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Overview on biofuels from a European perspective

Running title: European perspective on biofuels

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Abstract

In light of the recently developed European Union (EU) Biofuels Strategy, the literature is reviewed to examine: (1) the coherency of biofuel production with the EU non-industrial vision of agriculture, and (2) given its insufficient landbase, the implications of a proposed bio-energy pact to grow biofuel crops in the developing world to meet EU biofuel demands. The EU acknowledged that the use of food crops for biofuel production was based on wrong assumptions concerning climate change mitigation, and its support has now shifted to second generation nonfood crops. The bio-energy pact entails: (1) biofuel crops production in developing countries, especially Africa that in the absence of environmental and social regulations may lead to ethical trade-offs in land use (food vs. fuel); and (2) the use of transgenic technology that conflicts with the EU's own vision of sustainable agriculture.

Key words: Bioenergy crops, European Union, energy policy, cellulosic biomass, biopact, transgenic crops, land use change, ecosocial impacts.

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Introduction

Global production of biofuels (i.e. transportation fuels[1] derived from biomass) has tripled from 18.1 billion liters in 2000 to about 60.5 billion liters in 2007, 90% of which are produced in the United States (US; 43%), Brazil (32%), and the European Union (EU; 15%) (see Tab. 1) (Coyle, 2007). This rapid growth has been driven by high petroleum prices and favorable government policies (Kammen et al., 2008). At present, the predominant biofuels in use are ethanol and biodiesel, but combined they account for only 2% of global road transport fuel use (85% ethanol and 15% biodiesel) (Doornbosch & Steenblik, 2007; de Fraiture et al., 2008). Most of the world's biomass-derived ethanol is produced in the US (primarily from corn) and in Brazil (from sugarcane), while the EU is the world leader in biodiesel production (~90% from rapeseed) (Kutas, Lindberg, & Steenblik, 2007; REN21, 2008) (Tab. 1; see also Tab 2 for feedstocks used in biofuel production). Most of the EU biodiesel production (81%) is concentrated in four countries: Germany (54%), France (14%), Italy (9%) and the United Kingdom (4%). The EU produces less ethanol than biodiesel ranking third, behind Brazil and US (see Tab. 1) with more than four-fifth of the production concentrated in Germany (38%), Spain (35%) and France (26%). Consistent with global trends, biofuels represent only 2.6% of the energy content of all the fuels used in road transport in Europe today (Observ'ER, 2008).

Recently, policy support for biofuels worldwide has greatly increased based on the assumption that biofuels would not increase the concentration of greenhouse gases, and this has led to mandates for blending biofuels into vehicle fuels that have been enacted over the past 2-3 years in at least 36 states/provinces and 17 countries at the national level. Most mandates require blends of 10-15% ethanol with gasoline and 2-5% biodiesel with diesel fuel (Tab. 2) (REN21, 2008). The EU's Directive 2003/30/EC (European Parliament and Council, 2003) requires a minimum of 2% biofuel in road transport fuels beginning 2005. The same directive sets a 5.75% target for 2010, with a projected 10% goal by 2020 (Halleux, Lassaux, Renzoni, & Germain, 2008). Because less than a half of the 5.75% target has been reached so far, the EU will have to increase its production and/or focus even more on imports to meet

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[1] Biofuels are typically mixed with conventional car fuel gasoline and diesel, with blends varying between a few percent of biofuel to nearly 25% in Brazil. Note there is a difference between the broad term bio-energy used in households, transport and industry and the much more limited term "biofuels" used as transport fuels for cars, buses and trucks. (de Fraiture, Giordano, & Liao, 2008).

this goal. This is occurring at a time when biofuels are at the core of complex ecological and economic controversy (Observ'ER, 2008). However, concerns of economic sustainability and environmental impacts of biofuels are severe enough that the European parliament is considering a moratorium on biofuels (Ruth, 2008), while the UK parliament has strongly advised the government to adopt a moratorium on biofuel targets (UK House of Commons, 2008). A report from the Royal Society points out that governments have worried too much about setting policy targets for biofuels substitution of fossil fuels without proper consideration of biofuel's sustainability (The Royal Society, 2008).

Because there is insufficient land base in the EU and in many developed countries to meet current biofuel goals, this has led to the idea of a bio-energy pact (i.e. biopact) between the developed North and the developing South as a source for the biofuel shortfall (Mathews, 2007). Specifically, the bioenergy pact between Europe and Africa proposes to grow biofuel crops most notably in sub-Saharan Africa to meet European demands (Biopact, http://www.biopact.com). This approach was adopted by the EU Biofuels Strategy (European Commission, 2007b) to help meet the 2010 target of 5.75% market share for biofuels in the overall transport fuel supply.

