asia. On the long run, however, these systems may relax biomass constraints, both locally and on an international level. As they, further, may be expected to lead to increased input use efficiency (offering more biomass for the same input of water, nitrogen, phosphorus, etc.), their impact, in combination with other innovative photosynthetic related research (e.g. on transplanting C4-sytems into C3-crop), can be tremendous.

c. Research priorities

Current cereal research for advanced bio-refining focuses on improving starch and straw for biofuels. Maize hybrids bred for first generation bio-ethanol production have been released in the US. Cell wall structures and their degradability is expected to become an important breeding target while production of polymers and bio-plastics would require breeding for other, specialized, traits. In all instances trade-offs between genetic gains for different traits will occur. In addition, agronomic management of cereals is likely to be an important determinant of grain quality and quantity of plant polymers.

There are many lignocellulosic crops that are extensively found in developing countries. Choice of a specific crop will depend on agro-ecological and economic conditions. Poplar has been defined as an excellent research crop, exhibiting fast growth, easy vegetative propagation, and being native to temperate and subtropical regions. Poplar is attractive to molecular geneticists as it is easily genetically modified while its genome (40,000 genes) has been sequenced. Genetic research includes insect and disease resistance, herbicide tolerance and lignin content (Boerjan, 2007).

Miscanthus, a perennial grass, has substantial strengths in terms of yield potential and ability to grow successfully under low inputs of fertilizer and pesticides and presents a considerable opportunity for bioenergy production. It is, however, not fully developed for widespread cultivation. There are urgent needs to establish a robust breeding program and to develop molecular tools for fast-track breeding. Research is also required to establish a robust genetic transformation system (Möller, 2007). Other aspects for improving Miscanthus include tolerance to drought and low temperatures, stem borers and fungal diseases (Cllifton-Brown et al., 2008).

New concepts for increasing photosynthetic efficiency that currently being developed include (Arshadi and Sellsted, 2008):

- Artificial leaves, using light to extract electrons from water to produce hydrogen and syngas (synthetic gas). This requires ultra fast light harvesting, charge separation and two micro reactors that simultaneously produce hydrogen, a supramolecular photocatalysis system for hydrogen production and an inorganic nanostructured prototype that produces hydrogen and syngas;
- BioSolar Cells, organisms designed with synthetic biology to produce fuel (butanol, methanol, ethanol, lipids, and hydrogen) directly without the biomass intermediate, and with a positive contribution to solving the CO_2 problem. Solar energy may be temporary stored in a carbohydrate bio-film that can be grown on a low-cost bio-battery system;
- Plant microbial fuel cells (MFCs) allowing non-destructively *in situ* harvesting of bio-energy. Implementation in wetlands and poor soils limit competition with conventional agriculture. Energy production could exceed conventional technologies; systems in principle being carbon neutral and combustion emission free. MFCs depend on organic compounds produced by plant cells excreted by plant roots and are oxidized by electrochemically active bacteria. During the oxidation, electricity is be generated as the bacteria donate electrons to an anode which flow via an energy user to the cathode**;**
- Biofuel- and fatty-acid producing algae or cyanobacteria. Some algae are known to contain very high contents of oil, but these algae are slow growers. In addition, production of omega-3 fatty acid can be performed by marine algae. Optimizing the photosynthetic capacity of these algae will thus enable commercial algae-production for biofuels and food, especially when the algae are grown in the sea where there is no competition with arable land.

The suggestions discussed above link to innovative and exciting research on more efficient photosynthetic systems, e.g. the introduction of efficient C4-system with its high CO_2 upload capacity at the surface of the Rubisco-enzyme by the transfer of sets of genes to C3-crops like rice or wheat. This would allow an improvement of the Rubisco system which is less efficient at current CO_2-concentrations, and lead to more efficient water use. Another example is the combination of bacteria photosystems absorbing light in the near infrared where plants, algae and cyanobacteria are not active. Successfully combining such a system with the two photosynthesis systems already present in plants will increase photosynthetic efficiency. Application of advanced genomics technologies to transfer the responsible properties involved, poses a true scientific challenge.

