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AICGS POLICY REPORT

BIOENERGY IN THE UNITED STATES AND GERMANY

Bruce A. McCarl
Tobias Plieninger

AMERICAN INSTITUTE FOR CONTEMPORARY GERMAN STUDIES THE JOHNS HOPKINS UNIVERSITY

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FOREWORD

This Policy Report is another significant study in the area of climate change and energy, an important part of AICGS' research activities in 2008 and beyond. It was made possible through a generous grant from the *Daimler-Fonds im Stifterverband für die Deutsche Wissenschaft*.

In their studies, Bruce McCarl and Tobias Plieninger offer important insights into bioenergy policies and related measures in Germany, the European Union, and the United States, including these energy sources' domestic and international relevance. The report sheds light on different sources and production methods for bioenergy, their economic importance, their social and environmental impacts, and the multitude of measures addressing their production and consumption, as well as the actors involved in shaping these policies.

Bioenergy can play an important role in our efforts to mitigate climate change and enhance energy security. However, its generation has the potential to affect such different areas as agricultural employment, electricity prices, nature conservation, and water supply—and not only in a benign way. After high fossil fuel prices triggered a biofuels boom in the beginning of this century, the "food versus fuel" debate has recently cast a shadow on this energy source.

The growth of the bioenergy sector in Germany and the United States has been remarkable in recent years. In all probability, bioenergy will remain an important energy source in the future. Both authors conclude their chapters with important policy considerations addressing the negative side effects of bioenergies. They agree that the quantitative growth of the past has to be followed by qualitative improvements. Adverse environmental and socio-economic effects of bioenergy production have to be addressed if we want this resource to greatly contribute to solving this century's greatest challenge: securing the safe supply of energy while preventing a dangerous shift of the climate system.

AICGS is grateful to the *Daimler-Fonds im Stifterverband für die Deutsche Wissenschaft* for its generous support of this project and to the authors who have committed their time and energy. The Institute would also like to thank Jessica Riester for her work on this publication.

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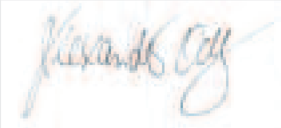

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ABOUT THE AUTHORS

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U.S. BIOENERGY

U.S. BIOENERGY: POTENTIAL, POLICY, AND ECONOMIC/CLIMATE CHANGE CONCERNS

BRUCE A. MCCARL

Section 1: Introduction

Globally, interest in bioenergy has been greatly stimulated by the recent petroleum price increase, as also happened during and after the late 1970s energy crisis. Drivers of this interest involve bioenergy as a way to: (a) protect against the political insecurity of importing large amounts of petroleum, enhancing national security; (b) provide lower cost domestic supplies, mitigating higher energy prices caused by expanding demand and a dwindling supply of conventional petroleum with increased reliance on more expensive sources; and (c) reduce combustion of fossil fuels which emit enormous quantities of greenhouse gas (GHG) emissions that in turn are argued to be precipitating climate change.[1]

All three of these factors influence demand for liquid biofuels such as ethanol and biodiesel. However, petroleum price increases and concerns for energy security do affect bioelectricity (biomass used in electricity production) albeit to a lesser extent, as it largely relies on abundant domestic supplies of coal and natural gas (68 percent as of 2005),[2] with only 3 percent of supplies fueled by petroleum. Also, due to the possibility of fuel substitution, any increases in oil and gas prices will likely further reduce petroleum dependence.[3]

Efforts to reduce GHG emissions could put pressure on fossil fuel use. Environmental Protection Agency (EPA) data show that coal is the source of about 42 percent of U.S. greenhouse gas emissions while petroleum use is of approximately equal size.

Agriculturally-based bioenergy may offer a way to help address the drivers mentioned above. Namely when biomass is used as an energy feedstock it results in (a) domestically-produced substitutes for fossil fuel products to fuel electric power plants or as inputs into processes making liquid biofuels, alleviating needs for imports and in turn alleviating energy security concerns; (b) lessened reliance on the increasingly costly fossil fuels switching to domestic sources that are in some cases cheap, from marginal lands, or co-products with conventional production; (c) GHG offsets since plant growth absorbs CO_2 while combustion releases it and, thus, using agricultural products to generate energy involves a substantial degree of recycling of CO_2; and (d) a source of agricultural producer income and energy producer cost savings if defined, GHG are costly.

Before embracing bioenergy as a strategy for GHG mitigation, one must fully consider the lifecycle GHGs emissions when growing, harvesting, and hauling feedstocks then subsequently converting them into bioenergy.

In addition, one must also consider the market effects and possible offsetting effects of production induced elsewhere.

Two issues arise in this context. First, what are the GHG offsets obtained when using a particular form of bioenergy and what does this imply for comparative economics of feedstocks? Second, when bioenergy production reduces traditional commodity production does the market reaction of other producers reduce net GHG effects?

This essay examines U.S. and some global bioenergy and GHG issues. In doing this I review the policy setting, production possibilities, and quantities of GHG offsets then conclude by discussing important issues that will influence the future of biofuels.

Section 2: Bioenergy Policies and Actors

U.S. POLICY AND BIOENERGY

Bioenergy has been known to man and exploited for thousands of years. During the twentieth century the U.S. and much of the world transitioned into a fossil fuel based energy economy largely because of the abundance of cheap, energy rich, fossil fuels. But starting in the late 1970s interest in bioenergy was revived. This was largely first stimulated by the "Energy Crisis" that arose when OPEC reduced world crude oil supply and fuel prices increased substantially. At that time there was a lot of policy debate and both the U.S. and Brazil launched ethanol programs supported by ethanol subsidies. Nevertheless, the subsequent collapse of energy prices in the mid 1980s minimized the interest, although the subsidized ethanol programs continued. Energy price increases in the early to mid-2000s has revitalized interest and activity. In fact until 2006, Brazil was the global leader in ethanol production but, subsequently, a mixture of U.S. subsidies, renewable fuel standards, and higher oil prices has caused U.S. ethanol production to surpass that of Brazil.

U.S. bioenergy subsidization of ethanol began with the 1978 Energy Policy Act. That act was justified by arguments that the subsidy would enhance farm income and, to a lesser extent, energy security. In 1990, ethanol received another stimulus with the passage of the Clean Air Act which required gasoline to have a minimum oxygen percentage. That policy favored additives like ethanol that contain a high percentage of oxygen but the role was filled initially by methyl tertiary butyl ether (MTBE), another oxygenate that was generally cheaper; this policy persisted through the 1990s. However, the MTBE use was banned in many U.S. states in the early 2000s, as it began to leach into water supplies and was found to be highly toxic and a carcinogen. Subsequently, ethanol was favored and production expanded rapidly with ethanol selling at a significant premium relative to gasoline. This premium peaked in June 2006, shortly after MTBE was totally banned. However, once the required oxygenate fraction for U.S. gasoline production was met, the demand for ethanol fell back toward its value as an energy source. Since it takes 1.4 gallons of ethanol to drive the equivalent distance one would drive on a gallon of gasoline, the premium for ethanol began to evaporate.

The subsidy was operating simultaneously. Between 1983 and 2003 the ethanol subsidy varied between $.40 and $.60 per gallon. Today the subsidy is $.51 per gallon, plus some state-level subsidies. This subsidy, together with oil in the $10 to $30 range, permitted a production expansion from about 430 million gallons in 1984 to about 3.4 billion gallons in 2004. A round of oil price increases began when, in 2004, the crude oil price began its steep climb to nearly $150 per barrel price. This, coupled with the subsidy, stimulated a tremendous boom in the construction of ethanol plants. Ethanol production in 2007 was about 7 billion gallons, and will likely surpass 13 billion gallons in 2008.

Biodiesel was also subsidized during this period. The U.S. biodiesel industry produced 450 million gallons in 2007, a 425 million gallon increase compared to the production level in 2004.[4] The federal government also subsidizes biodiesel with biodiesel originating from agricultural sources receiving a $1.00 per gallon subsidy while other biodiesel sources received a $0.50 per gallon subsidy.[5] This industry has had trouble in recent times as the costs of soybean and corn oil feedstocks have increased to the point that it is uneconomic to do the processing required to make biodiesel and then sell the product even in the presence of the subsidy. This subsidy was originally not renewed but was extended in the bailout bill.

Energy policy entered this arena in 2005. The Energy Policy Act of 2005 amended the Clean Air Act to establish a Renewable Fuel Standard (RFS) Program and mandated regulations ensuring that U.S. gasoline contained a specified volume of "renewable fuel." The mandate schedule began at 4.0 billion gallons of renewable fuel in 2006 and increased to 4.7 in 2007, 5.4 in 2008, 6.1 in 2009, 6.8 in 2010, 7.4 in 2011, and 7.5 billion gallons in 2012.

Today the RFS requirements are in the process of being expanded. The Energy Independence and Security Act (EISA) of 2007 extended the years covered by the RFS program by ten years, increasing the required volumes and adding new, separate mandates starting in 2009 for advanced biofuels, including cellulosic ethanol and biodiesel. The 2005 act set the 2007 mandate for renewable fuel at 4.7 billion gallons and the 2007 EISA raises this to 5.4 billion gallons then to 9.0 billion and 11.1 billion gallons in 2008 and 2009, ultimately reaching 36 billon gallons in total.

The 2007 EISA also imposes additional requirements on eligible fuel types. Specifically, a life-cycle analysis (LCA) of greenhouse gas (GHG) emissions associated with renewable fuels sources is required and advanced biofuels must meet a minimum level of GHG reduction. The EPA is currently formulating an associated set of renewable fuel standard rules, which will implement the renewable fuels provisions of EISA. The program creates side-by-side minimum use requirements for the following classes of renewable fuels:

- Conventional Biofuels: renewable fuel that is ethanol-derived from corn starch and renewable fuel, produced from facilities that commence construction after the bill is enacted that achieves a 20 percent reduction in GHG emissions compared to the LCA of the fuel it replaces. The 20 percent GHG emissions number may be adjusted downward but may not be reduced below 10 percent.

- Advanced Biofuels: renewable fuel other than ethanol-derived from corn starch, which is derived from renewable biomass and has LCA GHG emissions at least 50 percent less than baseline GHG emissions. This term includes cellulosic biofuels and biomass-based diesel. The LCA minimum may be lowered but not below 40 percent.

- Cellulosic Biofuels: renewable fuel derived from cellulose, hemi cellulose, or lignin in turn arising from renewable biomass and that has LCA emissions at least 60 percent less than the fuel it replaces. The 60 percent may be adjusted to no lower than 50 percent.

- Biomass-Based Diesel: renewable diesel fuel derived from renewable biomass with LCA at least 50 percent less than diesel. The 50 percent minimum can be reduced to no less than 40 percent.

- Undifferentiated Advanced Biofuels: renewable fuel other than ethanol derived from corn starch, which is derived from renewable biomass and has LCA at least 50 percent less than fuel replaced. This can be reduced but not below 40 percent.

Bioelectricity has largely been left out of the story with some small research and development undertaken but no large policy stimulus programs. This largely reflects the abundance of coal in the U.S. However, today's rising coal prices and demands for GHG abatement, coupled with the possibilities of substituting natural gas into the transportation portfolio, is stimulating expanded activity in renewable electricity including, but not limited to, biomass based sources.

The final policy initiative worth mentioning is just the anecdotal statement that the whole situation has stimulated considerable government-supported research and development activities with major government laboratories and considerable Department of Energy and other funding being placed into bioenergy related research.

STAKEHOLDER GROUPS INVOLVED WITH BIOENERGY

The bioenergy arena involves a number of stakeholders spanning from Congress, federal and state agencies, conventional energy firms to farm and forestry groups, bioenergy firms/groups, environmental/science groups, and international interests. Each is briefly discussed below

U.S. Congress

A number of stakeholder groups are present in the U.S. Congress who in turn represent their constituents. The principal areas where biofuels dialogue occurs falls in the domain of the Senate and House committees on Energy and Agriculture.

Federal Agencies

A number of U.S. governmental agencies are dealing with bioenergy issues. These include the Department of Energy through its main branch plus the Energy Information Agency and the Network of National Labs. The labs include the National Renewable Energy Laboratory where much technology is explored; the Argonne National Laboratory where much of the greenhouse gas accounting occurs along with the National Energy Technology Laboratory, the Oak Ridge National Laboratory, and the Pacific Northwest National Laboratory. DOE is also funding experimental plants in, for example, the cellulosic ethanol arena.

The Environmental Protection Agency is playing a major role as it is the lead agency for forming the rules involved with the Renewable Fuel Standard. It will also be the agency monitoring compliance and assessing whether the advanced biofuels and other features of the energy bill are being met.

The U.S. Department of Agriculture is another major player largely exploring production possibilities for biomass sources and the consequences of expanded bioenergy production.

Beyond these agencies there is involvement from the White House Office of Science and Technology Policy, the Congressional Budget Office, and the Library of Congress. These agencies are involved with evaluating consequences of policies and legislation.

State Agencies

Beyond federal agencies, state Departments of Energy plus environmental agencies play a role. Some are more active than others; for example, the California Air Resources Board is a major player. A number pursue subsidy policies and/or are formulating local regulations that affect renewable use.

Agricultural and Forestry Producers and Bioenergy Enterprises

Agriculture and forestry would produce much of the biomass and are heavily involved with bioenergy production as it exists today. Stakeholder groups include biofuel industry associations such as the National Biodiesel Board, Renewable Fuels Association, and the American Coalition for Ethanol. There are also general farm groups such as the Farm Bureau, Illinois Corn Growers Association, National Sorghum Growers, and National Corn Growers Association. Forest products groups are also involved, including the American Forest and Paper Association. Finally, there are companies within the biofuel industry such as Iogen and Archer Daniels Midland plus large Forest Products firms.

Energy Industry

Substantial interest is manifest in the energy industry both in the large oil/petroleum firms like BP, Shell, Chevron, Exxon, and Dupont along with associations like the American Petroleum Institute and the National Petrochemical Refiners Association. Firms and associations in coal and electricity generation and in natural gas industries are also stakeholders.

Environmental Community

Bioenergy is a controversial subject in the environmental community. Environmentalists have long advocated released dependence on fossil energy. On the other hand, many environmentalists are concerned about major land use changes with potentially damaging effects on species and habitats. The groups involved include the Natural Resources Defense Council, Union of Concerned Scientists, Environmental Defense, and World Resources Institute.

International Interests

A number of international interests concerned with (a) the possibility of importing energy into the U.S. that qualifies as renewable under the law (Brazil being one such interest); (b) the effects of U.S. policy on world markets, including agencies like the World Bank and the UNFAO; (c) effects on pollution/deforestation, including the International Council on Clean Transportation; and (d) international energy groups such as the International Energy Agency or the Global Bioenergy Partnership.

Private Households and Businesses

Private households and businesses are the consumers of bioenergy and pay for the products with their energy bills. They also alter demand with their transport and energy choices.

Section 3: Bioenergy Production and Sources

BIOENERGY PRODUCTION POSSIBILITIES

There are many ways that have been contemplated for producing bioenergy from U.S. agricultural and forest resources. Consequently, an overview of production possibilities for ethanol, biodiesel, and bioelectricity are provided as well as a small discussion on a possibly emerging possibility through pyrolysis.

Ethanol Possibilities

There are two principal ways of converting agricultural feedstocks into ethanol. The first converts the natural sugar and starch content of feedstocks to ethanol using dry or wet milling and is generation one ethanol.

The principal U.S. crop used in this process has been corn although sugar cane, sorghum, wheat, and a host of other crops could be used. The main byproducts of these processes are distiller's grain in wet or dry form, corn gluten meal, and corn gluten feed (the latter two from wet milling). These byproducts can be incorporated into animal feed or exported. Today the energy industry is creating a lot of these byproducts and there is much work on how to transport and use these items in a variety of animal feeds, for example, removing oil content to allow better penetration into poultry and hog feeding. Generation one ethanol feedstocks are directly completive with traditional food and fiber system usages of those commodities.

