December 2008 | ICTSD Programme on Agricultural Trade and Sustainable Development

Promoting Sustainable Bioenergy Production and Trade

Biofuel Production, Trade and Sustainable Development

ICTSD
International Centre for Trade
and Sustainable Development

Policy Discussion Paper

Biofuel Production, Trade and Sustainable Development

ICTSD
International Centre for Trade
and Sustainable Development

Policy Discussion Paper

Published by

International Centre for Trade and Sustainable Development (ICTSD)
International Environment House 2
7 chemin de Balexert, 1219 Geneva, Switzerland
Tel: +41 22 917 8492 Fax: +41 22 917 8093
E-mail: ictsd@ictsd.ch Internet: www.ictsd.net

Chief Executive: Ricardo Meléndez-Ortiz
Programmes Director: Christophe Bellmann
Senior Programme Manager - Environment Cluster: Moustapha Kamal Gueye
Manager of the Global Platform on Climate Change, Trade Policies and Sustainable Energy: Marie Chamay

---

Acknowledgements:

The paper is based on an initial draft by Andre Faaij, with additional inputs provided by Giulio Volpi and Moustapha Kamal Gueye. Marie Chamay and Samantha Fang provided research assistance.

We are grateful to Stephen Karekezi, José Goldemberg and Francis Johnson for their review and comments on the paper.

This project was made possible through the support of the Department of Development Cooperation of the Netherlands (DGIS), the Swedish International Development Cooperation Agency (SIDA) and Oxfam Novib.

For more information about ICTSD's programme on agriculture, visit www.ictsd.org.

ICTSD welcomes feedback and comments on this document. These can be forwarded to Marie Chamay, mchamay@ictsd.ch.

Citation: ICTSD (2008). *Biofuel Production, Trade and Sustainable Development*, Policy Discussion Paper ICTSD Programme on Agricultural Trade and Sustainable Development, International Centre for Trade and Sustainable Development, Geneva, Switzerland.

Copyright © ICTSD, 2008. Readers are encouraged to quote and reproduce this material for educational non-profit purposes, provided the source is acknowledged.

The views expressed in this publication are those of the author and do not necessarily reflect the views of ICTSD or the funding institutions.

ISSN 1817-3551

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF BOXES

ABBREVIATIONS AND ACRONYMS

€	euro
€ct	euro cent
ACP	African, Caribbean and Pacific countries
AoA	Agreement on Agriculture
ASCM	Agreement on Subsidies and Countervailing Measures
ASEAN	Association of Southeast Asian Nations
AVE	ad valorem equivalent tariff
BIG-CC	biomass gasification combined cycle
BSI	Better Sugarcane Initiative
BTL	biomass to liquid
CAFTA	Central American Free Trade Agreement
CAP	Common Agricultural Policy (of the EU)
CARB	California Air Resources Board
CBI	Caribbean Basin Initiative
CFB	circulating fluidized bed
CHP	combined heat and power
CO_2	carbon dioxide
DDGS	dry distillers' grains with solubles
DME	dimethyl ether
EBA	Everything but Arms (initiative)
EGS	environmental goods and services
EJ	exajoule (= 10^{18} joules; 1 EJ = 278 TWh; 1 Mtoe = 0.042 EJ)
ETBE	ethyl tertiary butyl ester
EtOH	ethanol
EU	European Union
FAME	fatty acid methyl ester
FAO	Food and Agriculture Organization of the United Nations
FFV	flex-fuel vehicle
FSC	Forest Stewardship Council
FT	Fischer-Tropsch
GATT	General Agreement on Tariffs and Trade
GBEP	Global Bioenergy Partnership
GGL	Green Gold Label
GHG	greenhouse gas
GHz	gigahertz (unit of frequency)
GJ	gigajoule (= 10^9 joules)
GJe	gigajoule (electrical output)
GSI	Global Subsidies Initiative
GSP	General System of Preferences
GW	gigawatt (thermal output)

H_2	hydrogen
Ha	hectare
HS	Harmonized Commodity Description Coding System
HTU	hydrothermal upgrading (diesel)
IEA	International Energy Agency
IFOAM	International Organization for Organic Agriculture Movements
IFPRI	International Food Policy Research Institute
IGCC	integrated gasification combined cycle
IIASA/WEC	International Institute for Applied Systems Analysis/World Energy Council
IISD	International Institute for Sustainable Development
IMAGE	Integrated Model to Assess Global Environment
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kWh	kilowatt hour
LCA	lifecycle assessment
LCFS	Low Carbon Fuel Standard
MDF	medium-density fibreboard
MeOH	methanol
MFN	most favoured nation principle
MSW	municipal solid waste
Mt	million tons
MTBE	methyl tert-butyl ether
Mtoe	million tons oil equivalent
MWe	megawatt (electrical output)
MWth	megawatt (thermal output)
N_2O	nitrous oxide
NAMA	non-agricultural market access
NDRC	National Development and Reform Commission (China)
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PPM	production processes and method
PPO	pure plant oil
RME	rapeseed methyl ester
RSB	Roundtable on Sustainable Biofuels
RSPO	Roundtable for Sustainable Palm Oil
RTFO	Renewable Transport Fuel Obligation (UK)
RTRS	Roundtable on Sustainable Soy
SCM	Subsidies and Countervailing Measures Agreement
SFA	State Forestry Administration (China)
SME	soy methyl ester
SRC	short rotation coppice
SRES	Special Report on Emission Scenarios (IPCC report)

SVO	straight vegetable oil
TBT	Technical Barriers to Trade (Agreement)
WTO	World Trade Organization
WVO	waste vegetable oil

FOREWORD

Unstable oil prices, the challenge of climate-change mitigation, and growing concerns over energy security are driving a growth in global production of bioenergy, particularly liquid biofuels such as ethanol and biodiesel, with implications for agriculture, energy, environment, development and trade. Biofuels could offer countries the potential to curb carbon dioxide emissions, reduce dependence on imported fuels, and maintain production and generate new employment in the agricultural sector.

For many countries, the potential of biofuels is contemplated in terms of supplying domestic energy needs and exports. Although international trade in biofuels is still limited – it is estimated that currently only one-tenth of global production worldwide is traded internationally – international trade in biofuels is expected to grow considerably given the divide between countries with comparatively lower production costs and countries with the greatest demand for biofuels. Clearly, social, economic and environmental opportunities abound.

Although the potential of biofuels could be enormous, so are the risks and challenges. The production of biofuels, especially from food crops such as corn, wheat, soybeans and sugarcane, has generated a range of concerns over their potentially negative impacts. With cereal grains making up 80–90 percent of the food of people worldwide, and with over 800 million people still affected by malnutrition, key questions need to be answered regarding the potential impacts on global food prices – which may be positive for some and negative for others –and the risks that shifting production from food consumption towards production of biofuels may cause for food security.

Large-scale expansion of production presents serious risks of further encroachment into the world's forest, damage to local and global biodiversity, and risks of propagating monocultural agriculture. Many of the environmental problems that countries have traditionally faced in the context of agriculture, including soil erosion, water pollution and chemical contaminants, are just around the corner and will require the same attention and action.

Although biofuels are meant to provide clean and alternative sources of energy, greater understanding of the effective energy and greenhouse balance of biofuels is needed: Do they produce more energy output than is needed as inputs in their production process? Do they offset more greenhouse gases than they generate from a lifecycle perspective?

Policymakers, scientists and business alike seem to agree on the fact that the current patterns of producing biofuels from food crops can only be a second-best, relative to fossil fuels. Technologies based on the so-called second-generation biofuels – solid fuels derived from forest and agricultural residues and other solid biomass – are already set to be the next strategic goal for the biofuel agenda. Adequate policies, resources and institutions would need to be put in place to fasten that transition. But time will be a critical factor.

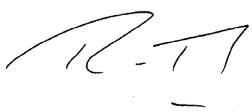
Attention and awareness need to be raised now of the urgent necessity to harness the promises of biofuels, while managing the potential risks. These would require both national and global regulatory and markets frameworks. It is certainly clear that production and trade would need to be based on sustainable development principles that are already well recognized, including environmental sustainability, economic viability and social justice. How these are likely to be translated into concrete policy instruments such as production standards and other criteria remains a matter of controversy.

Biofuels are a promising source of energy with major implications for global competitiveness, energy security and uncertain social and environmental impacts. Therefore, crafting policy and regulatory frameworks for biofuels nationally and internationally is likely to require intense debate, negotiations and compromise. Building on the current momentum that exists in almost all corners of the world, the stage could be set now for policies and instruments supportive of a biofuels strategy that would expand the benefits of globalization, and improve livelihoods and human wellbeing, while managing the social, economic and environmental challenges.

Extensive analysis has been done in recent years on the technological, environmental and social aspects of biofuel production and trade. This paper aims to provide a succinct overview of these analyses, with a view to identifying the potential opportunities and the limitations associated with large-scale biofuel production, and drawing out relevant lessons for policymakers, businesses and civil society. This study concludes that biofuels for transportation have the potential to contribute to sustainable development. However, the social and environmental benefits are neither intrinsic nor automatic and will be realized only if international and national sustainability standards and incentives that promote and reward environmentally and socially sound biofuel production and trade are put in place.

This paper seeks to contribute analytically to this debate. It gives an overview of biofuel technology and long-term future biomass production potential. It then provides an overview of current and projected trends in global biofuel production and trade and describes government policies underpinning this expansion. The paper then explores the major issues regarding biofuels and sustainable development, including economic, environmental and social aspects. Finally, the paper reviews ongoing initiatives to design sustainability certification schemes for biofuels and the associated issues, including the links with World Trade Organization (WTO) rules, and draws out key conclusion and recommendations on how to advance a sustainable biofuel agenda.

This paper is part of ICTSD's project on Promoting Sustainable Bioenergy Production and Trade, published under its Programme on Agricultural Trade and Sustainable Development, which seeks to promote food security, equity and environmental sustainability in agricultural trade.



Ricardo Meléndez-Ortiz
Chief Executive, ICTSD

EXECUTIVE SUMMARY

Biofuels are being promoted as an alternative to oil that can be grown by farmers across the globe. They are often pictured as a potentially simple and quick tool to address a number of problems, including increasing energy security, combating climate change, and promoting agriculture and rural development. However, biofuels are also increasingly criticized for being associated with tropical deforestation and the resulting greenhouse gas (GHG) emissions, food security problems, increased land concentration, loss of rural employment, poor labour conditions and increased social inequalities overall. While in recent years a growing body of research has been produced on the technological, economic, environmental and social aspects of biofuels, concerns and open questions still remain about the potential contribution of biofuels to sustainable development. Against this background, this policy paper aims to provide an overview of existing analyses, to identify the potential opportunities and the limitations of biofuel production and trade, and to draw out relevant lessons for policymakers, businesses and civil society.

After an introductory section, Part 2 of this paper explores the various technology options by which biomass can be converted into transport biofuels. Generally, one can make a distinction between first- and second-generation biofuels. First-generation biofuels include bioethanol from sugar and starch crops and biodiesel from animal fats and oilseed crops; they utilize simple and known conversion technologies. Second-generation biofuels can be produced from various feedstocks, including agriculture and forestry residues, algae and many forms of waste that contain high levels of organic matter; they use highly promising but less proven technologies. Second-generation biofuels hold the potential to deliver significant energy and GHG benefits, while reducing the risk of competition with food and feed production. However, the prospects and timing of full-scale commercialization of these technologies are uncertain. In addition, due to economies of scale, a number of logistical and economic barriers need to be addressed, including the availability of large-scale biomass resources.

The potential to produce energy feedstocks varies, depending upon a number of factors, including land availability, particularly with regard to marginal land; future food demand; increasing agriculture productivity; the extent of international trade; nature conservation; and climate change. Given that these elements are uncertain, intertwined and partially policy-dependent, estimates of future global bioenergy potential vary between one-third of and two times the current global energy demand over the long term, or between 200 and 1000 exajoules (EJ) by 2050. Although actual biofuels production will depend on other competing uses, such as heat, power and biomaterials production, these estimates suggest that the role that biofuels can play in meeting future transport needs is likely to be significant over the long term. In the short term, however, the use of biomass resources to produce heat and power generation should be prioritized over the creation of liquid biofuels, as power applications deliver higher energy displacement and GHG emissions reductions than transport applications.

Part 3 discusses current global trends in biofuel production and trade, and reviews domestic support policies and barriers affecting biofuels trade. Global markets for biofuels have seen enormous growth in the past decade, and in 2006 they contributed to about 2 percent of road transport fuels worldwide, or over 45 billion litres. Global ethanol production doubled between 2000 and 2005, reaching over 39 billion litres in 2006, equal to about 3 percent of the 1300 billion litres of gasoline consumed globally. Brazil and the USA manufactured the majority of the world’s ethanol: in 2006, the USA produced over 18 billion litres, followed closely by Brazil with almost 18 billion litres. Global biodiesel production jumped 50 percent in 2006 to over 6 billion litres globally.

A growing number of governments are actively supporting the development of biofuels in the form of volumetric production subsidies and tax credits. In most countries, government subsidies intervene at every important step of a biofuel's production process, supporting intermediate inputs, capital goods, value-adding factors, and biofuel production, storage, distribution and use. These subsidies are not only trade- and incentive-distorting but also far from cost-effective (Global Subsidies Initiative 2007). Currently, countries of the Organisation for Economic Co-operation and Development (OECD), in particular the USA and countries in the European Union (EU), offer the largest biofuel subsidies. Strong political interests dominate biofuels support policy, and proponents propose "energy security" and "rural development" as legitimate reasons for continuation of subsidies. The result is often unviable markets that are entirely reliant on government intervention for survival. Current subsidies on first-generation biofuels often not only boost supply but also create artificial demand in a way that is unsustainable and cost-ineffective for governments. In addition, policymakers still have problems addressing biofuel subsidies in a comprehensive way because multiple international trading rules apply to different parts of the biofuel sectors.

Turning to international trade, only 5 percent of global biofuels use in industrialized countries was traded in 2004, while 20 percent of global ethanol production was traded in the same year. Thus far, trade occurs mainly between neighbouring regions or countries, although it is increasingly happening over longer distances. For instance, Brazilian ethanol is now exported to Japan, the EU and the USA; Malaysia exports palm kernel shells to the Netherlands; and Canada exports wood pellets to Sweden. In the future, although the bulk of biofuel consumption will continue to be produced indigenously, the volume of international trade in biofuels is expected to grow significantly.

A number of policy and institutional barriers exist, both tariff- and non-tariff-related, which can cause market distortions and harm the development of sound biofuel markets. Notwithstanding these challenges, sound international trade of biofuels could provide a powerful new economic opportunity for rural regions that now often lack any export possibilities to finance development and modernization of agriculture.

Part 4 reviews the major issues of biofuels and sustainable development. First it discusses the economic aspects of biofuels, including production costs. Then it reviews the potential environmental and social aspects of biofuels and discusses ways to maximize benefits and minimize negative impacts. The relationship between biofuels and sustainable development is complex. The lifecycle energy efficiency, climate balance, and the environmental and social impacts of biofuels vary significantly, depending on feedstocks, production methods and location and scale. If perennial crops replace annual crops – such as corn now grown to produce ethanol – and are processed with biomass energy that offsets coal-fired power, then the resulting biofuel can significantly reduce GHG emissions compared with petroleum fuels. Alternatively, if prairie grassland is converted to corn or soy, treated with chemical fertilizers and pesticides, and refined with coal and natural gas, then the resulting fuel could have a greater impact on the climate over its lifecycle compared with petroleum fuels. Even efficient energy crops, such as palm oil and sugarcane, can have a negative climate impact if they directly or indirectly replace tropical forests, resulting in large releases of carbon from soil and existing biomass that will negate any benefits of biofuels for decades. Second-generation biofuels hold the promise of lower environmental impacts and higher energy and climate benefits, and so they should be promoted aggressively.

Turning to the social aspects, a move toward agricultural-based energy production via biofuels could help to absorb excess agricultural supply, while helping to maintain higher commodity prices. If biofuel programmes end up absorbing much of the surplus crop production in industrialized countries, then they could spare farmers in the developing world from commodity "dumping" and artificially low prices. Such a scenario could revert the historically low levels of investment in agriculture and agriculture research, particularly in developing countries. On the other hand, urban slum dwellers in countries that are net food importers are likely to be hurt by commodity price increases. Poor farmers are more likely to benefit if biofuel production is done in a small-scale, labour-intensive manner that keeps them employed and able to afford food. The alternative is large plantations of monocultures controlled by wealthy producers, who could drive farmers off their land without providing new opportunities.

Part 5 reviews the various initiatives carried out by governments, international agencies, companies and non-governmental organizations to establish certification and sustainability standards for biofuels, in an effort to address potential negative impacts and to promote sound biofuel production and trade. Although some of these efforts overlap heavily, they are all broadly consistent in their core aims – that is, promoting significant GHG emissions reductions and addressing the environmental (and social) impacts associated with biomass production. Among governmental initiatives, the UK's Renewable Transport Fuel Obligation (RTFO) has perhaps gone the furthest in developing operational standards, which entered into force in April 2008. However, this and other European schemes will be replaced by an EU-wide draft certification system that focuses mainly on climate and biodiversity impacts. This scheme is currently being discussed by the EU and is expected to enter into force in 2010.

At the global level, a number of international agencies, businesses and non-governmental groups have also undertaken a wide range of initiatives on biofuel sustainability with different levels of maturity. Although they can all contribute to advancing the policy and research debates on biofuel sustainability, there is a need for better international coordination in order to prevent the risk of proliferation of certification approaches and to ensure a common direction of efforts. This would also help to address concerns that biomass certification could become an obstacle for international trade and facilitate the development of trade restrictions due to proposed sustainability criteria.

In summary, this study argues that, if developed correctly, biofuels have the potential to help advance sustainable development by diversifying energy resources, helping to reduce overall GHG emissions associated with transportation and promoting rural development and employment. Alternatively, they could intensify the threat of global climate change and result in significant social impacts. As a result, the sustainable development benefits of biofuels are neither intrinsic nor automatic but depend on the type, scale and timing of biofuel development and on the support policy and regulations.

Based on this analysis, Part 6 concludes with the following recommendations:

- *Long-term sustainable potential of bioenergy and biofuel production is uncertain and requires further analysis.* In theory, the technical biomass potential could be large enough to supply between one-third of and two times the current global energy demand by 2050, without competing with food production. In practice, however, to what extent and how rapidly humanity can realize this potential is uncertain, as it would require major efforts such as a significant improvement in agricultural efficiency in developing countries, including livestock production and optimal integration of biomass and food production systems. More research is needed on the interactions between different land uses such as bioenergy and food and materials production – that is, of competition for resources and of synergies between different uses. This would improve the understanding of what is the socially and environmentally sound threshold for biofuel use.