Clearly, it is a long road before advanced systems for direct photosynthetic harvesting as described above can be expected. Major technological challenges that lie ahead include improving the genetic aspects of photosynthetic systems, increase insight in biochemical production and composition of photosynthetic products and enzymatic mechanisms, plus development of feasible, affordable and effective production systems. Other applications, like the use of algae or cyanobacteria are more close at hand. Successful application will require efficient production systems and organisms adapted to these systems.

Specific research requirements for artificial leaves include: development of the hydrogen harvesting from micro reactors; improved syngas production routes; and optimization of economic production systems. Research related to bio-solar cells should focus on extension and adaptation of photovoltaic technology; construction of devices mimicking photosynthesis, to collect, direct, and apply solar radiation and directly produce fuels; and tuning natural systems to produce (fuels such as) hydrogen and ethanol directly rather than carbohydrates that need further conversion before they can be applied as fuels. Plant microbial fuel cell research requires optimization of rhizodeposition of organic compounds; optimization of electricity production; and integration of plants in microbial fuel cells.

4 Bio-refineries

a. State of the art

The bio-refinery concept aims to make optimal use of available plant components, utilizing compounds of high added value and leaving remnants (waste) for energy-production. In this concept, energy production is not a primary but an additional application of biomass, adding to the overall economic value of the production chain. Valorisation of available functionalities and optimizing utilization of biomass potentials requires well organized feedstock selection, logistics and refining. This requires multi-input, multi-output chains that make optimal use of functionalities, materials and energy contents while offering optimal economic and social opportunities. The aim of this section is to provide an overview of bio-refinery (principles, pathways, organization), their contribution to development and sustainability, as well as research requirements.

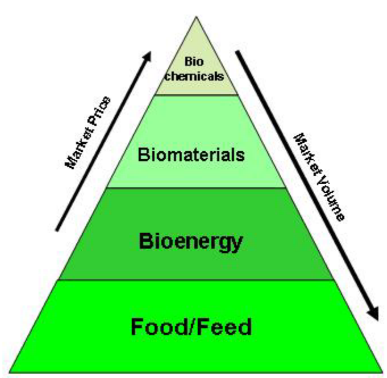


Figure 4 Market prices versus market volumes bio-based "products".
source: De Jong et al. (2009)

Bio-refinery types

The following bio-refinery types can be distinguished: (1) whole crop bio-refinery, (2) oleochemical bio-refinery, (3) lignocellulosic feedstock bio-refinery and (4) green bio-refinery. They will be discussed below[2].

Whole crop bio-refinery

A whole crop bio-refinery processes grain into a range of products, usually via 'dry' or 'wet' milling and consequent fermentation and distilling of grains (wheat, rye, maize). Wet milling starts with water-soaking to soften grain kernels, followed by grinding. It uses well-known technologies to separate starch, cellulose, oil and proteins. Dry milling grinds whole grains before mixing the flour with water, adding enzymes and cooking the mash to break-down the starch. This hydrolysis step can be eliminated by simultaneous use of enzymes and yeast. After fermentation, ethanol is distilled, concentrated, purified and dehydrated. The residue (stillage) is separated into a solid (wet grains) and liquid (syrup) phase which can be combined and dried to produce Distillers Dried Grains with solubles (DDGS) an animal feed. Alternatively, grains may be processed to generate starch, further to be processed into polymers or bio-plastics. In a simultaneous process, straw can be converted into energy or products, following the principles of the lignocellulosic feedstock bio-refinery discussed below (Clark and Deswarte, 2008).

Oleochemical bio-refinery

An oleochemical bio-refinery combines production of biodiesel with that of high added-value vegetable-oil based products. It uses oil-crop fatty acids, fatty esters and glycerol to produce (basic) chemicals, functional monomers, lubricants and surfactants. In the long run, oleochemical bio-refining may produce feedstocks for fossil-based refineries. Success of the bio-refinery will depend on its integration with existing fossil chains, its building blocks providing a neat interface (De Jong et al., 2009).

Lignocellulosic feedstock bio-refinery

Lignocellulosic feedstock bio-refinery encompasses transformation of lignocellulosic biomass into intermediate outputs (cellulose, hemicellulose, lignin) to be processed into a spectrum of products and bioenergy. Three processing routes may be chosen.

