Emerging Initiatives in the Production and Consumption of Bioenergy and Biofuels: A Review

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Abstract

Bioenergy systems offer developing countries an opportunity to transform the inefficient traditional biomass sector into an efficient and competitive bioenergy industry. However, rapid global expansion of bioenergy development could have unwanted environmental and economic consequences, possibly including reduced global capacity to produce food, fiber, and industrial materials. Furthermore, there has been considerable effort during the past few years aimed at the development of sustainability criteria for biomass and biofuels, both within regions and in the context of international trade. The paper is a review of emerging global initiatives in the production and consumption of bioenergy and biofuels. It is hoped that some of the key challenges and opportunities of such initiatives may be better understood as a guide to future research, as well as ongoing and future initiatives in policy and practice in developing countries.

Keywords: Bioenergy initiatives, biofuels, Jatropha, Woody biomass, Sustainability Criteria, challenges and opportunities

Introduction

Bioenergy refers to sources of energy (electricity and solid, liquid, or gaseous fuels) derived from biomass: plant- or animal-based materials such as crops, crop residues, trees, animal fats, by-products, and wastes. These materials are often obtained from agriculture and forests, but can also be derived from industrial and municipal sources. On its own, biofuel typically refers to biomass that has been converted into a liquid fuel such as ethanol or biodiesel, but biomass can also be converted into gaseous fuels via biological or chemical processes such as digestion and gasification. Biomass solids can also be burned alone or with fossil fuels to generate direct heat, steam, and/or electrical energy. The foundation of a bio-based industry depends on an abundant supply of biomass (UCS, 2007).

As identified by Larson (2008), the most widely used liquid biofuels are bioethanol and biodiesel. Ethanol is an alcohol that can be used directly in cars designed to run on pure ethanol, or blended with gasoline to make "gasohol". Ethanol can be used as an octane-boosting, pollution-reducing additive in unleaded gasoline, thereby substituting for chemical additives such as methyl tertiary-butyl ether (MTBE). Biodiesel is a synthetic diesel-like fuel. It can be used directly as fuel or blended with petroleum diesel. While there is much attention on biofuels for the transport sector, the use of biofuels for cooking is a potential application of great relevance globally, especially in rural areas of developing countries. Combustion of biofuels for cooking will yield far lower emissions of pollutants than emissions from cooking with solid fuels. Thus, biofuels could play a critical role in improving the health of billions of people (Larson, 2008).

About 1.6 billion people still have no access to electricity and over 2 billion still rely on traditional biomass for the everyday cooking and heating. The very accessibility of bioenergy to the poor represents part of a possible response to the challenge of increasing access to affordable energy services. Around the developing world there are examples of small-scale initiatives which are working to provide improved energy access through the development and transformation of various bioenergy resources into cleaner and more convenient forms of energy at local level (Practical Action Consulting, 2009).

Categories of bioenergy and biofuels

Biofuels are at present classified in two categories: “first-generation” and “second-generation” biofuels. While there are no strict technical definitions for these terms, the main distinction between them is the feedstock used. A first-generation biofuel is generally a fuel made from sugars, grains, or seeds; that uses only a specific (often edible) portion of the above ground biomass produced by a plant; and that is the result of a rather simple manufacturing process. First-generation fuels are already being produced in significant commercial quantities in a number of countries. Second-generation fuels are generally those made from non-edible lignocellulosic biomass, either non-edible residues of food crop production (e.g., corn stalks or rice husks) or non-edible whole-plant biomass (e.g., grasses or trees grown specifically for energy). The process to covert the lignocellulosic biomass into a fuel is rather complex (Larson, 2008).

First-generation biofuels have several limitations. They compete with food uses and plants have been optimized for food, not energy use. Only part of the plant is converted into biofuel. They bring only modest greenhouse gas (GHG) emissions mitigation benefits, except for sugarcane ethanol. While first generation biofuels can be blended with existing fossil fuels and so require minimal infrastructure change, there is limited large-scale experience outside Brazil and the United States. Also, they bear relatively high costs - except for sugarcane ethanol in Brazil - due to high feedstock cost. Second generation biofuels have some clear advantages. Plants can be bred for energy characteristics, and not for food, and a larger fraction of the plant can be converted to fuel. Also, second-generation biofuels have greater capital-intensity than first generation biofuels, but lower feedstock costs. The projected costs are less scale-sensitive for biological biofuels than for thermochemical biofuels.