- *First-generation biofuels produced in temperate regions (the EU, North America) offer lower carbon and environmental benefits.* Research on net carbon emissions is far from conclusive, and estimates vary widely, due partly to different methodological assumptions for energy sources used for processing and treatment of co-production. Although they have improved in recent decades, grain-based biofuels produced in Europe and North America often offer low GHG gains, have negative impacts on water, soil and biodiversity, and remain expensive compared with gasoline and diesel, even with high oil prices. Furthermore, they can be produced only on higher-quality farmland in direct competition with food production. Sugarcane-based ethanol production and to a certain extent palm oil and jathropha oilseeds are notable exceptions, given their high production efficiencies and lower costs. However, land-use change, and in particular deforestation, to allow for tropical biofuel cultivation can make a significant difference in lifecycle GHG emissions and in the worst cases can negate GHG savings. Research is therefore needed to improve data on GHG fluxes from land-use change, which today can be very uncertain. There is also a need to harmonize GHG methodologies for transport fuels and to fill gaps in the existing body of lifecycle studies. More analyses that cover the range of the biofuel feedstocks and pathways relevant to developing countries are needed, including biodiesel from palm oil or jathropha, for example.

- *Risks of indirect land-use change are poorly understood but can be significant and should be incorporated into estimates of GHG emissions.* As well as direct land-use impacts, increased biofuels cultivation can lead to indirect land-use changes with negative climate and environmental impacts. For instance, biofuels could displace agriculture or livestock production so that there is land-use change elsewhere in order to accommodate the lost food or cattle production. Indirect land-use changes, also called "leakage effects", with resulting loss of carbon-rich habitats, could partially or totally negate the climate benefits gained through biofuel use. Leakage in the context of biomass trade could stand for an unwanted shift of activities from the area of biofuel consumption to another area where it leads to negative effects on the environment. There is a need for clear guidance on how the risks of indirect land-use change should be assessed and how they may be incorporated into estimates of GHG savings in order to attain a more accurate picture of the full impacts of biofuel production on the global climate.

- *The development of second-generation biofuels is required in order to maximize environmental and social benefits.* In the future, next-generation technologies – advanced cellulosic technologies, in particular – offer the potential to significantly maximize energy and GHG benefits and to reduce the risk of competition with food production. Assuming oil prices remain high, it will be possible to achieve negative carbon dioxide (CO_2)-abatement costs in the process, while providing a host of other environmental and social benefits as well. Government policies should focus on commercializing these advanced technologies and driving down their costs as rapidly as possible in those cases where they appear to be efficient and sustainable in the long term. The use of new energy feedstocks, such as jathropha, could minimize potential conflicts between food and feed production, as these non-edible crops are not in direct competition with food use and can be produced on land that is unsuitable for conventional food crops.

- *Sustainability certification of biofuels is a critical tool to deliver sustainable development benefits.* As biofuels are increasingly promoted around the world as part of national and regional sustainable development strategies, sustainability standards and certification regulations need to be developed that include criteria for reducing GHG emissions and promoting environmentally and socially sound production methods. Certification should be developed through an open, transparent and non-discriminatory process, taking into account local conditions, where all concerned stakeholders are effectively represented. Support is needed to improve small-scale producers' capacity to play an active role in the development of biofuel certification, particularly in developing countries. In addition, incentives supporting biofuel development should be proportional to the actual environmental and social benefits. Among the policies reviewed, applying technology-neutral "low-carbon standards" may result in more energy and environmental gains than simple renewable fuel mandates and could help to promote the development of more efficient second-generation biofuel technology.

- *Sustainable trade of biofuels should be promoted through reduction of tariff and non-tariff barriers.* Although there is a great potential for sustainable trade between industrialized and developing countries, this is currently limited by tariff and non-tariff barriers. If trade is restricted or made more expensive by tariffs, then the utilization of resources will be economically unprofitable, leading to higher costs for society as a whole and to higher prices for consumers. The Doha Round should provide a unique opportunity to deliver tariff cuts for sustainably produced biofuels. Meanwhile, the adoption and application of sustainability certification to the production of biofuels should not create new non-tariff barriers.

1. INTRODUCTION

Soaring oil prices, growing concerns over climate change and energy security, and the goal of promoting agriculture and rural development are all driving the growth in global production of biofuels, particularly ethanol and biodiesel, with implications for agriculture, energy, environment, development and trade. Biofuels could offer countries the potential to curb CO_2 emissions, reduce dependence on imported fuels, and boost production and generate new employment in the agricultural sector. Although international trade in biofuels is still limited, it is expected to grow considerably, given the divide between countries with comparatively low production costs and countries with the greatest demand for biofuels. For many developing countries, biofuel production could promote economic development by providing a new export opportunity.

However, biofuels are characterized by a variety of resources and possible conversion routes, which complicate the understanding of their implications. Particular issues need to be clarified in order for us to understand the challenges and risks related to large-scale production of biofuels as a sustainable energy source: resources and land availability, energy and greenhouse balances, fuel chain costs, and environmental impacts and implications for global food security and rural development, particularly in developing countries. Unmanaged large-scale expansion of production could present serious risks of further encroachment into the world's forests, cause damage to local and global biodiversity, and risk propagating monocultural agriculture. Many of the traditional environmental problems that countries have faced in agriculture, including soil erosion, water pollution and chemical contaminants, are just around the corner and will require continued attention and action. Biofuels are intended to provide clean and alternative sources of energy, but greater understanding is needed of the effective energy and greenhouse balance of biofuels: Do they produce more energy output than is needed as inputs in their production process? Do they offset more GHG than they generate from a lifecycle perspective?

The production of biofuels, especially from food crops such as corn, wheat, soybeans and sugarcane, has generated a range of concerns over potential negative impacts on food security. With cereal grains making up to 80–90 percent of people's diets worldwide, and with over 800 million people still affected by malnutrition, key questions need to be answered as to the potential impacts on global food prices – which may be positive for some and negative for others – and the risks that shifting production from food consumption towards production of biofuels may cause food security concerns.

Extensive analysis has been done in recent years on the technological, environmental and social aspects of biofuel production and trade. This paper aims to provide a succinct overview of these analyses, with a view to identifying the potential opportunities and limitations associated with large-scale biofuel production, and drawing out relevant lessons for policymakers, businesses and civil society. This study concludes that biofuels for transportation have the potential to contribute to sustainable development. However, the social and environmental benefits are neither intrinsic nor automatic but will be realized only if international and national sustainability standards and incentives that promote and reward environmentally and socially sound biofuel production and trade are put in place.

The paper is structured as follows:

- Part 2 gives an overview of biofuel technology and the long-term future biomass production potential.
- Part 3 provides an overview of current and projected trends in global biofuel production and trade and describes government support policies underpinning this expansion.

- Part 4 explores the major issues regarding biofuels and sustainable development, including economic, environmental and social aspects.
- Part 5 reviews ongoing initiatives to design sustainability certification schemes for biofuels and the associated issues, including the links with World Trade Organization (WTO) rules.
- Part 6 draws out key conclusions and recommendations on how to advance a sustainable biofuel agenda.

2. BIOFUEL TECHNOLOGY AND POTENTIAL

2.1 Biofuel technology

The following section provides a background for the rest of the report by giving an overview of how biofuels are currently produced and the long-term future production potential. It explains the basic biofuel conversion technologies and discusses typical crops that can provide feedstocks for these conversion technologies. It concludes with a brief discussion of the trade-offs between different uses of biomass to produce power, heat and transport fuels.

As shown in Figure 1, there are a number of ways in which biomass can be converted into transport biofuels. Generally, one can make a distinction between first- and second-generation biofuels. First-generation biofuels, such as bioethanol from sugar and starch crops and biodiesel from animal fats and oilseed crops, utilize simple and known conversion technologies. Second-generation biofuels, which can be produced from various feedstocks, including agricultural and forestry residues, algae and many forms of waste that contain high levels of organic matter, use highly promising but less proven technologies. The following section briefly describes these production processes. Table 1 provides a compact overview of the main technology categories and their performance with respect to energy efficiency and energy production costs.

Table 1: Production costs of ethanol from energy crops

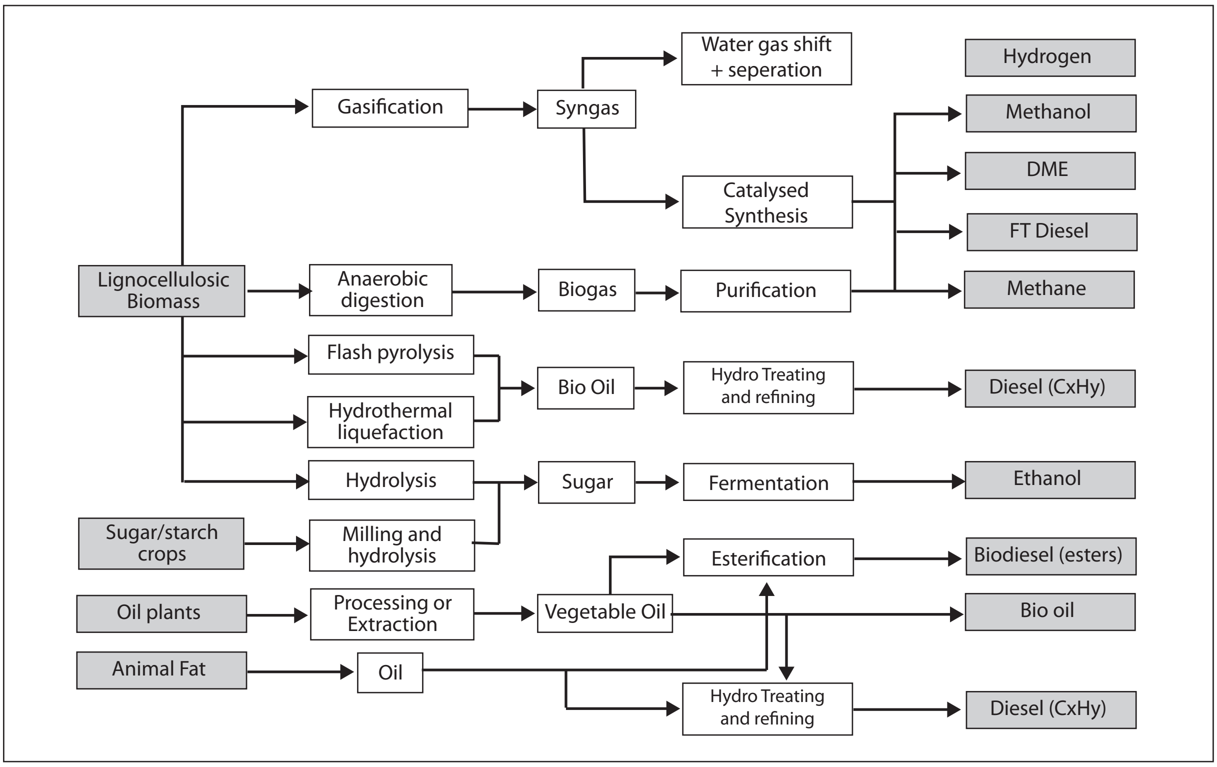
Country	Feedstock	Production cost (US$/litre)
Brazil	Sugarcane	0.20
India	Sugarcane	0.40
Zambia*	Sugarcane	0.50
Europe	Wheat	0.76
USA	Maize	0.80
UK	Sugar beet	0.97

Source: UK DTI (2003).

Note: sugar-beet ethanol UK, £15/GJ; wheat-grain ethanol €16.9/GJ (UK DTI 2003); corn ethanol, Iowa, USA, US$1.04/gallon.).

*Theoretical data based on Cornland et al. (2001).

Figure 1: Overview of conversion routes from crops to biofuels



Source: IPCC (2007), Chapter 5, p. 341, Figure 5.8, adapted from Hamelinck and Faaij (2006).

First-generation biofuels

Bioethanol

The main first-generation production route for bioethanol is fermentation of sugars and starches. Sugars can be fermented directly by microorganisms. The principal crops for this process are sugar crops, such as sugarcane and sugar beet. The process is relatively simple, involving extraction of sugar from the crop followed by fermentation and distillation of the final product. The major co-product is bagasse, which can be used to generate process heat and power in co-generation facilities. Starch crops are also used to produce ethanol, with a more complex process involving the conversion of starch to sugar. Starches comprise strings of glucose molecules that must first be released by hydrolysis before they can be fermented by microorganisms. The principal starch crops for bioethanol are corn (in the USA) and wheat (in Europe), although other starch crops can be used (e.g. potatoes, sweet sorghum, cassava). These processes result in co-products including lignocellulose fractions and dry distillers' grains with solubles (DDGS), which is used as a fuel or, more commonly, as animal feed. Ethanol, which is both hydrophilic and highly corrosive, can be blended in low concentrations in gasoline without negative effects, but in high concentrations it requires separate handling as well as vehicle engine modifications. A use of high-level blends such as E85 (85 percent ethanol, 15 percent gasoline) requires the building of a parallel infrastructure including tanks, pumps and nozzles that will not corrode when used with ethanol, and upgrading the existing vehicle fleet with flex-fuel vehicles (FFVs). Typically bioethanol is produced in large-scale plants given the difficulty to produce it commercially on a small scale due to the concentration and purification requirements (Fulton *et al*. 2004).

Biodiesel

The main first-generation production route for biodiesel is chemical conversion via esterification or trans-esterification. These are simple methods for converting vegetable oils, such as those derived from oilseed crops (e.g. soy, sunflower, rapeseed, non-edible plants such as jathropha) and animal fats (e.g. beef tallow, pork lard) into a diesel substitute

– biodiesel or fatty acid methyl ester (FAME). They operate at low temperatures and involve mixing the oils or fat feedstock with an acid or alcohol (usually methanol) and a catalyst followed by physical separation of the resultant product. The end products of this process are biodiesel and glycerine. Compared with some of the technologies being developed to produce ethanol and other biofuels, the biodiesel production process involves simple, well-developed technologies that are not likely to change significantly in the future. Biodiesel can be used in compression ignition diesel systems, either in 100 percent pure form or more commonly blended with mineral diesel. Biodiesel can be manufactured on a large scale (from above 5000 to 50 000 litres of biodiesel per year), but it can also be manufactured on a small scale (Worldwatch Institute 2006).

Use of vegetable oils as fuel

Many vegetable oils, such as waste vegetable oil (WVO; e.g. oil discarded from a restaurant), straight vegetable oil (SVO) and pure plant oil (PPO; e.g. made from peanut, cottonseed, rapeseed or jathropha seed oil), have similar fuel properties to diesel fuel, except that they have a higher viscosity, lower thermal and oxidative stability, and less favourable ignition qualities (low cetane number). If these differences can be overcome, then vegetable oil may substitute for diesel fuel, most significantly as engine fuel and home-heating oil. For engines designed to burn diesel fuel, the viscosity of vegetable oil must be lowered to allow for proper atomization of the fuel, otherwise incomplete combustion and carbon build-up will ultimately damage the engine. Today SVO and PPO from jathropha seed, coconut, rapeseed and others are used in certain countries to power mechanical pumps and for heating and cooking after a process of filtering and heating.

Second–generation biofuels

Cellulosic ethanol

Cellulosic biomass, including grasses, trees, and various waste products from agricultural crops, wood-processing facilities and municipal solid waste, can also be converted to ethanol, but the processing is more complex and less technologically developed compared with the processing of sugars and grains. To convert cellulose to ethanol, two key steps must occur. First, the cellulose and hemicellulose fractions of the biomass feedstock must be broken down into sugars through a process called saccharification. Second, the resulting complex sugars must be fermented to make ethanol, as they are in grain-to-ethanol processes. A co-product of all hydrolysis processes is lignin, which is removed as a solid cake and can be used as a fuel for power generation and process steam. The first step is a major technological challenge, and considerable research is being invested in a variety of thermal, chemical and biological processes to carry out this saccharification step in an efficient and low-cost manner. More specifically, efforts are focusing on the development of biological enzymes that can break down cellulose and hemicellulose, and the improvement of enzymatic hydrolysis processes mostly targeting improved efficiencies and yields (Fulton et al. 2004; Hameliinck et al. 2005).

Biomass gasification

Cellulose can also be transformed to produce a variety of gases, such as hydrogen, which can be used directly in some vehicles or used to produce synthesis gases, through gasification or pyrolysis of biomass feedstocks, which are further converted to a number of liquid fuels, such as dimethyl ether (DME) and even synthetic gasoline and diesel. These processes are often known as biomass-to-liquid (BTL). The advantage of these processes is their ability to use almost any type of biomass with little pretreatment other than moisture control. The first step is gasification, which is a high-temperature process followed by upgrading of the resulting gas to clean feedstock, with a fixed proportion of hydrogen and carbon monoxide. The gaseous product is commonly referred to as synthesis gas. As a second step, synthesis gas can be converted to methanol, methane, esters or alkanes (synthetic biofuels) by a catalytic chemical reaction known as the Fischer–Tropsch (FT) process. This technology is proven as it has been used a number of times with coal feedstocks in the past, but it is not yet at the point of commercial deployment with biomass feedstocks; it is estimated, however, that within the next decade it will be, particularly if waste feedstocks prove suitable.

Both hydrolysis-based ethanol production and production of synfuels via advanced gasification from biomass of around 2€/GJ can deliver high-quality fuels that are competitive with oil prices down to US$40/barrel. Net energy yields for unit of land surface are high, and up to a 90 percent reduction in GHG emissions can be achieved. This requires a development and commercialization pathway of 10–20 years, depending very much on targeted and stable policy support and frameworks.

Benefits and challenges

There are several potential benefits associated with developing commercially viable second-generation biofuels, including the following (Fulton et al. 2004; Worldwatch Institute 2006; International Energy Agency 2007):

- Access to a much wider variety of energy feedstocks than with first-generation biofuels, which opens the door to potentially greater ethanol production levels.
- Greater avoidance of conflicts with land use for food and feed production, as lignocellulosic feedstocks are not in direct competition with food uses, although in some instances there will be competition for land use with food production.
- A much greater displacement of fossil energy per litre of fuel and hectare of land utilized, due to higher productivity yields and nearly completely biomass-powered systems.
- Much lower net well-to-wheels GHG emissions than with grain-based ethanol processes powered primarily by fossil energy.

It should be noted, however, that the timing of the deployment of these second-generation technologies on a large scale is uncertain (Childs and Bradley 2007). As of late 2007, there were nine demonstration plants in the world, with an estimated production capacity of about 12 million litres (3 million gallons) per year. Although none of these is a commercial-scale plant, a large number of other plants are under development, and the results of their performance will be an important indicator of the scope for more innovative and better-performing biofuels.

The move to second-generation biofuels will increase the scale of the production plant, potentially marginalizing small-scale producers. As a result, a large quantity of feedstock is needed at large processing plants, which will require efficient transportation systems over long distances. There will need to be confidence in the feedstock availability before the large-scale investment in the conversion plants can take place. In order to address this question, the following section looks into the long-term potential availability of biomass resources.

2.2 Economics of biomass production

Production costs of energy crops vary over time; they may increase because of increased labour costs and decrease because of productivity increase per hectare. Global cost-supply curves have been constructed for the year 2050 based on the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES) (IPCC 2000). 'The report shows that in 2050 a significant part (between 130–270 EJ/year, depending on the scenario choosen) of the production potential may be realized below US$2/GJ, which is considered the upper level of the 1998 price for coal. The lowest costs are found at US$0.8/GJ, in the A1 scenario in eastern Africa (Hoogwijk et al. 2008).

Biomass production costs are influenced by yield, land rent, management system and labour costs. Increases in productivity are important to reduce production costs. Yields can be improved through crop development, production integration (multi-product plantation) and mechanization. Competition for land use should be avoided in order to minimize inflated land rental rates. Labour costs can be lowered through mechanization.