Sugar Platform Bio-refinery (Bio-chemical Bio-refinery)

Lignocellulosic biomass is treated to release cellulose, hemicellulose and lignin, the former further being converted with enzymatic hydrolysis into glucose, mannose and xylose. The sugars are converted into biofuels (ethanol, butanol, hydrogen) and/or added-value chemicals. Lignin is applied in combined heat and power combustion but may in the future be transformed into added-value chemicals (De Jong et al., 2009).

Syngas Platform Bio-refinery (Thermo-chemical Bio-refinery)

In this concept lignocellulosic biomass is pretreated to allow high-temperature-cum-pressure gasification into syngas. The gas is cleaned used to produce biofuels (Fischer-Tropsch diesel,

[2] Description of biorefineries is based on Kamm *et al*. (2006), Clark and Deswarte (2008), and De Jong *et al*. (2009),

dimethylether (DME), or alcohol) and/or a variety of base-chemicals (ethylene, propylene, butadiene, etc.) using catalytic synthesis processes (De Jong et al., 2009).

Two Platform Concept Bio-refinery (Integrated Bio/Thermo-chemical Bio-refinery)
This bio-refinery type integrates sugar and syngas refineries to generate bioenergy and/or bio-based products. For this purpose, sugars are treated and biochemically processed whereas lignin is thermochemically treated. Sugar refining (fermentation and distillation) and syngas residues are used for combined heat and power production which mainly covers internal requirements.

Green bio-refinery
Green bio-refineries, feeding grass to a cascade of processing stages, offer an innovative alternative processing route for grass feedstocks. Essential is the mechanical grass ("green biomass") fractionation into a liquid phase containing soluble compounds (lactic acid, amino acids) and a solid phase mainly consisting of fibres. Overall economic efficiency of the bio-refinery is mainly determined by the economic return of the fibres (De Jong et al., 2009).

Main characteristics of the bio-refinery types are presented in Table 2.

Table 2. Main characteristics of major bio-refinery types

Bio-refinery	**Feedstock & conversion**	**Impacts**	**Remarks**
Whole crop bio-refinery	Cereal crops, dry or wet milling	Link to monomer and polymer production, but large scale production leads to competition with food production. Straw applicable to lignocellulosic bio-refinery.	Mainly from maize, wheat. Moderately capital intensive.
Oleochemical feedstock bio-refinery	Oil crops (rape seed, soybean, oil palm).	Links to production of chemicals, functional monomers, lubricants and surfactants. Direct competition with food.	Close to full commercialisation. Capital intensity is moderate.
Lignocellulosic bio-refinery	Lignocellulosic crops, residues of food & feed crops	Reduced competition with food, feed production, high water use efficiency, high potential for GHG emission reduction	Not yet on commercial scale. Capital intensive.
Green Bio-refinery	Mainly grass	Links to production of proteins, sugars and fibres. No direct competition with food.	R&D phase.

Source: Kamm et al. (2006), Wolf et al. (2005), De Jong et al. (2009)

b. Potential for development impact

Under current high demand for agricultural produce, bio-refineries offer prospects of enlarged sector output value and prospects for growth in smallholder farmers' incomes. Value added and potential income effects will depend on product and market differentiation. The relevance of bio-refineries for development depends on, inter alia: link to available biomass resources; options for development of economic conversion routes for developing countries; and scale (and location) of the bio-refineries.

Major sugar and starch crops can be applied in fermentation processes providing inputs for production of chemicals, specialty products and fuels, while vegetable oils have a wide range of applications including plasticizers, lubricants dyes and resins. While most small scale farmers produce some of these crops, they will not necessarily profit from future bio-refinery (or bio-based) developments. Well endowed, and large scale farmers are the first to fill the need for extra biomass feedstocks that will arise (and partly has arisen). In order to realize real development potentials of bio-refinery, it should fit in the needs and possibilities of small scale and generally less well-endowed farmers and their families.