Our paper reviews the pertinent recent literature in the light of this recently adopted Biofuels Strategy to determine if biofuels are coherent with the EU non-industrial vision of agriculture, and in the process to discuss the global implications of the proposed EU-Africa biopact. A similar policy analysis was made concerning transgenic crop policy in the EU (Ponti, 2005)

A new generation of bioenergy crops

Industrialized economies with biofuels targets, such as those in the US and EU, are unlikely to have the land base needed to meet their growing demand for biofuels (Hill, Nelson, Tilman, Polasky, & Tiffany, 2006; Gibbs et al., 2008), and this drastically reduces the chances that current food-based biofuels can be used sustainably as an abundant and environmentally beneficial energy source (Tilman, Hill, & Lehman, 2006). In the US and Italy, for example, more arable land than is available would be required for a 15% blend of fuels (Gressel, 2008; Russi, 2008). In the United Kingdom, even if all existing sugar beet and oilseed rape production was used by the biofuel industry, an increase in land area devoted to sugar beet and oilseed rape of 178% and 89% respectively would be required to meet the EU

2010 target of a 5.75% fuel blend (Mattison & Norris, 2007). A 10% substitution of gasoline and diesel fuel is estimated to require 43% and 38% of current cropland area in the US and Europe, respectively (Righelato & Spracklen, 2007). These and other examples make clear the International Energy Agency (IEA) open statement that “if the United States and Europe are serious about biofuels, they must turn to the South for their supplies” (Mathews, 2007). However, the expansion of current biodiesel crops globally will eventually impact global food supplies and in the long-term the sustainability of agriculture production (Johnston & Holloway, 2007). Moreover, growing food crops in the South for the energy needs of the North would force developing countries to choose between farming for food or for energy, and this would threaten their food security.

Convinced that “[they]’re going to do much better this time” (Waltz, 2007), biotechnologists are proposing a new generation of nonfood more efficient bioenergy crops to make the impact of biofuels on food security and land requirements less problematic. The cost of rapeseed biodiesel and ethanol from cereals or beets (“first generation” biofuels; see Fig. 1) is much higher than that of gasoline and diesel, and hence substantial subsidies have been required to make them competitive (Hamelinck & Faaij, 2006). In contrast, “second generation” cellulosic biofuels (Fig. 1; see Tab. 3) under development are expected to be cheaper. First generation biofuels are inefficient and costly because only a fraction of the plant is actually converted to fuel (e.g. corn grains), while second generation biofuels can be obtained from the whole plant using the cellulose that make up most of the plants structure (Somerville, 2007). However, the development of transgenic cellulosic biofuel crops is seen as imperative if second generation biofuels are to become economically viable (Gressel, 2008). For example, perennial grasses such as switchgrass (*Panicum virgatum*) and *Miscanthus* need to be genetically engineered for lower lignin content in order to increase cellulose availability to hydrolytic enzymes, but this as well as many other desirable traits are not easily approached even through genetic engineering (Karp & Shield, 2008). Furthermore, the use of transgenic crops as a source of biofuels has the potential to spur unprecedented controversy (Stewart, 2007) fueled by the nexus of these two hotly debated topics: transgenics and biofuels.

The European biofuels strategy

In 2003, an EU Biofuels Directive on the promotion of the use of biofuels and other renewable fuels for transport (European Parliament and Council, 2003) set out indicative targets for EU member states. To help meet these targets, an EU Biofuels Strategy was adopted (European Commission, 2007b) consisting of seven policy actions for biofuels: (1) stimulate demand; (2) capture environmental benefits; (3) develop production and distribution capabilities; (4) expand feedstock supplies; (5) enhance trade opportunities; (6) support developing countries; (7) support research and development. According to this Biofuels Strategy, the EU supports biofuels with the objectives of reducing greenhouse gas emissions, decreasing reliance on oil imports, and fostering rural development, and in addition seeks to expand the geographic extent of the benefits by also promoting biofuels in developing countries.

Although most studies have found that replacing gasoline with biofuels modestly reduces greenhouse gases due to carbon sequestration in the bioenergy crop (Farrell et al., 2006; Sims, Hastings, Schlamadinger, Taylor, & Smith, 2006; Wang, 2006; Goldemberg, 2008; Kammen et al., 2008), these analyses usually fail to consider the carbon emissions associated with land-use change. Using a worldwide agricultural model to estimate emissions from land-use change, Searchinger and colleagues (2008) show that instead of producing a 20% reduction, corn-based ethanol nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Fargione, Hill, Tilman, Polasky, & Hawthorne (2008) found that land-use change associated with food crop-based biofuels creates a “biofuel carbon debt” of CO_2 emissions 17 to 420 times greater than the fossil fuels they replace. Based on a new geographically detailed database of crop locations and yields, Gibbs et al. (2008) provide estimates of the “carbon payback time” defined as the years it takes for the biofuel carbon savings from avoided fossil fuel combustion to offset the carbon losses associated with land-use change. They suggest that under current conditions, the expansion of biofuels into productive tropical ecosystems causes net increases in carbon emissions for decades to centuries.

On the other hand, Searchinger et al. (2008) suggest that second generation cellulosic biofuels increase emissions by 50% if grown on US corn lands, whereas Fargione et al. (2008) claim that if grown on degraded and abandoned agricultural land, little or no carbon debt is incurred. However, Gibbs et al. (2008) warn that the deployment of second generation biofuels requires technology that has not been implemented, and therefore only the carbon payback times under *current* conditions should be considered in policy decisions. Although a modeling study found that a policy aimed at a reduction of CO_2 in the atmosphere via large scale use of biofuels has a relatively low cost (Korobeinikov, Read, Parshotam, & Lermit, 2006), others feel there are much better ways policy makers may use to mitigate global warming as outlined below (Righelato & Spracklen, 2007).