The second technology is lignocellulostic fermentation, or generation two ethanol, and is just emerging, being largely prospective. Ethanol is manufactured from crop residues, wood residues, and energy crops. Lignocellulostic fermentation breaks down cellulose and hemicellose from these feedstocks into sugars. Lignocellulostic fermentation requires more processing and is likely a more capital-intensive process than generation one ethanol, but the feedstocks are the cheapest. Lignocellulostic ethanol produces a variety of byproducts including lignin which is a fiber that could be used to produce electricity or heat furfural, which could be used to make carpet fibers; and methane gas that could be collected and burned for heat or energy

Lignocellulostic ethanol refinery feedstocks do have competing uses. Farmers would leave some crop residues because they reduce soil erosion and increase organic matter in the soil. The lumber industry can use wood residues for a variety of products including paper, particleboard, and mulches. Although the energy crops, hybrid poplar, willow, and switchgrass are fast growing perennials, they switch land use away from crops, pastures, or forests.

Biodiesel Possibilities

Biodiesel is produced from vegetable oils and tallow. The main sources for the United States are soybean oil, corn oil, tallow, poultry fat, and yellow grease. All the oils could be blended with animal feeds and sold to the cattle, poultry, and swine feed markets. Further, soybean oil and corn oil could be exported or used in human foods. A large biodiesel industry, like the ethanol industry, would cause higher food prices from the larger demand for biodiesel feedstocks. Biodiesel production is quite efficient and is approximately a one-to-one gallon conversion for the oil into biodiesel.[6]

Glycerol is a byproduct of the biodiesel industry and is used in pharmaceutical, cosmetic, and chemical industries. A biorefinery would have to install more capital equipment to purify the glycerol. Unfortunately, glycerol is a relatively small market and a large biodiesel industry could saturate the market, causing prices to drop.[7] Therefore, biodiesel refineries could not rely on glycerol at current prices to offset production costs. In the U.S. the biodiesel industry has been mainly reliant on soybean oil. However, as of September 2008 soybean oil is worth about $3.50 per gallon and it takes about $0.50 per gallon to transform it into biodiesel the result of which sells for somewhere around $3.50; even with the $1.00 subsidy this is not a lucrative venture. In fact, today most of the soybean oil based biodiesel is being exported, receiving further subsidies upon use in Europe. Biodiesel capacity utilization is not high with above 2 billion gallons of installed capacity and about 450 million gallons of current utilization.

Bioelectricity Possibilities

All the feedstocks that producers can convert to lignocellulostic ethanol can also be co-fired with coal to produce electricity. Thus, the power plants would compete with the lignocellulostic ethanol industry for feedstocks. The feedstocks can be co-fired, replacing 0 to 100 percent of coal. However, a power plant has to invest in more capital to handle higher co-fire rates. Currently about 32 percent of the heat energy is recoverable but over time this is likely to increase to about 40 percent.[8]

Pyrolysis

Pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen where fast pyrolysis involves biomass being rapidly (5 to 10 seconds) heated to between 400 and 550°C while slow pyrolysis involves slower heating to less than 400°C with the biomass is typically heated for at least thirty minutes and possibly several hours.

During pyrolysis biomass is converted into three products: (a) a liquid product that is commonly called bio-oil, pyrolysis oil, or bio-crude; (b) a solid char that can be used in a range of applications including use as a soil additive or as a source of energy in the conversion process—"biochar"; and (c) a gas product containing carbon monoxide, carbon dioxide, hydrogen, methane, and higher hydrocarbons, "syngas" or "pyrolysis gas."

Slow pyrolysis yields relatively more biochar, but less bio-oil. Some studies indicate that fast pyrolysis yields about 15 percent biochar, 70 percent bio-oil, and 13 percent syngas.[9] Others indicate that under slow pyrolysis about 35 percent of the feedstock carbon ends up as biochar, 30 percent as bio-oil, and 35 percent as syngas.[10]

In both cases, the bio-oil can then be cleaned and further processed to produce higher quality fuels,[11] used to produce electricity, or it can be refined to produce chemical feedstocks such as resins and slow-release fertilizers as well as have selective food chemicals recovered from it.[12]

While biochar was initially viewed as a source of energy and can be burned to supply process energy, it can be used in water purification, gas cleaning, metallurgical industries, and for charcoal in home cooking. In addition, it has lately been regarded as a potentially valuable soil amendment where it sequesters carbon in stable form along with storing nutrients and water.

SOURCES OF FEEDSTOCKS

Many commodities can be used as feedstocks for bioenergy production processes. Several broad classes can be defined based on target energy type and processing method.

- Conventional crops like corn, wheat, oats, barley, sorghum, sugarcane, rice, or sweet sorghum can be converted to fuels like ethanol and replace gasoline in producing first generation biofuel.

- Residues from conventional crops like corn, wheat, rice, or sorghum can be transformed to fuels like ethanol again replacing gasoline (commonly called cellulosic ethanol or second generation biofuels). Residues from forest harvest can also be used, as can harvested timber. Use of these feedstocks also generates lignin byproducts that in turn can be used to generate electricity.

- Dedicated energy crops like switchgrass, poplar, willow, miscanthus, or energy sorghum can be transformed to fuels like ethanol, again replacing gasoline (being cellulosic ethanol or second generation biofuels). These feedstocks yield lignin as a byproduct that can be used to generate process heat or electricity.

- Processing wastes such as sugarcane bagass, lumber milling residues, rice hulls, municipal wood wastes, or certain forms of municipal wastes can also go into cellulosic processes.

- Oil commodities like soybean oil, sunflower oil, canola oil, or corn oil plus animal byproducts like tallow, poultry fat, and lard can be employed in the production of biodiesel that replaces petroleum based diesel. Waste grease from restaurants is also a current possibility while use of oil from algae is an emerging potential source.

In addition, feedstocks for cellulosic ethanol can be used as input to pyrolysis processes that can generate bio-oil/syngas that in turn can be refined or combusted displacing petroleum and possibly natural gas.[13] Other items such as wood wastes or municipal waster streams may also be used.

Finally, the feedstocks for cellulosic ethanol and the lignin by-product plus manure can be used as input to electric generating power plants replacing coal usage. This can involve co-firing with coal or total replacement. Co-firing is the more efficient as it allows more complete biomass combustion.[14]

Section 4: Bioenergy, Greenhouse Gases, and the Economy

GREENHOUSE GASES

Bioenergy production can provide an important GHG emission offset. Bioenergy forms reduce GHG emissions because their usage displaces fossil fuels like coal and petroleum, essentially entering into a carbon recycling operation. In particular, as plants grow they remove CO_2 from the atmosphere via photosynthesis. Then, when the biofeedstocks or their derivative fuels are combusted, the carbon is released into the atmosphere. Fossil fuel use, on the other hand, releases

100 percent of the contained carbon. The net GHG emission consequences of a form of bioenergy then depend on the amount of fuels from fossil sources used in producing that item in terms of the petroleum, natural gas, and coal-based electrical energy to raise, transport, and process the feedstock. The common way of examining such issues involves lifecycle analysis.[15]

Over the last couple of years I have tried to do a fairly comprehensive, consistent LCA across the full spectrum of agricultural bioenergy possibilities including possibilities for bioenergy to go into ethanol, biodiesel, and electricity.[16] The method for this is as follows:

■ Step a: A consistent regionalized set of crop budgets was adopted for the accounting that were obtained from the author's work on the FASOMGHG model[17] which in turn were developed based on extension service budgets and USDA Agricultural Resource Management Survey (ARMS).

■ Step b: GHG emission estimates of the GHG CO_2, methane (CH_4), and nitrous oxide (N_{20}) emitted when making fertilizer, lime, and specific pesticides were adapted from U.S. EPA assumptions and applied to estimate emissions based on levels of input use in the budgets.

■ Step c: GHG emission estimates embodied in gasoline, diesel, natural gas, and electricity (regionalized) use were adopted from EPA and GREET model work[18] and applied to estimate emissions based on levels of input use in the budgets.

■ Step d: Intergovernmental Panel on Climate Change (IPCC) default emission rates were applied to estimate fertilizer related N2O emissions.[19]

■ Step e: Crop soil sequestration rates were incorporated based on CENTURY model runs.[20]

■ Step f: The above data were unified on a regional basis using eleven regions as defined in the Forest and Agricultural Sector Optimization Model[21] to get regional average GHG emissions per acre and per unit (e.g., bushel) of crop.

■ Step g: Bioenergy processing budgets were drawn together based on the literature for a wide variety of agricultural feedstocks for transformation into ethanol, cellulosic ethanol, biodiesel, and electricity including alternative electricity co-firing rates. These budgets contained assumptions about the fuel being replaced (typically, gasoline, diesel, and coal), the foregone fossil emissions and emissions from transforming feedstocks into bioenergy.

■ Step h: Hauling cost was computed based on feedstock density in a region, crop yields and processing plant feedstock needs following the formula in previous research.[22]

■ Step i: Total GHG emissions per unit of energy output were computed unifying the emissions per unit of crop input, per unit hauled and per unit transformed on a regional basis and then were computed as the percent net savings in emissions per unit of fuel displaced.

■ Step j: A national set of results was generated using the regional results favoring areas where the acreage of the biofeedstock was the largest or where the prospect is commonly referred to (e.g., Cornbelt and south for switchgrass).

■ Step k: The byproducts like lignin and distillers dry grain were credited at the GHG emissions of the items they replaced.[23]

The resultant data for a number of bioenergy feedstock and final energy possibilities appear in Table 1. In these data, the net GHG contributions of a bioenergy depend upon the amount of fossil fuel used in (a) producing the feedstock, (b) making production inputs, (c) hauling, (d) processing transformation, and (e) byproduct credits.

The data within Table 1 show the percentage direct reduction in carbon dioxide equivalent emissions when gasoline or diesel or coal fired electricity is replaced. For example, the percentage reduction in net GHG emissions when using corn-based ethanol is 30.5 percent relative to using gasoline. This means 69.5 percent of the potential emissions savings from replacing the gasoline are offset by the emissions from the use of fossil fuels or fossil fuel using inputs in producing the corn, transporting it to the plant, and transforming it into ethanol. We also see higher emission offset rates for electricity principally because the feedstock is burned with little transformative energy

Table 1: *GHG offsets when raw products replace conventional fossil fuel-based energy*

Commodity	Crop Ethanol	Cell Ethanol	Bio diesel	Electricity Co-fire 10%	Electricity Fire 100%
Corn	30.5				
Hard Red Winter Wheat	31.5				
Sorghum	38.4				
Log Residue		80		99.1	97.4
Corn Residue		74		93.4	87.3
Wheat Residue		72.9		95.5	91.1
Lumber Milling Residue		84.8			
Manure				99.4	96.5
Switch Grass		68.6		94.4	89.5
Hybrid Poplar		61.9		94.2	89.1
Willow		67.7		96.7	93.7
Soybean Oil			70.2		
Sugarcane	64.8				
Corn Oil			55		
Bagasse		90.1		100	100
Lignin				100	100

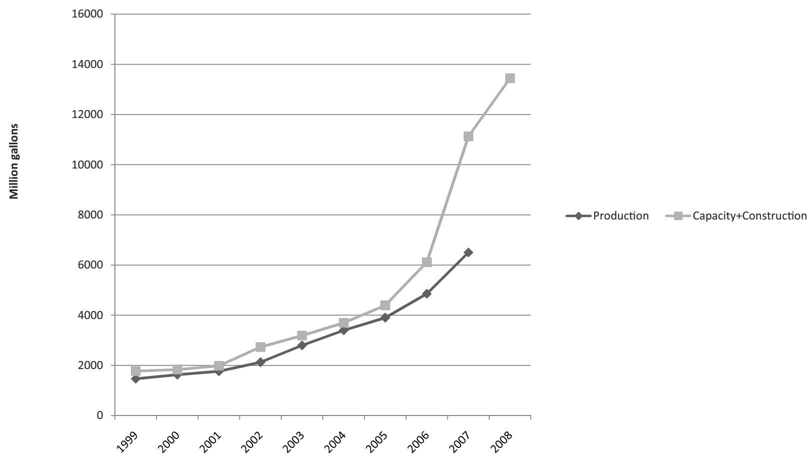
needed once it is at the processing site. Co-firing generally has a higher degree of offsets because hauling distances are shorter as lower feedstock volumes are required and because of the hotter burning caused by the presence of coal which increases feedstock heat recovery.

Broadly, the results illustrate and/or reflect a number of things. First, there are relatively lower offset rates involved with the production of liquid fuels as opposed to electricity. Second, we see that the lowest liquid fuel offsets arise for grain-based ethanol while relatively higher values generally arise from cellulosic ethanol and biodiesel from soybean oil. Third, the results show that differential offset rates arise across the different feedstocks and processes. This reflects that, for example, production of some requires substantial use of GHG emission intensive inputs (corn is a large fertilizer user). Fourth, more GHG emission-intensive transformation processes go in to making ethanol along with successively less so processes to make cellulosic ethanol, biodiesel, and electricity. Fifth and finally, economically it is apparent that if higher GHG prices were to arise there would be a shift in production away from grain-based ethanol toward cellulosic and a trend to move toward electricity.

BIOENERGY AND THE ECONOMY

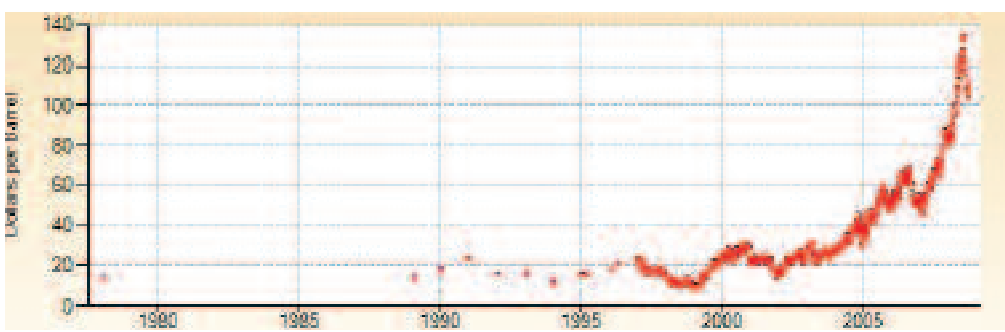
U.S. bioenergy has exhibited dramatic changes during the recent past. Figure 1 displays ethanol production and capacity figures drawn from the Renewable Fuels Association web site (the national trade association for the U.S. ethanol industry). These data show a dramatic industry expansion largely stimulated by the rising price of petroleum.

Figure 1: Ethanol Production and Capacity plus new construction 2001-2008



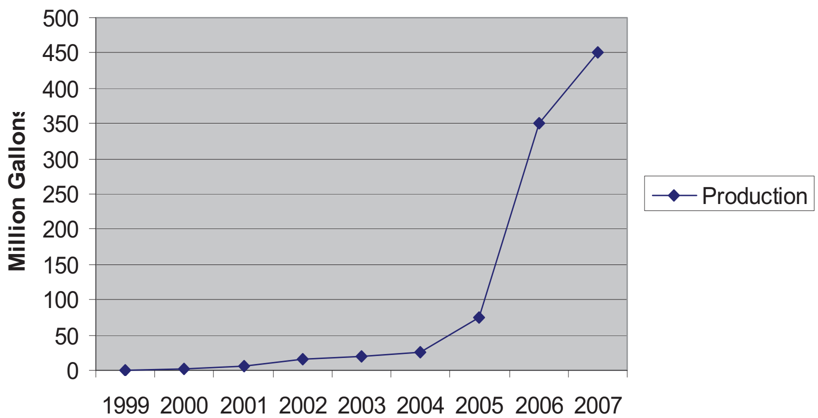
This oil price increase is illustrated by Figure 2 which was drawn from the Energy Information Agency website.

Figure 2 : Weekly United States Spot Petroleum Price from EIA in Dollars per Barrel



Biodiesel production has also expanded rapidly as indicated by data on the National Biodiesel Board Web site and as graphed in Figure 3.