Further, their role in production chains should be such that sufficient perspectives exist for a profitable feedstock provision and/or integration in labour patterns and local employment, while negative impacts (e.g. increased demand for land or water) may not go at their access to such critical resources. Probably best perspectives are systems with limited capital requirements or systems providing guarantee for a long collaborative relation. Any refinery offering cheap and local sources of energy, plus refining activities that reduce water contents of (intermediate) products (hence limiting transportation costs and risks of decay) may offer best development options.

The area of lignocellulosic plant production in developing countries is huge, but current use or ecosystem services (wood or fuel production, biodiversity, water capture) place limits on their application in refining for bio-based purposes – nevertheless, fast growth rates could be expected in this sub-sector. Soil quality, marginal lands may provide only low to moderate yield levels. The potential for the production of chemicals, lubricants, other bio-materials has to be evaluated; but meanwhile second generation bio-ethanol production appears to be a viable alternative in some locations.

Sugar beet has been identified as model crop for research on chemical building blocks, but its relevance for developing countries is limited with some irrigated cultivation in semi-arid areas of Africa –Middle east (e.g. Morocco, Iran, Afghanistan). Cassava, a local low cost source of starch, with interesting perspectives as a source of bio-ethanol, may provide an alternative. EMBRAPA has bred cassava cultivars with high sugar content specifically designed for bio-ethanol production.

c. Research priorities

Perspectives for bio-refinery research are mainly found in determining their potential for development applications. What refinery systems will offer opportunities to especially less or poorly endowed farmers in isolated areas? How to link to existing systems for production and processing of food and feed (animals). What routes are there to follow in the development of cheap, robust but efficient and adequate systems that do not threaten the position of vulnerable groups.

In this respect priorities for research should be linked to those formulated for crop applications (bio-products, biofuels) above. Clearly, not all options are equally promising. As was discussed above, the combination of market size, price, perspectives for cost effective and competitive bio-based feedstock production must be taken into account against the needs and (im)possibilities of rural poor plus farmers. Extra attention will be needed for the fitting of existing crop production with possible bio-refinery systems, as to define systems that are best fit to serve local needs while preserving fragile social and ecological systems. Part of this may be related to issues of location and logistics.

5 Discussion

If one takes a value chain and systems perspective, the bio-based economy opens a range of research issues which can be grouped into four principal thrusts along a "U impact pathway/value chain" framework (Dixon *et al.* 2007). These are (1) consumer preferences, (2) process engineering, (3) socio-economics and (4) production.

Consumer preferences

First, market research on trends in consumer preferences for bio-products will be required, principally private sector funded. While of less importance where bio-products are used in intermediate steps, consumer acceptance of natural fibre in clothes, building materials in houses, pharmaceuticals, etc. will have to be assessed. In many cases OECD consumers may prefer bio-products to petroleum products provided quality is equal. While there has been consumer resistance to GM products in many countries, it is expected that GM products will be widespread in the coming decades especially for non-food applications.

Process engineering

Related to this, and moving down the produce value chain, second, a strong growth in private sector funded process engineering research may be expected, especially related to food safety and risk assessments. In this connection, Good Agricultural Practices (GAP) promoted in agriculture and processing by FAO are of significance. Public private partnerships could coalesce around improved (crop cultivars and) production practices for smallholder farmers. Last but not least, research could refer to ex ante impact assessment with a particular focus on equity outcomes of bio-based economy. There is no *a priori* reason to expect economies of scale in production of bio-based products to exceed those of food crop production chains, but economies of scales may still be expected for bio-refineries. This raises the question of bio-refinery location in relation to infrastructure markets policies and production units. In many instances bio-refineries will cluster feedstock production near the facilities, which in turn may often be located in higher potential, e.g., irrigated areas – thus indirectly leading to negative equity outcomes. Implementation of remote and local pre-treatment units linked to central processing facilities provide an interesting alternative for this problem which deserves further study (Clark and Deswarte, 2008).