The production costs of plantation biomass are already favourable in some developing countries. Eucalyptus plantations in Brazil supply wood chips for US$1.5–2/GJ. At present, sugarcane delivers bioethanol at competitive cost levels in Brazil (about US$6–7/GJ ethanol) and some African countries. In industrialized countries, costs of biomass can be much higher (up to US$4/GJ), but by around 2020 better crops and production systems are expected to cut biomass production costs in the USA to US$/1.5–2/GJ for substantial land surfaces. Typical cost ranges for perennial woody crops under northwestern European conditions are US$3–6/GJ (compared with about US$1–2/GJ for imported coal) (Rogner 2000).

Costs of biomass energy production are influenced especially by the yield, the land rent and the costs of labour. Changing these factors is important for reducing biomass production costs. Competition for land should be avoided because of the impact on land rental rates. Labour costs can be reduced by using plantation-like production systems and mechanization. The yield can be improved in many ways (e.g. crop development, production system, machinery) and continuous improvement is observed.

Another method to reduce the cost of biomass used for energy is the introduction of biomass production systems that have more than one function (multifunctional land use) and more than one output (multi-product plantations). Multi-product systems could have great similarities to commercial forestry or various forms of agriculture but could be optimized towards a new output. The potential and impacts of such systems on related markets deserve more research. Certainly, for large areas in the world, low-cost biomass can be produced in large quantities. Its competitiveness will, to a large extent, depend on the prices of oil, coal and natural gas.

2.3 Long–term biofuel potential

This section explores the potential long-term bioenergy potential, at both the global and the regional level, and discusses challenges associated with its realization. Current bioenergy production trends are described in Box 1. The availability of biomass for energy production varies, depending on a number of factors, including land availability, particularly with regard to marginal land; future food demand; increasing agricultural productivity; the extent of international trade; nature conservation; and climate change. Given that these elements are uncertain, intertwined and partially policy-dependent, it is difficult (if not impossible) to present the future bioenergy potential in one simple and exact figure (Hoogwijk 2004).

BOX 1: CURRENT BIOENERGY TRENDS

Bioenergy is energy produced from biomass fuels such as wood, energy crops, and organic wastes and residues. According to the best data available, bioenergy provides about 10 percent of the total of the world's total primary energy supply (47.2 EJ of bioenergy out of a total of 479 EJ in 2005, i.e. 9.85 percent). In 2005 bioenergy represented 78 percent of all renewable energy produced, making it by far the most important renewable energy source used to date (GBEP 2007). On average, bioenergy accounts for 33 percent of energy use in developing countries, with large variations between different regions: 60 percent in Africa, 34 percent in Asia and 25 percent in Latin America (Hazell 2006). A large part of this bioenergy is, however, based on traditional and non-efficient use of biomass sources, such as fuel wood and charcoal, consumed mainly by rural households for cooking and space-heating needs.

In industrialized countries, bioenergy makes a lower but still significant contribution in the range of 3–4 percent of energy use (Hazell 2006). Most of this is modern bioenergy, which relies on efficient conversion technologies for production of electricity, heat and liquid biofuels for transport. Over recent years, deployment of co-firing of biomass materials in coal-fired boilers has increased, and some gasification technologies are nearing commercialization. It is estimated that, at the end of the 1990s, some 40 billion watts (GWe) of biomass based electricity production capacity was installed worldwide, as well as 200 billion watts (GW) of heat production capacity.

In a review of 17 studies on the future global biomass availability, Berndes et al. (2003) concluded that no complete integrated and complete bioenergy assessment was available at that time. The studies reviewed arrived at widely different conclusions about the possible contribution of biomass to the future global energy supply, ranging from below 100 EJ to above 400 EJ per year in 2050. The major reason for the differences is that the two most crucial parameters – land availability and yield levels in energy crop production – are very uncertain and are subject to widely different opinions. For instance, the assessed 2050 energy plantation supply ranges from below 50 EJ/year to almost 240 EJ/year. In addition, the expectations about future availability of forest wood and of residues from agriculture and forestry vary substantially among the studies. Note that the 17 studies reviewed have been mostly top-down evaluations, derived from anticipated demand for biomass or from extrapolation of current supply. The question of how an expanding bioenergy sector would interact with other land uses, such as food production, biodiversity, soil and nature conservation, and carbon sequestration, has been analysed insufficiently in the studies. A refined modelling of interactions between different uses and bioenergy, food and materials production – i.e. of competition for resources, and of synergies between different uses – would facilitate an improved understanding of the prospects for large-scale bioenergy and for future land use and biomass management in general.

Smeets et al. (2007) found that the long-term technical potential of bioenergy could be very large. They estimated that biomass resources could potentially supply up to two times the current global energy demand of 430 EJ/year, or more than 1000 EJ/year by 2050, without competing with food production. Generally, the bulk of this potential comes from pastureland, large areas that are currently used but that could be made available if more intensive agriculture and livestock production systems are used. According to the authors, "if a type of agriculture management is applied similar to the best available technology in the industrialised regions, the world would be capable of producing the demand for food projected by 2050 using only a fraction of the present agriculture land" (Smeets et al. 2007). These conclusions are based on a robust methodology, incorporating data from, among others, the Food and Agriculture Organization (FAO), the International Food Policy Research Institute (IFPRI) and the Integrated Model to Assess Global Environment (IMAGE) to assess land-use patterns, future food demand and population growth, production efficiency and the impact of agriculture technology.

The regions with the largest potential surplus cropland are the Caribbean and Latin America and sub-Saharan Africa. The Caribbean and Latin America have potential surplus lands of 0.2–0.6 billion hectares (Gha), equal to a bioenergy potential of 47–221 EJ/year. Sub-Saharan Africa has potential surplus lands of 0.1–0.7 Gha, or an energy potential of 31–317 EJ/year. The large potentials originate mainly from the large surplus pastureland presently used and present inefficient production systems and land use. The Near East and North Africa, South Asia and partially East Asia are land-stressed regions, classified as not suitable for crop production, but still with some production potential for bioenergy that can be met by imports from other regions. The Community of Independent States and Baltic States has a considerable potential of 0.1–0.5 GHz or 45–199 EJ/year. Due to the collapse of the communist system and the economic restructuring that followed, income, consumption, production and yields have decreased significantly. It is estimated that it will take several decades before consumption levels are back to levels common in the Soviet period. In addition, the population is projected to have decreased by 2050. Consequently, the agricultural land area is relatively large compared with the projected demand for food, which gives this region the most robust potential of all regions of the industrialized world.

Oceania has the greatest potential to increase yields and reduce the area of agricultural land. Some 42-84 percent of the total agricultural land use in 1998 was estimated to be abandoned land, potentially available for bioenergy production, with a potential for energy generation of 38-102 EJ/year. North America has a potential of 20-174 EJ/year, despite a projected increase in population. Harvest and processing residues account for 58-75 EJ/year of this potential. The surplus production potential of wood from natural forests is estimated at 20-36 EJ/year globally. Various limiting factors, such as the exclusion of undisturbed forests and economically unattractive potential, may, however, reduce this potential to zero.

Exploiting the bioenergy potential described in this study requires major efforts, particularly significant improvement in agricultural efficiency in developing countries. However, according to the authors, it is uncertain to what extent and how rapidly such transitions can occur. Under less favourable conditions, the regional bioenergy potential could be quite low. It should be noted that technological developments in the conversion of biomass into transportable pellets and liquids, as well as long-distance biomass supply chains, would dramatically improve the competitiveness and efficiency of bioenergy (Worldwatch Institute 2006).

Bioenergy sources

Potential sources of bioenergy include agriculture and forest residues, organic waste, and dedicated energy crops grown on agricultural or marginal lands. Table 2 provides an overview of the long-term potential contributions of each type of biomass to global energy supply, which are also discussed in more detail below.

Table 2: Current and projected energy and economic performance of biofuels

	Energy efficiency (HHV) + energy inputs		Estimated production costs (€/GJ fuel)	
Concept	Short term	Long term	Shorter term	Longer term
Hydrogen: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible; for production of liquid hydrogen additional electricity, use should be taken into account.	60% (fuel only) (+0.19 GJe/GJ H_2 for liquid hydrogen)	55% (fuel), 6% (power) (+0.19 GJe/GJ H_2 for liquid hydrogen)	9–12	5–8
Methanol: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible.	55% (fuel only)	48% (fuel), 12% (power)	10–15	6–8
Fischer–Tropsch liquids: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible.	45% (fuel only)	45% (fuel), 10% (power)	12–17	7–9

Table 2: Current and projected energy and economic performance of biofuels cont.

	Energy efficiency (HHV) + energy inputs		Estimated production costs (€/GJ fuel)	
Concept	Short term	Long term	Shorter term	Longer term
Ethanol from wood: production takes place via hydrolysis techniques and subsequent fermentation and includes integrated electricity production of unprocessed components.	46% (fuel), 4% (power)	53% (fuel), 8% (power)	12–17	5–7
Ethanol from beet sugar: production via fermentation; some additional energy inputs are needed for distillation.	43% (fuel only), 0.065 GJe +0.24 GJth/GJ EtOH	43% (fuel only), 0.035 GJe +0.18 GJth/GJ EtOH	25–35	20–30
Ethanol from sugarcane: production via cane crushing and fermentation and power generation from the bagasse. Mill size, advanced power generation, and optimized energy efficiency and distillation can reduce costs further in the longer term.	85 l EtOH/ tonne wet cane, generally energy–neutral with respect to power and heat	95 l EtOH/ tonne wet cane. Electricity surpluses depend on plant layout and power–generation technology	8–12	7–8
Biodiesel RME: takes places via extraction (pressing) and subsequent esterification. Methanol is an energy input. For the total system it is assumed that surpluses of straw are used for power production.	88%; 0.01 GJe + 0.04 GJ MeOH/ GJ output; efficiency power generation 45% in shorter term, 55% in longer term	25–40	20–30	

Source: IEA (2007)

Notes:

- Due to the variability of data in the various references and conditions assumed, all cost figures should be considered as indicative.
- Assumed biomass price of clean wood: €2/GJ. Biodiesel RME (rapeseed oil methyl ester) cost figures varied from €20/GJ (short term) to €12/GJ (longer term). For sugar beet a range of €8-12/GJ is assumed. All figures exclude distribution of the fuels to fueling stations.
- For equipment costs, an interest rate of 10 percent and an economic lifetime of 15 years are assumed. Capacities of conversion unit are normalized on 400 MWth input in the shorter term and more than 1000 MWth input using advanced technologies and optimized systems in the longer term.
- Diesel and gasoline production costs vary greatly, depending on the oil prices, but for an indication recent cost ranges (end of 1990 to 2006) are around €4-9/GJ. Longer-term projections give estimates of roughly €6-10/GJ. Note that the transportation fuel retail prices are usually dominated by taxation and can vary from $€_{ct}$50/l to $€_{ct}$130/l, depending on the country in question.

Agriculture and forest residues

A vast amount of agriculture residue exists that could potentially be used as feedstock for biofuel production. Much of the plant matter produced by common crops is left in the fields after harvest, and a large portion of this decomposes into CO_2 rather than returning to the soil. The production potential for agricultural residue depends on the various yields of different agricultural products, the total agricultural land area and the type of production system. Less intensive management systems require the reuse of residues for maintaining soil fertility, reducing the total amount that can be sustainably removed. However, more intensively managed systems allow for higher use rates of residues but also typically rely on crops with lower crop-to-residue ratios, such as corn. Research suggests that agriculture residues could supply anywhere from 15 EJ/year to 70 EJ/year. The latter figure is based on the regional production of food in 2003 multiplied by harvesting or processing factors and the assumed recoverability factors (Smeets et al. 2007). These figures do not subtract the potential alternative use for agricultural residues. As indicated by Junginger et al. (2001), competing applications can reduce the net availability of agricultural residue for energy or materials significantly.

Forestry practices leave behind large quantities of unharvested wood, and fire mitigation practices have allowed forest underbrush to accumulate. Forest residues can be an ecologically benign feedstock for energy production, although large uncertainties remain regarding their sustainable energy potential. In an evaluation of forest reserves and development of demand for wood products, Smeets et al. (2007) conclude that even the highest wood demand projections found in the literature could (in theory) be met without causing further deforestation. Harvesting and processing residues and surplus natural forest growth could potentially supply, respectively, anywhere between 32 EJ and 52 EJ per year and 1 EJ and 98 EJ per year by 2050. The most promising regions are the Caribbean and Latin America, the former Soviet Union and parts of North America. Key variables are the demand for industrial round wood and fuel wood, plantation establishment rates, natural forest growth, and the impact of technology and recycling. Despite this potential, the amount of energy that can be obtained from forest residue and other waste biomass resources will be limited in comparison with energy crops; moreover, these reserves will likely be depleted first as demand for bioenergy grows. Finland, which has focused on harnessing biomass energy for many years, has already used a large part of its accessible residue and waste and is now importing wood energy.

Organic wastes

This category includes waste wood (e.g. demolition wood), the organic fraction of municipal solid waste (MSW), grass clippings, sludges, wood from tree trimmings and land clearing activities in urban areas, and animal dung. Organic wastes are a particularly attractive source of biomass energy because they can have a "negative" price. In other words, collecting and utilizing these can result in savings from landfill tipping fees. MSM and other organic wastes have the potential to supply 5–50 EJ per year of energy by 2040, depending on the assumptions regarding economic development, consumption and the use of biomaterials. Higher values may be possible when more intensive use is made of biomaterials (Fischer and Schrattenholzer 2001). In addition, dried dung could potentially generate 5–55 EJ per year worldwide; the low estimate is based on current global use, and the high estimate is the technical potential. Utilization (collection) in the long run is uncertain because this is particularly considered a "poor person's fuel" (Hoogwijk et al. 2003). There are also sociocultural constraints in this waste utilization, which somewhat explain the wide differences in waste utilization across different regions and cultures.

Biomass residue and organic waste have several advantages over dedicated energy crops. Most of them would require no additional land acreage, as they are typically pre-collected into piles at large agricultural and forestry facilities and often represent waste that must otherwise be disposed of. As a result, this feedstock is cheaper and is likely to be the first source of biomass to be tapped. Already, the wood-products industry uses most lumber residue and much of the forestry residue in Europe and the USA for processing purposes and to generate co-products such as wood chips and fibreboard. For sustainability reasons, however, estimates of potential bioenergy from waste and residue would likely be lower than those suggested above. In general, it is a good idea to retain some portion of biomass residue in the field or forest in order to hold carbon, water and other nutrients in the soil, and to provide habitat for various species. Leaving a protective amount of residue behind is especially important on steep slopes and on ecologically sensitive sites that have particularly erodible soils or are near riparian areas.

In general, biomass residues (and wastes) are intertwined with a complex set of markets. Many residues have useful applications such as fodder, fertilizer and soil conditioner, raw material (e.g. for recycled paper), and particle boards and medium-density fibreboard (MDF) used in the construction industry. Net availability and the market prices of biomass residue and waste therefore generally depend on market demand, local and international markets for various raw materials, and the type of waste-treatment technology deployed for remaining materials. When waste treatment is paid for, the latter is particularly relevant, giving some organic waste streams a theoretical negative value. Typically, the net availability of organic wastes and residues can fluctuate and is influenced by market developments, but it can also depend on climate (high and low production years in agriculture) and other factors.

Dedicated energy crops

Dedicated production of crops for energy production, generally called "energy farming", can be done with a multitude of agriculture crops, including annual and perennial crops:

- *Annual crops* such as rapeseed and cereals (such as maize) are presently cultivated for energy purposes in temperate regions. Both crops are intermixed with conventional agricultural production and find an application in the production of transport fuels. Sugarcane used for the production of bioethanol is grown in tropical regions and is the most important energy crop, covering at present some 3.5 million hectares in Brazil, by far the world's most important producer of sugar bioethanol. The acreage of sugarcane for ethanol production in Brazil, but also various African and Asian countries, has grown rapidly in recent years.
- *Perennial crops* are planted for a longer period of time (e.g. 15–20 years) and harvesting can take place at regular intervals. Willow is a good example of a short-rotation coppice (SRC) suited for temperate climate zones that is harvested every 2–5 years over a period of some 20–25 years. Most of the experience with SRC willow systems has been gained in Sweden, where this crop is produced on some 14 000 hectares. Poplar and grasses such as miscanthus (which are harvested each year) and sweet sorghum are also examples of perennial crops that have gained recent attention in Europe and North America. The commercial use of perennials for energy production, however, is negligible at present (Rogner 2000).

In general, dedicated biomass production is more expensive per unit of energy produced than the use of available residue and waste. Typical cost ranges for perennial woody crops under northwestern European conditions are €3–6/GJ (compared with €1–2/GJ for imported coal). Biomass production costs of dedicated production systems are especially dependent on the costs of land and labour and the average yield per hectare. Typically, land costs (i.e. through land rent) can contribute to about one-third of the total biomass production costs under northwestern European conditions (van den Broek 2000).

Both land and labour are relatively expensive production factors in Europe, which are indirectly maintained due to the structural agricultural subsidies, which are in turn part of the Common Agricultural Policy (CAP) of the EU. In addition, agricultural surpluses in the EU are partially counteracted by measures to take agricultural land out of production (fallow land). This land category could in theory be available for energy crop production, but the total fallow land surface varies over the years, varying from 10 percent to less than 3 percent of the arable land, and is generally taken up in typical rotation systems of farmers, making introduction of perennial crops difficult. This is also a partial explanation for the relative popularity of annual crops for energy purposes, such as rapeseed and the interest in hemp.

Implementation issues

While the above-mentioned estimates highlight the potential for bioenergy to become an important source of energy during the twenty-first century, it is still uncertain to what extent and how quickly this potential can be realized. The sustainable use of different types of land – marginal and degraded, as well as good-quality agricultural and pasture land – depends on two key factors: first, the capacity to increase agricultural productivity in developing countries, which would result in considerably higher land-use efficiencies and consequently in a surplus of productive land; and second, the integration of biomass production in a sustainable way within current land-use patterns. Our understanding of how these two elements could be realized from region to region is often limited. On the one hand, in developing countries (e.g. in sub-Saharan Africa), very large improvements can be made in agricultural productivity given the current agricultural methods deployed (often subsistence farming), but better and more efficient agricultural methods will not be implemented without investment and proper capacity-building and infrastructure improvements. On the other hand, current experiences with energy crops such as willow (in Sweden) and sugarcane (in Brazil) give leads on how biomass production can gradually be introduced into agriculture and forestry. However, much more experience is needed with such schemes, in which the introduction of bioenergy can play a pivotal role in creating more income for rural regions through the addition of bioenergy production. Financial resources generated could then accelerate investments in conventional agriculture and infrastructure and also lead to improved management of agricultural land.

Critical issues that require further research and especially more regional demonstrations and experience with biomass production are:

- *Competition for water resources*. Water is logically a critical resource for both food and biomass production and a constrained resource in many world regions. Water scarcity in relation to additional biomass production has been addressed to a limited extent. A large-scale expansion of energy crop production would lead to a large increase in evapotranspiration appropriation for human uses, potentially as large as the present evapotranspiration from global cropland. In some countries this could lead to further deterioration of an already stressed water situation. But there are also countries in which such impacts are less likely to occur. One major issue for future research is for assessments of bioenergy potentials to consider restrictions from competing demands for water resources.