Figure 3: *Biodiesel production 1999-2007*

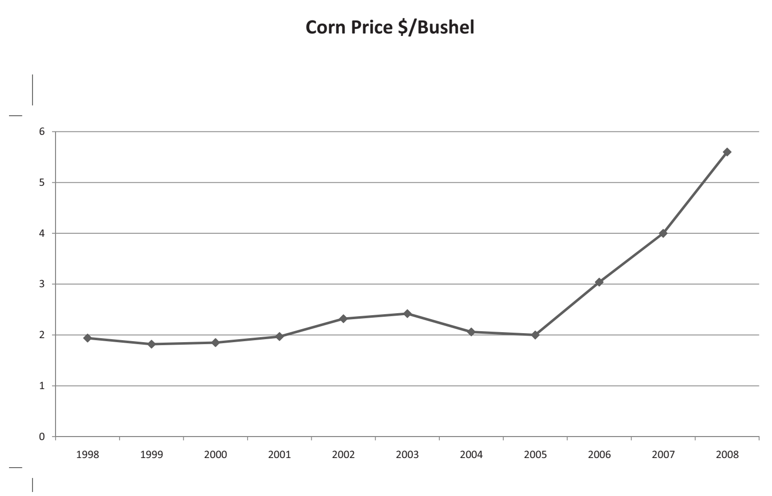


On the other hand bioelectricity is relatively small with the Energy Information Agency data indicating all renewables had about a 2.4 percent market share in 2005.

EFFECTS ON COMMODITY PRICES

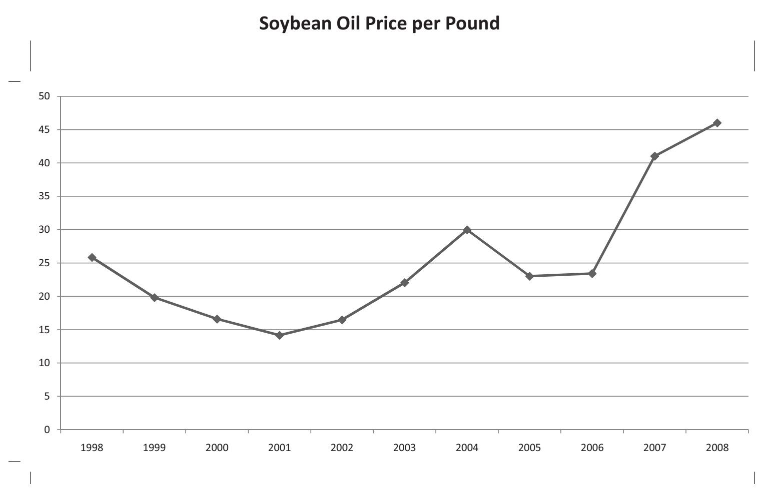
Biofuel developments have coincided with large rises in some commodity prices. Figure 4 shows corn price rises as reported in USDA NASS data.

Figure 4: *U.S. Average Corn Price in $ per Bushel*



Similarly soybean oil prices have changed.

Figure 5: *U.S. Average Soybean Oil Price in $ per Pound*



Prices of these and almost all other agricultural commodities have increased substantially over the past few years. Some have singled out one or two factors as the primary drivers with bioenergy often identified as the culprit. Analysts reviewed the situation and argue that the drivers involve a mixture of economic growth, international trade, currency markets, oil prices, government policies, and bad weather.[24] They identified the following broad sets of forces driving price increases:

- Global changes in production and consumption of key commodities, where they elaborate and indicate: (a) rapid economic growth in developing countries has led to growing food demand and a dietary transition from cereals toward more animal protein, leading to growing global consumption; (b) growth in agricultural productivity has slowed with investments in agricultural research slowing; (c) weather and crop diseases affected commodity markets in 2006 and 2007; (d) stocks of many agricultural commodities are and have been low; (e) policy actions of some countries to isolate their domestic markets made the situation worse; and (f) oil prices have raised transport and production costs.

- Depreciation of the dollar: the U.S. dollar has been falling for the past six years.

- Growth in the production of bioenergy as driven by higher oil prices plus contributing policies including subsidies and mandates in the United States, Brazil, and the European Union. The growing bioenergy industry and its demand for agricultural commodities as feedstocks then contributed to the price increase.

Section 5: Issues Regarding Economics, Environment, and Bioenergy

Bioenergy has been a major factor in the U.S. agricultural economy the last several years. A number of things in the agricultural arena have evolved, being at least partially affected by bioenergy. For example, (a) agricultural product prices have risen substantially; (b) farm incomes have been high; and (c) land values have exhibited substantial increases.

Bioenergy have also been controversial with the general market conditions and alleged links to bioenergy stimulating a healthy debate over the policies that the United States should adopt toward bioenergy. Inherent across this whole argument are a number of economic and environmental factors.

SUPPLY RESPONSE

One of the fundamental areas of debate has involved how the agricultural sector domestically and internationally will respond to the higher prices that have been coincidental with the development of bioenergy. This debate has proceeded along two different lines, one involving land use change and the other intensification. Both have involved economic and environmental concerns.

Land Use Change

High agricultural prices stimulate increased production. Increased production is achieved through intensification or extensification. Under extensification the argument is that the high agricultural prices, income potential, and land values stimulate additional land being brought into production use either in the United States or internationally.

Inside the United States the argument is that the bioenergy contribution to higher prices, farm income, and farmland value will cause: pastureland to be converted to cropland; conservation reserve program (CRP) and other fragile retired lands to revert back into agricultural cropping; forested lands to be deforested and moved into agricultural production; and other forms of land development like wetlands exploitation. Internationally the argument is basically the same but also involves potential conversion of rain forest lands into cropping uses or to augment grazing land so that grazing lands elsewhere can be transformed into cropping.[25]

This concern is a reflection of a long-standing agricultural economic finding that higher prices and/or land-related policy like conservation programs cause countervailing reactions that offset environmental gains. This has been labeled leakage in the international GHG/Kyoto accord context. It has also been called slippage in farm policy settings.[26] Namely, market forces such as today's high commodity prices can cause increased GHG emissions from expanded production in other areas of the world or portions of the economy.[27] Today it is common to hear about many forms of leakage being stimulated by high agricultural commodity prices including: U.S. forested acres being harvested and converted to cropland; possible reversion of CRP lands into cropland; or expansions of crop acres in Brazil and Argentina at the expense of grasslands and rainforest.[28]

Key factors in the size of this leakage include (a) the amount of marketed production that is offset. Note use of residues and waste product feedstocks tend to have lower market offsets while use of conventional commodities are one to one substitutes; (b) the land use that replacement acres come from and the embodied emissions. Large offsets occur when say rainforest or forest or possibly CRP land is involved; (c) the supply responsiveness of competitive areas; and (d) the market share of the country producing the bioenergy.[29]

McCarl constructs leakage estimates based on a formula by Murray, McCarl, and Lee and shows that international leakage easily offsets nearly 50 percent of the domestic diverted production.[30] In turn, when GHG offsets per acre are equal, this offsets 50 percent of the GHG gains. McCarl's calculations show the offset occurs at an even higher rate if acres with higher emissions are involved. Searchinger et al compute that when acres are directly replaced by rainforest reductions that net GHG emissions would increase.[31] Fargione et al point out the risks of emission increases vary with land use and feedstocks.[32]

Note that market forces may also cause reductions elsewhere where, for example, feed commodity price increases may reduce livestock production and accompanying emissions as covered in McCarl.[33]

Certainly embodied within the concerns about extensification are concerns that environmental quality will be negatively affected, including: (a) loss of habitat for endangered species and consequent loss of biodiversity; (b) loss of future opportunities for exploitation of species that are made extinct; (c) loss of carbon sequestered in rain forests; (d) loss of water purification and other ecological services from the lands transformed; (e) increases in runoff and other emissions from agricultural land due to increased chemical use relative to the prior land use; and (f) increased use of water for irrigation.

Intensification

Increased production may also involve intensification. Under intensification the argument is that farmers will increase input usage on existing lands since the increased marginal returns can justify additional costs of production. This would be manifest in higher usage of irrigation, fertilization, and pesticides plus more intense cropping patterns and tillage, among other possibilities. Again this is argued to be environmentally sensitive in terms of added usage of scarce resources like water, increased chemical usage, increased agricultural runoff, diminished water quality, and threats to biodiversity among other environmental concerns. Such actions can occur either in the United States or internationally.

FOOD PRICES AND POVERTY

Another concern that has been directed toward bioenergy has been concern for the world's poor given the change in food prices. In particular, the rise in commodity prices has led to increased prices for food commodities. Given that the price increase has been simultaneous with the boom in bioenergy, this has been blamed on bioenergy. A number of the critical food commodities for which prices have increased are well outside the domain of items used for widespread bioenergy production. For example, rice has exhibited a large price increase. Part of this price increase is due to demand expansion, exchange rate changes, production conditions, and policies but bioenergy is also a contributing factor.[34]

The controversy basically is that with the higher commodity prices, the world's poor finds it difficult to afford their basic food needs. While this is undeniably true, it is also true that much of the world's poor derives its income from agricultural production. It has certainly been a classic argument of development economists that one strategy for alleviating poverty in the long run has been to increase agricultural commodity prices through market and infrastructure development plus removing trade barriers. Higher commodity prices would mimic the implementation results of such a strategy. Since much of the rural poor derives substantial proportions of their income from agriculture, the market price increases would address rural poverty concerns and in fact be a more permanent solution than, say, short-term food subsidies. Nevertheless, this does not address the short run situation or the situation of the urban poor. Still, it is important to note that many of the urban poor have migrated from rural areas because of a lack of rural income opportunities and, again, enhanced agricultural prices would help address that situation.

Actually this whole line of argument, coupled with the land use change argument above, shows a tension between localized development issues in many of the world's poor areas and Western values for environmental preservation. In particular, keeping food prices low maintains poverty in many rural areas—but letting food prices rise influences land use which, while contributing to local income creates "environmental bads." In the long run there may be a need for avoided deforestation policy that creates income flows to such rural areas, alleviating poverty without undesirable environmental consequences.

DEMAND FOR ENERGY

Clearly the demand for energy has been one of the important driving forces in the bioenergy boom as manifest in high petroleum prices. Agriculture today, and even under the more aggressive domestic renewable fuel standards, is a relatively minor player in the total energy market. This means that, unlike under production of conventional crops for conventional markets, increased production of agricultural crops for bioenergy feedstocks will not lead to commodity market price declines. Agricultural entry into the energy market involves producing against what economists call a relatively elastic demand curve where commodity prices will not fall very much as production is expanded. This is quite different in comparison to traditional agricultural markets. Consequently, agricultural bioenergy feedstock prices will likely rise to meet energy prices, provided energy prices remain high in the long run. It also means that the profitability and the sustainability of the bioenergy boom is entirely dependent on the level of energy prices and the fact that agriculture must at least initially be a low-cost source of supply relative to energy prices. This was not the case during the 1980s and led to a rapid decline in bioenergy related interest.

Thus a key factor in the bioenergy boom is the potential for sustained higher energy prices. In this author's judgment, sustained high prices are likely given: (a) the burgeoning demand for transportation fuels and electricity in many countries around the world like China, India, those in the former Soviet Union, parts of South America, and elsewhere. Clearly energy is an engine of development throughout the world and many countries need additional energy to pursue their development goals; (b) the likelihood we are reaching a peak in conventional oil production; (c) the likelihood that future supplies will have the ever-increasing costs as argued by the International Energy Agency; and (d) the likelihood that climate change-related policies will place pressure on the carbon emissions that are inherent in fossil fuel consumption.

COST COMPETITIVENESS, PRODUCTION COST, AND COMMODITY PRICES

One statement that is certainly true is that agriculture will not be a supplier of energy if the cost of developing agricultural bioenergy far exceeds the cost of developing energy from alternatives (although energy security and GHG offsets would contribute). Many economists have produced breakeven charts that show under the prevailing energy prices of today that processing plants can afford to pay high commodity prices.[35] For example, Tyner and Taheripour indicate that $100 per barrel petroleum allows firms to pay $4.25 or more for a bushel of corn.[36] This shows commodity prices are likely to remain high if oil prices remain high and the agricultural share of the liquid fuels market remains somewhat low. It also shows that under traditional levels of agricultural commodity prices that agriculture is at least initially a low-cost supplier. It also shows why higher energy prices have stimulated bioenergy production and contributed to higher commodity prices. Finally it shows why many farmers and agricultural interests are highly supportive of bioenergy production. On the other hand, this is a double-edged sword where, for example, the high price of soybean oil (as discussed above) has brought the biodiesel industry to the edge of profitability with only 25 percent or so capacity utilization.

COMPETITIVENESS WITH FOOD

The underlying reason that bioenergy has been alleged to be behind many of the commodity market prices is that generation one ethanol is directly competitive with the use of the commodities for traditional food-related usages. Corn that is refined into ethanol is not corn that can go directly into animal feed. Sugar that is refined into ethanol cannot be used to sweeten someone's drink.

On the other hand, generation two ethanol, bioelectricity, and pyrolysis can use inputs that are complementary with traditional commodity production. For example, if crop residues can be effectively turned into cellulosic ethanol then this is a complement not a substitute. Furthermore second generation ethanols have the potential to get ethanol yields per unit of land from dedicated energy crops that are substantially higher than ethanol from traditional crops thereby reducing land competition. For example, an acre of Iowa corn with a 200 bushel per acre yield could generate 500 to 600 gallons generation one ethanol but with switchgrass might be able to generate an ethanol amount almost double that.

EFFECTS OF GHG FORCES

Another major item of discussion with respect to bioenergy involves their GHG offsets. Certainly there has been controversy regarding whether a U.S.-based GREET derived LCA is in fact is a good way to measure global GHG offsets. This has arisen in part because LCA typically does not pay attention to the international leakage as discussed in the land use change section above;[37] GHG offsets may be negative. Nevertheless, it has been very important to look at LCA analysis which inherently considers not just the offsets gained when combusting the bioenergy but also the GHG emissions that are inherent in the inputs used in producing the commodity, plus the emissions generated in hauling and processing, along with the avoided fossil fuel combustion adjusted for the GHG offset of byproducts.

The leakage issue is not the only problem with LCA. McCarl argues that a more general equilibrium analysis is needed which takes into account the effects on livestock herds of altered feed availability and the ripple effects on altered crop production, etc.[38]

There is another issue that will undoubtedly emerge if the U.S. gets to the point that the advanced bioenergy concept envisioned in the 2007 Energy Bill is fully implemented or if the GHG offset price were to become significant (note the price on the voluntary U.S. Chicago Climate Exchange has often been about $4 dollars per ton CO_2 whereas the European price is about ten times that). Namely, given strong economic incentives to reduce GHG emissions will stimulate innovation and factor substitution reducing bioenergy process associated GHG emissions.[39] This means that the LCA assumption that the GHG contribution of inputs used in production are constant may be questionable. This is manifest in recent changes in the GREET model where a recent email indicated that there has been a recent large percent reduction in GREET agricultural emissions assumptions. Such an adjustment was undoubtedly stimulated by farmers' reactions to increased energy prices. That adjustment would be equivalent in many ways to a carbon price signal or an advanced bioenergy definition. This would be manifest in many ways; for example, bioenergy processing facilities could switch the sources from fossil fuels to corn stover or other renewables.

Finally on the GHG topic, it is worthwhile mentioning the effect that any GHG allowance price would have on the U.S. employed portfolio of bioenergy feedstocks and production processes employed. As carbon equivalent prices rise that bioelectricity would become ever more important.[40] Similarly, McCarl and Riley showed that generation one ethanol would be phased out in favor of generation two ethanol with growing bioelectricity as GHG prices rose.[41] Furthermore, technologies like pyrolysis could become much more important since McCarl et al's calculations indicate that pyrolysis can have offset efficiencies greater than 100 percent when compared with the emissions of the fossil fuel inputs that are replaced.[42]

TECHNICAL PROGRESS

A final issue that is important although not widely discussed involves technical progress both in terms of progress in producing traditional agricultural commodities and in recovering energy from agricultural feedstocks.

It is vital, given a growing population, that agricultural technology continues to advance, generating greater productivity and lower production costs. In fact, technological progress throughout the twentieth century advanced at a rate faster than population growth leading to declining real food prices. If this continues there is a definite role for bioenergy in maintaining farm income and using abundant land resources. On the other hand if technical progress does diminish (and there is some indication that this may be happening),[43] then bioenergy will likely be minor at best.

In terms of energy recovery, technological advances in the form of higher yields of energy feedstocks per acre and increased bioenergy recovery efficiency per ton of biomass could steadily reduce the economic cost and environmental implications of bioenergy and thus be important. In this regard one must ask when exactly will generation two ethanol and possible new technologies like pyrolysis become commercially viable. The answer is not today but perhaps in a couple of years.