In their environmental policy essay, Righelato & Spracklen (2007) argue that if the prime objective of policy on biofuels is mitigation of global warming via reduction of greenhouse gas emissions, policy makers should concentrate in the short term (30 years or so) on increasing the efficiency of fossil fuel use, conserving the existing forests and savannahs, and restoring natural forest and grassland habitats on cropland not needed for food for carbon sequestration. In addition, restoration of large areas of secondary forest provide other environmental services such as prevention of desertification, provision of forest products, maintenance of biological diversity, and regional climate regulation, whereas large scale deployment of biofuel crops may place additional strains on the environment. Because the global potential for biomass energy production can replace no more than a few percent of current fossil fuel usage, large-scale biomass energy production would likely exacerbate forcing factors of climate change and threaten food security (Field, Campbell, & Lobell, 2008) and would do little to reduce reliance on oil imports. Furthermore, Frondel & Peters (2007) demonstrate that biofuels in Europe are not a cost-efficient emission abatement strategy and suggest a number of less expensive alternatives such as enhancing the efficiency of conventional power plants.

Another reason the EU promotes biofuels is to spur rural development, but to do this, the bioenergy crops must be grown domestically. European agriculture is not profitable and is heavily subsidized (ca. 46% of the total EU budget) to maintain its multi-functions for society including conservation of landscape and biodiversity as well as food production (Russi, 2008). Russi (2008) also points out that while subsidizing farming for biofuel production might support European agriculture without interfering with the international food market, other strategies like promoting organic agriculture are far better suited to foster rural development. In her assessment of biodiesel production in Italy, Russi argues that contrary to intensive large-scale monoculture typically required for biofuels, organic agriculture tends to be smaller scale and can exert multiple positive functions such as reduction of human pressure on local ecosystems, conservation of soil fertility, production of healthier and better-tasting food, together with an overall increase in energy efficiency. Moreover, organic farming has been shown to strengthen eco-social resilience in rural communities (Milestad & Hadatsch, 2003) that is a key factor for survival amidst global change.

Currently, a framework of economic incentives must be used to support biofuels due to their higher production costs compared to fossil fuels. In the EU, biofuels are subsidized in three ways: (1) agricultural subsidies of 45 euros per ha of energy crop that are granted within the framework of the EU Common Agricultural Policy ; (2) a total or partial exemptions on the taxes that account for approximately half of the final price of gasoline and diesel; (3) obligatory mandates that fuels sold at the pump contain a given percentage of biofuels (Universitat Autonoma de Barcelona, 2007). Additionally, indirect economic support is provided when sugar produced for ethanol is not included in the EU sugar quotas. The rationale of these economic incentives is based on the assumption that biofuels are a renewable source of energy that can reduce greenhouse gas emissions from 30-35% for first generation biofuels and up to 90% with second generation biofuel technologies currently under development (European Commission, 2007a). In contrast, Plieninger & Bens (2008) point out that current pathways of biofuel production have low to negative net energy outputs (see Pimentel & Patzek, 2005) and are not entirely renewable (Dewulf, VanLangenhove, & VanDeVelde, 2005). In addition, Crutzen, Mosier, Smith, & Winiwarter (2008) show that emissions of N_2O (a greenhouse gas with global warming potential 296 times larger than an equal mass of CO_2; see IPCC, 2001) associated with nitrogen fertilization of bioenergy crops are 3 to 5 times larger than assumed under current lifecycle assessments of biofuels. According to Crutzen and colleagues, when this extra N_2O emission from biofuel production is included in a lifecycle assessment, it becomes clear that first generation biofuels may actually exacerbate global warming or at best are neutral. For this and other reasons, including the presence of significant natural resource constraints (e.g. water) as opposed to all other renewable sources of energy (Martinot, Dienst, Weiliang, & Qimin, 2007), the term *renewable* with respects to biofuels should be used with greater caution than it is currently the case.

The progress report on the Biofuels Strategy (European Commission, 2007a) examines the economic and environmental impacts of biofuels in the EU based on a scenario of 14% blending by 2020. The report states that achieving this 14% share of biofuel by 2020 primarily through domestic production would lead to increased employment (144,000 new jobs) and GDP growth of +0.23%. However, a central conflict in expanding biofuel production in the EU consists of interactions with other land uses and especially with nature conservation (Plieninger & Bens, 2008). This is evident when considering Italy as an example. Italy is a net importer of all categories of food except fruit and wine, and hence meeting even only the 5.75% blending target of the European Biofuels Directive is unrealistic as approximately one-third of Italian agricultural land would have to be diverted (Russi, 2008). A 14% blending scenario is therfore very unlikely, and hence the bioenergy crops would mostly have to be grown elsewhere. The Biofuels Strategy suggests this be done in eastern Europe and Africa where biomass production has potential for generating economic growth and employment, and where a comparative advantage exists in the production of biofuels due to lower labor costs and higher resource availability (European Commission, 2007b). But no matter where the required large-scale production of biofuel crops occurs, it will involve industrialized (and polluting) agricultural techniques, and will shift the environmental impacts of energy farming to less-developed countries outside the EU (Russi, 2008) under the guise of rural development policies and aid.