- *Availability and impacts of fertilizers and pest control*. Increases in agricultural productivity, in particular in developing countries, can be achieved only when better management and higher productivities are achieved. This implies availability of fertilizers and pest-control techniques. This use needs to be within environmentally sound limits. Sound agricultural methods (e.g. agroforestry, precision farming, biological pest control) exist that can achieve major increases in productivity with neutral or even positive environmental impacts. Such practices must, however, be secured by sufficient funds, human capacity and knowledge.

- *Biodiversity impacts of agriculture intensification*. Concerns have been raised that further intensification of agriculture and large-scale production of biomass energy crops may result in larger losses of biodiversity than current land use, even when international standards for nature protection (10–20 percent of land reserved for nature) are respected. Biodiversity standards are still to be interconnected with biomass production when changes in land use are considered. The fact is that perennial crops, which are the preferred category of crops for energy production, have a better ecological profile than annual crops, and benefits with respect to biodiversity can be achieved when annual crops are displaced. However, there are limited insights into the ways in which biodiversity effects can be optimized (and improved compared with current land use) when sound landscape planning is introduced. Some indications are given by experiences in Sweden and the UK with integration of willow production on landscape level with overall positive effects. Here also more regional efforts, experience and specific solutions are needed.

- *Feasibility and impacts of cattle raising intensification*. A key land category in making the use of land for food production more efficient is grasslands, now used for grazing. It should be realized, though, that such changes also have sociocultural implications for pastoral traditions and that at the same time the feasibility of switching to more intensive methods is impacted by land tenure and property rights associated with such traditions. The analyses discussed above show that much land can be released when production of meat and dairy products is done in more intensive (partly land-less in closed stables) schemes. Grasslands could then be used for production of energy grasses or partly converted to woodlands. Such changes in land-use functions are poorly studied so far, although similar conversion has taken place in, for example, the mid-south of Brazil. The impacts of such changes should be evaluated closely, including their implications in terms of GHG emissions.

- *Socioeconomic impacts, in particular in rural regions*. Large-scale production of modern biofuels, partly for the export market, could provide a major opportunity for many rural regions around the world to generate significant economic activity, income and employment. Given the size of the global market for transport fuels, the benefits that can be achieved by reducing oil imports and the possibility of net exports of bioenergy are vast. Nevertheless, it is not a given that these benefits end up with the rural population and the farmers who need these benefits most. Also, the net impacts for a region as a whole, including possible changes and improvements in agricultural production methods, should be kept in mind when developing biomass and biofuel production capacity. Although various experiences around the globe (Brazil, India) show that major socioeconomic benefits can be achieved, new biofuel production schemes should ensure the involvement of the regional stakeholders, in particular farmers. Experience with such schemes needs to be built around the globe.

- *Macroeconomic impacts of changes in land-use patterns*. Although the analyses discussed indicate the potential that there would be enough land to accommodate significant production of energy crops while meeting the world's projected food demand, more intensive land use and additional land use for biomass production may lead to macroeconomic effects on land and food prices. Although this is not necessarily a bad mechanism (it could be vital for farmers to enable investment to improve current production methods), the possible implications on the macroeconomic level are poorly understood. More analysis is needed to highlight the speed of implementation and change necessary in order to avoid undesired economic effects.

2.4 Competing uses of bioenergy

As the above studies have shown, the global technical potential for producing biomass resources for energy use is very large. However, it should be noted that not all of this biomass will be converted into biofuels for transportation. Among the competing uses for biomass are heating, power and materials.

From an energy and climate point of view, using biomass for heat and electricity generation is often a more efficient option than converting it into liquid biofuels. Nonetheless, it is estimated that biofuels are likely to draw on an important portion of future biomass supplies. In fact, although there is a range of other renewable and carbon-free ways to produce heat and electricity (e.g. wind, solar, hydropower), few alternatives to petrol exist in the transport sector. In addition, energy-source petroleum has a far more constrained supply than coal, the dominant resource of power generation. A rapid and significant increase in petrol prices due to a scarcity of cheap supplies, combined with structural increases in demand for transport fuels, would make even second-generation biofuels – which are still relatively expensive – an economically attractive alternative for the production of heat and power. It is thus likely that using biomass for producing transport fuels will become more attractive from an energy security perspective in the medium to longer term beyond 2020 (Worldwatch Institute 2006). Table 3 provides an overview of the global long-term bioenergy supply potential by source.

However, in the short term, if the primary goal is to reduce GHG emissions and help combat climate change, then biomass can reduce carbon emissions significantly more by displacing coal (for electricity) than by displacing petroleum. For instance, co-firing of biomass in coal-fired power stations has a higher avoided emission per unit of biomass than does using biomass to displace diesel or gasoline. This is even true when second-generation biofuels are concerned. Over the next 5–10 years, therefore, careful strategies and policies are needed in order to avoid the enthusiasm for biofuels diverting biomass resources away from efficient utilization in heat and power generation end-use. Table 4 gives an overview of the perspectives for bioenergy processes combined with their main biomass resources.

Production of heat and power

The production of heat and electricity dominates current bioenergy use. At present, the main growth markets for bioenergy are the EU, North America, Central and Eastern Europe and Southeast Asia (Thailand, Malaysia, Indonesia), especially with respect to efficient power generation from biomass waste and residue and for biofuels. The two key industrial sectors for application of state-of-the-art biomass combustion (and potentially gasification) technology for power generation are the paper and pulp industry and the cane-based sugar industry.

Power generation from biomass using advanced combustion technology and co-firing schemes is a growth market worldwide. Mature, efficient and reliable technology is available to turn biomass into power. In various markets the average scale of biomass combustion schemes increases rapidly with improved availability of biomass resources and the economic advantages of economies-of-scale of conversion technology. It is also in this field that competitive performance compared with fossil fuels is possible, in which lower-cost residues are available. This is particularly true for co-firing schemes (i.e. combined combustion of biomass with fossil fuels such as coal) in which investment costs can be minimal. Specific national policies (e.g. carbon taxes, renewable energy support by direct investment subsidies or feed-in tariffs) accelerate this development. Gasification technology (integrated with gas turbines/combined cycles) offers even better potentials for power generation from biomass in the near future and can make power generation from energy crops competitive in many areas in the world once this technology has been proven on a commercial scale. Gasification also offers excellent possibilities for co-firing schemes.

With biomass prices of about €2/GJ, state-of-the-art combustion technology at a scale of 40–60 Mwe (electricity) can result in electricity costs of around €ct4-6/kWh produced (typical production costs of power generation from coal and natural gas are in the range €ct3-7/kWh, depending on the market considered (IEA 2006). Co-combustion, particularly at efficient coal-fired power plants, can give similar or lower cost figures, largely depending on the feedstock costs. When biomass-based integrated gasification combined cycle (IGCC) technology becomes available commercially, electricity costs could drop further to about $€_{ct}$3-4/kWh, mainly due to greater electrical efficiencies. On a larger scale (i.e. over 100 MWe), cultivated biomass will be able to compete with fossil fuels in many situations. Future prices of carbon could be a very important factor in this equation as well. The benefits of lower specific capital costs and increased efficiency may in many cases outweigh the increased costs and energy used for transport, once a reasonably well-developed infrastructure is in place.

Decentralized power (and heat) production is generally more expensive but could be economical for off-grid applications. The costs that could ultimately be obtained, e.g. with gasifier/diesel systems, are still unknown and depend strongly on the emissions and fuel quality that are considered acceptable. Combined heat and power (CHP) generation is generally attractive when heat is required with high load factors. The traditional use of biomass is to produce heat for cooking and space heating. It is not expected that the traditional use of biomass will diminish in coming decades. Nevertheless, modernizing bioenergy use for the poorer part of populations is an essential component of sustainable development schemes in many countries. This creates opportunities and major markets, for example for improved stoves, production of high-quality efficient fuels for cooking (e.g. biofuel-based fuels such as ethanol and Fischer-Tropsch liquids) and health advantages due to cleaner combustion properties. Furthermore, biogas (e.g. produced with digestors on the village level) has proved to be very effective in various countries, including China and India, in solving waste-treatment problems and in supplying high-quality energy carriers (clean gas and power when used in gas engines) along with hygienic biofertilizers.

Commercial heat production technology (e.g. boilers, advanced stoves) is commercially available for many applications (industrial, district and domestic heating). Also CHP generation is becoming more attractive in various markets. Especially for specific industrial applications, production of heat and process steam from biomass is an economically attractive option, as is evident in the paper and pulp and sugar industries worldwide.

Table 3: Global long-term bioenergy supply potential by source, 2050

Biomass category	Bioenergy potential, 2050 (EJ)	Main assumptions and remarks
Agriculture residues	~15-70	Based on estimates from various studies. Potential depends on yield/product ratios and the total agricultural land area as well as type of production system: extensive production systems require reuse of residues for maintaining soil fertility. Intensive systems allow for higher utilization rates of residues.
Forest residues	30-150 (or possibly 0)	Figures include processing residues. Part is natural forest (reserves). The (sustainable) energy potential of the world's forests is unclear. Low estimates based on sustainable forest management; high value reflects technical potential.

Table 3: Global long-term bioenergy supply potential by source, 2050 continued

Biomass category	Bioenergy potential, 2050 (EJ)	Main assumptions and remarks
Organic wastes	0–50+*	Based on estimates from various studies. Include the organic fraction of MSW and waste wood. Strongly dependent on economic development, consumption and the use of biomaterials. Higher values possible by more intensive use of biomaterials.
Animal dung	5–55 (or possibly 0)	Use of dried dung. Low estimate based on global current use; high estimate reflects technical potential. Utilization (collection) in longer term is uncertain.
Energy farming (on current agricultural land)	0–700 (100–300 is more average)	Potential land availability: 0–4Gha, although 1–2 is more average. Based on productivity of 8–12 dry tonne/ha/year** (higher yields are likely with better soil quality). If adaptation of intensive agriculture production systems is not feasible, bioenergy supply could be reduced to zero.
Energy farming (on marginal lands)	60–150 (or possibly 0)	Potential maximum land area of 1.7Gha. Low productivity of 2–5 dry tonne/ha/year.** Bioenergy supply could be low or zero due to poor economics or competition with food production.
Biomaterials	Minus 40–150 (or possibly 0)	These provide an additional claim on biomass supplies. Land area required to meet additional global demand is 0.2–0.8Gha. Average productivity: 5 dry tonnes/ha/year.** Supply would come from energy farming if forests are unable to meet projected demand.
Total	40–1100 (250–500 is more average)	Pessimistic scenario assumes no land available for energy farming, only utilization of residues; optimistic scenario assumes intensive agriculture on better-quality soils. More average potential: more likely in a world aiming for large-scale utilization of bioenergy.

Source: Hoogwijk (2004), Hoogwijk et al. (2005, 2008), IEA (2007), Smeets et al. (2007).

*The energy supply of biomaterials ending up as waste varies between 20 EJ and 55 EJ (1100-2900 Mtonne) dry matter per year (biomass lost during conversion, such as charcoal, is logically excluded from this range). This range excludes cascading and does not take into account the time delay between production of the material and release as (organic) waste.

**Heating value: 19 GJ/tonne dry matter.

Table 4: Overview of projected performances for different biomass resources in the shorter (~5 years) and longer (>20 years) term

Biomass resource	Heat		Electricity		Transport fuels	
	Short-term; stabilizing market	**Longer-term**	**Short-term; strong growth market worldwide**	**Longer-term; growth may stabilize due to competition of alternative options**	**Short-term; growing market, but highly policy driven**	**Longer-term; potential key market for (cultivated) biomass**
Organic wastes (e.g. MSW)	Undesirable for domestic purposes (emissions); industrial use attractive; in general competitive	Especially attractive in industrial setting and CHP) (advanced combustion and gasification for fuel gas)	Less than $€_{ct}$3/kWh to €ct5/kWh for state-of-the art waste incineration and co-combustion. Economics strongly affected by tipping fees and emission standards	Similar range; improvements in efficiency and environmental performance, in particular through integrated gasification/combined cycle technology on large scale	NA	In particular possible via gasification routes (see below)
Residues: forestry, agriculture	Major market in developing countries (<€ct1/kWh to €ct5/kWh thermal); stabilizing market in industrialized countries	Especially attractive in industrial setting and CHP. Advanced residential heating systems possible but not on global scale	$€_{ct}$4-12/kWh (see below; major variable is supply costs of biomass); lower costs also in CHP operation and industrial setting depending on heat demand	€ct2-8/kWh (see below; major variable is supply costs of biomass)	NA	€5-10/GJ; low costs obtainable with lignocellulosic biomass (<US$2/GJ) advanced hydrolysis techniques and large-scale gasification (i.e. <1000 MWth) for MeOH/H2/FT, as well as improved sugarcane production and subsequent ethanol production in optimized distilleries

Table 4: Overview of projected performances for different biomass resources in the shorter (~5 years) and longer (>20 years) term

Biomass resource	Heat		Electricity		Transport fuels	
Energy crops: oil seeds, sugar/starch, sugarcane, perennial crops (i.e. short-rotation cropping trees and grasses)	NA	Unlikely market due to high costs feedstock for lower value energy carrier; possible niches for pellet or charcoal production in specific contexts	€ct5–15/kWh; high costs for small-scale power generation with high-quality feedstock; lower costs for large-scale (>100 MWth) state-of-the art combustion (wood, grasses) and co-combustion	€ct3–8/kWh; low costs, especially possible with advanced co-firing schemes and BIG/CC technology over 100-200 MWe	€8–25/GJ; lower figures for ethanol from sugarcane; higher figures for biodiesel (RME) and sugar and starch crops in Europe and North America	

Source: Faaij (2006), IEA (2007).

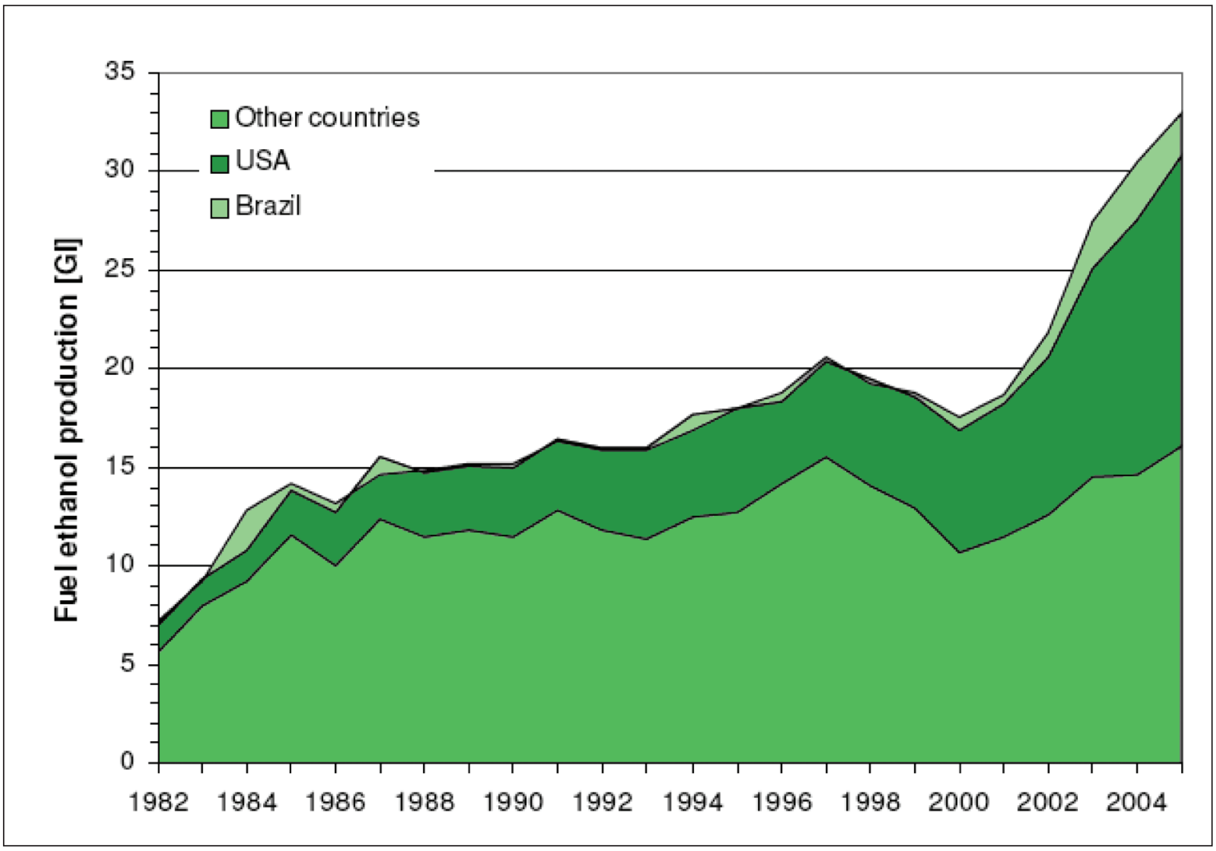
3. BIOFUEL PRODUCTION AND TRADE

This section provides an overview of current and projected trends in global biofuel production and government support policies underpinning this expansion. It also describes the current status of international trade in biofuels and explores the key barriers to its future expansion, including tariffs, lack of international fuel quality standards, and poorly developed markets. It concludes with a discussion of the sustainable development risks and opportunities associated with the biofuels trade.

3.1 Global biofuel production

Global markets for biofuels (ethanol, biodiesel) have seen enormous growth in the past decade: in 2006 they contributed to about 2 percent of road transport fuels worldwide, or over 45 billion litres. Global ethanol production doubled between 2000 and 2005, reaching over 39 billion litres in 2006, equal to about 3 percent of the 1300 billion litres of gasoline consumed globally. Jointly, the USA and Brazil produced almost 90 percent of the world's bioethanol in 2006: the USA produced over 18 billion litres, followed closely by Brazil, with about 17.5 billion litres. Other countries producing fuel ethanol include Australia, Canada, China, Colombia, the Dominican Republic, France, Germany, India, Malawi, Poland, South Africa, Spain, Sweden, Thailand and Zambia (REN21 2008). Figure 2 shows world ethanol production between 1982 and 2005, and Table 5 gives an overview of the 2006 global biofuel production for the top 15 countries.

Figure 2: World ethanol production 1982–2005



Source: Walter et al. (2007).

Table 5: Biofuel production, top 15 countries plus EU, 2006

Country	Fuel ethanol	Biodiesel
	Billion litres	
1. USA	18.3	0.85
2. Brazil	17.5	0.07
3. Germany	0.5	2.80
4. China	1.0	0.07
5. France	0.25	0.63
6. Italy	0.13	0.57
7. Spain	0.40	0.14
8. India	0.30	0.03
9. Canada	0.20	0.05
9. Poland	0.12	0.13
9. Czech Republic	0.02	0.15
9. Colombia	0.20	0.06
13.Sweden	0.14	–
13. Malaysia	–	0.14
15. UK	–	0.11
EU total	**1.6**	**4.5**
World total	**39**	**6**

Source: REN21 (2006).