SUBSIDY POLICY

The U.S. has a substantial subsidy for ethanol and biodiesel. The usual justification for such a subsidy is to nurture an infant industry—although energy security, farm income support, and environmental/GHG gains are also involved. The U.S. corn ethanol industry is no longer in an infant stage and was in recent times very profitable, likely not needing a subsidy to continue. This implies that the subsidy might be altered, either being eliminated or redone based on petroleum and commodity prices.[44] This also argues for continuation of the biodiesel subsidy since that industry is shrinking. Furthermore, establishment of a subsidy for cellulosic ethanol and biopower may well be justified by the infant industry, and GHG arguments.

Section 6: Policy Considerations

The above discussion introduces a number of items that should be considered as U.S. policy evolves. In summary form these are discussed below.

- Reducing market competitiveness: There is substantial competitiveness between conventional crop markets and current forms of biofuels. It would be desirable for policy to reduce this competitiveness. Such a goal can be achieved by pursuing several avenues including (a) raise productivity of current crops by substantially investing in productivity research; (b) reduce competitiveness by moving energy forms created by crop or forest byproducts (such as cellulosic, pyrolysis, or biopower from crop and logging residues), waste products (processing or municipal); (c) developing competitive but high yielding energy crops that reduce the displaced conventional commodities; (d) developing energy commodities that are not competitive on traditional agricultural lands such as degraded or under used lands; and (e) improving efficiency of energy conversion from biomass through research on biopower, pyrolysis, cellulosic ethanol, and other forms.

- Reducing environmental footprint: There is a substantial environmental footprint being observed in terms of land use change including deforestation and CRP reversion along with increased chemical use and resultant water quality impacts. Such a phenomena would be addressed by developing agricultural production practices that are less input intensive and by avoiding massive land use change, perhaps by coupling biofuel policy with sensitive lands protection, including rainforest protection. Input policy may also be needed to encourage more efficient fertilization and pesticide use. Policies allowing GHG trading may also help.

■ Recognition of the limits of bioenergy expansion: Obviously U.S. energy and GHG policy cannot solely be a biofuels policy. Other policies addressing energy efficiency, conservation, wind, solar, nuclear, carbon capture and storage, along with other forms are needed.

Conclusions

Bioenergy will most likely be part of the portfolio of solutions addressing high oil prices, energy security concerns, and greenhouse gas emission reduction desires. U.S. policy is certainly promoting some forms of bioenergy, particularly liquid ones. However, bioenergy potentially places stress on agricultural land use and the environment both domestically and internationally. For bioenergy to really become a major player it must use feedstocks that are less competitive with food plus it must be supported by increases in rates of technological progress, complementary environmental programs to reduce things like rates of deforestation, and policies to better the lot of the urban poor. Rapid expansion of bioenergy production can have unintended and undesirable consequences for agricultural commodity costs and environmental quality. Information on net greenhouse gas benefits is also needed. As policies are formulated and implemented to promote larger volumes of bioenergy, these factors must be considered.

In addition the future of bioenergy depends on its profitability and the continued availability of cheap food. Essential to this will be high oil prices and rapid technical change in both agricultural production and energy recovery.

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02 BIOENERGY IN GERMANY

BIOENERGY IN GERMANY: POLICIES, PITFALLS, AND PROSPECTS

TOBIAS PLIENINGER

Section 1: Introduction

Reaching back into prehistory, the use of renewable energy derived from biomass is one of the oldest land-use forms—albeit it has only recently been conceptualized as "bioenergy use." Being the "carrier of fire and flame," fuelwood was of outstanding importance for mankind over the past 400,000 years. At the beginning of forest use in central Europe, the main emphasis was to meet the demand for firewood. Wood had such a fundamental importance as a natural resource that the era before 1800 is commonly referred to as the "wooden era."[1] Karl Mantel, a German forest historian, said that human life was "carried by wood and surrounded by wood."[2] The forests had to meet the population's demands for domestic fuel, but also the enormous energy needs in industry, handicraft, and trade, e.g., in ironworks, salt mines, brickyards, and glassworks. Excessive wood uses in the eighteenth and nineteenth centuries provoked a "wood misery"—the first large energy crisis—that finally triggered the emergence of the notion of sustainability and the introduction of a well-regulated forestry.[3] Not only forestry, but also premodern agriculture was largely self-sufficient with regard to energy supply through the use of draught animals, firewood, and hydropower, among others.[4] From this perspective one may see that the "energetic use of renewable primary products" is a very old issue.

Despite its extended history, the energetic use of biomass is a new and an old issue at the same time, as it has been considered an anachronism for a long time. The neglect of traditional bioenergy started with the industrial revolution in the late eighteenth and nineteenth centuries, when firewood was replaced by lignite, hard coal, and newly emerging industrial resources. During most of the twentieth century energy policies boosted centralized, technology-intensive energy plants, in particular coal-fired burning plants, nuclear energy, and electric, oil, and gas heating. Timber production became the dominant goal of forest management, and fuelwood was degraded to a byproduct of negligible economic significance. In the less developed parts of the world, however, traditional bioenergy use has remained widespread, especially in sub-Saharan Africa, India, China, and the rest of Asia. The International Energy Agency (IEA) estimates that 40 percent of the world population (and the number is growing) depend on traditional biomass for cooking and heating—although it is related to significant problems such as health hazards and deforestation of native forests.[5]

In the industrialized countries, the assessment of the sustainability of energy supply from plant biomass has changed immensely since the shortcomings of the dependency on fossil fuel energy carriers became evident. Alternatives to fossil energy sources have been boosted by the concerns about rising oil prices, climate change, and energy security. As these concerns have grown, the scientific and political dedication to bioenergy experienced three stages: The first stage started with the 1973 oil crisis and the publication of the Club of Rome's report on "The Limits of Growth."[6] The second stage at the beginning of the 1980s was a discussion on reducing agricultural surplus production and creating additional income in agriculture by growing energy crops. The third stage—mainly driven by the concerns for mitigating climate change—started at the end of the 1980s and continues until today. Meanwhile the promotion of renewable energy sources has become a "societal mainstream request"[7] and has arrived at the top of the political agendas. Both Christian-Democratic Chancellor Angela Merkel and Social-Democratic Minister of the Environment Sigmar Gabriel have made personal commitments to advance renewable energy supply. These efforts culminated in August 2007 in the adoption of an integrated energy and climate program (the so-called

Meseberg resolution) in which the German government gave renewable energies a very high significance.

Bioenergy did not take a front position in the first years of the renewable energies boom in Germany. Compared to wind energy and photovoltaics it was considered technologically underdeveloped. But by and by, biomass proves equivalent and in some aspects even superior to other renewable energy carriers. Technological progress has facilitated the use of almost all kinds of biomass today—far more than the traditional use of firewood. Biomass has the largest unexploited energy potential among all renewable energy carriers and can be used for a wide range of possibilities—whether the provision of heat, cooling, fuel, or electricity. Bioenergy is constantly available, can easily be stored, and can replace power generation in baseload plants. It is suitable for use in a diversity of plant types, whether in small domestic heating plants, power and heat supply stations, or for co-firing in coal-fired power plants.

The (re-)appearance of bioenergy is provoking paradigmatic changes in the agricultural sector, often described as a transition from food/feed to energy farming. In consequence a completely new "agricultural bio-economy"[8] has emerged. In Germany, public perception has been overwhelmingly positive in the first years of bioenergy diffusion. For example, Germany's former minister of the environment, Jürgen Trittin, heralded the coming "age of biomass,"[9] and then secretary of state in the ministry of agriculture, Matthias Berninger, proclaimed a "revolution in agriculture."[10] The German news magazine *Der Spiegel* celebrated "the power of renewable resources,"[11] *Süddeutsche Zeitung* put "the farmer" on a par with "the sheik,"[12] and large parts of German society shared this unconditional compassion for bioenergy.

It took a few years until this perception started to change, when the public began to understand that bioenergy is not a silver bullet, but may come with an ecological and social price, particularly in the less-developed countries: In 2007, the OECD published a report titled "Biofuels: Is the Cure Worse than the Disease?"[13] (a question which the report answered with a clear yes referring to currently dominant ways of biofuel production); around the same time Ernst Ulrich von Weizsäcker, former president of the German Wuppertal Institute and member of the Club of Rome, declared biofuels a "major assault on biodiversity,"[14] and was accompanied in his judgment by Jeffrey McNeely, Chief Scientist of the International Union for the Conservation of Nature (IUCN), who coined the term "deforestation diesel" for palm oil-based biodiesel.[15] Finally Jean Ziegler, UN special rapporteur for the right to food, condemned the growing use of energy crops as a crime against humanity (as they are assumed to displace food production) and called for a five-year ban on producing biofuels.[16]

These debates are also prevalent in the discussion on domestic bioenergy use in Germany, although the land use conflicts are less dramatic in an affluent society where hunger and deforestation ended long ago. Still, there remain significant societal implications of bioenergy, as has been stressed by the fact that at least four nation-wide scientific commissions published assessments on bioenergy in recent years:

- The Federal Environment Agency Soil Protection Commission (KBU) warned that growing use of biomass may entail considerable water, air, and soil pollution.[17]

- The German Advisory Council on the Environment (SRU) confirmed the potential of bioenergy to mitigate climate change, but exerted strong criticism in energy policies that push bioenergy into unsustainable directions.[18]

- The German Council for Land Stewardship (DRL) highlighted especially the landscape-level impacts of biomass use and concluded that biomass would have the largest spatial impact among all renewable energy carriers.[19]

- The Scientific Board for Agricultural Policy at the Federal Ministry of Food, Agriculture, and Consumer Protection (BMELV) stated that current bioenergy policies would fall short of contributing to climate protection goals as long as large amounts of payments would continue to be invested into expensive and inefficient lines of bioenergy.[20]

This essay aims to review current practices and policies of bioenergy use in Germany, with an outlook toward the European and international dimension of bioenergy. The most relevant concepts, technologies, policies, and actors will be presented. The historical and potential development of the sector will be described, which is followed by a discussion of its environmental and social impacts. Finally efforts to put bioenergy onto sustainable pathways will be sketched.

Section 2: Biomass Feedstocks, Conversion, and End Uses

In this report the term biomass refers to all crops and residues that are processed as fuel for power generation, heat supply, or as automotive biofuel. In Germany's Biomass Ordinance (*Biomasse-Verordnung*), biomass is defined as an energy carrier consisting of plant and animal matter. It includes biogenic derivatives and byproducts, residues, and wastes, but disqualifies fossil fuels, peat, mixed municipal waste, contaminated recycling wood, paper, sewage sludge, textiles, animal carcasses, landfill gas, and sewage gas.[21] Energy derived from biomass is referred to as "bioenergy."

Bioenergy can be extracted from a confusing diversity of cultivation forms and conversion pathways. In Germany the most important land cover forms from which biomass is drawn from are arable lands, forests, grasslands, landscape management areas (lands dedicated to cultural landscape and biodiversity conservation), and energy forests which represent a transitional stage between arable field and forest (Table 1).

Table 1: Land cover types and options of biomass supply[22]

Land cover type	Biomass option	Examples
Crop field	Annual energy crops	Corn (whole plant) Rapeseed
	Perennial energy crops	*Miscanthus*
	Residues	Residual straw
Energy forest	Perennial energy crops	Willow (short rotation) Poplar (short rotation)
Forest	Wood trunks	Coppice, coppice-with-standards
	Residues	Thinning material Residue from timber harvesting
Grassland	Loppings	Various grass and sedge species
Landscape management areas	Landscape management clippings	Clippings from hedges and woodlots Native grass species

Biomass can be either cultivated purposefully or used as residue from cultivation processes that target other main products. The so-called "cultivation biomass" may consist of cereal plants (e.g., corn), woody plants (e.g., willows or poplars in short rotation plantations), and oleiferous and amylaceous plants (e.g., rapeseed, sugar-beet). Residues may be manure, straw, or thinning materials from forestry. Biomass-based fuels vary in their physical condition at the moment of their energetic use: There are solid (e.g., wood pellets), liquid (e.g., bioethanol, biodiesel, plant oils), and gaseous bioenergy carriers (e.g., biogas, wood gas). Depending on the biomass and the final energy use (e.g., automotive biofuel, heat, or power) there is a diversity of conversion technologies. Biomass may either be combusted directly or processed in an intermediate step to liquid or gaseous secondary energy carriers with improved properties. These may be a higher energy density, more favorable storage or transportation properties, or a more efficient and less-polluting energetic use. Thermochemical, physical-chemical, and biochemical refinement processes are all applied. Gasification, a thermochemical process using high temperatures, converts solid biomass into gaseous energy carriers and is often applied in power generation. A widely used physical-chemical process is the transesterification of plant oil in order to adapt biofuels to the specifications of conventional diesel motors. Biochemical conversion takes place in biogasification plants, where organic substances are fermented under absence of oxygen into a gas mixture that consists of methane and other gases and is combusted in gas burners or motors.

Although there are so many pathways, current bioenergy use in Germany concentrates on just four basic production and conversion lines:[23]

- The combustion or gasification of solid biomass for heat and power supply in small and large plants. These are the most common techniques for the conversion of woody biomass from the forestry sector and the wood processing industry.

- The anaerobic fermentation of a range of organic substances such as food wastes, liquid manure, dung and energy crops to biogas, a mixture of methane, CO_2, and other gases. Biogas is mostly used as fuel in combined heating and power (CHP) plants. This is the common utilization form of biomass wastes and energy crops.

- The transesterification of plant oils, especially of rapeseed oil, or of animal fats to biodiesel, an alkyl ester and diesel equivalent to be used as diesel engine fuel.

- The fermentation of agricultural substances rich in carbon hydrate such as cane sugar, corn, rye, or sugar beets into liquid hydrocarbons, especially bioethanol. Bioethanol can be added to gasoline or other alcohols and used as a fuel in Otto engines, fuel cells, or turbines. Ethanol production is one of the most common forms of the use of plant biomass from agriculture.

Other, less usual processes are the application of plant oil, biodiesel, bioethanol, and residues in power and heat plants and the use of pure plant oil and biogas in the transportation sector. Synthetic biofuels that will be able to process heterogeneous biomass feedstocks from all kinds of land uses are not yet ready for the market in Germany, but large-scale production of more than 1 million tons (t) of fuel per year is projected for 2012. Besides energetic uses there is a broad array of material uses of biomass. Most notably, fibers, oils, fats, starch, and sugars are processed to lubricants, insulants, detergents, drugs, varnish, and other products. The use of biomass as a supplement of petroleum in Germany's traditionally strong chemicals industry will probably increase as soon as the concept of a "green biorefinery," a complex technology for the comprehensive purification, separation, and refinement of biomass, has been further advanced.

Section 3: Policies and Actors

POLICIES DRIVING BIOENERGY EXPANSION

The bioenergy boom in Germany is, as this essay intends to emphasize, not the result of unregulated market developments, but rather of intensive and cross-sectoral political efforts—which presents both a problem and a chance. Current profit margins merely reflect the incentives given by a set of public subsidies, tax breaks, and purchase guarantees. In an unregulated market, probably none of the currently pursued bioenergy pathways would be profitable. For example, production costs for domestic bioethanol in Germany amounted to €0.8–0.9 per liter gasoline equivalent compared to a price level of €0.2 per l (2005 tax-free prices for fossil gasoline).[24] Electricity generation costs of a manure-based biogasification plant averaged €79 per MWhel compared to €45 per MWhel in conventional hard coal power plant.[25]

Although the drivers pushing governments to promote bioenergy are manifold, five lines of arguments have been cited in the political arena with high frequency (although some of them may not withstand scientific scrutiny):

■ Bioenergy is a renewable energy source and able to substitute finite energy resources (substitution of petroleum).

■ The use of bioenergy generates far lower emissions of greenhouse gases than that of fossil fuels (climate protection and emission reduction).

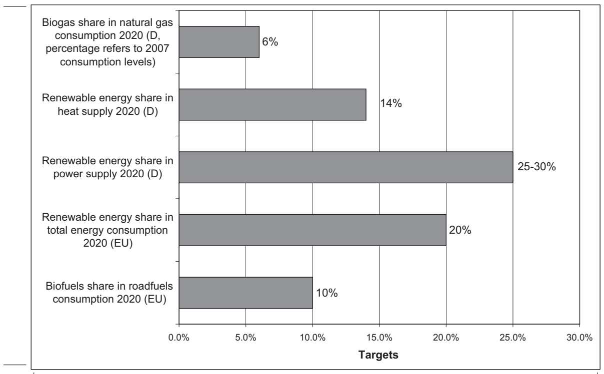
■ Bioenergy carriers can be produced domestically or purchased from a variety of countries and world regions, which alleviates Germany's one-sided dependency on fossil resources from the Middle East and from Russia (security of energy supply).