The 2007-2013 Seventh Framework Programme for Research and Technological Development (FP7; http://cordis.europa.eu/fp7) that coordinates and funds most of EU research activities, strongly supports the development of biofuels in the EU, and has given high priority to research on the “bio-refinery” concept and to second generation biofuels (European Commission, 2007b). With over 50 billion euros, FP7 is the largest single public research program in the world (CORDIS, 2008) and a substantial share of the funding is targeted to biofuel-related projects, this despite the substantial controversy that exists on the sustainability of this energy path. The FP7 program supports cooperation between universities, industry, research centers and public authorities throughout the EU and beyond. Among the collaborative research themes on biofuels supported by FP7’s cooperative “bio-refinery joint calls” are: (a) “Nanosciences, nanotechnologies, materials and new production technologies”, (b) “Energy”, (c) “Food, agriculture and fisheries, and biotechnology”, and (d) “Environment (including climate change)”. Additional support for biofuel research is provided via calls open for projects dealing with the so-called “knowledge-based bio-economy” (see FP7 website for details). This level of funding shows substantial bias for biofuels despite controversial scientific evidence (Field et al., 2008) that is compounded by pre-allocation of research funds without peer-review of proposals. The FP7 cooperative research program also funds an industry-led “Biofuel technology platform” (http://www.biofuelstp.eu/) to develop and implement a Strategic Research Agenda (SRA).

SRA is heavily influenced by private capitals pursuing profit and not necessarily public interest, and includes a vision that up to 25% of road transport fossil fuels will be substituted by biofuels by 2030 (see technology platform website); an unrealistic vision according to current science (Moore, 2008).

A root problem is that the biofuel industry has not been dominated by market forces but rather by politics and the interests of a few large companies (Ford Runge & Senauer, 2007). The 500 million dollars of funding by the oil firm British Petroleum (BP) to establish the Energy Biosciences Institute (http://www.energybiosciencesinstitute.org/) at the University of California, Berkeley provides additional evidence of the commercial attractiveness of the biofuel sector (Cockerill & Martin, 2008), and parallels the FP7 practice of diverting public research infrastructure and research to support private interests. This public policy bias is disputed by analyses on potential sources of 100% renewable energy, where only photovoltaic, wind, and solar thermal power, but not biofuels are included because the latter has serious natural resource constraints (Martinot et al., 2007).

A biopact between the North and the South

The EU seeks to promote biofuels in developing countries in the tropics because biomass productivity is highest and the production costs, notably for ethanol, are comparatively low (European Commission, 2007b). Using Brazil as an example (for details on the Brazilian biofuel industry, see: Wang, 2006; Goldemberg, 2008), the EU claims that biofuel production in the developing South is more efficient and emits less greenhouse gases compared to the developed North. The EU's Biofuels Strategy support for bioenergy crops in developing countries (policy action n. 6) is not explicitly presented as a mean to overcome domestic land base constraints in meeting biofuel blending targets, but rather its purported purpose is to extend the benefits of biofuels to the developing world by creating additional employment, reducing their energy import bills, and opening up potential export markets – particularly in sugar-producing countries affected by the 2006 EU sugar reform that substantially reduced economic incentives to sugar production in the EU and in other commercially-associated countries in the developing world. Moreover, the Strategy's policy action n. 5 encourages preferential market access conditions for imported bioethanol, especially from African, Caribbean, and Pacific countries (ACP) under the Cotonou Cooperation Agreement with the EU. While no bioenergy pact to meet European blending targets by growing biofuel crops in the developing countries with supposed economic benefits (see http://www.biopact.com) was officially endorsed under the Cotonou agreement, is readily apparent to impartial observers that it clearly emerges from the policy goals set forth in the EU Biofuels Strategy (Schnepf, 2006).

An insufficient land base in the EU to meet biofuel goals is the underlying rationale for the proposed North-South bioenergy pact that seeks to grow biofuel crops for the EU in the developing world (most notably in sub-Saharan Africa) (Mathews, 2007). However, the shift from a fossil fuel to a biofuel system may cause substantial changes in how land is impacted, and result in a number of ethical trade-offs related to land use change (Jordaan, 2007). While the EU Biofuels Strategy stems from the highly controversial claim that biofuels can reduce greenhouse gas emissions and contribute to the mitigation of detrimental climate change effects on ecosystems, in reality the land-use change associated with large-scale biofuel production have potential to devastate societies and ecosystems, especially in developing countries. And as new data is produced, much of it questions the touted greenhouse gas benefits making tropical biofuels less and less green (Kintisch, 2008).