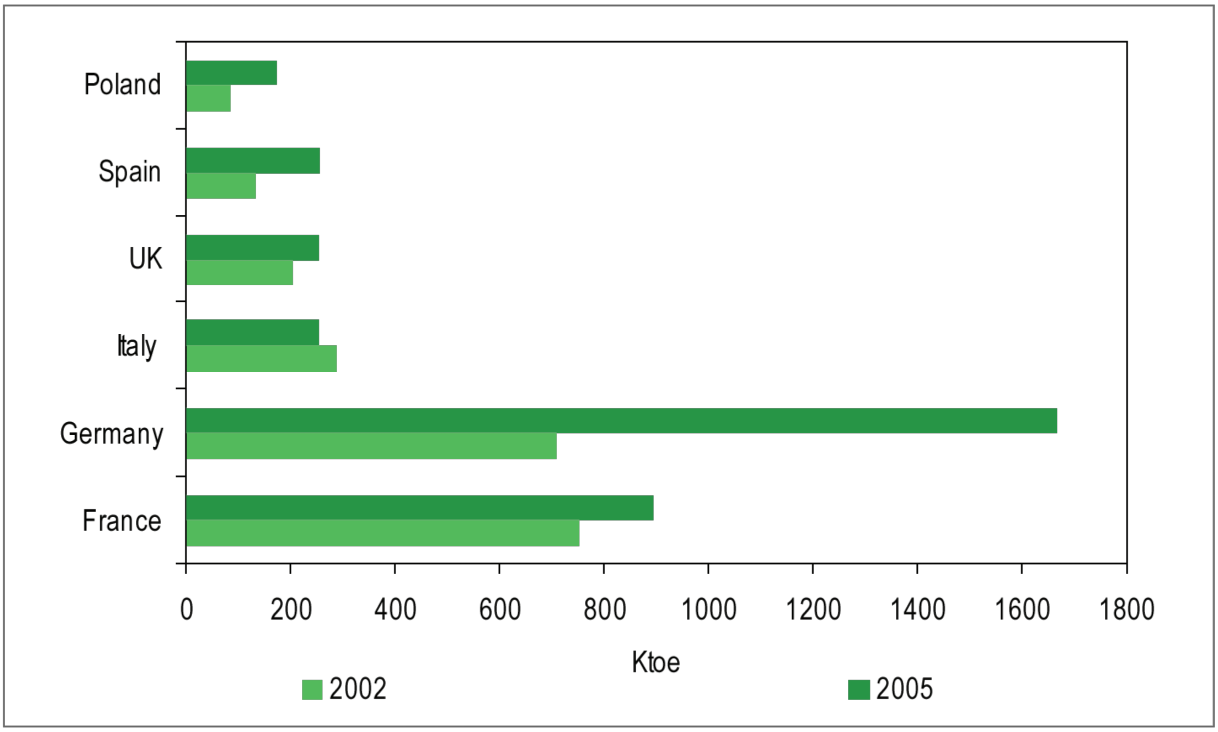
Note: Numbers for fuel ethanol only; total ethanol production figures will be significantly higher. Table ranking by total biofuels.

Global biodiesel production jumped 50 percent in 2006 to over 6 billion litres globally. Half of the world biodiesel production continued to be in Germany. Significant production increases also took place in Italy and the USA. In Europe, supported by new policies, biodiesel, produced mostly from rapeseed, gained broader acceptance and market share (Figure 3). Aggressive expansion of biodiesel production also occurred in Asia (Malaysia, Indonesia, Singapore, China), Latin America (Argentina, Brazil), and southeastern Europe (Romania, Serbia). Malaysia's ambition is to capture 10 percent of the global biodiesel market by 2010 based on its oil plantations. Indonesia also planned to expand its oil palm plantations by 1.5 million hectares by 2008 to reach 7 million hectares in total, as part of a biofuels expansion programme that includes US$100 million in subsidies for palm oil and other biofuels such as soy and maize (REN21 2008).

Future production prospects[1]

Future projections for biofuels production have been made by the International Energy Agency (IEA) in its World Energy Outlook (International Energy Agency 2006). *The IEA* undertook two global energy scenarios: the "reference" case of continuing current trends, and the "alternative policy" case, which sees a sharp reduction in energy demand, due to additional policies related to energy and climate security that were under consideration by governments in 2006. In addition, a number of new biofuel production policies are taken into account, including larger subsidies for producers and consumers on the fuels and on FFVs, more extensive vehicle-purchase mandates, and increased spending on research and development. The alternative scenario also assumes a reduction in trade barriers for agricultural products. Such barriers restrict access in many industrialized countries to

Figure 3: Biofuels consumption in selected EU countries, 2002–2005 (million litres)



Source: F.O. Licht (2006).

imported biofuels, which is holding back the growth of the industry in countries with the lowest production costs (International Energy Agency 2006). Under both energy scenarios, the IEA expects the demand for road-transport fuels to increase strongly in the coming decades, especially in developing regions. By 2030, global energy use in that sector is expected to be 56 percent higher than today in the reference scenario and 42 percent higher in the alternative scenario.

The IEA expects biofuels to play an increasingly important role in meeting transport demand, although the rates of penetration differ substantially between the two main scenarios (Table 6). In the reference scenario, biofuels meet 4 percent of world road-transport fuel demand by 2030, up from 1 percent in 2005 (Figure 4). Total world biofuel production is projected to climb from 20 million tons oil equivalent (Mtoe) in 2005 to 42 Mtoe in 2010, 54 Mtoe in 2015 and 92 Mtoe in 2030. The average annual rate growth is 6.3 percent. To meet this demand, cumulative investment in biorefineries of US$160 billion (based on 2005 estimates) over the projection period is needed. In the alternative scenario, biofuel use reaches a 7 percent share, thanks to lower total transport fuel demand and higher biofuel demand. World biofuel production rises much faster than in the reference scenario, at 8.3 percent per year, reaching 73 Mtoe in 2015 and 147 Mtoe in 2030. A cumulative investment totals US$225 billion over the scenario period. In both scenarios, the biggest increase in biofuels consumption occurs in the USA before 2010, which overtakes Brazil as the second-largest consuming (and producing) region. Biofuels use outside these regions remains modest, with the biggest increases occurring in developing Asia.

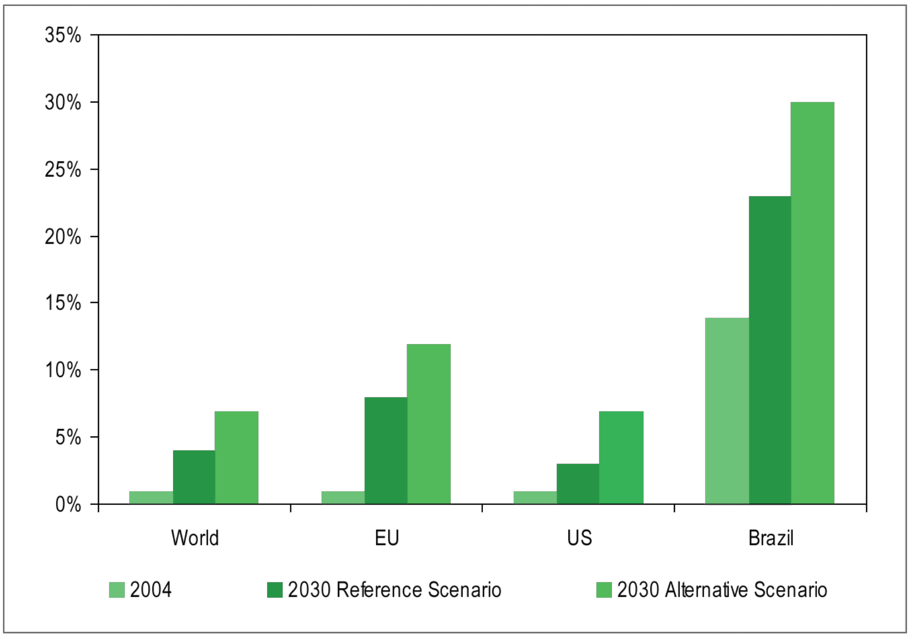
Table 6: World biofuels consumption by scenario (million tons oil equivalent, Mtoe)

		2010		2015		2030	
	2004	RS	AS	RS	AS	RS	AS
OECD	**8.9**	**30.5**	**34.7**	**39.0**	**51.6**	**51.8**	**84.2**
North America	7.0	15.4	17.4	20.5	28.8	24.2	45.7
USA	*6.8*	*14.9*	*16.4*	*19.8*	*27.5*	*22.8*	*42.9*
Canada	*0.1*	*0.6*	*1.0*	*0.7*	*1.3*	*1.3*	*2.8*
Europe	2.0	14.8	16.4	18.0	21.5	26.6	35.6
Pacific	0.0	0.3	0.8	0.4	1.4	1.0	2.9
Transition economies	**0.0**	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.5**
Russia	0.0	0.1	0.1	0.1	0.2	0.3	0.5
Developing countries	**6.5**	**10.9**	**14.0**	**15.3**	**21.1**	**40.4**	**62.0**
Developing Asia	0.0	1.9	4.6	3.7	8.5	16.1	32.8
China	*0.0*	*0.7*	*1.2*	*1.5*	*2.7*	*7.9*	*13.0*
India	*0.0*	*0.1*	*0.1*	*0.2*	*0.3*	*2.4*	*4.5*
Indonesia	*0.0*	*0.2*	*0.3*	*0.4*	*0.6*	*1.5*	*2.3*
Middle East	0.0	0.1	0.1	0.1	0.1	0.5	0.6
Africa	0.0	0.6	0.7	1.1	1.2	3.4	3.5
North Africa	0.0	0.0	0.0	0.1	0.1	0.6	0.5
Latin America	6.4	8.4	8.6	10.4	11.2	20.3	25.1
Brazil	6.4	8.3	8.6	10.4	11.0	20.3	23.0
World	**15.4**	**41.5**	**48.8**	**54.4**	**73.0**	**92.4**	**146.7**
EU	*2.0*	*14.8*	*16.4*	*18.0*	*21.5*	*26.6*	*35.6*

Source: International Energy Agency (2006).

Note: AS, a1lternative scenario; RS, reference scenario.

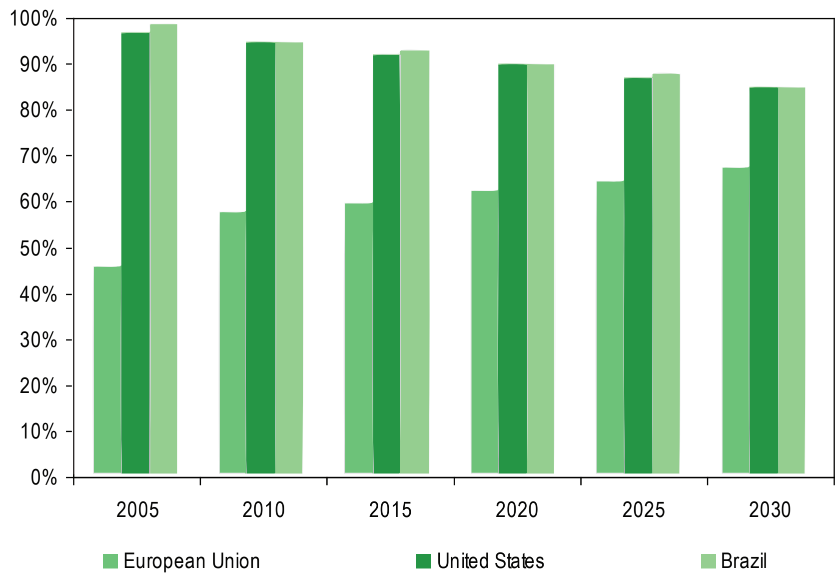
Figure 4: Share of biofuels in road-transport fuel consumption, 2005-2030



Source: IEA (2006).

Ethanol is expected to account for most of the increase in biofuels use worldwide, as production costs are expected to fall faster than those of biodiesel (Figure 5). The share of biodiesel production globally nonetheless grows in both scenarios, mainly because of the take-off of biodiesel production in the USA and Brazil. By 2030, biodiesel is expected to account for about 15 percent of total biofuels use in both countries and in both scenarios. By contrast, the biodiesel share in the EU is projected to drop from well over half today to under a third in 2030.

Figure 5: Share of ethanol in total biofuels consumption in energy terms in Brazil, the EU and the USA



Source: IEA (2006).

According to the IEA projections, the bulk of the biofuels consumed in each region will continue to be produced indigenously, although the volume of biofuels traded internationally is expected to grow. Only those regions that have the potential to produce biofuels without subsidy are expected to export. Most exports will probably take the form of ethanol, because there will be less need to subsidize it compared with biodiesel, and because countries that subsidize biodiesel are unlikely to permit producers to export that fuel. Brazil is expected to remain the largest ethanol exporter over the projection period. Some developing Asian and African countries have ethanol production costs close to those of Brazil and may emerge as significant exporters in the coming decades, depending on domestic requirements and trade policies. Within the developing world, Malaysia, Indonesia and the Philippines could become exporters of biodiesel derived largely from palm oil. The EU and the USA may become sizeable net importers of biofuels, especially in the alternative scenario, as demand outstrips domestic production. The development of international trade in biofuels will depend critically on the removal of trade barriers and timely investment in production facilities.

The costs of both ethanol and biodiesel production using conventional technologies are expected to fall in both scenarios in line with incremental efficiency improvements in the conversion processes and in agricultural productivity. In neither scenario are second-generation biofuels technologies, such as lignocellulosic ethanol or biomass gasification, assumed to penetrate the market. This is because important breakthroughs in developing these technologies will be necessary before they can be deployed commercially on a large scale. It is nonetheless possible that such breakthroughs could occur in the near future, which could pave the way for faster development of biofuels markets.

3.2 Trends in global biofuels trade

Today, trade in biofuels is limited (approximately only 5 percent of the total use of biofuels in industrialized countries is traded internationally) and occurs mainly between neighbouring regions or countries, although it is increasingly happening over longer distances. For instance, Brazilian ethanol is now exported to Japan, the EU and the USA; Malaysia exports palm kernel shells to the Netherlands; and Canada exports wood pellets to Sweden. This is happening despite the bulky and lower calorific value of most biomass raw material. Ethanol, vegetable oils, fuel wood, charcoal and wood pellets are the most important products that are currently internationally traded for energy purposes. Nevertheless, the international trade of these energy products is much smaller than the international trade of biomass for other purposes. Table 7 provides an overview of the volumes of global production and international trade of various biomass products in 2004.[2] Table 8 gives a preliminary and rough estimate of the current scope of the international trade of biomass for energy purposes in 2004. The indirect trade of biofuels through trading of industrial round wood and material by-products composes the largest share of the trade.

Table 7: World biomass production and international trade, 2004

Product	World production in 2004	Volume of international trade in 2004
Industrial wood and forest products[a]		
Industrial round wood	1646 million cubic meters (Mm^3)	121 Mm^3
Wood chips and particles	197 Mm^3	37 Mm^3
Sawn timber	416 Mm^3	130 Mm^3
Pulp for paper production	189 Million tons (Mt)	42 Mt
Paper and paperboard	354 Mt	111 Mt
Agricultural products[b]		
Maize	725 Mt	83 Mt
Wheat	630 Mt	118 Mt
Barley	154 Mt	22 Mt
Oats	26 Mt	2.5 Mt
Rye	18 Mt	2 Mt
Rice	608 Mt	28 Mt
Palm oil	37 Mt	23 Mt
Rapeseed	46 Mt	8.5 Mt
Rapeseed oil	16 Mt	2.5 Mt
Solid and liquid biofuels[c]		
Ethanol	41 Mm^3	3.5 Mm^3
Biodiesel	3.5 Mt	<0.5 Mt
Fuel wood	1 772 Mm^3	3.5 Mm^3
Charcoal	44 Mt	1 Mt
Wood pellets	4Mt	1 Mt

[a]*Source: FAOSTAT (2006).*

[b]*Source: FAOSTAT (2006), excluding production of palm and rapeseed oils, which were sourced from Indexmundi (2006).*

[c]*Source: Ethanol (Rosillo-Calle and Walter 2006) (refers to fuel ethanol); biodiesel production (Worldwatch Institute 2006): trade volume is an estimate by the authors; fuel wood and charcoal (FAOSTAT 2006); wood pellets: volumes were estimated based on (Dahl et al. 2005, Swaan 2006).*

Table 8: Estimate of the scope of international trade of biofuels in 2004 (excluding tail oil, ethyl tertiary butyl ester (ETBE) and wastes)

Indirect trade	0.54
Industrial round wood[a]	0.41
Wood chips and particles[b]	0.13
Direct trade	0.22
Ethanol[c]	0.09
Biodiesel[d]	0.02
Fuel wood[e]	0.03
Charcoal[f]	0.02
Wood pellets[g]	0.02
Palm oil[h]	0.04
Total	**0.76**

[a]Round wood in FAO's statistics is without bark, so 10 percent bark was added. Other assumptions: average density 0.8 t/m^3, 45 percent average conversion into biofuels, calorific value 9.4 GJ/t.

[b]Assumptions: average density 0.8 t/m^3, 45 percent average conversion into biofuels and 9.4 GJ/t calorific value.

[c]Assumed calorific value 27 GJ/m^3.

[d]Assumed calorific value 37 GJ/t.

[e]Assumed density and calorific value 0.7 t/m^3 and 13 GJ/t.

[f]Assumed calorific value 22 GJ/t.

[g]Assumed calorific value 17.5 GJ/t.

[h]According to Indexmundi (2006), the global industrial use of palm oil was 6.8 Mt in 2004. Palm oil use for energy purposes (for power generation and biodiesel production) was estimated at 1 Mt, which approximately equals the volume of industrial use of palm oil in EU–25 indicated by Indexmundi. The calorific value of palm oil was estimated at 37 GJ/t.

Growing interest in a wide variety of biomass resources, many of which are underutilized in much of the world, is likely to foster new trading relationships in the near term. The greatest demand for biofuels is concentrated in industrialized regions that consume large amounts of energy, such as the USA, the EU and Australia, as well as in rapidly industrializing nations, such as China and India. The largest potentials for producing these fuels, meanwhile, are found in the tropical countries of South America, sub-Saharan Africa and East Asia, and in eastern Europe. International trade is therefore a natural outcome of such imbalances. In general, the decision to facilitate trade in these fuels must be balanced with domestic and regional energy needs. Compared with the long-term potential, the development of international trade of biomass for energy purposes is in its initial stages. Taking the local production and usage potentials into account, Hansson and Berndes (2006) have estimated the theoretical maximum potential for international trade in biofuels to be anywhere between 80 EJ and 150 EJ per year by the year 2050.

Trade in ethanol

About 20 percent of the ethanol produced in the world today is traded internationally (see Figure 5). Historically, most of this trade has been for non-transportation uses – as a base for alcoholic beverages, as a solvent and for other industrial applications.[3] However, fuel ethanol is becoming an increasingly popular global commodity as oil prices rise and as governments adopt new policies promoting biofuel use. As a result, the volume of bioethanol traded worldwide grew to 7.8 billion litres in 2006, compared with 5.9 billion litres in 2005 and 3.2 billion litres in 2002 (GBEP 2007).[4] The rise in recent years was due mostly to the noticeable increase in trade reported in Brazil when 2006 exports of fuel ethanol reached 3.5 billion litres, a threefold increase over 2002 figures (F.O. Licht 2006).