Socio-economics

Third, in relation to sustainable development, research on production and processing scale is important. In the early stages of the development of a bio-based economy, downsizing processing technologies and plant sizes to local level will contribute to three economic drivers. A larger share of the farm population will have the opportunity to grow feedstocks, including those in poor marginal environments. Local employment opportunities will be created in regions lacking in development opportunities, while short feedstock value chains may raise farm gate feedstock prices. As is already observed, by-products can stimulate the development of secondary income generating opportunities, e.g., distiller's grains as concentrate feed for animal fattening activities. Therefore, livestock extension may well be an ideal complement to bio-refinery development.

Production

A fourth major research area will be sustainable feedstock production practices. As demand for agricultural products increases for food, feed and industrial bio-products, there will be a tendency for food prices to increase, thus increasing income and land values for large farmers and reducing net income/increasing food insecurity for the majority of small farmers who are net purchasers of food. The tendency for expansion of production onto marginal land will threaten soil health, for which two major research thrusts are required: first, conservation agriculture systems which maintain soil cover, increase water use efficiency and reduce soil erosion; and second the substitution of perennials for annual feedstocks for similar reasons, perhaps in agroforestry or mixed food-feedstock-livestock plantation systems. Agroforestry can be a source of low cost and reliable biomass, avoiding annual cultivation and management costs while stabilizing standing biomass in times of drought, quite apart from the self-evident advantages in relation to habitat and biodiversity. While current technologies have underpinned a comparative advantage of temperate (and often developed) regions in food and feed production, the comparative advantage for bio-based economies underpinned by biomass production may well shift to tropical (currently under-developed) regions with ample solar radiation and water.

The increased demand for biomass will tend to lead to the harvest of crop residues, i.e. straw and stover, as feedstock, whether for biofuels, bio-materials or bio-refineries. The removal of a high fraction of crop residues will lead to a shortage of fodder for ruminants, and reduce the chances of adoption of mulch cropping systems which protect the soil surface, reduce erosion, reduce weed pressure and improve water productivity. Noting that cereal straws may be removed for second generation bio-ethanol production, Sayre and Dixon (2006) call for research on the proportion of crop straw which is required for maintaining or enhancing soil health. Such research would also be relevant to the sustainable use of whole crop or straw for bio-refineries. There is considerable potential for the return of nutrients contained in byproducts from bioenergy and bio-refinery systems to farmers' fields – Alex et al (2007) report a potential return rate of 78 % of applied N in maize or switchgrass production..

From the above discussion one might expect growing opportunities for private research. As of the year 2000, private sector already accounted for 36 % of global agricultural research funding, growing annually at 2.1 % (Pardey et al 2006). Private sector tends to invest in research into input supply chains, e.g., seed, agrochemicals (Pray and Fuglie 2001), and produce chains. As these grow along with value added on the farm, one can expect considerable growth in private sector funding in a bio-based economy. Such investment is most likely to produce sustainable rural development outcomes if organized in public-private partnerships,

6 Concluding remarks

The bio-based economy has a huge potential

The magnitude of the potential growth of agriculture as we move towards a bio-based economy is immense. To capitalize on this potential, there is a need for expanding capacity, to apply systems and participatory approach to the evolution of agriculture practices, institutions (including markets) and production/processing systems. However, the anticipated growth of the bio-based economy will strengthen the demand for biomass and may well threaten ecosystem function in biomass scarce regions such as South Asia. There will be need for resource planning, including water, energy and byproducts, and associated transportation, storage and processing infrastructure to ensure optimal supply of agricultural produce to a variety of global markets.

Focus on optimization rather than maximalisation

While the food versus fuel debate has been overheated, we conclude that food security should not be threatened by the plethora of new options. Focus should be on optimizing economic and energetic efficiency while protecting the position of vulnerable groups in developing countries. The reality is that most poor rural households are net food consumers; in this context one pathway to household food security and poverty reduction comprises household entitlements (income) associated with high value added products from biomass, through small scale local bio-refineries producing bioenergy or bio-products in poor marginal and remote areas. Incentives for such decentralized investment in bio-refineries would require pro-poor institutional and policy environments.