■ Bioenergy technologies are a fast-growing "sunrise industry." The development of corresponding industries safeguards "first mover advantages" and opens up export options to German industry (technology development).

■ Bioenergy opens up new income opportunities for agriculture and forestry (rural development).

In response to this variety of issues, but with a clear focus on climate protection, most European governments have set up ambitious goals for a future-oriented energy policy. Most declarations encompass goals for the expansion of renewable energies in general, some have specific biofuel targets. However, an overall bioenergy target is so far missing both in the European Union and in Germany. In its 1997 White Book on Renewable Energy and its 2007 Renewable Energy Roadmap, the EU has determined to supply 10 percent of total energy consumption from renewable sources by 2012 and 20 percent by 2020. Individual targets are appointed for each member state, depending on the respective economic potential. The farthest-reaching targets have been made in the power sector, with 22 percent to be reached by 2010, whereas biofuels shall reach 5.75 percent in 2010 and 10 percent in 2020. In 2007 the German government substantially revised its renewable energy targets, intending to disproportionally contribute to renewable energy expansion in the EU. By 2020, renewable energies are supposed to have a 20-30 percent share in the German electricity sector, 14 percent in the heat sector, and 17 percent in the transportation sector (Figure 1).[26] With the sustainability of biofuels being increasingly questioned, however, the latter target has come under serious scrutiny.

Figure 1: *Political targets for renewable energy supply*[27]



These targets are implemented by a set of policies, which have been the main driving forces of bioenergy expansion. Instruments are located both in energy and agricultural policies and are in most cases focused specifically either on the power, heat, or automotive biofuel pathways. Currently, three main instruments are used:

■ Guaranteed feed-in remuneration, to be paid by electricity consumers (power sector);

■ Minimum quotas for bioenergy use, to be paid by fuel consumers and house owners (transportation and heat sector); and

■ Subsidies and tax breaks, to be paid by taxpayers (various sectors, cross-sectoral).

The Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, EEG) is one important pillar of bioenergy support in Germany. The federal government is proud to announce that it has served as an exemplar for the legislation of eighteen other European countries.[28] The EEG obliges power network operators to induct renewable electricity into their networks and to pay a specified minimum remuneration. This remuneration is approximately cost-covering for plant operators. Investment into renewable energy supply has multiplied after its introduction. In the field of bioenergy, the act intends to control the development into several directions: First, it intends to promote power generation in both large and small power plants. Second, it is designed to spread combined-heat-and-power plants (CHP) by a special bonus scheme. Third, since its 2004 amendment it has provided an extra incentive for the use of unprocessed biomass from agriculture, forestry, horticulture, and landscape management. The idea of this amendment was to make the so far undeveloped biomass potential from agriculture and forestry better available.[29] It resulted in a large growth of on-farm biogasification plants in rural Germany. In the most recent amendment in 2008 a further incentive for the promotion of using biomass wastes was introduced.

The second pillar of bioenergy promotion targets the transportation sector. In the past, pure biofuels (plant oil, biodiesel, bioethanol) were completely or partially exempt from petroleum tax. Since 2003, a blend of maximum 5 percent biodiesel to fossil diesel has become tax-privileged as well. This incentive proved so attractive that the market share of biodiesel grew heavily, which resulted in a considerable tax deficit. Therefore, the governing Christian Democratic Party and Social Democratic Party declared the stepwise abolition of the tax exemption until 2009 in their coalition treaty. An exception was made for biofuels used in agriculture and forestry. Tax income was estimated to increase by €1 to €1.5 billion per year in consequence. The tax exemption was replaced by a new law, the Biofuels Quota Act (*Biokraftstoffquotengesetz*), which obliges petroleum and diesel producers to blend fossil fuels with a 6.75 percent biofuels share by 2010. While biodiesel had become competitive to fossil diesel through tax exemption, the industry entered a deep crisis after the end of tax exemption, and even recently-opened biodiesel refineries were forced to shut down. The quota imposed by the new law increases subsequently. The cost difference between the cost of biofuels and the market price for fossil fuels (an estimated €0.03 per liter in 2007) has to be covered by the oil companies and is expected to be imposed on fuel prices in the long run. As a reaction to heavy criticism on negative environmental and social side effects of biofuels production, especially in the tropics and subtropics, the federal government is currently busy establishing environmental minimum standards for biofuels to be acknowledged in this quote. Criteria are directed toward certain management standards of agricultural land, the conservation of natural ecosystems, and a minimum of GHG emission reduction.[30]

A field that has been little supported by policy instruments is the supply of heat. This seems surprising, as bioenergy use has both its longest tradition and its greatest potential in this sector. So far the only measure promoting renewable heat use has been a Market Launch Program (*Markteinführungsprogramm*) in which a part of the German eco-tax is invested to promote—among others—the installation of biomass heater facilities in buildings. Its aim is to introduce bioenergy technologies in a multitude of applications. The promotion is intended to help overcome existing thresholds of cost-effectiveness. Finally, by 5 December 2007, the federal government decided to suggest a law on the promotion of "renewable heat," which is supposed to raise the share of renewable energy in the heat sector to 14 percent by 2020. Its main foundation will be to prescribe a minimum quota of renewable energy use (or, alternatively, energy saving practices) in newly built houses. House owners can choose between several renewable heating or energy saving measures. Prescriptions for bioenergy are as followed: 30 percent for biogas heating (in combination with power generation), 50 percent for solid biomass heating, or 50 percent for heating with liquid biofuels (certain sustainability standards provided). To ease the introduction of the act, it has been coupled with a significant increase of the Market Launch Program budget.

Bioenergy is supported not only by renewable energy policies, but also by European agricultural policies. The idea behind it is to develop new sources of income for farmers. The Common Agricultural Policy (CAP) grants a specific prime (€45 per ha and year) for the cultivation of energy crops. In response to the EU's enlargement toward eastern Europe, the maximum area of agricultural land eligible for this prime was increased from 1.5 million hectares (ha) to 4.5 million hectares in Europe. A second agricultural policy tool allows farmers to grow renewable primary products (including energy crops) on those 10 percent of Europe's crop area that are designated as "set-aside agricultural lands" (where food and fodder cultivation is prohibited with the motivation to reduce agricultural overproduction). Therefore a large part of energy crops is cultivated on formally "set-aside" lands. By this farms both receive a "set-aside" grant and may generate income through selling of biomass from the set-asides. EU member states may further support the cultivation of perennial energy crops on set-aside land with additional national grants, and other agricultural policies support the adoption of energy cropping by granting investment aids, e.g., for the establishment of on-farm biogasification plants and rape-oil presses. A recent development is that

European Union has temporarily suspended the compulsory set-asides in reaction to the increase of worldwide demand and prices for grain. In consequence, German set-aside surface was reduced from 648,000 ha (2007) to 310,000 ha (2008) in just one year.[31] The future of set-asides will be decided within the scope of the "health-check" of the Common Agricultural Policy in 2008.

Looking at Germany's bioenergy policy landscape, several issues attract attention: First, the various schemes target specific bioenergy lines, i.e., the use of bioenergy either for electricity, heat, or transportation. This may have historical reasons, but in fact hampers an efficient allocation of biomass, especially regarding the lack of coordination between these schemes. Currently, the Biofuels Quota Act and the preceding tax exempt for biofuels have proven overly powerful and directed the largest part of available biomass crops into the transportation sector. A general, cross-sectoral master plan for efficient biomass use and land use policy is currently unavailable, although the EU Biomass Action Plan from 2006 has been a step in this direction.[32] Second, programs such as the EEG and the Biofuels Quota Act merely define quantitative targets of bioenergy use, but neglect the efficiency of a respective bioenergy line in terms of GHG reduction potential and energy efficiency. Differences between energy crops, cultivation systems, or conversion pathways as well as other ecological and social side-effects have been mostly disregarded, and instruments for ecological quality assurance are still in a very early stage. In consequence, many of the established bioenergy facilities are technically underdeveloped, and byproducts such as waste heat or fermentation residues often remain unutilized. Third, an economic cost and benefit assessment of most policies has not been carried out. In contrast, the production of biodiesel and bioethanol is exactly that line of bioenergy in which Germany is least competitive internationally.[33] In sum, the bioenergy policy framework has put focus on a strong quantitative growth of biomass use, but has led to suboptimal environmental and economic results.

Bioenergy diffusion follows from considerable investment of resources through societies, as its market introduction has been substantially induced by state interventions. Future profitability of the sector strongly depends on the maintenance of these public incentives as well as on the relative development of prices for fossil and biomass resources. As bioenergy policies are financed so heavily by the community of energy users and taxpayers, the sector can and must be expected to contribute to public welfare to a particularly great extent. At the same time, this situation offers opportunities and the responsibility to lawmakers to strengthen the sustainability of publicly promoted bioenergy through the specific arrangement of support schemes. After intensive lobbying from environmental organizations, the remuneration of renewable power in the amended EEG has been coupled to at least some ecological criteria. In the future, incentives for nature conservation as well as for processes with high emission reduction potential and energy efficiency should be introduced into the EEG.

Despite the powerful economic incentives, the rise of bioenergy use has not exclusively been the result of the top-down policy schemes mentioned so far. There is a growing number of regional bottom-up initiatives in many parts of Germany, bringing together farmers, researchers, local politicians, citizens, and enterprises that aim to increase regionalized provision of energy from renewable sources. A current call for "bioenergy regions," launched by the German Ministry of Food, Agriculture, and Consumer Protection has received more than two hundred proposals from 210 German regions.[34] A successful example is the barum111 initiative that intends to produce 111 percent of current energy demand levels in the Barnim-Uckermark region from renewables. Barum111 is an initiative of two county administrations (Barnim and Uckermark). It emphasizes the participation of both actors from the energy supply and the energy demand side and integrates a local college, enterprises in the field of wind and bioenergy, and committed citizens. Objectives are the expansion of renewable energy supply in the region; promotion of renewable energy networks; expansion of research, consulting, and education; and an accelerated authorization process in the field of renewable energy projects. Often these initiatives have the form of a government-organized non-governmental organization (GONGO) and thus stand between public and private institutions. Motivation of local and regional initiatives is in most cases a blend of climate protection, energy security, environmental conservation, and rural development. Important reasons for farmers to engage in bioenergy may be a diversification of farm production, minimization of risks, the closure of nutrient cycles (by returning fermentation residues to the fields), a reduction of external energy inputs, and a cost-effective and convenient disposal of manure and other wastes.[35] Regional initiatives can prove valuable for bioenergy development, as they can help to fit targeted bioenergy lines into the context of the local situation and thus may reduce land use conflicts. Moreover they can push forward innovative forms of bioenergy that are not yet on the political agenda. Regions thereby precede rather than follow external changes and drivers, and may become pioneers of bioenergy development. By this they can be more successful in the diffusion of innovations than the state, although the latter usually disposes of far more financial and regulatory resources.[36] Their task can be, on the one hand, to critically accompany bioenergy diffusion on a local or regional level, and on the other hand, to develop their own positive visions for future land uses. An example might be the activities of the southern German "Regional Power Initiative Ravensburg"[37] where nature conservation-oriented power consumers provide financial incentives to farmers for the energetic utilization of landscaping materials resulting from the maintenance of high nature value-farmland.

SPECTRUM OF ACTORS IN THE BIOENERGY SECTOR

Besides the dominating role of policymakers in the bioenergy sector, there is a large number of actor groups involved. Actor constellations differ along the energy supply chain, from biomass production (where farm and forestry enterprises are the dominant actors) via fuel supply and energy conversion (a domain of the power and fuel industry) to the end users of bioenergy (private households and businesses).[38] Some actor groups such as scientists, politicians, or environmental organizations are involved with bioenergy across the entire energy supply chain.

Agricultural and Forestry Enterprises

Agriculture and forestry are the principal producers of biomass. Whereas in agriculture most biomass is specifically cropped, biomass from forestry is mostly a byproduct. In some bioenergy pathways, farms are nothing more than the supplier of raw materials, for example for bioethanol fuels. In other cases, further processing and energy conversion takes place on farms by means of onsite biogasification plants and generators. Accordingly, the economic impulses for agriculture are weaker or stronger. Altogether it appears that the agricultural sector is open-minded toward bioenergy as a new economic branch. Forestry is the actor with the longest tradition of bioenergy use. Still, forestry acts almost purely as supplier of raw materials and does not participate in further steps of the bioenergy value chain. Forest wood can be either combusted or gasified in a broad spectrum of plant types, whether in domestic fireplaces, CHP plants, or as co-substrate in large coal fired power plants.

Energy Industry

The energy industry in the EU is in a phase of transformation.[39] Many power plants need to be renewed in the coming years, energy prices are rising and, at the same time, public awareness for climate protection is increasing. In central Europe the energy industry is differentiated in a few large transnational corporations and smaller local enterprises, sometimes public services, sometimes private enterprises. The recent liberalization of energy markets and the introduction of competition through the breaking of the traditional regional monopolies of power companies has led to the emergence of new private energy companies. Meanwhile, even large power corporations, car manufacturers, and the oil industry have committed to bioenergy, although frequent conflicts about the future role of alternative energies remain.

Environmental Community

The assessment of bioenergy in the environmental community is relatively controversial. On the one hand, environmentalists have long demanded a turn from fossil and nuclear to renewable energy sources and warned about the exhaustibility of oil, coal, and gas. On the other hand, many environmentalists decline new land use forms with potentially damaging effects on species and habitats.

Regional Politicians

Regional policies promote the settlement of bioenergy businesses in many ways in order to boost local economies. In the economically underdeveloped regions of the EU in particular, a multitude of public programs offers incentives for regional development, and bioenergy projects are found in most of these programs. In addition, local administrations often support bioenergy by heating public buildings with regionally produced biofuels.

Private Households and Businesses

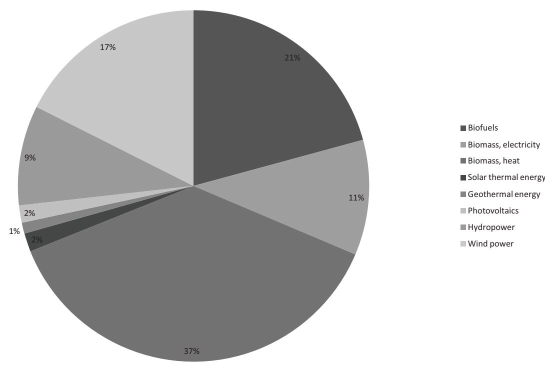
Private households and businesses are the potential recipients of bioenergy and finance the sector with their energy bills. There are two basic ways of financing bioenergy use. First, Germany has established a renewable energy portfolio standard and forces oil companies to add a share of biofuels. Hence the costs for the promotion of renewable energies are passed on to all energy users, whether they agree or not. Second, energy consumers have the choice of paying an increased fee for green power. Certification schemes guarantee that this power has been generated from 100 percent renewable sources.