Ethanol produced from Brazilian sugar cane accounts for the vast majority of liquid renewable fuel traded today. Figure 7 shows trade in bioethanol in Brazil between 1975 and 2005. In 2005, this country was the world's dominant ethanol exporter, accounting for approximately half of total global trade, for all uses (Table 9). As shown in Table 10, the main recipients of these exports in 2004 were India, the USA, South Korea and Japan. Some Brazilian exports also flow into the USA indirectly via Central America and the Caribbean, where it is processed and can enter tariff-free under the Caribbean Basin Initiative (CBI), a regional preferential trading program. Several other producer countries, including Pakistan, the USA, South Africa, Ukraine, and countries in Central America and the Caribbean, also contribute to ethanol trade, although their relative exports compared with Brazil are quite small. Due to preferential access to the European market, small amounts of ethanol are shipped from Africa and Asia to Europe. Pakistan has historically been the largest exporter of ethanol to the EU. However, over the past couple of years, Brazilian ethanol exports to Europe increased sharply (F.O. Licht 2006).

Table 9: Ethanol-exporting and -importing countries, 2005

Import	%	Export	%
USA	18	Brazil	48
Japan	11	USA	6
India	8	France	6
Germany	8	South Africa	6
The Netherlands	8	China	5
UK	6	UK	5
Korea	5	The Netherlands	4
France	4	Germany	2
Others	32	Others	18

Source: Walter et al. (2007).

Table 10: Brazilian ethanol exports, all grades, 2004

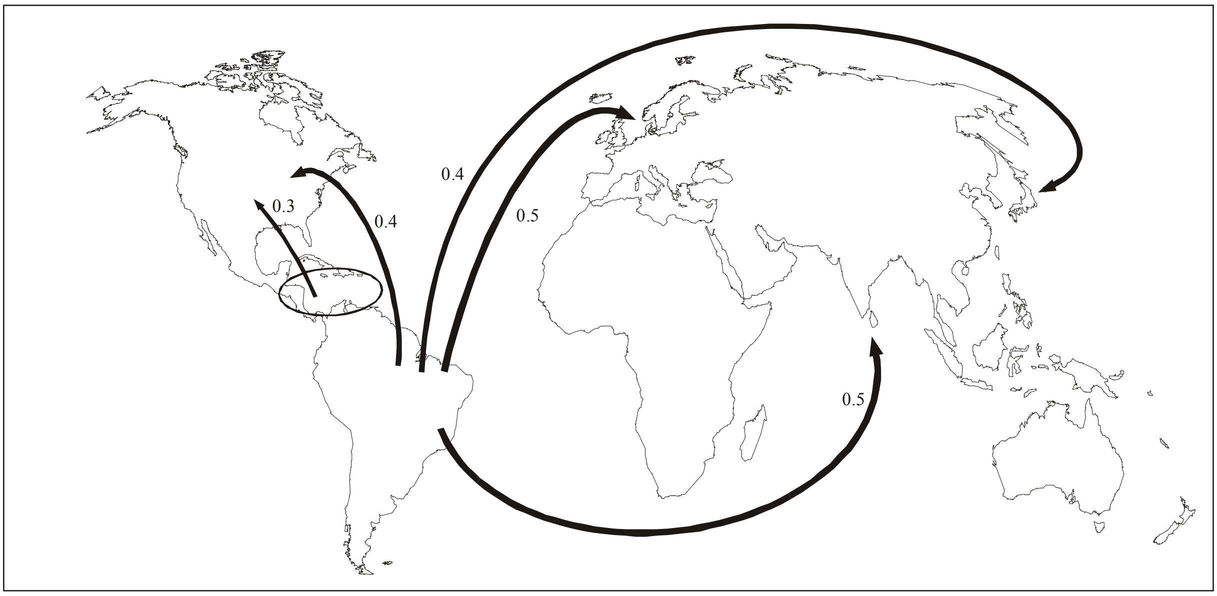
Importing country	Exports (l)
India	475
USA	426
South Korea	239
Japan	209
Sweden	198
Netherlands	156
Jamaica	133
Nigeria	106
Costa Rica	106
Others	361
Total	2447

Source: Walter et al. (2007).

Note: figures include fuel, industrial and beverage uses.

Most of the ethanol traded today is pre-processed ethanol, manufactured in the country where the feedstock is grown, because it is not currently economical to transport feedstock long distances for ethanol production. However, some corn from the USA is transported to Canada for ethanol production. Since sugar is the cheapest feedstock, many low-cost producers of sugarcane in Africa, Latin America and Asia plan to increase their share of global ethanol trade. Future ethanol trade will be driven in large part by countries that are not necessarily interested in developing domestic biofuel production but have a desire to use biofuels in order to reduce oil dependence and meet carbon emissions targets under the Kyoto Protocol. Japan, for instance, was the fourth-largest market for Brazilian ethanol in 2004. In 2005, Brazil's leading oil company, Petrobras, and Japan Alcohol Trading Co. launched a joint venture, Nippaku Ethanol KK, to import ethanol into Japan. To accommodate forecasted shipments of 25 million litres (6.6 million gallons) a month, Petrobras will invest US$330 million over the next five years in developing the requisite export infrastructure. Other biofuel-producing nations may develop similar relationships to facilitate trade in ethanol and other fuels.

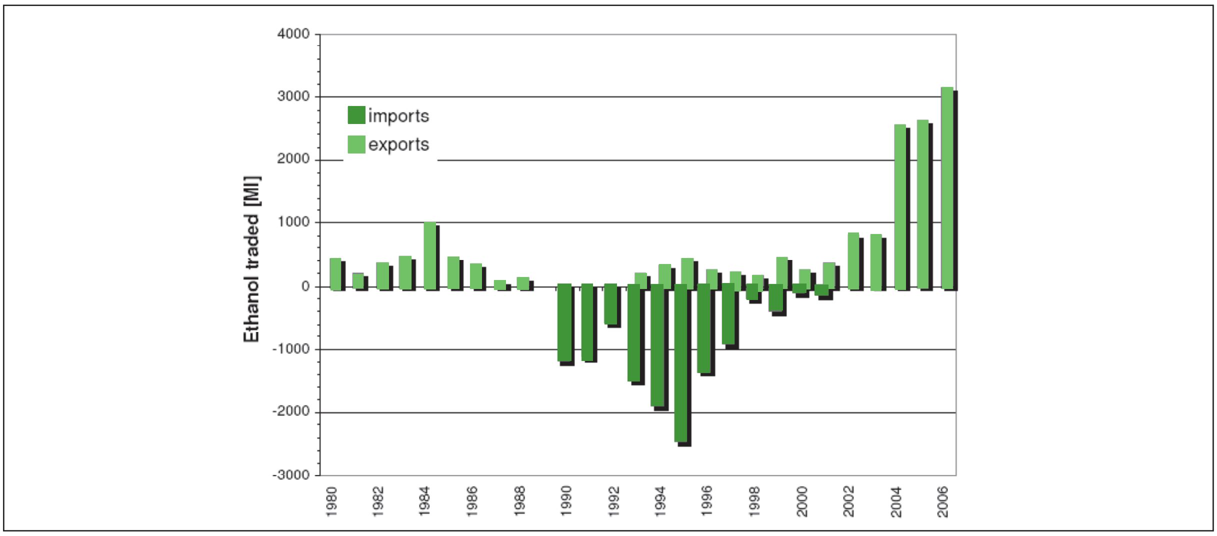
Figure 6: Major ethanol trade streams, 2004 (billion litres)



Source: Rosillo-Calle and Walter (2006); Walter et al. (2007).

Total volume of the trade was approximately 4 billion litres in 2004.

Figure 7: Trade in bioethanol in Brazil, 1970–2005



Source: Walter et al. (2006)

Trade in biodiesel

At present, there is no significant international trade in biodiesel. Germany is the world's largest producer of the fuel (from rapeseed), but this is mainly for use domestically and within the EU. This leaves considerable potential for lower-cost producers to enter the market, including major oilseed-producing countries. Of the seven major oilseed crops, just two (soybeans, palm) account for 85 percent of global oilseed exports. The largest soybean producer and exporter is the USA, followed by Brazil, Argentina and China. The largest palm oil producers are Malaysia and Indonesia.

Despite its smaller share of the global market, it appears that the international biodiesel market may also expand rapidly in response to growing global demand. Although Europe currently manufactures 95 percent of the world's biodiesel, developing countries are building infrastructure to supply regional and international biofuels markets. Both Malaysia and Indonesia, for instance, have plans to export the fuel to the EU, and Malaysia is also planning exports to Colombia, India, South Korea and Turkey. To satisfy both international and domestic demand, Malaysia aims to convert all domestic diesel to biodiesel by 2008. The international energy trading company EarthFirst Americas plans to import palm-based biodiesel into the USA from Ecuador, at a quantity equivalent to half the projected US production of 200 million litres in 2007. However, this rising trade in palm oil products has raised substantial concerns about forest loss and environmental degradation in producer countries and associated implications for global climate change.

Trade in pellets

International trade of wood pellets has occurred in several countries in the EU, including Sweden, the Netherlands and the Baltic States. The major trade flows over the past few years have been from Estonia, Latvia, Lithuania and Poland to Sweden, Denmark, Germany and the Netherlands. Austria remains the stronger trader in Central Europe. Swedish imports of biomass in 2003 were estimated at 18–34 petajoules (PJ). Sweden imported tail oil and pellets from North America and the Baltic states, pellets and logging residues from Belarus, and MSW and recovered wood from mainland EU. Additionally, Canada and Finland exported approximately 350 000 tonnes of pellets to Sweden in 2003. The Netherlands imported an estimated 1.2 million tonnes of biomass for use in power plants; this included palm kernel shells (residue from palm oil production) from Malaysia and wood pellets from other EU nations. According to the IEA, these examples and various analyses show that biomass can be transported economically over long distances, provided that transport occurs in bulk (such as by train or ship), and that biomass can be increased in density to reduce its volume and make transport more cost-effective (GBEP 2007).

3.3 Domestic biofuels production supports

Governments use two primary instruments to support domestic biofuels production: border protection (i.e. import tariffs) and subsidies in the form of volumetric production subsidies and tax credits. The first protects domestic production from foreign competition, while the second effectively creates artificial demand and significantly lowers the cost of biofuels production.

In most countries, government subsidies intervene at every important step of the biofuels production process, supporting intermediate inputs, capital goods, value-adding factors, biofuels production, storage, distribution and use. A pivotal 2007 report released by the Global Subsidies Initiative (GSI) under the International Institute for Sustainable Development (IISD) found that these subsidies were not only trade- and incentives-distorting but also far from cost-effective. (For detailed facts on current subsidies and policy recommendations for select OECD countries, see the Global Subsidies Initiative (2007) report.)

Currently, OECD countries offer the largest biofuels subsidies. The USA, with an estimated US$6.8 billion spent in 2006, and Europe, at about €3 billion in the same year, are by far the greatest subsidizers. While governments argue that subsidies are necessary and temporary, government support for biofuels production is often decades old. The oil supply shocks of the late 1970s raised concern about energy dependence. Concurrent overproduction of feedstocks such as corn, supported by subsidies, led to an excess supply that ended up as biofuels raw material. However, it appears today that dismantling biofuels subsidies is a politically arduous task. Strong political interests dominate biofuels support policy, and proponents of subsidies invoke energy security and rural development as legitimate reasons for subsidies continuation.

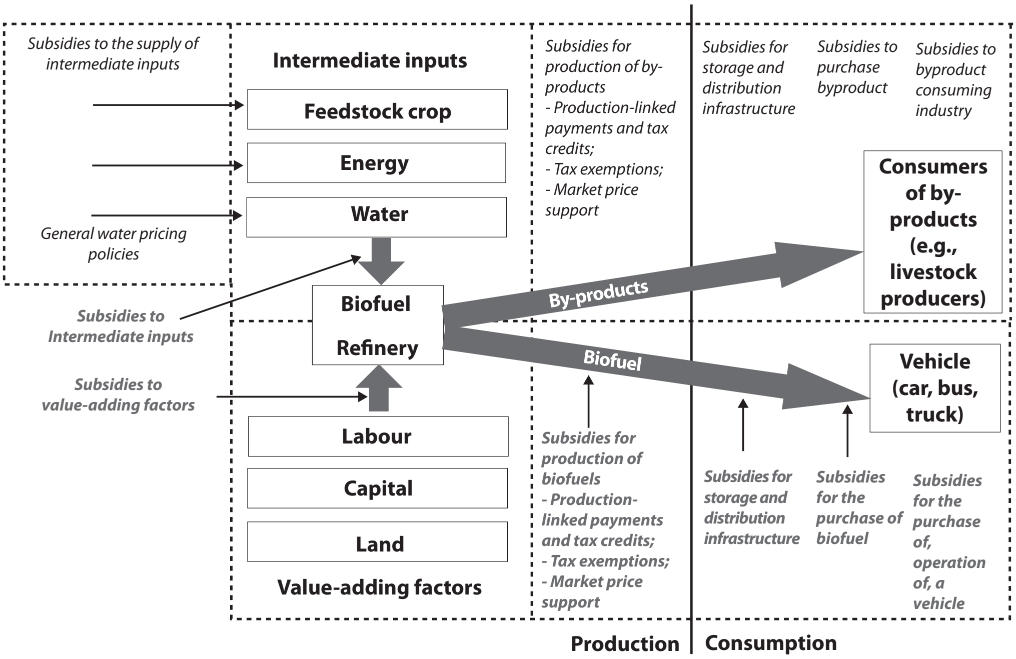
The result is often unviable markets that are reliant entirely on government intervention for survival. Current subsidies often not only boost supply but also create artificial demand in a way that is unsustainable and cost-ineffective for governments. It is important to recognize that there are legitimate arguments to subsidize and develop second-generation biofuels, although care and further study will determine their environmental and economic impact. Developing countries, in particular Brazil, India and China, are currently building institutional supports for biofuels as alternative energy increase, encouraging first-generation biofuels but focusing mainly on more sustainable and cost-effective second-generation biofuels.

Subsidies through the production chain

In both OECD countries and developing biofuels producers, government provides substantive support at every step of the production supply chain (see Figure 8). The largest subsidies of agricultural crops are given to producers of corn, wheat, sugar beet and sugarcane, as well as oilseed rape and soybeans – crops used as intermediate inputs in ethanol and biodiesel production. Intermediate input subsidies form the critical juncture of the "food-versus-fuel" debate, as subsidies make it more profitable to sell feedstock for biofuels production rather than for the domestic and international food market. The distorting effect of crop subsidies depends on its size: if crop subsidies are small enough, then they will not necessarily have an effect on prices or supply.

Output-linked production support makes up the bulk of government biofuels support. Governments provide grants and tax credit for biofuels production, exemptions from fuel-excise taxes, and grants and tax credit for value-added inputs such as capital goods, land and labour. Output-linked support is variable based on production; therefore, increasing production would increase absolute benefits. Output-

Figure 8: Subsidies along the biofuels supply chain



Source: Global Subsidies Initiative (2007).

linked support makes up about 65 percent of production subsidies in the USA, 93 percent in the EU and 65 percent in Canada for total biofuels. Therefore, as production increases with increasing demand created artificially by government, governments additionally will bear more of the cost of production. Missed tax revenue further adds to distortion and ultimately will prove to be unsustainable in the long run. On the supply side, this support is also paired with import taxes that prevent foreign competition. This creates a marginal tax on consumers, which governments further compensate for through subsidies, creating interlinked distortions. Subsidies are also offered on storage and distribution, and grants have been offered to build infrastructure for the distribution and retailing of biofuels.

Much of government support is supply-side, but increasingly support focuses on the demand side. Governments further complement production subsidies with mandates, setting targets that require certain levels of renewable fuels in biodiesel-diesel and ethanol-petrol blends (see Table 11). In the USA these mandates are framed as "standards" in the 2005 Energy Policy Act, but they are in fact not voluntary but required. Production, distribution and storage subsidies are extremely distorting, but mandates more greatly affect incentives across the country's industries. By requiring a fixed minimum of renewable fuels, mandates essentially transfer risk from the biofuels industry to other industries. While this process ensures the continued use of current biofuels, it inhibits risk-taking and innovation in energy substitutes, and therefore it could arguably stagnate the production of alternative energy sources with higher demand and viability. IISD (2007) further points out that specifying future targets should be cautious, as future biofuels feedstock supply and the commercial viability of second-generation biofuels are unknown.

Table 11: Global ethanol blending mandates

Brazil	All gasoline must contain 20–25% anhydrous ethanol (since 1977). The mandate is currently 23%.
Canada	By 2010, 5% of all motor vehicle fuel must be ethanol or biodiesel.
France	Set target rates for incorporation of biofuels into fossil fuels (by energy content). Calls for 5.75% in 2008, increasing to 10% in 2010.
Germany	Mandates 8% energy content in motor fuels by 2015, 3.6% coming from ethanol.
India	Requires 5% ethanol in all gasoline since October 2006. Plans to raise the requirement to 10% blends in October 2007 unsuccessful, but considering 10% and 20% blends.
China	Five Chinese provinces require 10% ethanol blends by 2006: Heilongjian, Jilin, Liaoning, Anhui and Henan.
USA	Energy Policy Act (2005) established mandate that 4.2% of fuel volume in 2007 come from renewable resources.

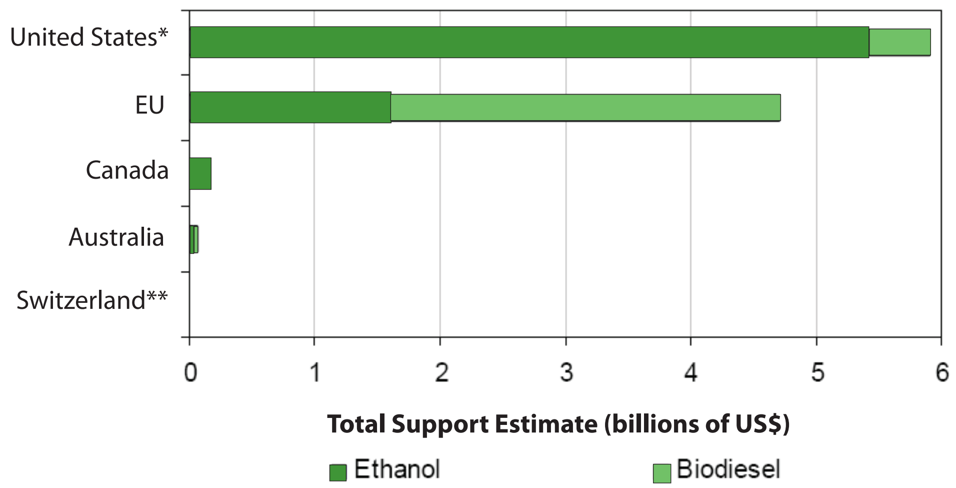
Source: Renewable Fuels Association (2008).

Measuring subsidies of production-related processes, IISD (2007) found that policies that directly affect production and consumption have the greatest distortion, followed by subsidies on intermediate inputs and value-adding factors such as capital goods for biofuels production. However, government subsidization of research and development, which is exploring the possible use, sustainable and viability of commercial second-generation biofuels, is considered least distorting in current literature.

Country–specific implementation

This section provides information on interesting country-specific subsidy policies for selected countries: the USA, EU countries, Brazil, India and China. The facts presented here are by no means complete and are summarized primarily from the IISD reports on OECD biofuels subsidies and sources on developing country policies. The USA in 2005 provided the most biofuels support, with the EU a close second. This trend continues today (Figure 9). Although the conditions vary from country to country, support for ethanol and biodiesel stems from growing concerns about energy security, alternative energy and rural job creation.