Sustainable rural development should be the starting point

Balanced rural development will be essential to position the growth of the bio-based technologies and economy in sustainable development space. Mankind requires a wide range of products from agriculture, including food, feed, ecosystem services alongside newer bio-products described in this paper. Experience of the green revolution suggests that agricultural intensification is necessary but should be dispersed rather than concentrated in high potential well watered zones; it should also be “pro-poor, pro-women and pro-environment” – for example, embodying sustainability and equity principles such as promoted in the doubly green revolution. A combination of supply side and demand side institutions and policies will be required for such balanced development, which offer social protection mechanisms while strongly fostering participation, learning, rapid innovation, widespread sharing of technology and knowledge and incentives for investment at all levels. Consideration could be given to developing a Biocare movement fashioned after the Landcare movement which has spread from Australia to developed and developing countries.

Innovative research is essential

A focus on rural development does not imply that technological research should be slowed down. The challenge is to foster an innovative bio-based economy that is technically feasible, profitable, and socially desirable. With respect to crop R&D, there is need to understand how to capture more value from existing crops. Some crops can be modified to yield not only food but also high quality fibre or other byproducts. In a few cases there might be opportunities for contract growing of tailored crops that produce high value molecules.

There is a wide range of technical research required for efficient, pro-environment, biomaterial and bio-refinery systems – and a majority of this research will be funded by private sector. In bio-refinery, it will become increasingly essential to maintain the utility of other value products in the feedstocks from agriculture, forestry and marine biomass. In this way, integrated bio-refineries with multiple output streams will open up many opportunities for sustainable development (Möller, 2007).

N' one size fits all' options

There is of course great heterogeneity in farming systems which should be recognized when developing, appraising or sharing experience with technology. Introduction of new technologies should also be done with due recognition of the evolving agricultural production systems, i.e., in an incremental manner for the specific farming system.

There is a need to aim for ecological efficiency but residue recovery and biomass harvest demand more of water and soil resources that are already heavily stressed. Consequently, it is important that processing must be integrated with biomass production to yield ecological improvements. Demand for biomass as a feedstock may allow a redesigning of agriculture, in terms of crops, cropping systems and nutrient management. But there are no economic incentives that will facilitate this. Comparisons of annual and perennial biomass crops show that the latter do offer the potential for environmental advantage through building and conserving soil, capturing and storing carbon, holding and filtering water, providing wildlife habitat and cycling nutrients efficiently. But there are disadvantages such as long establishment periods, reduced farmer flexibility and increased financial risk.

Regional optimisation should be pursued

In the US, the lack of support systems for perennial grasses is also a barrier to uptake. In order to move towards a sustainable bioeconomy it is necessary to improve resource and energy efficiency, particularly water use efficiency and nitrogen use efficiency. In addition, future policy should "level the playing field" for biomass feedstock crops and also provide a vehicle for payment for the environmental benefits and services delivered. Cellulosic biomass conversion demonstrates that processes can be very efficient, delivering ecological integration and benefits such as reduced and recovered nitrogen inputs, low nitrate leaching, low soil erosion and high carbon storage.

Bio-refineries will be a key component of a resilient and sustainable bioeconomy, preferably with viable small scale options to foster local economic development in marginal and remote areas. The various components of healthy agricultural and industrial ecosystems need to be integrated. Bio-refineries will need to be optimized so that a wider range of the ecological functions that agricultural and natural lands currently provide, such as nutrient cycling, carbon sequestration and the protection of water and soil resources, will be delivered. However, it should be noted that this is unlikely to happen unless appropriate economic incentives are created (Annex *et al.*, 2007).

Some of the key research needs for production and processing are:

- Development of bio-solar cells may help in relaxing existing pressure on biomass production systems. They should develop options for efficient, economic and effective production of bioenergy whilst preventing environmental or social damage;
- Selection of key bio-based model crops with the potential to offer development perspectives for less favoured producers or underdeveloped rural areas;
- Development of bio-refinery concepts for these crops that are technically innovative, economically viable, energetically efficient and effective;
- Bio-products that offer most development perspectives combine large market volumes to medium to high price levels, thus comprising products like fine chemicals, lubricants and solvents;
- Design and implementation of decentralized production chains that can serve both local needs for energy, materials and nutrients as their requirement for viable economic development linked to larger markets;
- Organization of effective public support for tailor-made solutions that can serve local development needs without jeopardizing fragile ecological or social infrastructure.

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