Section 4: Status Quo of Bioenergy Use and Biomass Potentials

In 2007 around 2,044,600 ha (corresponding to 17.2 percent of German arable land) were cultivated for the production of renewable resources.[40] Since 1998, the area of land dedicated to renewable resources production has grown by almost 400 percent. Eighty-seven percent of this area was used for energetic purposes, while that used for material purposes was comparatively low (13 percent). Dominating uses are the cultivation of rapeseed for biodiesel and plant oil production (1,120,000 ha), of corn and other cereals for biogasification (400,000 ha), and of sugar and starch containing plants for ethanol production (250,000 ha). Additionally, a part of German grasslands is used to cultivate gramineous biomass, and agricultural and forestry residues have applications in the bioenergy industry. Still, it is hardly possible to indicate the area impact of these uses. Energetic use of woodfuels from forests was estimated to around 20-25 million cubic meters (m^3) (25 percent of total forest harvest) in 2006.[41]

In Germany 690 PJ equivalents of primary energy were generated from biogenic fuels in 2007. Figure 2 shows that bioenergy is currently the most important regenerative energy carrier: About 69 percent of renewable end energy is biomass-based. Ninety-three percent of renewable heat, 100 percent of renewable fuels, but only 22 percent of renewable electricity are derived from biomass. Biomass was overwhelmingly used to generate heat (303 PJ), while power generation (177 PJ) and biofuels production (210 PJ) were less dominant in terms of energy provision. In sum, bioenergy contributed around 7.3 percent to Germany's 2007 total end energy consumption.[42]

Figure 2: *Energy supply from renewable resources, Germany, 2007*[43]



The situation is similar in the European Union: Bioenergy provided around 62 percent of renewable energy generation in 2006, which corresponds to about 5 percent of total end energy consumption. Front runners in terms of absolute biomass-based end energy generation were Germany (128.5 TWh), France 124.6 TWh), and Sweden (95.3 TWh).[44]

Total electricity generation from biomass added up to 19.7 billion kWh in 2006 (FNR 2007) and took place in combined heating and power plants using biogas, plant oil, or solid biomass as feedstocks. The number of biogas plants has more than doubled in recent years. In 1999 there were around 850 plants; in 2006 around 3,300 plants with an installed load of 950 megawatt electrical (MWel). These plants are situated on agricultural enterprises in most cases and are powered with animal excrements, biogenic wastes, and energy crops. In the same year around 237 MWel were installed in 1,800 plant oil CHPs and around 1,094 MWel in 162 solid biomass CHPs.

Heat supply came partly from CHPs, partly from own heating plants. The number of small heating systems for solid biomass (e.g., fireplaces, tiled stoves) was estimated at 8.9 million in 2002, the number of pellets-fueled heating systems and stoves at 70,000 in 2006. In the industrial sector, an estimated 77,500 biomass-fired boilers were operating in 2002.[45]

German production capacity of biodiesel augmented heavily from 250,000 t in 2000 to 2.72 million t in 2006. In the latter year thirty-four plants produced biodiesel; sixteen additional plants were under construction or planned. Large-scale plants for bioethanol are rare yet: In 2006 five plants with a capacity of around 612,000 t per year were operating, and four additional plants were in construction or in the planning stage, especially in northern and eastern Germany.[46] Biodiesel consumption accounted for 2.50 million t in 2006, bioethanol consumption for 0.48 million t, and consumption for plant oil as pure fuel in converted motors for 1.08 million t.[47]

The availability of bioenergy carriers is a figure both highly decisive and very difficult to assess. Theoretical, technical, economic, and accessible potentials may vary seriously, and their assessment depends on external conditions that are changing over time.[48] A scenario approach appears therefore advisable. A seminal study of biomass potentials in Germany[49] formulated various scenarios that demonstrate the array of possible developments. Two contrasting scenarios are *UMWELT* (environment) and *BIOMASSE* (biomass). The *UMWELT* scenarios includes strong restrictions of bioenergy development in terms of environmental and nature conservation and identifies the lower end of biomass potentials. The *BIOMASSE* scenario presents the upper limit of biomass potentials without far-reaching conservation restrictions. Moreover it assumes maximal technical progress and a determined political support of biomass use. According to these scenarios biomass might cover a share of 6 percent (*UMWELT*) or 9 percent of primary energy consumption by 2020. This corresponds to 596 PJ from biomass residues and 226 PJ from energy crops in the *UMWELT* scenario and 623 PJ from residues and 519 PJ from crops in the *BIOMASS* scenario. Interestingly, 2007 de facto bioenergy uses seem very close to the *UMWELT* scenario, and even the potential of the *BIOMASSE* scenario seems to be fully developed soon if bioenergy growth continues at its current pace.

Assuming a "sustainable" scenario which is located between the more extreme variants of *UMWELT* and *BIOMASSE*, the 2050 contributions of biomass to energy supply might be larger than those of all other regenerative energy carriers in combination. This considerable potential becomes visible by the fact that biomass use in 2050 would take the same share as energy supply from hard coal and lignite.[50]

The use of biogenic residues will outperform that of energy crops in these scenarios. According to them the use of wood and straw residues, of biogas from wastes, liquid manure, and whole plants, and the cultivation of perennial energy crops will become important. Among those feedstocks losing significance will be oil plants as feedstock for biodiesel, cereals as basis of bioethanol, and corn as feedstock for biogas production.[51] The *UMWELT* scenario includes the energetic use of grasslands on 240,000 ha (*BIOMASSE* scenario: 190,000 ha) until 2020. Perennial energy plants will then cover 550,000 ha (*UMWELT*) or 220,000 ha (*BIOMASSE*), and other arable land will be used by 1.65 million ha (*UMWELT*) or 3.04 million ha (*BIOMASSE*).

Various studies have shown that bioenergy carriers might contribute around 100,000 to 400,000 PJ per year to global energy supply by 2050. Global primary energy consumption amounted to 410,000 PJ per year in 1999-2000. However, there is a large variation in estimates. This is owed to the fact that the two most decisive variables, the availability of land for biomass production and future biomass yields are extremely difficult to predict.[52]

Section 5: Environmental and Socio-Economic Impact

CLIMATE CHANGE MITIGATION AND ENERGY BALANCES

A key variable for the assessment of bioenergy is the potential reduction of GHG emissions. This potential varies strongly between different bioenergy lines. Life cycle analyses (LCA) for bioenergy uses are complex and highly controversial: The system limits in terms of included environmental parameters and steps of the production process are rarely standardized, and assessments can hardly keep up with the rapid developments of the field.

Common opinion suggests that the energetic biomass use has no impact on climate as it releases only so much CO_2 to the atmosphere as is assimilated through plant growth at the same time. This view, however, neglects that biomass production requires inputs of fossil resources through fertilizer and pesticide production and through other effects during cultivation and conversion of biomass. To reliably assess GHG reduction potential of the different pathways and end uses of bioenergy, a comparable methodology that looks at the complete life cycle is essential. Environmental impacts occur along the complete chain that reaches from crop breeding over biomass cultivation, transportation, processing, energy conversion to emissions, and wastes produced. The comparison of various bioenergy strategies is aggravated as most life cycle assessments have chosen different system limits, and many have neglected those emissions that result from biomass production. This neglect is severe as agriculture is Germany's largest source of laughing gas (N_2O) and methane (NH_4) emissions and contributes around 13 percent of total GHG emissions, mainly due to nitrogen fertilizer inputs.[53] Moreover, indirect land use changes caused by the spread of energy crops may reduce carbon sinks in soils: If, for example, organic soils (which are widespread in northern Germany) are drained or tilled for energy cropping, the GHG balance will be very negative due to the resulting loss of soil carbon storage. Research has shown that a 5 percent decrease of terrestrial carbon stored in forests, grassland, fens, bogs, etc. would release GHG in the same dimension as the complete combustion of fossil energy carriers produces in Europe within a year.[54] Therefore, enhancing terrestrial carbon sinks through afforestation of farmland or avoided deforestation may yield considerably higher mitigation effects per area of land than bioenergy production.[55]

Life cycle assessments of bioenergy in Germany and the EU have been presented by leading experts.[56] Just one of these has included GHG emissions through production of mineral fertilizers and pesticides, energy consumption in the processing and transportation process, and the release of GHG other than CO_2 during combustion, and none has considered induced land use changes, soil carbon losses through tillage, petroleum consumption of agricultural machinery, and GHG emissions resulting from irrigation.[57] The Scientific Board for Agricultural Policy[58] concluded in a comparative review of available LCAs that combined heat and power generation based on wood chips from energy forests or on biogas from manure achieve the lowest GHG avoidance costs (around €50 per t CO_2 eq.). In contrast, rapeseed-based biodiesel and corn-based biogasification produced avoidance costs from €150 up to €300 per ton carbon dioxide equivalent (CO_2 eq).[59] In terms of land area, combustion or gasification of wood chips provided more than 12 t CO_2 eq. per ha, while corn-based biogasification rendered 8 t CO_2 eq. per ha and bioethanol or biodiesel production only 3 t CO_2 eq. per ha. The assessment by the German Advisory Council on the Environment has come to the same results.[60]

A decisive parameter for the calculation of reduction potentials is the reference system chosen, as the substitution of GHG intensive processes is most efficient in terms of GHG emissions reduction. In consequence biofuels have a far lower reduction potential than substituting coal by biomass in power generation.

The specific energy yield per area is another important figure for the comparison of different bioenergy strategies and for the preference of those pathways with the largest net energy output. A comparison of the most common pathways has pointed out that the use of solid biomass (e.g., woodfuels from short-rotation crops) for heat or combined heat and power supply achieved the highest energy yields (more than 150 GJ per ha).[61] Biogas-based CHP also proved to be quite energy efficient, while power generation based on plant oil and first-generation biofuel production from rapeseed and cereals had the lowest energy yields. This corresponds to studies carried out in the U.S. that concluded that current forms of bioethanol and biodiesel production have low or even negative net energy outputs.[62] An approach that might be tested in Germany as well is the use of mixtures of native grassland for biomass cultivation (low input-high diversity systems) that provided substantially more usable energy, greater GHG reductions, and less agrichemical pollution per hectare than both corn grain ethanol or soybean biodiesel.[63] Specifically, the ratio of energy output per energy input (necessary in farming and conversion processes) was 5.44 in the case of ethanol from mixed grassland biomass compared to 1.25 for corn grain ethanol. Previous studies came to similar results, finding that native switchgrass were fifteen times more energy efficient and thirty times more efficient in GHG reduction than corn.[64]

Despite the lack of specific and comparable information, a few generalized insights can be concluded:

First, the use of most kinds of residues is generally superior in terms of both GHG reduction and energy efficiency to that of energy crops. Second, low-input cultivation systems have in most cases a better energy balance than conventional farming systems relying on intensive fertilizer, pesticide, machinery, and irrigation inputs, especially if perennial and lignocellulosic crops are used. Third, stationary applications (heat and power) reduce GHG emissions more cost-effectively than biofuels. Efficiency increases further if energy conversion processes are kept simple. It has been estimated that changes in public support toward the most efficient bioenergy lines (at constant investment of land and financial resources) would more than triple contributions of bioenergy to GHG reduction.[65]

NATURE AND LANDSCAPE CONSERVATION

A comprehensive assessment of the impact of energy crops on nature and landscape conservation is impossible without knowledge of specific site conditions and land management forms. Among the site factors that need to be considered are ecological sensitivity of the area, soil types, geomorphology, and a possible protected area status. Moreover, the assessment depends on the comparison with a previous or potential alternative land use option and on possible leakage effects. Depending on the production system, bioenergy may trigger land cover changes (e.g., conversion of grassland into arable land), changes of agricultural systems (e.g., changes of crop rotations), and changes of the management practices within an agricultural system (e.g., increased fertilizer input).

Shifts in the distribution of forest, grassland, and arable land in the cultural landscape are the best visible form of change.[66] The assessment of a potential transition from agricultural to forest land depends on the local settings: In an intensively used agricultural landscape, increased forest cover may provide net benefits for conservation through a diversification of available habitats and an increased recreational value of the landscape.[67] In forest rich landscapes, e.g., in Germany's low mountain ranges, a further increase of forest cover would be considered undesirable. Thus the assessment of forest expansion needs a regionalized assessment and localized visions for the future landscape.[68] Conversion from forest to arable or grassland is not possible in most cases, as this is prevented by effective forest legislation in Germany. The transition of grassland into arable land has clear negative environmental effects, as especially low-intensity grasslands harbor a rich biodiversity and such a transition is related to considerable releases of GHG emissions from soils. It has been estimated that up to 8 percent of grasslands have been converted to arable land in past years, especially in northern Germany. Meanwhile some German states have even been warned by the EU Commission to take effective measures against grassland conversion. As the grassland to cropland conversion often occurs on wet sites and on organic soils, it proves counterproductive both for nature conservation and climate protection.[69] Rather, a reverse transition of arable land (especially in environmental risk areas such as lands subject to heavy soil erosion or sites close to river courses) into grassland or perennial cultures would be desirable.[70] From a nature conservation perspective the establishment of energy forests on intensively used arable land would be favorable in most cases.[71] Conflict potential is generally lower when using residues from agriculture and forestry compared to energy crops: they do not lead to changes at land cover level, although they can imply ecological consequences at the level of management practices.[72]

An important aspect is that biomass production may cause not only direct land cover changes but also so-called leakage effects. Leakage has been defined as "activity-induced changes in land use that occur outside the area in which the activity takes place." [73] For example, biomass production might displace fodder cultivation from fertile sites. In consequence fodder cultivation might be moved to more marginal sites, where it would induce land cover changes. Leakage may take place both at a regional (when hitherto existing uses are shifted to adjacent land) and a global scale (when uses shift to other parts of the world).

The impact of these land cover changes for nature conservation varies in regard to first generation and second generation scenarios of biomass use. First generation biofuels (e.g., grain ethanol or rapeseed-based biodiesel) are overwhelmingly produced in the form of energy crops. In most cases these are placed on fertile soils, where direct competition between food and fuel production arises. Relevant for conservation is the case of theapproximately 10 percent of

European crop lands that EU agricultural support regulations require to be set aside, i.e., to be retired from any kind of conventional agricultural production. But set aside land may be used for energy crop cultivation, which compromises the conservation value that fallow set-asides have, especially as habitats for farmland birds.[74]

As the limits of land available to conventional energy crops become more evident, second generation biofuel strategies (e.g., "Biomass to Liquid" synfuels or "cellulosic ethanol") focusing on biomass feedstock based on wastes instead of specific energy crops are under way. Using biomass wastes from landscapes is a double-edged sword: It may trigger low-intensity landscape use, which contributes to shaping high nature value farmland in Europe. For example, a conservation-oriented management of traditional coppice forests, hedgerows, or marsh lands might be enhanced. But environmentally destructive forms of residue use may also be promoted through using biomass wastes, e.g., intensive wood harvesting, the complete removal of woody debris and dead wood from forests, or excessive straw use from crop fields.

Regarding the level of agricultural systems and management practices, several factors determine the environmental outcome: The crops and cropping systems used, land use practices and management intensity, and residue management (i.e., the amount of agricultural residues extracted, stubble management, and a potential return of fermentation residues to the land). As quality demands are lower than for food production, biomass crops might in principle allow less intensive practices. Diversification of crop rotations, reductions in mineral fertilizer and biocide use, the use of a broader spectrum of traditional and modern crop species and varieties, the design of mixed cropping systems, longer harvest intervals, and an increase of physical landscape structure are conceivable. However, the incentives of the current policy framework follow a different approach, and so far biomass cultivation practices have been largely derived from conventional intensive agricultural systems.[75] Therefore the opportunities that bioenergy offers for more environmentally sound agricultural practices have so far remained unused in Germany.

In forestry the impact of biomass production has been lower than in agriculture, as timber production remains the dominant goal of forest management. But depending on the amount of biomass removed and the management practices applied there might be environmental impacts. Expected changes are increased biomass removal from forests, an expansion of extracted wood fractions (e.g., small-sized thinning residues and brushwood), and an intensified use of harvesting and processing machinery. This may have consequences for nutrient budges, for habitats and physical structures of conservation value, for forest soils and water cycles, and for forest stand structures.[76]

Along conventional biomass production systems there are research and demonstration activities to use landscaping materials from conservation lands for bioenergy supply. The idea is to establish low-input land use systems that generate win-win situations for renewable energy supply and nature conservation. Potential land use systems include traditional hedgerow landscapes,[77] traditional coppice forests,[78] extensively used grassland in low mountain ranges,[79] and fens.[80] Biomass use on conservation lands might develop a largely undeveloped biomass potential, offer a productive way for the disposal of landscaping residues, and help alleviate the costs of nature conservation management. Both technical and economic reasons hamper a large-scale diffusion of such energetic uses. Often energy density of this kind of biomass is too low to support the costs of its harvest, and advanced harvesting technologies are lacking, especially for woody biomass. Still, with the recently introduced bonus payment for the use of landscaping materials in the EEG this might change in future.