Figure 9: Total support estimates for OECD countries



(1) All values should be considered provisional.
*Low end of the range of estimates.
**Values are too small to display at this scale.
Data source: Chapter 4.

Source: Global Subsidies Initiative (2007).

Brazil

Since the 1970s Brazil has been at the forefront of efforts to produce biofuels, in particular ethanol from sugarcane. Due to a combination of climate, soil and 30 years of sustainable technological research and development, Brazil is currently the lowest-cost producer of sugarcane to date and, consequently, of ethanol for automotive transport. In 2006, there were 320 combined sugar mills and bioethanol distilleries in the country, with a total installed processing capacity in excess of 430 million tonnes of sugarcane. A further 51 are under construction, including new plants and expansion of those existing. Together they could produce up to 30 million tonnes of sugar and 18 billion litres of ethanol per year (GBEP 2007). The largest plant in Brazil has a production of just below 330 million litres of ethanol per year. There are about 250 separate producers, but most of them are grouped in two associations that make up 70 percent of the market.

Unlike other countries with substantial biofuels production, Brazil does not offer production subsidies for bioethanol. However, the government has made it mandatory since 1977 for light vehicles to have the E20 blend, with vehicles running also on using up to E25 blends. Brazilian sugarcane ethanol is the only ethanol that is competitive with petroleum, and the E20 mandate causes minimum distortion because it requires ethanol up to the cost-equivalent level. As a result, Brazil has been hailed as an example of successful biofuels subsidization, and its current mandate is purportedly for environmental rather than economic reasons. However, Brazil's current ethanol infrastructure was extremely costly to set up for the government and taxpayers, and it required decades of taxpayer subsidies before it became economically viable (Xavier 2007). That Brazil has a comparative advantage in ethanol production and still suffered substantial drawbacks through subsidies serves as an interesting lesson, especially for countries with less cost-effective biofuels such as the USA and EU nations.

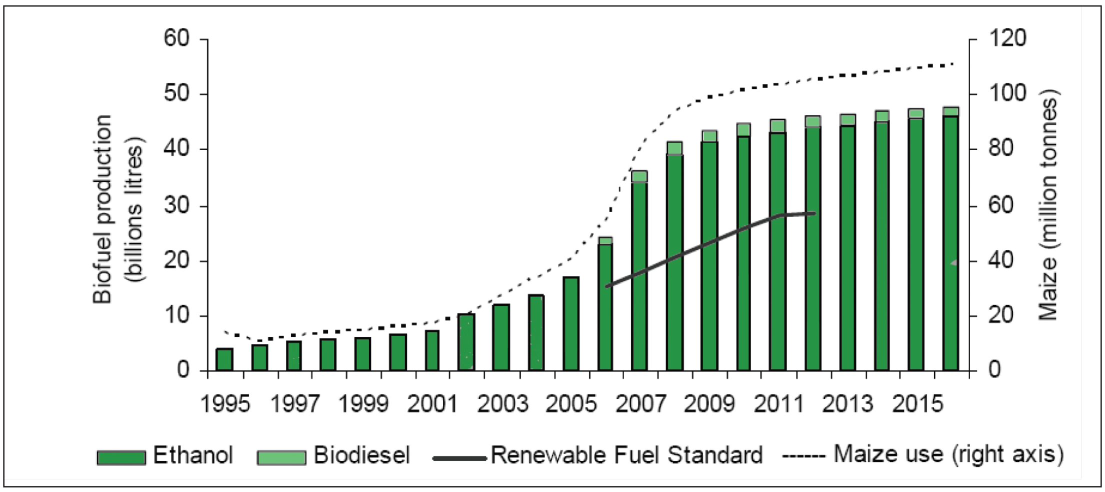
Although bioethanol is currently not subsidized, the government has given tax breaks to company producers of biodiesel to support domestic production and the research and development of biodiesel. The Brazilian government created the Brazilian Biodiesel Programme in 2003 in order to encourage domestic production of biodiesel from SVO and to limit import of biodiesel. Companies compete for the distribution and sale of produced biodiesel and are evaluated for social sustainability plans. The ministry of agrarian development claimed that 30 000 families were employed in the raw-material production of biodiesel production, although Brazil has recently come under criticism that projects do not contribute significantly to rural development and job creation from biodiesel is far lower.

By the mid-1980s, more than three-quarters of all cars in Brazil were running on hydrous ethanol. A surge in sugar prices at the end of the 1980s, coupled with lower oil prices, led to a slump in ethanol production as growers diverted their production to the export market and to a loss of public confidence in the security of ethanol supply. By the end of the 1990s, sales of ethanol-fuelled cars had almost dried up. Interest in ethanol rebounded in the early 2000s with higher oil prices and the introduction of the first flex-fuel cars. Rising demand for oxygenates has also driven up ethanol prices, boosting the profitability of ethanol production, and has stimulated investment in new sugarcane plantations and biorefineries. Less then three years after they were introduced, FFVs now make up more than 70 percent of the vehicles sold in Brazil. Vehicle prices are no higher than for conventional gasoline cars. All refuelling stations in Brazil sell near-pure hydrous ethanol (E95) and anhydrous gasohol, and about a quarter also sell a 20 percent anhydrous ethanol blend (E20). In total, almost two-thirds of the ethanol currently consumed in Brazil is anhydrous. The price of ethanol has risen faster than that of gasoline in the past year, due mainly to high international sugar prices. This has prompted the government to lower the minimum ethanol content in gasoline blends from 25 percent to 20 percent in order to prevent an ethanol shortage. Gasoline that does not contain ethanol can no longer be marketed in Brazil.

The USA

Subsidies in the USA range from US$5.5 billion to US$7.3 billion annually and support the exponentially growing production of corn ethanol. Driven by subsidies, US ethanol production has grown from 16.2 billion litres in 2005 to an estimated 24.5 billion litres in 2007. Given current subsidies and support, production is estimated to reach almost 50 billion litres by 2015 (Figure 10). Ethanol production in 2006 represented about 3.5 percent of motor vehicle gasoline supplies in the country. Most ethanol is used in low-percentage gasoline blends, but sales of high-percentage blends are rising. About 6 million FFVs are now running on E85 (a blend of 85 percent ethanol and 15 percent gasoline).

Figure 10: US ethanol and biodiesel production and corn use, 1995–2016 (projected)



Source: Global Subsidies Initiative (2007); OECD and FAO (2007).

The USA has a long history of tax reductions for biofuels, and it exempted gasohol (E10) in 1978 from the US$0.04/gallon fuel-excise tax. This was replaced by an income tax credit in 2004. However, many US states still retain fuel-excise tax reductions on pure biofuels and blends, with a value of about US$0.20/gallon. These tax reductions are complemented by biofuels mandates that further support biofuels consumption. The 2005 Energy Policy Act established a mandate that requires renewable resources account for at least 4.2 percent of transport fuel distributed to US motorists. The failed Liebermann–Warner bill proposed raising this target to 36 billion gallons (136 billion litres) annually by 2027.

US subsidies, like those of other OECD countries, boost supply at every step of the production process. Investors in biofuels also benefit from tax credits and grants from local, state and federal governments, a trend called "subsidy stacking". Municipal governments can offer free land and utility; the state offers tax credits for investment and economic development grants; and the federal agency provides support through environmental, agricultural and regional development programmes. The 2005 Energy Policy Act expanded grants for capital inputs, authorizing an average of US$250 million over two years in grants for cellulosic ethanol plants, as well as loans for ethanol production from cellulosic biomass or municipal solid waste. Municipalities and states have offered further support through similar grants and investment incentives. See the Global Subsidies Initiative (2007) report for more complete details.

The production capacity of the US ethanol industry is rising sharply as new plants have been built or are under construction. By the end of 2007, over 126 ethanol plants were in operation and another 100 were under construction. Most of them are dry mills, which produce ethanol as the primary output; wet mills are designed to produce a range of products alongside ethanol, including maize oil, syrup and animal feed. Production capacity in the industry is expected to exceed a staggering 36 billion litres (10 billion gallons) by 2008, but even this addition will not be sufficient to meet all of the new demand. The US ethanol demand is outstripping supply, with about 2.3 billion litres imported in 2006, mostly from Brazil. As a result, there are calls for import tariffs to be removed to prevent domestic ethanol prices from rising further, which would push up gasoline prices at the pump, and for fuel standards to be eased. The price of ethanol has risen sharply in recent years in absolute terms and relative to gasoline.

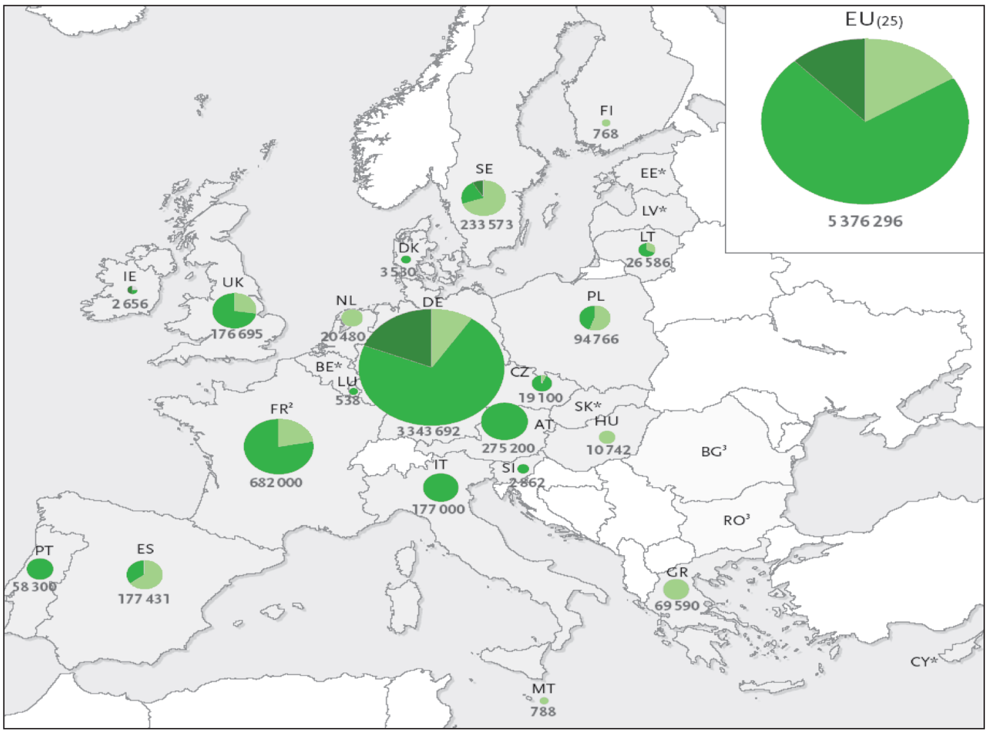
Ironically, despite significant support, the US biofuels policy appears to have had little net impact on the nation's oil use. This is because the amount of fuel displaced by ethanol is more than offset by increased gasoline consumption due to less energy stringent vehicle efficiency standards permitted by a loophole in legislation promoting flex-fuel vehicles (Childs and Bradley 2007). While ethanol's share in the overall gasoline market is relatively small, its importance to the corn market is comparatively large. About 14 percent of corn use went to ethanol production in the 2005–06 crop year. Carryover stocks of corn represented about 17.5 percent of use at the end of 2006, but expanded use of corn to produce ethanol in the 2006–07 crop year will leave the ending stocks-to-use ratio at 7.5 percent (USDA 2007). With continued strong ethanol expansion, the USDA's 2007 long-term projections indicate that more than 30 percent of the corn crop will be used to produce ethanol by 2009–10, remaining near that share in subsequent years.

The USA also produces a small volume of biodiesel, mainly from soybeans; output totalled 220 ktoe in 2005 – less than half of 1 percent of that of ethanol – although production capacity is growing rapidly. Support for biodiesel is much more recent. Minnesota was the first state to introduce a requirement that diesel contain at least 2 percent biodiesel in 2005. A federal excise tax credit of 1 cent per gallon of crop-based biodiesel for each percentage point share in the fuel blend was introduced in January 2005. Soybean producers also receive hefty subsidies from the federal government.

The EU

Over recent years, the EU has significantly increased its consumption of biofuels (Figure 11). According to the first estimates for 2006, biofuels consumption in the EU grew from just below 3 Mtoe in 2005 to approximately 6 Mtoe in 2006 – growth of 86.5 percent – reaching a 1.9 percent share of fuels used in transport (EurObserv'ER 2007). Biodiesel predominates, representing 71.6 percent of the energy content of biofuels dedicated to transport, significantly ahead of bioethanol (16.3 percent) and the other biofuels (12.1 percent, i.e. 629 809 tonnes oil equivalent (toe) of vegetable oil and 13 940 toe of biogas) (EurObserv'ER 2007).[5] Consumption of biodiesel increased 71.4 percent between 2005 and 2006, compared with 57.5 percent growth for bioethanol. Data for 2005 show that the total area used for energy crop production was around 2.8 million hectares, representing about 3 percent of total EU-25 arable land (EC 2006). Biodiesel and ethanol are mainly used blended with diesel and gasoline, respectively, in low proportions, but high-proportion blends (e.g. ethanol used for FFVs) and pure forms are also available in some countries, such as Sweden. Most ethanol is processed into ETBE to be used as an additive to gasoline. Other transport fuels are developed at currently low market volumes, e.g. biogas in Sweden and pure vegetable oil in Germany.

Figure 11: Biofuels consumption in the EU, 2006 (Mtoe)



Source: EurOberv'ER (2007).

Dark green = bioethanol; medium green = biodiesel; light green = vegetable oil + biogas

Biodiesel is produced primarily from rapeseed. In 2004, an estimated 4.1 million tons of rapeseed was used, equal to slightly more than 20 percent of EU-25 oilseed production. Germany is the main producer, followed by France, Italy and the Czech Republic. Since the EU is by far the world's biggest producer of biodiesel, there is no significant external trade. Import duties on biodiesel and vegetable oils are between 0 and 5 percent (EC 2006). EU production of bioethanol is estimated to have used around 1.2 million tons of cereals and 1 million tonnes of sugar beet from 2004's raw materials. This represented 0.4 percent of total EU-25 cereals and 0.8 percent of sugar beet production. Apart from France, where three-quarters of bioethanol is obtained from sugar beet, the majority of EU plants process grains (mainly maize, wheat and barley). The leading EU producers are Spain, Germany and Sweden.

In Europe, biofuels have been championed as an energy source that can provide new incomes for farmers both domestically and abroad, increase security of energy supply, and reduce GHG emissions from transport.

The EU currently does not have a community-wide excise tax on transport fuels, and member states can grant tax preferences according to their individual needs. However, there are coordinated efforts to increase the use of biofuels to meet a proposed mandate to fill 10 percent of transportation energy needs with biofuels by 2020. At the European Council summit on 8–9 March 2007, the EU's member states formally endorsed the 10 percent biofuels target but made it clear that such a goal must be subject to sustainable biofuels production and that so-called "second-generation biofuels" become commercially viable (EC 2007). This conditionality is linked to increasing concerns about the sustainability of the first-generation biofuels currently available (e.g. biodiesel, bioethanol), which are made from agricultural crops. In early 2008, the European Commission proposed a mandatory sustainability certification scheme for both imported and domestically produced biofuels, requiring at least a 35 percent reduction in GHG emissions compared with fossil fuels (see Section 6.1).

While Europe lags behind the USA and Brazil in ethanol production, it has provided support to its growing biodiesel industry. Energy crops in EU member states are heavily subsidized, and farmers are compensated for setting aside land. Set-aside land makes up about 10 percent of total EU farmland, and it is used 95 percent of the time to grow energy crops. Energy crops further qualify for set-aside payments and energy crop aid, and they are excluded from production quotas. Nine member states have further set mandatory blending requirements, and the majority couple the mandate with fuel excise-tax exemptions. While information on capital investment support is difficult, given individual member programmes, available data show that state aid to industry may account for up to 60 percent of initial investment, with governments regularly providing grants that account for 15–40 percent of capital infrastructure investment. See the Global Subsidies Initiative (2007) report for more complete details.

India

India's biofuels production efforts are centred on second-generation biodiesel made from jathropha. While mandatory blends are currently E5, there are discussions to raise the standard to E10 and eventually E20 blends as biodiesel from jathropha becomes more cost-effective. Individual states in India have adopted various policies to support the growing of jathropha and research into biofuels production. The state of Andhra Pradesh formed a public–private partnership with the firm Reliance Industries, giving the firm 200 acres of land for jathropha planting for biodiesel use. Similarly, the states of Karnataka, Chhattisgarh and Rajasthan are promoting the planting of jathropha saplings. In particular, Chhattisgarhand aims to become self-reliant on energy by 2015, using biodiesels and selling jathropha seeds for profit. In addition to encouraging jathropha planting, the state of Tamil Nadu has abolished the purchase tax on jathropha in order to promote its distribution and use.

China

Biofuels production in China is directed by the state through the state-owned industry. Production and demand are stringently planned and controlled. The Chinese government has recognized the importance of using sustainable energy, and the National Development and Reform Commission (NDRC) is directing increased production of biofuels, with a target to produce 2 million tonnes of biodiesel by 2020. China has a large variety of feedstock options for biodiesel production as well, with promise in jathropha, rapeseed and soybean. The State Forestry Administration (SFA) recently allocated 7000 hectares in Hebei province for biodiesel production. Hebei is one of seven regions that will be used as biofuels demonstration forests. In 2007 the NDRC signed a "memorandum of understanding" with the US Departments of Energy and Agriculture to facilitate the further development of biofuels and facilitate transfer of scientific and technical knowledge on feedstocks and biofuels production. Although widespread mandates have not yet been established in China, there are mandatory E10 blends in five provinces: Heilongjian, Jilin, Liaoning, Anhui and Henan.

Rationale for support

Biofuels subsidies have been justified on multiple grounds over decades of government support. Among the countries that have supported aggressive biofuels plans such as the USA, the EU, Japan, Mexico and India, the main reasons are energy security, environmental concerns, rural development and job creation. Biofuels were originally viewed as a viable alternative energy source during the high oil prices of the late 1970s, and government support of biofuels primarily continues to be viewed as a backup plan for energy. Similarly, first-generation biofuels such as corn ethanol were touted as the next generation of carbon-clean energy, driving support for sustainability reasons. But, most arguably, in the example of corn ethanol, the confluence of high petroleum prices and excess supply of corn (driven by subsidies) in the 1970s provided the most convincing rationale for biofuels. Proponents argue that demand for biofuels feedstock expands growth in agricultural regions, and biofuels production, which is extremely labour-intensive in most countries, creates much-needed jobs.

However, critics are sceptical that a lone instrument such as subsidies can deliver all of these purported benefits. Indeed, recent literature has discounted many of the benefits cited in the 1990s, showing that corn ethanol production has limited, or perhaps even adverse, environmental impacts and is unsustainable in the long run. The production of first-generation ethanol requires intermediate stages – planting, fertilizing, harvesting, transportation, etc. – that involve substantial energy inputs and release CO_2 into the air. It is important to note, however, that Brazilian sugar ethanol has escaped much of this criticism, and there is promise in the research and development of second-generation biofuels. Environmental impacts and cost-effectiveness ultimately depend on the biofuels production process and the feedstock used.