A socio-economic analysis by Rajagopal, Sexton, Roland-Holst, & Zilberman (2007) acknowledged that biofuels are a land and water intensive technology (Berndes, 2002) that subtracts land from food production and environmental preservation, and has greater impact on food prices than on energy prices. The analysis points out that the effect of rising grain prices related to the expansion of first generation biofuel crops will be felt most acutely in developing countries, where grain comprises a larger share of the food budget. First generation biofuels from sugarcane, cereal grains and oilseeds threaten directly world food security (Cassman, 2007; Gressel, 2008). Moreover, the scenario analysis by Msangi, Sulser, Rosegrant, & Valmonte-Santos (2007) reveals that second generation biofuels obtained from nonfood crops will likely also have a negative impact on food price, hunger and malnutrition especially in developing countries. Further expansion of biofuel productions will ultimately mean cars for the rich and starvation for the poor (Rajagopal et al., 2007), not to mention the almost completely overlooked issue of increased water scarcity due to additional biofuel biomass production (Junginger, Faaij, Rosillo-Calle, & Wood, 2006; de Fraiture et al., 2008).

The use of marginal lands for biofuel plantations may engender greater insecurity for the landless poor in developing countries who currently rely on degraded lands for their fuel wood and fodder needs (Rajagopal, 2008) and is ecologically unsustainable (Gutierrez & Ponti, this issue). Indirect socioeconomic impacts of biofuel production resulting from the subtraction of marginal lands actively used by a range of communities for subsistence may add to the direct and highly debated detrimental environmental effects (Kammen et al., 2008). Cotula, Dyer, & Vermeulen (2008) indicate that the spread of commercial biofuel production in Africa (e.g. Tanzania and Mozambique), Latin America (e.g. Colombia and Brazil), and Asia (e.g. India, Indonesia, and Papua New Guinea) will result in the poor losing access to indispensable land with major negative effects on local food security and on economic, social and cultural dimensions of land use. There are also concerns that biofuels will adversely affect the diversity of foods and increase widespread malnutrition (Karen, 2007). The emerging question is how can Europe expand biofuel use without creating negative social and ecological impacts in developing countries and emerging economies in the absence of social and ecological standards (Foerster, Scholz, & Faaij, 2005).

Transgenic crops and biofuels

The need for transgenic technologies is often overlooked in the biofuels debate, but they are becoming increasingly linked. Transgenic biofuel crops are expected to be essential components for biofuel production because they appear to provide the quickest, most efficient, and often the only way to convert plants to biofuel feedstocks (Gressel, 2008). The EU Biofuels Strategy is prepared for large-scale use of biofuels and explicitly supports second generation biofuels, particularly ethanol obtained from cellulosic crops (European Commission, 2007b). The latter involves growing species such as the perennial grasses switchgrass and *Miscanthus* in high-yielding monocultures; species that have not undergone years of breeding let alone millennia of selective domestication (Gressel, 2008). To make cellulosic ethanol a reality, genetic engineering is currently seen as the only way to maximize the conversion of cellulose biomass to sugars (Lynd et al., 2008), as this and many other polygenic traits desirable for a bioenergy crop are intractable to plant breeding (Gressel, 2008). Solutions to this problem are not easy even via genetic engineering using multiple gene insertions (Karp & Shield, 2008). The main roadblock currently rendering unachievable the industrial-scale production of ethanol from cellulosic biomass (Himmel et al., 2007) is recalcitrance or natural resistance of the plant-cell wall to microbial and enzymatic breakdown. Plants have evolved an extremely complex array of structural and chemical devices to protect them from external assault (e.g. epidermal tissue, vascular bundles, thick wall tissues, and molecular arrays of microfibrils and polymers) that make the current technology of biomass conversion to biofuel costly, complex, and energy intensive (Koonin, 2006). The challenge then is to replace oil and coal that took nature hundreds of millions of years to produce with equivalents that are produced in the laboratory in a matter of hours (Moore, 2008). These difficulties pose an obvious dilemma for society: because first generation biofuels are unsustainable, should society support the development of second generation biofuels that will likely still have a large negative impact on food price, hunger and malnutrition especially in developing countries? Furthermore, only multinational agribusiness corporations will profit from biofuel technologies, and even more so if the technology package includes genetic engineering.

Delgado (2008) in a sociopolitical analysis in Latin America suggests that biofuels and transgenic crops are becoming part of the same technology package sponsored by global agribusiness companies. Delgado argues that like transgenic food crops, biofuel crops bring about a host of scientific uncertainties and a long list of neglected socioeconomic and environmental impacts and implications. In both the case of biofuels and transgenic crops, a clash of paradigms is evident between the large-scale high-input industrial monocultures pushed by global agribusiness' technology packages and the right of small farmers for access to land, water and seed, and to the preservation of local knowledge as the basis for food sovereignty and national sovereignty. The germane question Delgado poses is: if during the last 20 years, 300 million hectares of monocultures – mainly oil palm, rubber tree, soybean and sugarcane – were planted at the expense of forest worldwide, will transgenic bioenergy moncrops be an exception to this exploitation trend? The answer is clearly no. Cellulosic conversion processes will demand uniform feedstocks that will translate into high-input and environmentally destructive biofuel monocultures that are unlikely to be sustainable (Palmer et al., 2007; Gutierrez & Ponti, this issue). As Palmer points out in his letter to the journal Science, increase in agroecosystem uniformity and modification of evolved cell wall structure (both required for cellulosic conversion) will lead to crop standings with an unprecedented susceptibility to structural and pest failure. Despite the absence of a supporting scientific evidence, biofuels are currently being promoted in Europe as a bridging technology to cellulosic ethanol that for the moment is a bridge to nowhere (Morrow, 2008) because the development of cost-effective motor-fuel production from biomass conversion is unlikely be realized before 2030 (Himmel et al., 2007) if then. While this kind of comment may reflect a degree of hyperbole, Morrow observes, there are serious (*economic, ecological and social*) concerns that need to be answered before we embark upon costly bioenergy programs;

concerns that cannot be allayed by application of elegant yet simplistic genetic engineering technologies.