There has been an extensive theoretical debate about the conceptualization of changing agricultural regimes.[81] In Europe a gradual shift from productivist to post-productivist schemes has been confirmed since the 1980s, although the post-productivist transition varies strongly over space and time and is in no means a unidirectional development.[82] Productivism in this context refers to an intensive, production-oriented land use that is specialized towards few products and concentrated on a small number of sites. It is focused exclusively on agricultural production and related to a number of environmental problems. Post-productivism is a more extensive, less productive, diversified, and disperse use of cultural landscapes and rural areas that strives for compatibility with environmental objectives.[83] This conceptual debate clarifies the basic significance of bioenergy for rural areas: Bioenergy has provoked a new trend toward "productivism," with all related benefits and costs—the consolidation of the agricultural sector on the one hand and environmental problems related with intensive land use on the other hand.

SCARCITY OF LAND

With a population density of 230 people per km², land is a scarce resource in Germany. Around 53 percent of land cover is agricultural land, 30 percent forests, 13 percent settlement and infrastructure areas, and 4 percent other land cover.[84] In order to fulfill the various societal demands on land, the notion of multifunctionality (the idea to promote a variety of functions, from agricultural commodity production to landscape beauty to biodiversity conservation, on the same piece of land) takes an important position both in agriculture and forestry. While land scarcity has been a pressing issue in central Europe over centuries, the debates on agricultural policy of the 1990s have been dominated by issues of agricultural surplus production. As a result, several policy schemes reaching from early retirement schemes to schemes for the afforestation of agricultural land to the forceful set aside of 10 percent arable land were designed to reduce excessive commodity production in the EU. Land abandonment was a major issue, especially in the mountain areas of Europe.

The strong demand for biomass has reverted this trend and led to a new scarcity of agricultural land. In contrast to other renewable energy sources, e.g., wind power, that imply only a single identifiable point source of environmental effects, biomass production spreads out across extensive areas of the terrestrial biosphere. As mentioned, an approximately 7 percent share of bioenergy supply is impacting 17 percent of arable lands even today (plus an unspecified area of forests, grasslands and arable lands outside Germany). By this, bioenergy may be the renewable energy carrier with the highest relevance for other land uses, especially for nature and landscape conservation. The real dimension of land scarcity depends on a number of land use trends, which partly act in opposite directions. These comprise the Common Agricultural Policy of the EU, the future significance of organic agriculture, developments in forestry and nature conservation, the reduction of agricultural land through urban sprawl, and future agricultural yields.[85]

Overall agricultural policies in the EU have experienced a basic reform in past years, whose exact impact on the availability of land is as yet unknown. From 2013 farm subsidies will be generally decoupled from agricultural production and allocated as area payments. This payment occurs independently whether agricultural land is used for commodity production or just for landscape management. Consequently, market demands will drive agricultural production stronger than today. Another determinant on land availability may be the enlargement of the EU to a total of twenty-seven member states. The expansion of the European Union has increased the amount of arable land per EU inhabitant, as eastern Europe has relatively large areas of arable land, and a relatively small population. Therefore the enlargement may reduce land scarcity and offer potentials for biomass production.[86]

As result of bioenergy dissemination, energy and food/feed crop markets have started to interact, which may be in part responsible for the worldwide increase in food prices. For example, the recent increase of world market prices for sugar has been attributed to the expansion of ethanol production. In 2006, about 75 percent of renewable resources crops were cultivated on regular arable land (and not on set aside lands), which was then no longer available for food and fodder production. For instance, Isermeyer and Zimmer reported a regional displacement of animal production through the spread of biogasification facilities in Germany.[87] Indicators of growing competition for land are leasehold prices for arable land that have been rising for years in Germany. An allocation of arable land toward food or biomass production through land use planning has proven unfeasible so far.[88]

The consumption of organic foods has steadily grown in Germany and the EU over recent years. Organic agriculture has higher area demands than conventional agriculture, as area yields are lower due to more extensive cultivation forms. Area demands vary depending on the product, but have been estimated to be on average 30 percent above those of conventional agriculture. German agriculture is less and less able to feed the demand for organic food, and a greater and greater share of organic food is important, as for domestic agriculture energy crops seem more profitable. One possible explanation for the gap between high consumer demand and low supply of organic food by German farmers is that biomass cultivation proves easier to implement and more profitable than conversion to organic food farming.

Competition for commodities increases not only in agriculture, but also in forestry, although the mean stock of wood in Germany's forests increased by 18.8 percent from 1987 to 2002, which is the highest value among all European countries.[89] However, the bioenergy sector is competing for thinning wood with a wood-processing industry that is long established and quite strong, especially in eastern Germany. In theory, a considerable additional amount of wood could be taken sustainably without lowering the standing stock in the long run. But in practical implementation the bioenergy industry is very often hampered by not cost-covering prices offered by the bioenergy sector, strong demand for forest wood from competing industries, lacking mobilization of forest wood, a preference among forest managers to sell products to the wood-processing industry, and lacking heat distribution infrastructure.[90]

Further competition may arise with nature conservation, especially when agricultural land is supposed to be converted into conservation lands, e.g., in large protected areas or for reasons of creating habitat connectivity. Specifically, Germany's federal conservation act requires that 10 percent of the country should be used for the establishment of a nationwide network of habitats. Other area demands arise from the "Natura 2000" conservation network of the European Union, which currently extends to over 9.3 percent of terrestrial Germany.[91] However, most of these designated conservation lands are cultural landscapes. Only in very few areas (e.g., in the core zones of national parks or lands dedicated to the conservation of evolutionary processes) would agricultural and forestry uses be outright forbidden. In most cases certain forms of land management that are compatible with conservation goals will be tolerated or even requested.

Another factor that contributes to increasing land scarcity is the ongoing conversion of agricultural land into settlement and traffic areas. The drain of land resources was reduced from a long-term average of 125 ha per day to 106 ha per day in 2006, but is still far from the 30 ha per day-value that has been defined target in the federal government's sustainability strategy for the year 2030.[92] As forest area is strictly protected by law, most conversion losses pertain to agricultural land.

But there are also factors that will reduce land demand in Germany. Increases in per area-yields have been impressive, and improved cultivation systems, crop breeding, and precision farming promise further progress. In past decades, productivity on Germany's crop fields was increased by 1-2 percent per year. Continuing progress would provide an area reserve of 100,000 ha per year (if demand for agricultural commodities would remain static).[93] Although the impact of climate change on agricultural productivity is subject to a lot of speculation, the effects of climate change and increased atmospheric CO2 are expected to lead to overall small increases in European crop productivity. Combined yield increases of wheat by 2050 could range from 37 percent to 101 percent, depending on various scenario assumptions.[94] However, these increases will probably much smaller than those resulting from new crop varieties and better cropping practices. Finally, demographic change leads to sinking population numbers in the years to come. By this domestic demand for food, fiber, and energy will decrease. Predictions assume that population will decline from 82 million inhabitants in 2006 to 69-74 million inhabitants in 2050.[95] However, area demand per inhabitant depends not only on the number of inhabitants, but also on food consumptions, and especially on the consumption of animal products, which is far more area-intensive than a vegetarian lifestyle.

COMPETITION OF BIOMASS OPTIONS

The diffusion of bioenergy has not only created competition for land with uses other than bioenergy. Rather, it has also led to a competitive situation between different bioenergy lines, and some actors might become victims of the very success of bioenergy growth. For instance, Germany's largest ethanol plant in Schwedt (in the state of Brandenburg) had to shut down its operation within one year after opening, as the recent rise of rye prices no longer allowed a competitive ethanol production (meanwhile the plant has opened again, but now on the basis of imported sugar). In general, prices for most agricultural commodities had increased so much (among other reasons through the boom of bioenergy) that the remuneration for electricity from biogasification had to be increased in the latest amendment to the EEG to secure the future profitability of biogas facilities.

As indicated in Section 3 there is an ongoing debate whether scarce biomass resources should be used primarily for power and heat or for biofuel production. An argument for use in transportation is that biofuels remain the most immediate sources of alternative energy for vehicular use.[96] The only mid-term alternative to biofuels would be fuel production from liquefied coal—which implies more than twice as much carbon emissions as from fossil diesel.[97] Still, these arguments would be true only after fossil fuels would have been completely replaced in all other sectors except transportation—a scenario very far from today's reality. Arguments for the preference of heat and electricity are clearly higher energy efficiencies, lower costs of GHG saving, and a higher allocation of added value to rural areas. Moreover, there is a significant potential for energy saving through sinking the automobile fleet consumption, so that the arguments for preferring biofuels seem hardly convincing.

A problem of defining priorities for one of the three strategies "biofuels," "heat generation," and "CHP" is that there are potential conflicts between the targets of mitigating GHG emissions, fostering energy security, and increasing employment, so that trade-offs need to be addressed.[98] If GHG emission reduction is the main target, then CHP seems the superior strategy, especially when based on woodfuels. Decentralization and cost-efficiency of energy supply are realized most effectively in the heat sector. Automotive biofuels, in contrast, contribute little to climate protection and decentralized energy supply, and they incur high costs for fuel consumers. The intensity of employment has not been studied for the different bioenergy lines, but it can be assumed that small bioenergy plants are generally more employment-intensive than larger ones. Biofuels for transport reduce the dependency on imported oil, while the use of biomass for heat and power generation lowers the dependency on imported natural gas and improves the security of electricity supply. As Berndes and Hansson stated: "The relative appeal of the different bioenergy options […] depends on how oil and gas import dependencies are weighed relative to each other."[99] If coal-to-liquid fuels should expand in transportation, then the specific role of the different bioenergy lines in relation to climate targets and security of supply will have to be newly defined. An area that has been widely neglected in Germany is the production of biomaterials from biomass, although there is evidence for a positive environmental balance.[100] For example, the creation of value achieved by using thinning wood for material uses is estimated around ten times higher than that by energetic uses.[101]

RURAL DEVELOPMENT AND EMPLOYMENT

Biofuel supporters argue that bioenergy diffusion may secure the future of rural populations reliant on the cultivation of crops that are no longer globally competitive.[102] The story goes that bioenergy triggers investment and creates or at least stabilizes jobs and thereby supports agrarian-based rural and regional economies.[103] If biomass is used for decentralized energy supply, the related regional business cycles are supported. However, a comprehensive balance of all costs and benefits for rural areas is not available yet.

In 2007 around 96,100 persons were employed in the bioenergy industry (including those employment effects that are induced by the demand for fuels); the renewables industry altogether employed around 250,000 persons.[104] Approximately 53 percent of employment effects in bioenergy occurred in the area of biomass supply. From 2004–2006 the number of employees in the bioenergy industry had increased by 38,600 (which was the highest increment among all renewable energy sectors). Unfortunately, the available data do not allow allocating these effects specifically between rural and urban areas. But a comparison of renewable energy use in four German regions has shows that in rural eastern Germany a great part of inputs have been obtained from other regions. In consequence, a significant part of value creation in the field of power plant construction does not remain in the region, which is the result of the lack of the respective industry clusters.[105]

Bioenergy plant production realized a total business volume of €2.39 billion in 2007 (power generation: €1.04 billion, heat supply: €1.35 billion). Plant operation had a €7.86 billion volume (automotive biofuels: €3.82 billion, power: €2.47 billion, heat supply: €1.57 billion).[106]

Table 2: Scenarios of gross employment in the German bioenergy sector until 2030[107]

Demand component	2010	2020	2030
Automotive biofuels production	29,432	39,335	66,098
Biomass supply	15,191	24,089	30,203
Production and operation of plants ('cautious')	48,116	47,717	43,870
Production and operation of plants ('cautiously optimistic')	51,488	54,239	54,709
Bioenergy total ('cautious' export scenario)	92,739	111,141	140,171
Bioenergy total ('cautiously optimistic' export scenario)	96,111	117,663	151,010

The further development of employment in bioenergy depends on a multitude of factors. A study of the German Ministry of the Environment (BMU) differs between "cautious" and "cautiously optimistic" assumptions about the development of world market shares of German enterprises. A decisive variable is whether fuels are produced domestically or imported from abroad. The BMU study assumes that fuels for heat and power plants are produced exclusively within Germany, while 45 percent (2020) or 20 percent (2030) of automotive biofuels will be imported from abroad. According to these scenarios, the number of jobs in the bioenergy sector might further increase significantly (Table 2). The study calculates a total number of 330,000–415,000 jobs in all areas of renewable energy use until 2030. Assuming a significant decrease market growth of renewable energies and of public support, the number of jobs would reduce to only approximately 180,000–197,000 by 2030.[108]

The numbers of jobs mentioned are gross employment effects, which are, at least for 2007, not very controversial. Very difficult to assess are net employment effects. They consider the so-called budget effect which describes the additional costs that the national economy has to cover for renewable energy supply compared to that from other energy sources. Net employment effects also consider effects of import substitution, i.e., the fortification of domestic demand and supply through the replacement of mostly imported fossil energy carriers. Net employment effects are probably significantly smaller than gross employment effects.

Net employment effects can be best assessed in a comparison of two internally consistent scenarios across a longer period of time. A comparison of one scenario assuming a dynamic, target-oriented expansion of renewable energies with another on assuming a long-term low expansion of renewable energies shows that the former has a clearly positive net employment of 73,600 jobs by 2020 and 84,410 jobs by 2030. This positive macroeconomic impact can be deducted on the demand side to investments in equipment and exports. With an increasing growth of the world market for renewable energy technologies export effects become more important. The budget effect strongly depends in its—positive or negative—effect on the assumed development of energy prices. Negative employment effects can be expected for the improbable case that technology exports are disrupted and that energy prices sink to the level of 2000–2002.[109]

In the case of bioenergy, critics argue that the impact on employment in agriculture would be a zero-sum game, as long as biomass displaces food and feed production and, for example, corn would be used for biogasification in place of cattle fattening.[110] More promising, strategies that use biomass residues that have not been used so far and that are not in competition with food demands, e.g., the use of straw or landscaping clippings.

In conclusion, to maximize employment, public support needs to differentiate more. Employment potential seems to be in plant development for exportation, on the one hand, and in use pathways that imply a high regionalized creation of value, especially in rural areas, on the other hand. The former can be promoted through research and demonstration activities, the latter via regional development schemes. Blanket subsidies for facilities seem minimally helpful.

Section 6: The International Dimension

The rise of bioenergy use in Germany has created, as demonstrated in the previous chapter, an enormous demand for land. In consequence, a significant share of biofuels will need to be imported from abroad to cover the needs for existing and planned bioenergy facilities. Importation of both unprocessed and processed biofuels can be expected.

In order to diversify energy supply and to reduce global GHG emissions to a significant degree, bioenergy production needs to be cost-efficient. Therefore a global trade of bioenergy carriers seems desirable in principle, as e.g., bioethanol can be produced at a significantly lower price from sugarcane in Brazil than from rye in German ethanol plants.[111] Moreover, the potential for GHG reduction is around 6.5 times superior for ethanol based on Brazilian sugar cane compared to U.S. grown corn—2.08 t carbon per ha and year[112] compared to 0.32 t C.[113] Consequently, the European Commission has opted for a "balance" between domestic biomass cultivation and biomass imports[114] and thus strives to achieve domestic agricultural development and at the same time promote global bioenergy development.

The European Union has always been a net importer of agricultural commodities—even before the current biofuels boom. For the 1990-2000 period the agricultural land area needed for the production of 45 basic agricultural resources and 102 processed agricultural products per inhabitant of the EU-15 was estimated to 0.37 ha within and an additional 0.07 ha outside Europe.[115] Thus, the European Union has been living beyond its environmental limits (in terms of demand for land) even before the rise of bioenergy, caused among others by high levels of feed importation. This "virtual" occupancy of agricultural land use outside Europe is very likely to increase through bioenergy expansion. It will cause pressure to convert natural and nature-like ecosystems to intensive farming area in regions of the world with weak governance. It has been estimated that—without any other change of the production and consumption of agricultural goods—the agricultural land needed to supply 18 percent of the 2030 EU-15 gas and diesel consumption by biofuels would increase up to a range between 0.48 and 0.61 ha per inhabitant.[116] This has to be discussed against the background of a limited global agricultural surface and a growing world population, as the global availability of arable land and land for permanent cultures is expected to decline to 0.19 ha per inhabitant by 2030.[117] Three quarters of the global land use of the EU-15 is allocated to animal and dairy production. As animal based food requires roughly about ten times more land than plant based food, using the same amount of net primary production, the global availability of land for biomass production will depend strongly on future patterns of meat and dairy consumptions.