Global production of first-generation bioethanol in 2006 was about 51 billion litres, with the United States becoming the world's largest producer with 18.3 billion litres from corn and Brazil a close second with around 17 billion litres from sugarcane. China and India contributed 3.8 and 1.9 billion litres respectively (Houghton *et al.*, 2006). Production levels were much lower in other countries, with feedstocks that include sugarcane, corn, and several other sugar or starch crops (sugar beets, wheat, potatoes).

Global trend in the Production and Consumption of Biodiesel

At the meeting of the European Council in Brussels in March 2007, it was decided to set a mandatory target of 20% share of renewable energies in overall EU energy consumption by 2020, and a mandatory 10% minimum target for the share of biofuels in overall EU transport petrol and diesel consumption by 2020 (Brussels European Council, 2007). Biodiesel production worldwide has been growing rapidly since 2005, with the EU producing 77% of the total in 2006. EU biodiesel production (primarily from rape seed oil and sunflower seed oil) has risen from 1.9 million tonnes (approximately equivalent to 2.2 billion litres) in 2004 to 4.9 million tonnes (approximately 5.6 billion litres) in 2006, marking a further acceleration in the continuous expansion of this sector. In the United States, biodiesel production (primarily from soy beans) rose from 2 million gallons (approximately 7.5 million litres) in 2000 to 250 million gallons (approximately 950 million litres) in 2006 (Carriquiry, 2007).

In Brazil, the government has mandated the addition of 2% biodiesel to conventional diesel starting in 2008, with the percentage increasing to 5% in 2013. Interest in palm biodiesel is growing, especially in Southeast Asia (Malaysia, Indonesia and Thailand) where the majority of the world's palm oil for food use is made today. Jatropha, a non-edible-oil tree, is drawing attention for its ability to produce oil seeds in semi-arid lands. In India, Jatropha biodiesel is being pursued as part of a waste-land reclamation strategy (Larson, 2008).

Biofuels are increasingly traded internationally both because a number of developed countries which are transferring to biofuels do not have the land capacity to grow the required amount of biomass, and because several countries from the South enjoy the appropriate land and labor conditions for positioning themselves as efficient biomass and biofuels producers and exporters. World ethanol exports grew from 3.2 billion litres in 2002 to 7.8 billion litres in 2006, with the Americas being by far the largest exporting region with a total of 4.7 billion litres exports (Schuetz, 2007).

Challenges and Opportunities of Bioenergy and Biofuels

If developed in a sustainable way, bioenergy has the potential to produce both electricity and fuel with fewer risks than those associated with oil, coal, and nuclear technologies. Also, bioenergy generates far more jobs than any other energy source – renewable or non-renewable. These jobs are created mainly in rural areas where poverty is worst, and thus can help to slow down or even reverse migration to urban centres. Smeets *et al.*, (2004) in their study revealed that the bioenergy potential of sub-Saharan Africa – after accounting for food production and resource constraints – was the greatest of any of the major world regions. Using four scenarios, the potentials included various categories of biomass, among which residues and abandoned agricultural land were the most significant globally. The high potential results from the large areas of suitable cropland in the region, large areas of pasture land presently used and the low productivity of existing agricultural production systems.

Among the key issues that developing countries grapple with in biofuels is the high cost of alternative fuel option. Unlike developed countries, they are in no position to provide huge subsidies for the promotion of biofuels except a few tax concessions. In that situation, developing countries would be keen to explore technological options. It is often suggested that the biotechnology could be utilized in different ways such as genetically modifying plants to increase the yield. An alternative option could be to create new enzymes, bacteria or fungi that would be used to convert the biomass into biofuels more efficiently. In Asia, the options for producing ethanol are limited. Many Asian countries face frequent droughts and are finding it difficult to replicate Brazil's success with sugarcane, which needs a huge volume of water. Thailand and Indonesia are tapping palm oil as a potential fuel. Indian scientists, have high hopes for Jatropha, which tolerates drought well. The three major options available for bioenergy in Asia are biodiesel, bioethanol and biomass gasification, which have huge potential among Asian economies for the development of viable biotechnologies.