Scientific uncertainty, biosafety concerns, and eco-social impacts of biofuels parallel and compound those of transgenic crops. Biotechnologists should have learned from agricultural applications that it is a huge mistake to underestimate biosafety concerns (Stewart, 2007), for despite assurances that it is unlikely that genes will flow, they eventually will. Agricultural biotech is trying to avoid the biosafety concerns that plagued food crops by embracing supposedly less problematic nonfood crops for biofuel production. Nevertheless, we must keep in mind that biosafety problems of transgenic crops go well beyond the food domain to include the ecosystem at large (Ponti, 2005), and this also fully applies to genetically-engineered second-generation biofuel crops. For example, several traits deemed characteristics of an ideal bioenergy crop such as low maintenance to biomass production energy ratio, efficient light, water and nutrient use, C_4 photosynthesis, nutrient translocation to storage organs during the non-growing season, and perennial growth, are also common features of invasive plants (Raghu et al., 2006). Therefore, genetic engineering of perennial grasses and trees for biofuel production could generate plants with very higher invasive potential that may just contribute to the already raging plague of invasive species (Hoenicka & Fladung, 2006; Raghu et al., 2006).

Biosafety concerns exist also for fast-growing trees such as poplars (*Populus* spp.) and willows (*Salix* spp.) that are currently studied as potential source of cellulosic biofuel production (Karp & Shield, 2008). Genetic engineering is crucial to alter lignin content in trees (Sticklen, 2006; Groover, 2007) as this is the only way to get accelerated breeding rates comparable to that for annual crop plants (Hoenicka & Fladung, 2006). Valenzuela, Balocchi, & Rodríguez (2006) reviewed over 200 field trials with genetically engineered forest trees of which more than 50% were with *Populus* species with the main target traits being herbicide tolerance (31%), marker genes (23%), and insect resistance (14%). The only recorded commercial tree plantation is of insect resistant Bt *Populus nigra* in 2003 in China. In their review, Valenzuela et al. highlighted serious biosafety issues with transgenic trees including gene flow to related species. They noted that introgression of traits such as low lignin content that are controlled by multiple genes are less likely to occur compared to single-gene traits (e.g. herbicide resistance and insect resistance) making it more difficult to model the impacts of tree-based biofuel production on biodiversity (Valenzuela et al., 2006). Compared to annual crops, trees have specific and more serious biosafety concerns related to gene flow

(González-Martínez, Robledo-Arnuncio, & Smouse, 2005): (a) trees have long life spans and may propagate vegetatively, and this extends the time scale over which introgression can occur making the assessment of the long-term effects difficult; (b) recurrent gene flow over several reproductive cycles may be sufficient to overwhelm fitness disadvantages of the hybrid seed (González-Martínez et al., 2005); (c) trees outcross considerably more than annual crops. Transgene flow from insect-resistant poplars into native poplar stands has been shown to occur (Di Fazio, 2002), it increases over time becoming significant over 100 years (9.50%), and may confer growth benefits in the wild. Vertical gene transfer can be limited by induction of sterility in transgenic trees, but the gene flow cannot currently be completely controlled (Kikuchi, Watanabe, Tanaka, & Kamada, 2008). Other biosafety concerns of transgenic trees include transgene instability, horizontal gene flow, impact on non-target organisms, and effects on non-targeted characteristics. Scientific uncertainties and the relative lack of baseline information about forest ecosystems compared to agroecosystems, which are still poorly understood, poses great challenges to the existing methods of analyzing risks and benefits of transgenic trees (Hoenicka & Fladung, 2006) including those grown for bioenergy purposes.

Conclusions

Overall, our review confirms concerns about EU biofuels policy outlined in a recent statements by the EU Environment Commissioner admitting important unforeseen problems (UK House of Commons, 2008). EU policy support for biofuels stems from the assumption that they would mitigate climate change – a rationale used to divert considerable public resources for biofuel research despite the fact that first generation biofuels have provided minimal contributions (if any) to carbon emission mitigation and have increased food prices and threatened natural habitat by diverting them into energy crop production (Rajagopal et al., 2007). In addition, second generation biofuels obtained from nonfood crops will likely also have a negative impact on food price, hunger and malnutrition especially in developing countries (Msangi et al., 2007; Nash, 2007), and on the environment at large (Scharlemann & Laurance, 2008). Since there is essentially no current environmental (Farrell et al., 2006) and social regulation (Delgado, 2008) of biofuels, how will the EU reach its biofuels policy targets without accessing the bioenergy cropland in developing countries and especially Africa (i.e. the biopact) and consequently undermining fragile societies and ecosystems?