The importation of biofuels from developing countries is related to a plethora of social and ecological problems, whether deforestation or the displacement of small-scale subsistence agriculture. Therefore, German society bears responsibility for using the environmental space beyond the borders of the EU in a sustainable way, and it should watch very carefully that bioenergy support does not turn into "perverse subsidies."[118] Promoting primary tropical forest conversion into palm oil plantations in Indonesia is a prime example of green subsidies gone wrong terribly. It is therefore imperative to develop ecological and social minimum standards for biomass production which need to be supervised through sustainability certificates for internationally traded biofuels.[119] Other sectors, e.g., food production, forestry, and fishery, have demonstrated the feasibility of such an approach.

An important aspect is that all biogenic resources are considered directly competitive and substitutable agricultural commodities in a legal definition. By this they are subject to the negotiations of the World Trade Organization (WTO) on the cutback of trade barriers. As many countries outside Europe are able to produce biofuels at significantly lower costs, the European biofuels industry might experience a considerable pressure of competition. An important aspect of expanding domestic biomass production is whether this remains economically sustainable after a possible dropout of agricultural protection. Current tariffs and technical trade barriers that are imposed on the importation of bioethanol and biodiesel have protected domestic biofuel production quite effectively. For example, an import tariff of €0.192 per liter is currently imposed on Brazilian ethanol. Also, European norms have so far inhibited biodiesel production from crops other than rapeseed.[120] In the case of biofuels it seems clear that domestic agriculture will not be competitive against imports of, for example, Malaysian palm oil or Brazilian ethanol on sugar-cane base if these barriers should fall one day. More sustainable seem biomass-based power and heat generation as these—unlike biofuels—are not considered agricultural commodities for the purpose of WTO negotiations. Therefore, decentralized systems such as on-farm biogasification plants seem more sustainable in terms of long-term competitiveness than centralized plants such as biodiesel refineries.

Section 7: Pathways to Sustainable Biomass Use

Bioenergy use has grown at a fast pace in Germany. In general, bioenergy use can substitute petroleum, mitigate climate change, and create rural employment, but the currently dominating bioenergy technologies have often contributed disappointingly little to these sustainability goals. The massively subsidized production of biodiesel and bioethanol has proven especially harmful to the environment and cost-intensive to taxpayers and energy consumers. Therefore, steps in all fields of the bioenergy sector are needed to get bioenergy into sustainable pathways. Necessary measures include:

- Recognition of the limits of bioenergy expansion
- Making use of policy tools for bioenergy sustainability
- Prioritization of bioenergy pathways
- mprovement of energy conversion efficiency
- Maintaining the integrity of ecosystem services and multifunctional landscapes
- Development of waste biomass potentials
- Establishment of novel land use systems

RECOGNITION OF THE LIMITS OF BIOENERGY EXPANSION

As agricultural and forestry land is highly demanded from various user groups, future expansion of domestic bioenergy provision will necessarily be limited—even when assuming that the massive public support of bioenergy will continue and that petroleum prices will further rise. In the long run, solar energy techniques might outperform bioenergy, as it produces higher energy yields per area and does not depend on arable land. Challenges such as competition with food production, leakage effects, and related reductions of carbon sinks in soils are far smaller challenges for solar energy than for bioenergy. Therefore bioenergy can cover only a relatively small part of energy demand and should be just one (and maybe not the most important) in a blend of various energy carriers. Moreover, even improved bioenergy systems will have certain negative effects on the environment if applied on a large scale. All efforts to achieve sustainable development by bioenergy are therefore in vain if society does not decrease its primary energy needs through a combination of energy sufficiency and rational energy use, i.e., through a resource saving application of energy through thermal insulation, application of high-efficiency devices, optimized logistics, and reduction of traffic.

MAKING USE OF POLICY TOOLS FOR BIOENERGY SUSTAINABILITY

The high dynamics of developments in the field require active control by state and society. Fortunately, governments can turn certain adjustment screws to control bioenergy development, as the whole sector has been built up through large amounts of public investment and other support policies. For example, the promotion of renewable power generation within the EEG framework imposed an extra €0.01 per kWh (around 5 percent of the costs of 1 kWh) to power consumers in 2007.[121] Therefore, the bioenergy sector should be expected to take its obligations to contribute to common welfare very seriously. The existing support framework offers various opportunities to prescribe more sustainable bioenergy strategies. In the EEG measures have been taken to promote more sustainable bioenergy uses (although more remain, especially in regard to the promotion of environmentally compatible biomass cultivation), whereas the implementation of sustainability issues into the German biofuels quota act are at a very premature stage.

PRIORITIZATION OF BIOENERGY PATHWAYS

It is important to notice that the production of a maximum amount of bioenergy should not represent a political goal per se. In fact, public policies should focus on the outcome and promote these bioenergy strategies that contribute most to climate change mitigation while considering overall ecological, economic, and social sustainability. Solutions may lie in a clearer definition of targets to be achieved with bioenergy and a straightforward orientation of support schemes along these targets. Currently, biogasification and solid biomass plants that combine power and heat supply are best able to reduce GHG emissions and to contribute to most of the other sustainability goals. In contrast, the construction of plants with a huge demand of homogenous biomass fuels with specified quality restrictions gives incentives for a large-scale monocultural agriculture and hampers the use of residues from landscape management and nature conservation activities, among others. These different contributions should be reflected in public promotion schemes. Parts of the specific problems of biodiesel and bioethanol can be met with the introduction of second generation biofuels (e.g., by using residues instead of energy crops), but others cannot (e.g., due to the necessarily centralized structure of fuel production). A focus on regionalized economic cycles in biomass logistics and conversion may help to keep a greater part of added value in rural areas and to optimize net energy outputs. It may also allow to return residues from fermentation or combustion processes onto agricultural land and thus to close nutrient cycles.

IMPROVEMENT OF ENERGY CONVERSION EFFICIENCY

The efficiency of energy conversion has often been neglected, which has corrupted the energy balance of many bioenergy paths. For example, processing heat is often wasted in biogasification and solid biomass plants—despite a special bonus in the EEG for combined heat and power use. Ideas to increase energy efficiency include the feed-in of biogas directly into the natural gas distribution system, which allows the supply of heat at those places where heat is actually needed, i.e., in urban areas. In all bioenergy fields there remains a huge potential of enhancing energy efficiency to the ingenuity of engineers. A shift of public means from the support of plants to the support of research and development might further boost ingenuity. For example, robust plant technologies need to be developed that allow the use of diverse fuels, as well as biomass with low calorific value or problematic matter composition in order to realize the synergies between cultural landscape management and energy provision as mentioned in Section 5.

MAINTAINING THE INTEGRITY OF ECOSYSTEM SERVICES AND MULTIFUNCTIONAL LANDSCAPES

Productivist agriculture and forestry have been responsible for a suite of environmental problems, from groundwater pollution to the degradation of natural habitats. Environmental research and advocacy over decades have led to a public recognition of the ecosystem that natural and seminatural ecosystems provide to society and to an implementation of environmental aspects into agricultural policies. Multifunctional cultural landscapes that are able to serve both productive and consumptive demands are highly appreciated and have evolved as a guiding principle of landscape development in central Europe. Unfortunately, there is a danger that uncontrolled bioenergy growth causes a rollback of land use toward productivism. So far, intensified and monostructural cultivation of energy plants focuses on quantitative biomass output per hectare. This tendency does not only neglect all other services of the agroecosystem to society; it also produces agricultural landscapes with a low resilience toward external stress and disturbances. Sustainable bioenergy strategies do not decrease the variability of land uses, but strive to rather increase the diversity and multifunctionality of landscapes and ecosystems. This is also important to gain societal acceptance for bioenergy use. Sustainable energy cropping systems:

- use robust plant breeds that are adapted to local site conditions and have low requirements toward soils, fertilization, and plant protection;
- maintain a diversity of crop species and varieties;
- apply the precautionary principle to the introduction of genetically modified organisms;
- utilize rotations of at least three crops;
- minimize inputs of mineral fertilizer and pesticides;
- minimize GHG emissions; and

- avoid conversion from grassland to arable land.[122]

DEVELOPMENT OF WASTE BIOMASS POTENTIALS

Despite the lack of a general framework for a sustainability impact assessment of bioenergy, it seems obvious that an increased use of biomass residues is a "no regret option" that is generally superior to that of energy crops. Ideally, the use of so far unused residues from cultural landscape elements (e.g., hedgerows, fens, coppices, extensively used grassland) might achieve considerable synergies between energy generation and cultural landscape management. Therefore, fuel supply policies should prioritize the use of biogenic wastes and residues from forestry, agriculture, and landscape management. However, the potential of unused biogenic wastes is limited, and environmental harm may arise if residues are taken excessively from forests or crop fields.

ESTABLISHMENT OF NOVEL LAND USE SYSTEMS

The changes caused by bioenergy growth demand a suite of adaptations in agricultural and forestry practice, as current forms of energy cropping are related to a multitude of negative effects on the environment. This results from the fact that production systems have been inherited from intensive food and fodder cultivation. To solve these issues, we need a two-tiered strategy: At short notice, good-practice standards for biomass production need to be designed. These might correspond to similar approaches in food production and could, for example, comprise principles of integrated crop protection, a reduction of fertilizer use, a minimum three-part crop rotation, and minimum shares of structural elements in the agricultural landscape. In the long run novel cropping systems are needed that are different from established agricultural systems and specifically designed for biomass production. These systems could offer the chance to learn from the errors that have been made in industrial agriculture and forestry over the past decades and to integrate current knowledge on sustainable land use. Novel cropping systems are supposed to reconcile biomass yields, resilience, and biodiversity. They may comprise new seeds, crops, and rotations, as well as new harvesting and transportation techniques. Possibly the strict separation between agricultural and forestry uses would be abandoned, e.g., through the introduction of agroforestry practices. Inputs of energy-intensive mineral fertilizer and biocides would be minimized, wildflowers tolerated, and a high diversity of genetic resources (including old plant varieties and crop rotations) be used. The techniques would contribute to water pollution control, permit the recycling of nutrients in unused residues, minimize nitric oxide emissions, and accumulate carbon in soils and vegetation (e.g., through establishing perennial woody plants on arable land). They prioritize the option "minimization of matter inputs" over "maximum yields." Promising examples for novel ways to cultivate energy plants are alley cropping[123] and double cropping[124] systems.

Section 8: Conclusion

In quantitative terms, the growth of the German bioenergy sector has been impressive, and the German government is right to give bioenergy an important role in its energy, climate, and agricultural policies. But the low energy density of biomass and the resulting large demands for agricultural or forest land are powerful limiting factors of further bioenergy expansion. To make matters worse, current bioenergy support has not been efficient from an economic point of view and has caused a number of environmental and social aberrations. Impacts on nature, landscapes, and rural communities have been enormous. In the face of the significant negative side effects that came with the rapid bioenergy diffusion, it will be imperative to establish a priority for quality improvement over a further quantitative growth of biomass production. The dynamic of the developments requires an active control through governments and society. It demands adaptations in agricultural and forestry practices, in spatial planning, regional development, and the public support and control of Germany's land use sector. By this, concerns for the conservation of multifunctional landscapes and the ecosystem services they provide should be carefully balanced with the interests of promoting biomass as a new, socially desirable energy carrier. Governments must to consider the two aspects of sustainable development: "You do not only have to do the right things, you do to have the things right."[125] Establishing a powerful bioenergy sector in Germany has been the right thing, but now is the time to get bioenergy right.

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03

TRANSATLANTIC COOPERATION ON SUSTAINABLE BIOENERGY DEVELOPMENT

TRANSATLANTIC COOPERATION ON SUSTAINABLE BIOENERGY DEVELOPMENT

Bioenergy has had a daunting impact on agriculture, landscapes, and the environment both in Germany and the U.S. In both countries the driving forces for promoting bioenergy are complex, and motivations usually comprise a combination of arguments such as greenhouse gas emissions reduction, energy security, and rural development. Germany has a strong focus on emissions reduction, while energy security is the key topic in the U.S. Although not prominently discussed in most cases, the idea of supporting domestic farms, forests and agribusinesses is a powerful driver of bioenergy development in both North America and Europe.

Both countries have defined targets of biofuel shares for the next years. The U.S. specifically aims to achieve a 20 percent biofuel share in overall fuel consumption by 2022, while Germany has defined a 10 percent target until 2020. Still, a big difference between the two countries is on the role of transportation fuels versus other bioenergy possibilities: Whereas U.S. policy concentrates almost exclusively on biofuels (in the short term focused on corn-based ethanol and biodiesel), such fuels are just one pillar of a larger bioenergy strategy in Germany (but are likewise heavily criticized). Rather, bioenergy targets are integrated into a comprehensive European renewable energy policy that aims at a renewables share of 20 percent in the EU's overall energy mix by 2020.

A common caveat of bioenergy promotion schemes in Germany and the U.S. is that they define quantitative targets for bioenergy shares, but do not entirely deal with the quality, i.e., the sustainability of the bioenergy pathways selected is not totally dealt with—although the U.S. Energy Bill cellulosic ethanol features and the German efforts toward a biomass sustainability ordinance begin to address this. In both countries existing bioenergy policies have triggered intensive energy crop cultivation on productive land, conversion feeding into large, centralized biorefineries, and end uses in the transportation sector. Correspondingly, these policies have generated similar problems in both countries: Promotion of input-intensive technologies; environmental damages to soil, water, and biodiversity; displacement of food and feed production; rising agricultural prices; and a comparatively low creation of rural jobs. It is common sense that bioenergy is largely a market response and is not sustainable *per se*. Specific policies may well be needed to enhance the sustainability of the development of bioenergy. An exchange over how such bioenergy policies can be designed is an important field for transatlantic cooperation. Ideally, political targets should refer not only to bioenergy replacement of imports, but also to other societal benefits (e.g., quantified reduction of net GHG emissions and continued environmental improvement). With growing importance of GHG emissions trading schemes in Germany and rising concerns in the U.S., the analysis and management of the interactions between bioenergy and emissions trading does also deserve more attention.

Fortunately there is intensive research on more sustainable forms of bioenergy use in both countries. Conversions to less competitive forms such as bioenergy arising from cellulosic sources is a major research subject along with attention toward cropping and forest management systems to create biomass feedstocks. In Germany, current studies intend to increase species and structural diversity of energy crops by developing new cultivation systems. There is a common view that double cropping systems fit the specifics of more productive soils, while novel agroforestry systems might be suitable for marginal agricultural sites. In the U.S. considerable research has been carried out on “low input-high diversity” cultivation systems. Ideas for the dissemination of novel energy cultivation systems in agricultural practice are needed in both countries.

One omitted factor in both countries involves large scale fuelling of biopower electrical generation. Many feedstocks are more easily combusted than converted into biofuels. This may be an important area of collaboration given the large percentage of GHG emissions from electrical generation, particularly coal-fired.

A German peculiarity seems to be the strong promotion of on-farm biogasification for power and (to a smaller degree) heat generation. With their decentralized structure and high energy efficiency, they have been shown superior to biofuels in environmental terms. Transatlantic cooperation in research and development might test the transferability of biogasification technologies to the U.S. farm sector.

Finally, by importing biomass/biofuel (largely in Germany) or diverting traditionally traded commodities such as corn (largely in the U.S.), bioenergy policy is having substantial implications for land use change internationally, including deforestation in rain forest area. Therefore both should be expected to take great care on the impact of their bioenergy policies beyond their national borders. The American and German publics are now very sensitive to these issues, and policymakers are under pressure to find responses. The German government has tried to react by including sustainability criteria into its biofuels act, but is currently experiencing difficulties in defending these standards against the EU Commission. In the U.S. no current action has been undertaken but the definition of Life Cycle Accounting is now expanding to include international considerations which will in turn provide a role in implementation of the Energy Act. Nevertheless, it is quite difficult to implement environmental conservation efforts in any form in a globalized world. As these difficulties concern not only biofuels but all imported goods, Germany and the U.S. could well find it beneficial to cooperate tightly on including sustainability standards into biofuels and associated policy.

Finally it is important to note that the available potential of agricultural, forestry, and waste biomass are limited, and that biofuels are therefore not a panacea for the solution of the energy and environmental problems faced today. Bioenergy is just one component of a total policy approach to address a sustainable, GHG sensitive, economic energy future for society.

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