Summarily, modern bioenergy and biofuel systems offer developing countries an opportunity to transform the inefficient traditional biomass sector into an efficient and competitive bioenergy industry. Technical advances are steadily improving the economic attractiveness of this transition, while at the same time social and environmental concerns are making them more politically attractive. To developed countries, modern bioenergy offers an opportunity to revive rural economies and to market advanced technologies to developing countries, enabling them to leapfrog over the technologies of previous decades (Johnson, 2007).

However, rapid global expansion of bioenergy development could have unwanted environmental and economic consequences, possibly including reduced global capacity to produce food, fiber, and industrial materials. Such challenges represent an opportunity to improve the resiliency of our agriculture and forestry sectors.

Increased production and use of biofuels raise indeed a number of concerns. Some shortcomings refer to the danger that rapid growth in demand for energy crops would divert too much cropland to fuel feedstock production, jeopardising food security and resulting in socially detrimental increases in the prices of agricultural commodities (Moreira, 2003). Concerns refer also to the risk that increasing biofuel demand will lead to the cultivation of previously uncultivated lands, including land having high biodiversity value or high carbon stock. Large use of water and pesticides for feedstock production could jeopardise the environmental advantages of biofuels (Berndes, 2002). The process of transforming feedstocks into biofuels may also be environmentally unfriendly and possibly eclipse the greenhouse benefits of biofuels (Zarrilli, 2008).

Impacts and Sustainability Issues in Bioenergy Production

According to Johnson (2007), bioenergy is inherently land-intensive, meaning that the associated socioeconomic and environmental impacts are generally much more significant than those of other renewable energy systems. Some key concerns are relate to loss of ecosystem habitat, deforestation, loss of biodiversity, depletion of soil nutrients, and excessive use of water. In addition to the provision of a renewable energy source, some positive environmental impacts might include restoration of degraded land, creation of complementary land use options, and provision of non-energy resources and materials. Some specific issues that arise in the case of sugar crops, woody biomass, and oil-bearing crops, are outlined below. In general, the main impacts are on the agricultural side, and therefore where there are multiple products available, as is the case with sugar cane, it is useful to consider multiple-product--multiple-benefit scenarios (Cornland *et al.*, 2001).

i. Sugar crops: The environmental impacts of sugarcane have been analysed in considerable detail in the case of Brazil. When Brazil began its effort to expand sugarcane for ethanol production in the 1970s, the environmental impacts were quite significant, especially the disposal of large streams of waste effluent from ethanol distilleries. Over the past thirty years, dramatic improvements have been achieved in technical efficiency and in the efficiency of key resource inputs (e.g. water). The case of water use is particularly interesting, since cane requires significant amounts of water during a key period in the growth cycle. Cane is rain-fed in Brazil, and furthermore, the amount of water that is recycled in the cane-ethanol processes is on the order of 90% (Macedo, 2005). In other parts of the industrial world where water is more scarce, sweet sorghum could provide a useful alternative, with its low water requirements, less than half of that of cane, and has the ability to remain dormant during periods of drought (Bassam, 1998). This creates better opportunities for small scale farmers with no access to irrigation. The use of sweet sorghum as an energy crop in southern Africa has been clearly identified and evaluated favourably (Woods, 2001). Sweet sorghum has low requirements for nitrogenous fertiliser – about 35-40% of sugar cane – with clear benefits for the farmer, as the crop will require less investment in inputs, as well as possible environmental benefits from avoiding impacts of fertiliser run-off. Sweet sorghum has high potassium uptake, however, and is therefore highly depleting of this mineral (Bassam, 1998). Sugar cane can operate on a closed-loop with respect to potassium, since it can be extracted from the filter mud residues and recycled.