Policy experts agree that extensive biofuel production in Africa will intensify agriculture with consequent ecological and social impacts on land use changes (Lovett, 2007) and habitat and biodiversity losses (Koh, 2007; Groom, Gray, & Townsend, 2008) with concomitant loss of ecosystem services (Alcamo et al., 2005). Furthermore, it is an EU policy that future biofuel options must include transgenic crops (Gressel, 2008) that are themselves deemed unfit for EU's multifunctional vision of sustainable agriculture for environmental, economic and socioeconomic reasons (Ponti, 2005), and that also have potential for ecosocial disruption in developing countries (Gutierrez, 2005). In addition, the yield and range of biofuel crops in Europe may be limited by climate change, with fewer crop species available (Tuck, Glendining, Smith, House, & Wattenbach, 2006), negative impacts on crop yields (Lobell & Field, 2007) and greater yield variability (Schmidhuber & Tubiello, 2007).

As with many technology-driven self-justifying options for agriculture (e.g. transgenic crops), the first question we should ask about biofuels is: are they needed? This question has been implicitly silenced by switching the focus to technical issues, when in fact a broader ecological view of the problems would avoid diverting already scarce public R&D resources to important but ancillary technology options that do not mitigate climate change.

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Tables

Table 1. Biofuels production 2006: top 15 countries plus the EU and their share of ethanol and biodiesel (%) of global production (billion of liters in parenthesis) (modified from REN21, 2008).

Rank	Country	Fuel ethanol	Biodiesel
		% (billion liters)	
1	United States	46.9	14.2
2	Brazil	44.9	1.2
3	Germany	1.3	46.7
4	China	2.6	1.2
5	France	0.6	10.5
6	Italy	0.3	9.5
7	Spain	1.0	2.3
8	India	0.8	0.5
9	Canada	0.5	0.8
9	Poland	0.3	2.2
9	Czech Republic	0.1	2.5
9	Colombia	0.5	1.0
13	Sweden	0.4	–
13	Malaysia	–	2.3
15	United Kingdom	–	1.8
–	EU Total	4.1	75.0
–	World Total	100.0 (39)	100.0 (6)

709 **Table 2.** Biofuel blending targets in selected countries (adapted form Coyle, 2007).

Country	**Feedstocks**		**2007 production forecast (million liters)**		**Blending targets**
	Ethanol	*Biodiesel*	*Ethanol*	*Biodiesel*	
Brazil	sugarcane	soybeans, palm oil, castor seed	18,804.3	242.7	25 % blending ratio of ethanol with gasoline (E25) in 2007; 2 percent blend of biodiesel with diesel (B2) in early 2008, 5 % by 2013.
Canada	corn, wheat, straw	animal fat, vegetable oils	1,000.3	96.1	5 % ethanol content in gasoline by 2010; 2 % biodiesel in diesel by 2012.
China	corn, wheat, cassava, sweet sorghum	used and imported vegetable oils, jatropha	1,600.4	113.2	Five provinces use 10 % ethanol blend with gasoline; five more provinces targeted for expanded use.
EU	wheat, other grains, sugar beets, wine, alcohol	rapeseed, sunflower, soybeans	2,303.5	6,557.3	5.75 % biofuel share of transportation fuel by 2010, 10 % by 2020.
India	molasses, sugarcane	jatropha, imported palm oil	400.2	45.4	10 % blending of ethanol in gasoline by late 2008, 5 % biodiesel blend by 2012, and 20% in 2020
Indonesia	sugarcane, cassava	palm oil, jatropha	–	407.7	10 % biofuel by 2010.
Malaysia	none	palm oil	–	328.6	5 % biodiesel blend used in public vehicles; government

					plans to mandate B5 in diesel-consuming vehicles and in industry in the near future.
Thailand	molasses, cassava, sugarcane	palm oil, used vegetable oil	300.2	260.4	Plans call for E10 consumption to double by 2011 through use of price incentives; palm oil production will be increased to replace 10 % of total diesel demand by 2012.
United States	primarily corn	soybeans, other oilseeds, animal fats, recycled fats and oil	24,605.6	1,682.9	Use of 28.4 billion liters of biofuels by 2012; proposals to raise renewable fuel standard to 136,3 billion liters (mostly from corn and cellulose) by 2022.

Ponti L., Gutierrez A.P., 2009. Overview on biofuels from a European perspective. Bulletin of Science Technology and Society, 29: 493–504. (accepted manuscript)
Definitive version available at http://dx.doi.org/10.1177/0270467609349048

Table 3. Comparison of commercial first and second-generation biofuels at current technological development (modified from Moore, 2008 based on present review).