ii. Woody Biomass: Woody biomass is a major source of primary energy for the majority of the world's poor. In some African countries, over 95% of households depend on wood for cooking and heating (Johnson, 2007). Unsustainable extraction practices of forest and wood products industries are a major source of environmental degradation in many regions. The environmental impacts of wood fuel use by industries and households are well known, and include: health effects of indoor air pollution, which kills more women and children than tuberculosis and malaria (UNDP, 2004); contributing to deforestation; and soil degradation and erosion problems. A common impact from the use of wood fuels relates to the opportunity cost of the time spent collecting wood. The gathering of wood can require several hours per day, sometimes preventing children from attending school, and women from improving their livelihood by engaging in other, possibly profitable enterprises. However, the consumption of woody biomass as a fuel need not be inherently unsustainable. Improvements in conversion efficiency and use are needed, especially in more densely populated regions. Improved charcoal and wood burning stoves have important roles to play in poor areas where modern energy services are unlikely to penetrate for many years.

iii. Oil-bearing and other biomass crops: Jatropha trees yield oil that is highly suitable for use in raw form or for refinement into bio-diesel. This tree is reported to have strong environmental benefits when intercropped with other produce. It can be used as a hedge to prevent soil erosion, and can also have regenerative effects on the soil, being a nitrogen fixer (Openshaw, 2000). Several oil bearing crops, currently used predominantly in food products, are strongly associated with severe environmental impacts. In particular, soy bean plantations are encroaching on rainforests in Brazil, and the palm oil industry is a major cause of deforestation in Malaysia and Indonesia. In order to preserve the credibility of bioenergy as an environmentally sustainable source of energy, particularly in the context of a possible future international trade in biofuels, such sustainability concerns will have to be addressed. Some form of social and environmental certification would seem to be desirable.

Sustainability Criteria

There has been considerable effort during the past few years aimed at the development of sustainability criteria for biomass and biofuels, both within regions and in the context of international trade. It is worth reiterating that in the context of bioenergy projects, 'there are no "one size fits all" solutions' (ESMAP, 2005). Socio-economic and environmental impacts must be assessed for every new bioenergy project in the context of the pre-existing ecological, cultural, agro-industrial and land use systems that are specific to the area under consideration. However, it is possible to devise a 'check list' of sustainability criteria most likely to be relevant to a bioenergy project.

Sustainability criteria for bioenergy will inevitably have to address certain core criteria, which will differ considerably in different regions and for different crops. The core criteria would likely cover the following areas (Fritsche et al, 2006):

- land use and land ownership, including food security;
- maintenance of biodiversity;
- reduction of greenhouse gas emission;
- soil erosion and degradation;
- water use and contamination;
- socio-economic impacts;

The criteria would also have to be applied at varying levels: local, regional, national, and international (i.e. particularly in relation to trade). Undoubtedly there will be conflicts across the scales and consequently a governance system or an environmental regime would have to be somewhat flexible but also capable of maintaining fairly high standards.

Global Small-Scale Bioenergy Initiatives

Today, 1.6 billion people still have no access to electricity and over 2 billion still rely on traditional biomass for their everyday cooking and heating needs which are fundamental to human life (Practical Action Consulting, 2009). However the very accessibility of Bioenergy to the poor represents part of a possible response to the challenge of increasing access to affordable energy services. Around the developing world there are examples of small-scale initiatives which are working to provide improved energy access through the development and transformation of various Bioenergy resources into cleaner and more convenient forms of energy at local level. The aspiration of these initiatives is however not just to provide energy access but also for the production of Bioenergy to power rural development through the creation of new Livelihoods opportunities. It is increasingly recognised that both improved energy access and the Livelihoods created through its production and use are essential if the Millennium Development Goals are to be achieved. Some of the identified global small-scale bioenergy initiatives in a study conducted by Practical Action Consulting (2009) include:

1. Mali Jatropha Electrification: The Garalo Project in Garalo community, Mali, was established to provide the local community with access to electricity produced from Jatropha oil. Small-scale farmers are at the heart of the business model supplying Jatropha oil to a hybrid power plant (Fig. 1). Electricity is then sold by the private power company ACCESS to residential and business consumers. Out of a forecast of 10,000 ha of Jatropha, 600 ha, involving 326 rural families, are already under cultivation on land previously allocated to cotton - a product which has significantly dropped in market value over recent years. The project provides a stable income to farmers as well as access to modern energy services for the community, both stimulating the local economy. Furthermore, producer and consumer rights have been promoted through the establishment of co-operatives and associations.