	First generation	**Second generation**
Biomass source	Produced only from the primary crop product (e.g. grain, sugar, or oil-seed component of the plant); the rest of the plant is not used for fuel	Produced from whole plant, or crop residues, forestry redisues or wood processing waste
Fuel source	Substance converted into fuel: starch, sugar and oil	Substance converted into fuel: mainly lignocellulose
Crops	Mosty annuals (e.g. corn, wheat, sugar cane and sugar beet, rapeseed, oil palm, soybean)	Perennials (e.g. switchgrass, *Miscanthus*, coppice willow, alfalfa)
Processing	1. Carbohydrate contents of grains, and sugars (cane and beet), are easily fermented to ethanol with low technology apparatus 2. Oils are processed into automotive grade fuel (Both methods are of relatively low monetary cost)	Entire plant material is converted into fuel. Main methods: 1. Fermentation, producing ethanol and methane, leaving solid waste for pelleting and burning, e.g. in heat-and-power stations (relatively cheap method) 2. High-temperature/high pressure decomposition and catalytic synthesis processes (relatively expensive method)
Land	Crops are grown on existing agricultural land by existing farmers. This land is easily defined and worked: yields are predictable	Crops can in principle be grown on less valuable land that is not suitable for food/feed agriculture. But it is unlikely that significant amounts of fuel could ultimately be made from such ‘marginal’ and low-quality land
Food issues	Crops are directly in competition with food, hence leading to food security and price-linkage issues	Crops cannot not be used for food, but could still compete with food crops for land

Inputs	Crops are energy-intensive: for example need large quantities of fertilisers, pesticides, and machinery	Crops in principle need less fertiliser and are less energy-intensive but the ability to produce biofuel feedstocks abundantly on unproductive lands remains questionable
Energy yield	Energy balances[a] tend to be modest or even negative due to the high-input nature of food-crop agriculture	Energy balances[a] were found to be both positive and negative. Successful industrialization of cellulosic processing remains to be demonstrated.
Prospects	Generally doomed, contribute to global warming due to N_2O emissions	Development tightly linked to genetic engineering, and deployment on a large scale threatens food security and exacerbates climate change

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[a] Energy balance is the per unit mass ratio of total energy released on burning the fuel to total energy inputs in producing the fuel (from plant seed production to fuel distribution).

Figure Legends

Figure 1. Pathways of biofuels production (modified from Doornbosch & Steenblik, 2007).

Figures

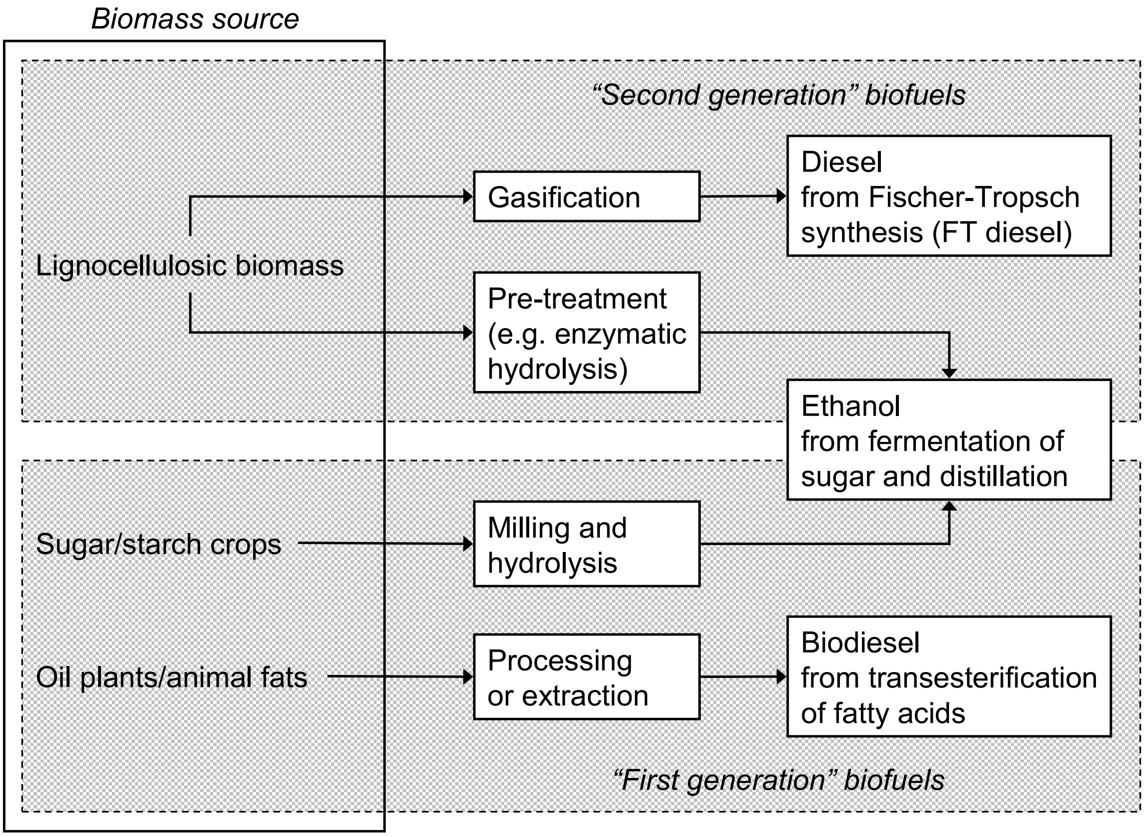

Figure 1