Fig. 1: One of three 100kW dutch generators at Garalo able to run on

Jatropha oil, diesel or a blend (Photo: Smail Khennas)

2. Jatropha oil in cook stoves: In recent years, Germany has developed a technology that allows the use of diverse crude or refined plant oils, such as jatropha oil, in a pressure stove with a special burner that does not require blending with other fuels. The stove technology has been tested in the Philippines and, since 2006, in Arusha, Tanzania, using oil from a local Jatropha plantation. Production of the stove began at both locations at the end of 2006, using mainly local material, but still relying on the import of one crucial high technology component from Germany.

3. India Jatropha Electrification: The Ranidehra rural village electrification initiative of Winrock International India (WII) is to electrify a remote tribal village through the use of biofuel in the state of Chhattisgarh. The objective of this initiative is to demonstrate the technical and financial viability of running diesel generation sets using vegetable oil as fuel in place of conventional diesel to provide electricity. The initiative aims to design and implement a replicable model of remote village electrification via use of Jatropha as feedstock. The experiments undertaken in WII proved the use of Jatropha oil in conventional diesel engines as fuel instead of converting into Biodiesel. In the predominantly tribal village 110 households are accessing 3 hours of domestic and 3.5 hours of street lighting per night using 1 tonne of Jatropha seed per month. The project continues to evolve over time with weaker elements being addressed and improvements made. The initiative establishes the idea of rural electrification through active community participation. The promotion of small scale village energy generation helps to boost the village economy by providing alternative livelihood opportunities.

4. India Biodiesel Water-pumping: The biodiesel-based water pumping project is being implemented in the remote and tribal belts of two neighbouring Ganjam and Gajapati districts in Eastern Orissa, India. This was later extended into critical irrigation of crops through a bioenergy system that eventually led to regeneration of land resources and improved livelihood opportunities. A biodiesel production unit uses the local underutilised seeds of *Pongamia pinñata*, *Madhuca indiaca* from Forest and *Guizotia abyssinica* (Niger) as feedstock. Biodiesel is produced using a pedal powered reactor for grinding oil seeds (Fig. 2), pressing oil from seeds and getting biodiesel from the oil. The biodiesel can be used in the regular pump-sets and generator sets. The press is hand operated while the grinder and biodiesel reactors are pedal operated. The local community uses the by-products, such as pressed oil cake and glycerine, as natural fertilizers and cattle/poultry feed. Although this project is successful on a small scale, and has established the technical feasibility, there is concern that fragile village level institutions, vested political interest, and the absence of strong local level governance could prove to be challenging on a larger scale, particularly as the technology lends itself to enabling social change.

Fig. 2: Pedal-driven biodiesel reactor (Photo: CTxGreEn)

5. Thailand Jatropha Co-operative: In 2006, the University of Kasetsart and the Viengsa Agricultural Co-operative initiated a zero-waste Jatropha development project in Viengsa District, Northern Thailand. The University and the Co-operative have played a key role, not only in establishing and supporting market actors but also in facilitating the sale of products at highly competitive prices (lower than on the open market) to consumers within the Co-operative. The University is running a Jatropha School to train Co-operative members in Jatropha production, processing and marketing. For its part, the Cooperative has formalised agreements between members to guarantee and fix prices of raw materials and Jatropha products. The project has not only provided an income to 1,000 farmers but has also established local access to an affordable and renewable source of energy to help the community reduce the costs of production and thereby increase energy and food security

6. Tanzania Sisal Biogas: Tanga region in Tanzania depends on sisal as its most important cash crop. Using current production methods, only 4% of the actual plant is recovered as fibre, the residue either burnt, producing carbon dioxide, or rotted naturally, producing methane. At Katani Ltd, a sisal growing and processing company, this residue is now converted to biogas, and then to electricity (about 150KW), used to power the factory and excess power used by those living on company premises. Other benefits of the project include land accessibility by local farmers to grow sisal; increased income which has enabled farmers to build better houses, buy bicycles, mobile phones and better clothes; access to cleaner drinking water; light for work in non-daylight hours, and to run small-scale industries; and energy services to the local schools and hospital. However, higher standards of living, alongside increased levels of employment have already decreased rates of migration from rural to urban areas.

7. Ethiopia Ethanol Stoves: Ethiopia is one of the poorest countries in the world. As indicated in the survey conducted by Practical Action Consulting (2009), the most widely used fuel for cooking in the capital, Addis Ababa, is kerosene (42.2%) followed by fuelwood (29.4%). Furthermore, charcoal, LPG, electricity and residues are used by a much smaller section of city households. The number of people cooking on kerosene dropped as a result of the government removing fuel subsidy. Ethiopia established an ethanol manufacturing plant at the Finchaa sugar factory in 1999. Seeking potential markets for the ethanol, Project Gaia was invited to do pilot studies in Addis Ababa households in 2004. Since then, Gaia has been working to promote ethanol as a household energy fuel. Results of a pilot study by Practical Action

Consulting (2009) have shown that the project households readily accept the new cooking technology (a stove called the 'CleanCook'), and ethanol fuel, and that ethanol could effectively substitute for kerosene, for charcoal and for fuel wood use, where the cooking task could be completed with the ethanol stove. Gaia has been working with Makobu Enterprises PLC to produce CleanCook stoves in Ethiopia. The two partners have a bilateral agreement that has helped them to work on establishing a local stove manufacturing plant. Benefits include reduced fuelwood use, with consequent reduced risks for those gathering fuel, reduced indoor air pollution, time and money savings for those using the stove, locally-available fuel saving imported kerosene, and employment in manufacture and distribution of stoves and ethanol.

8. Guatemala Jatropha Biodiesel: The Ministry of Agriculture of Guatemala has identified 600,000ha of land across the country that is considered suitable for the growing of Jatropha. This project was established early in 2008 and is situated in Cuyotenago in Guatemala covering 170ha of land, which is owned by a total of 150 families, and is projected to produce 361,000 litres of Jatropha oil per year. The plan is to organise the farmers into clusters by a co-operative, the first cluster has already been set up. For the first cluster, the processing equipment to transform the oil into usable fuel is owned and operated by an industrial partner, but in future it may be owned by the co-operative. The processing of the oil also produces products that can be used variously for cosmetics, and fertiliser.

9. World Bank gelfuel in stoves: Between 2000 and 2003, the World Bank's Development Marketplace Program shepherded the Millennium Gelfuel Initiative (MGI), a public-private partnership aimed at adapting and disseminating gelfuel for African households. Gelfuel is based on ethanol, produced through the fermentation and distillation of sugars (derived from molasses, sugar cane, sweet sorghum, etc.) or starch crops (cassava, maize, etc.). It is renewable and can be produced locally in most African countries. Projects are under different stages of preparation in Benin, Ethiopia, Madagascar, Mozambique, and Senegal. Direct ethanol itself costs only about 70 percent as much as gelfuel, but until recently was not considered appropriate for cooking due mainly to incompatibility with stoves and the potential for spillage. With the recent development of new low-cost (US $15) direct-ethanol stoves, cooking with biofuel will lower the expense of cooking even more, making direct ethanol competitive even with fuel wood and charcoal (REN21, 2005)

10. Biogas Systems: Biogas systems are mainly used in rural areas. Biogas generation is an alternative to burning biomass, particularly cow dung. Biogas substitutes LPG and kerosene for cooking and heating. As of 2005, around 16 million Asia-Pacific rural households cooked and lit their homes using biogas produced in household-scale anaerobic digesters. Biogas has advantages over other technologies, because it has the added benefit of producing very fertile slurry that can boost agriculture productivity. Moreover, the systems can feed generators to produce electricity and motive power, in addition to providing energy for cooking and heating (Heruela and Wickramasinghe, 2008).

Guiding Principles for Production and Consumption of Bioenergy and Biofuels

According to the Union of Concerned Scientists (2007), some of the recommended principles that should help guide bioenergy development in a manner that maximizes the opportunities and helps address the challenges associated with this renewable resource include the following:

1. ***Minimize global warming pollution.*** Our energy choices should give priority to production methods and materials that produce the lowest amount of global warming pollution per unit of energy and offer the greatest overall potential for emission reductions. To realize substantial reductions, we must transit as quickly as possible to new biofuels derived from abundant and diverse materials including energy crops, ecologically safe amounts of forestry and agriculture residues, and other waste materials.

2. ***Protect public health.*** Some bioenergy applications can degrade air, water, or land quality, creating tradeoffs between the potential benefits and public health risks. We must therefore evaluate the health risks and potential unintended consequences of bioenergy production and use, and make choices that maintain and improve public health.

3. ***Protect air, water, and soil quality.*** Bioenergy feedstocks should be produced and used in ways that maintain or improve the quality of environmental resources. To accomplish this, we must analyze the impact bioenergy production and use will have on air, water, and soil quality, and establish criteria that ensure its production in a sustainable manner. Progress in light of these criteria should be monitored as bioenergy resources are developed.

4. ***Protect biodiversity and ecosystem services.*** The development of new sources of biomass will involve major changes in domestic and international land use and management. These changes could either enhance or degrade the quality of agricultural, forest, rangeland, and wildland ecosystems and the ecological services they provide (e.g., clean water, crop pollination). Biomass production should conserve biological diversity, protect wildlife habitat, and ensure the continued delivery of ecosystem services. Protected areas, lands possessing high conservation value (such as old-growth forests, wilderness, and wildlife habitat), and other areas considered rare or valuable should not be used for biomass production.

5. ***Use biotechnology wisely.*** Genetically engineered biomass should be supported only where the benefits outweigh the risks, and where traditional breeding or other alternative approaches are not feasible. Risks and benefits should be assessed on a case-by-case basis prior to commercialization. Outdoor releases of genetically engineered crops, trees, and microorganisms deserve special scrutiny because modified organisms or the novel genetic traits they carry can spread into the environment with little or no hope for recall. Any genetic modification to commodity crops that are also grown for food (corn, soy, wheat, etc.) should not endanger the food system or undermine the value of these crops as food or feed for domestic consumption or export.

6. ***Limit the risk of invasive species.*** Hundreds of supposedly

beneficial plant species have been introduced into the United States only to become costly pests. As far as possible, biomass production should not exacerbate this already serious problem by using plants or microorganisms with invasive properties. Nor should we confer invasive properties on plants modified through conventional breeding or genetic engineering. If potentially invasive plants are introduced, containment and monitoring should be required.

7. ***Promote a responsible shift to bioenergy production through effective government policies and investments.*** To compete with existing crop and energy subsidies, and quickly and fully realize its potential benefits, bioenergy production must be supported by government policies that set appropriate performance standards. Effective, targeted public investments in the form of research, market-creating purchases and mandates, and producer price supports should be provided for emerging bioenergy technologies and industries.

8. ***Create opportunities for stable economic development.*** Investments in bioenergy should ideally strengthen each "link" in the commodity chain, including producers, processors, and distributors. Accomplishing this goal, however, will entail overcoming historical economic inequities among these groups, lessening the centralization and vulnerability of our current energy system, and increasing the resiliency of bioenergy production. Therefore, policies should seek to maximize the benefits of bioenergy use for local populations in biomass-producing areas, which will help rural communities profit from the processing and production of bioenergy.

Conclusions

If developed responsibly, bioenergy and biofuels have the potential of producing both electricity and fuel with fewer risks than those associated with oil, coal, and nuclear technologies. But this opportunity will only be realized fully if we make wise decisions about how the technology is developed. Given the urgency of reducing our global warming emissions, it is essential that we choose those forms of bioenergy that, over the full life cycle of the fuel, promise the greatest emission cuts in the shortest period of time. In addition, bioenergy development should not create or exacerbate health or environmental problems such as air and water pollution or degrade biological diversity. Investments in bioenergy development should bolster the economic foundation and quality of life in those communities where biomass is produced and processed.

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