There are also direct counters to the energy security argument. The idea of a domestic source of energy harvested from domestic crops, which limits dependence on foreign oil, has made biofuels politically popular. However, biofuels currently remain expensive to produce, and demand (with Brazil as another critical exception) remains low despite government efforts to encourage biofuels use. Mandatory biofuels blends, used to promote biofuels, instead make biofuels a complement to petroleum rather than a meaningful substitute. Also, while biofuels may offer energy security answers to developing countries that are experimenting with second-generation biofuels, evidence does not support the OECD argument. For example, even if the entire US corn crop were used to create ethanol, the fuel would replace only 12 percent of current gasoline use (Lobe 2007). Cost-effectiveness also remains a major problem. Studies have shown that biofuels are successful in displacing petroleum, but at high cost: displacing one litre of petroleum requires US$0.45–0.65 per litre for ethanol and US$0.65–0.80 per litre for biodiesel in the USA (IISD 2007). Furthermore, although proponents argue that biofuels subsidies could lower energy prices for domestic consumers, the fact that biofuels account for only a small fraction of energy source means that subsidies will have very little effect on international oil and petroleum prices.

For example, IISD (2007) estimates also show that combined subsidies at all production stages and border protection give ethanol in the USA a cost of US$1.05–1.38 per gallon of ethanol, a production cost that is already 50 percent higher than consumer value at the pump. This evidence shows that, although governments intent on pursuing corn ethanol agendas may insist that subsidies are only temporary, a reality of sustainable corn ethanol is far from realizable. In the USA alone, one-sixth of the country's total grain harvest supplied less than 3 percent of its automotive fuel (Lobe 2007). Furthermore, it costs about US$500 of federal and state subsidies to reduce one metric tonne of carbon-equivalent emissions (Koplow 2006). Critics have argued that most subsidies, and in particular the USA's subsidies, are poorly coordinated and targeted and should take into account the impact of subsidies on the global trade of biofuels and food products and the environment (Upton 2006).

Despite these criticisms, there remains legitimate rationale for the support of research and development in second-generation biofuels, which hold promise in yielding energy with possible cost-effectiveness and great environmental benefit. US investment in second-generation biofuels has begun, but there remain large subsidies to corn ethanol, perhaps driven by the political importance of the Corn Belt region. Developing countries are levelling their focus on second-generation biofuels, hoping to create infrastructure on which they can capitalize in the future. While subsidies as currently conducted are extremely distorting, it is possible to use subsidies in less distorting ways, either through auctions or through the funding of research and development (IISD 2007). It is possible that subsidies can be beneficial in encouraging the development of sustainable second-generation biofuels, creating a domestic market and harnessing the economy of a subsidizing developing country that has a comparative advantage in biofuels production. This remains to be seen.

Implications on sustainable development

Although critics have legitimate environmental and food security concerns regarding biofuels, studies provide evidence that international biofuels trade could indeed generate economic, environmental and social benefits (Haverkamp and Parker 2007). The growing energy needs and high production costs of the US and the EU necessitate trade in biofuels if the industry is going to be sustainable. Expanding international trade in biofuels and lowering barriers give countries with the comparative advantage in biofuels production the opportunity to supply biofuels, with more efficient and cost-effective results.

Because the effectiveness of biofuels depends on the process and feedstock used, it is possible to produce biofuels that are more energy and environmentally sustainable as well. There are substantial opportunities for biofuels export from developing countries – i.e. oil palms and biodiesel from jathropha – that could lead to greater economic growth. However, there is currently no functioning global market for biofuels. Subsidies constrain and restrict the emergence of a global market and eliminate economic opportunities for countries that have a comparative advantage in biofuels production. It is clear that, given an international market, only the countries that can create biofuels without subsidies will be exporters. Therefore, domestic energy self-sufficiency and established lobbies give OECD countries very few incentives to support the burgeoning international trade of biofuels. As a result, biofuels policy in predominately developed countries currently in place will be difficult to alter, despite being distorting and unsustainable.

There are many attacks levied directly at biofuels, but subsidies in particular form an important component of the "food-versus-fuel" debate. As presented in the country case studies above, governments often further subsidize farmers to sell feedstock for biofuels. Marginal profit therefore increases by growing feedstock for biofuels rather than food, decreasing the ready supply of food. Furthermore, because the biofuels industry essentially is held up only by mandate and subsidies, these policies result in improper allocations for agriculture. Domestic prices for staple crops become artificially high, while additional international barriers make food too costly for the world's most destitute people.

Despite these problems, there remains substantial promise for biofuels as an agent of positive change if an international biofuels market can be adopted and its benefits realized. Subsidies for research and development can expand the range of cost-effective and energy-efficient biofuels, as well as mark the entry of developing countries into a nascent international market. However, it is important that these subsidies are applied in a way that does not distort trade, harm the environment or disadvantage developing countries. If subsidies can help to promote variety and encourage biofuels production in developing countries with a comparative advantage, than they can be useful aids in sustainable development. However, as currently applied in OECD countries, they are by far the most potent barriers to economic development and sustainability.

Specific WTO linkages: areas to address

Policymakers still have problems addressing biofuels in a comprehensive way because multiple international trading rules apply to different parts of the biofuels sector. Overlapping jurisdictions complicate the enforcement and notification of biofuels subsidies. As such, clarity on WTO rules is needed in order to promote global trade of biofuels so that both developed and developing countries can recognize its benefits. In the WTO, tariff bindings are negotiated using product classifications from the Harmonized Commodity Description Coding System (HS) established by the World Customs Organization. Under HS classification, ethanol is considered as an agricultural good, while biodiesel is considered an industrial good (see Box 2). Therefore, while these products essentially serve similar purposes, they are subject to different trade rules. As an agricultural good, ethanol is subject to further restrictions under the WTO Agreement on Agriculture (AoA). The AoA mandates that WTO members reduce their agricultural subsidies, though they can maintain support that has minimum trade-distorting effects. In this context, the widespread prevalence of distorting ethanol subsidies provides impetus for greater examination of the treatment and notification of biofuels subsidies. Officials at the WTO are currently discussing whether to classify biofuels as "environmental goods and services", which would result in faster liberalization.

BOX 2: CLASSIFICATION OF BIOFUELS

Before 2005, both biodiesel and bioethanol used to be traded as agricultural products. In 2005, the World Customs Organization decided to put "biodiesel" in Section VI (Chapter 28–38) on "products of chemical and allied industries" (HS 382490). It is therefore traded as an industrial good. Bioethanol is still traded under HS 2207 in Chapter 22 on "beverages, spirits and vinegar", as an agricultural product. This classification has several implications with respect to the WTO disciplines on tariff rates and subsidies that apply to bioethanol and biodiesel, and they tend to be more favourable to biodiesel. For example, the EU tariff duties are relatively low for biodiesel (6.5 percent), whereas tariffs on ethanol are to an ad valorem equivalent (AVE) tariff of 40–100 percent, depending on the price of ethanol; the lower the price of ethanol, the higher the AVE (Jönsson 2007).

At the WTO, the outcomes of the Doha negotiations on agriculture and non-agricultural market access (NAMA) will apply respectively to ethanol and biodiesel. Some countries (e.g. Brazil) have questioned the rationale for this categorization, noting that the results discriminate against agriculture, the reason being that the tariff cut formula for industrial goods is more ambitious than for agricultural products. In the context of the ongoing WTO negotiations on the liberalization of trade in environmental goods and services (EGS) under the Doha Mandate (Paragraph 31 (iii)), it has been suggested that ethanol should qualify as an environmental good and benefit from the fast-track cut in tariff and non-tariff barriers envisaged in those negotiations. However, a joint proposal submitted by the USA and the EU in November 2007, proposing fast-track liberalization of a package of goods especially relevant to climate change, did not include ethanol. As WTO negotiations continue, biofuels are likely to remain on the agenda, and future trade rules will be affected by the outcome of the talks on agriculture and NAMA, and possibly on EGS.

Both ethanol and biodiesel, as agricultural and industrial goods, are subject to the Agreement on Subsidies and Countervailing Measures (ASCM). Article 25 of the ASCM requires the notification of trade-distorting subsidies "to enable other Members to evaluate the trade effects and to understand the operation of notified subsidy programmes". Therefore, the ASCM considers subsidies – i.e. excise taxes, grants and production support from the government – that confer competitive advantage as actionable and falling under the jurisdiction of the ASCM. Lack of transparency and non-compliance with the ASCM increases the complexity when dealing with biofuels subsidies and merits discussion, perhaps with a transparency and enforcement framework embodied within the ASCM text.

In addition to international confusion about biofuels, the biofuels sector has internal regulations and standards enforced by national and local governments. These requirements include mandates, blending limits or restrictions, technical specification and environmental sustainability criteria (International Food and Agricultural Trade Policy Council 2006). For example, Brazil's National Biodiesel Programme grants a 67 percent tax reduction on biodiesel and a 100 percent tax reduction on biodiesel certified with the Social Fuel Seal standard. Because only Brazilian firms can qualify, this policy essentially becomes a subsidy, one that the Brazilian government argues promotes the production of sustainable biofuel. With such situations, it is difficult to determine "like" products, and countries can use domestic standards and policy concerns to legitimate product protection. Much work can be done to see how the Technical Barriers to Trade (TBT) Agreement applies to biofuels, ensuring that restrictions are the least trade-restricting as possible and legitimately address concerns and do not simply protect products.

3.4 Barriers affecting biofuel trade

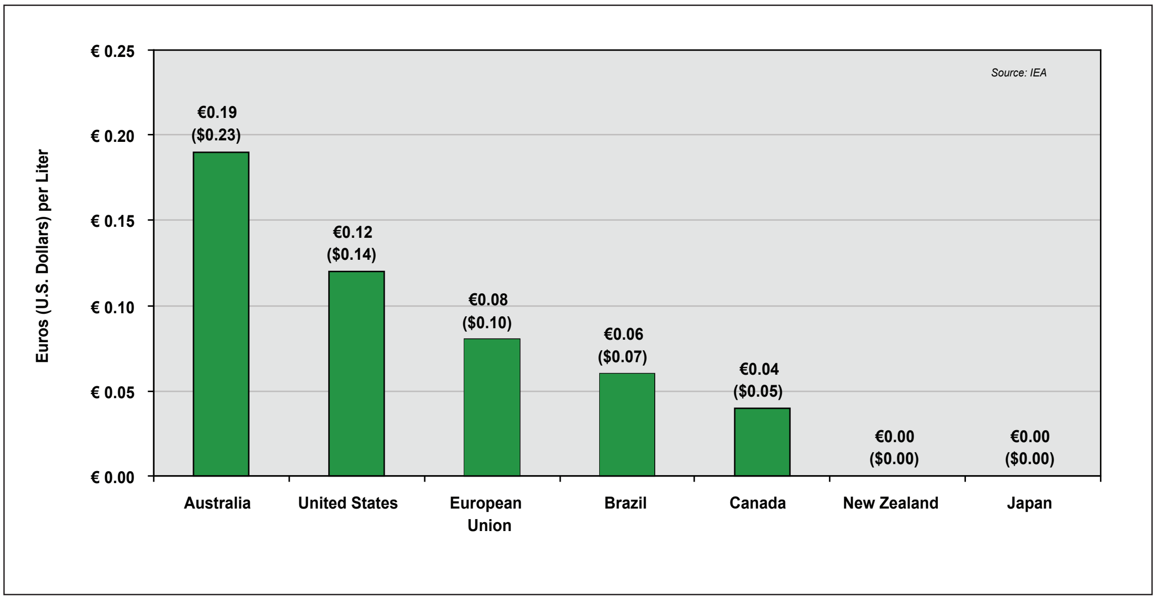
Although international biofuel markets are developing very rapidly and international trade is expected to grow significantly given market demand and potential supplies, many barriers are also present that could disturb or at least slow down the sound development of such markets. This section reviews the key barriers affecting international trade in biofuels, including tariff, technical, logistical and economic barriers (Junginger and Faaij 2006).

Tariff barriers

The *classification of a product* is important to define which tariff levels and which set of disciplines and domestic subsidies are applicable (see Box 2). Product classifications for biofuels are not consistently aligned with the actual consumer market in question, which leads to a number of problems with respect to consistency, certainty and non-discrimination of existing WTO obligations. An approach would be to define "new" products for biomass-derived energy carriers. However, this is a complex process that can take many years (Howse and van Bork 2006). Subsidies are arranged in the AoA and the Subsidies and Countervailing Measures (SCM) Agreement, the latter prohibiting export subsidies and subsidies contingent upon the use of domestic products over imported products. Based on the SCM Agreement, subsidies should not have certain adverse trade affects or cause adverse effects (injury) to a group and should be non-specific, i.e. not directed at a limited group of particular products (Howse and van Bork 2006).

The EU, the USA and Australia are among the largest agricultural exporting economies that have imposed import duties and other restrictions on foreign ethanol, biodiesel and their agricultural inputs. Figure 12 shows ethanol import duties in selected countries in 2004. Simultaneously, the EU and the USA both offer preferential market access to developing countries by way of unilateral tariff reductions that encourage imports of certain agricultural commodities and biofuels. Ethanol is taxed at varying rates, depending on its intended use. In the EU, the import duty for pure alcohol is €0.19 per litre, while for denatured alcohol (ethanol with additives) it is €0.10 per litre. Despite the differing tariff rate, both denatured and un-denatured alcohol are imported under customs classification 2207 in Europe, making it difficult to identify how much ethanol is used for fuel production. Only fuel ethanol that is pre-blended with gasoline is classified separately under heading 3824 and charged a normal customs duty of around 6 percent. In the USA, ethyl alcohol is classified under the agriculture chapter and again under Chapter 99 for fuel-grade ethanol. The USA taxes ethanol imports at $0.18 per litre ($0.54 per gallon).

Figure 12: Ethanol import duties in selected countries, 2004



Source: Fulton and IEA (2004).

Biodiesel imports are also taxed at varying rates, due in part to the different feedstock options. Global trade in whole oilseeds, particularly soybeans, is relatively unrestricted by tariffs and other border measures; however, oilseed meals, and particularly vegetable oils, have higher tariffs. For soybean oil, tariffs average around 20 percent, while tariff rates for whole soybeans are generally around 10 percent. In the EU, plant oils for biodiesel face low or no tariffs. For biodiesel in the form of FAME that is imported from the USA, a non-member state duty of 6.5 percent applies, and there are no quantitative restrictions. In addition, these conditions apply only to the import of the biodiesel (FAME) itself, not to the import of source products such as tallow or used cooking oil. Rules and tariffs governing SVOs are separate and specific because of the potential for these oils to enter food production.

Under the CBI, the USA exempts to some degree import tariffs on ethanol from Central American countries and the Caribbean. Specifically, imports produced from foreign feedstock made up 7 percent of US demand in the previous year. CBI countries have never come close to meeting this ceiling; in the past five years, CBI exports as a share of US production have hovered around 3 percent. CBI countries also may import feedstocks or fuel (e.g. from Brazil) for export to the USA, as long as 35 percent of the value of the product is produced in a CBI country. The Central American Free Trade Agreement (CAFTA) will supersede CBI when it takes effect for countries that are party to it, potentially including five Central American countries and the Dominican Republic. Like CBI, it will allow continued tariff-free exports through CAFTA countries for ethanol produced by non-CAFTA and non-CBI countries, such as Brazil, up to the 7 percent cap of total US production. All other ethanol produced by CAFTA, or CBI country feedstock, can be imported tariff-free. CAFTA was supposed to take effect in January 2006, but it has been delayed due to unresolved legal issues, including pending approval by some legislatures in Central America.

In Europe, the EU grants special trading preferences to African, Caribbean and Pacific (ACP) countries under the so-called Everything but Arms (EBA) initiative. EBA countries are exempted from EU duties on ethanol, and significant (though erratic) exports come in from the Democratic Republic of Congo, varying from 86 000 litres in 2003 to 19 000 litres in 2004. The EU also has a General System of Preferences (GSP) that encompasses additional developing countries in the Middle East and Asia that could become exporters of biofuels. Altogether, biofuel imports into the EU under preferential trading arrangements nearly doubled between 2002 and 2004, to 3.1 billion litres (Table 12). As a result of the GSP, Pakistan was the largest supplier of ethanol to the EU for much of the past decade, producing a range of 1.3 million to 2.1 million tons of the fuel from sugar cane during the period 1994-2004. In July 2005, however, the WTO ruled that the EU was unevenly granting preferences to the 12 countries included under this policy, and, as a result, a new GSP Plus system has been designed. Pakistani ethanol is now eligible for only a 15 percent tax reduction on its exports to the EU, a change that has caused two ethanol plants in Pakistan to close and halted plans for seven new plants. Other countries may step in to fill the gap: under the GSP, the two other countries supplying the majority of ethanol to the EU are South Africa and Ukraine.

Table 12: Biofuel imports into the EU under preferential trading arrangements, 2002–2004

Trade agreement	2002	2003	2004	Average, 2002–2004	Share of total biofuel trade, 2002–2004
	Million litres %				
GSP normal	227	183	288	233	9
GSP plus	553	1569	1413	1178	47.5
ACP	291	269	155	238	9
EBA	30	86	19	45	1.5
Others	107	104	123	111	4
Total preferential	1208	2211	1998	1805	70
Total MFN	657	495	1125	759	30
Grand total	1865	2706	3123	2564	100

The EU is also in the process of conducting negotiations with MERCOSUR (the Latin American trade bloc) that would significantly lower or remove trade barriers for these countries; however, negotiations have stalled. The conclusion of a MERCOSUR agreement could allow large amounts of Brazilian ethanol to enter the EU. Most of this ethanol would flow to Germany because imports there would be completely tax-exempt. But other European nations with higher production costs, such as France, Spain and Sweden, have voiced concerns that they could be negatively affected by such a change, so some limits would likely be imposed (e.g. tariff rate quotas). The relative tariff levels levied on developing country exports can largely determine the degree of success for emergent biofuel industries (over 60 percent of ethanol imported to the EU was imported tariff-free). Similarly, the quantity and placement of agricultural subsidies have a profound effect on the quantity and type of feedstock available for biofuels production.

Technical barriers

A lack of clear technical specifications for biomass and specific biomass import regulations can be a major hindrance to trading. In the EU, most residues that contain traces of starches are considered potential animal fodder and thus are subject to EU import levies. For example, rice residues containing 0-35 percent starch are levied €44/ton (i.e. about €3.1/GJ). For denaturized ethanol of 80 percent and above, the import levy is €102/m3 (i.e. about €4.9/GJ), representing substantial additional costs. Other biomass streams such as wood pellets are currently levy-exempted in the EU. It is important to bear in mind that some technical trade barriers can be imposed in order to constrain imports and to protect local producers. Possible contamination of imported biomass with pathogens or pests (e.g. insects, fungi) can be another important limiting factor in international trade. For example, round wood from outside the EU can currently be rejected for import to Finland (and the whole of EU) if contaminated with pests. Similarly, agricultural residue that could be used as both fodder and biomass may be denied entry if it does not meet certain fodder requirements. However, these limitations are not exclusive to bioenergy. Biomass trade may be limited also by international environmental laws, which lack clear rules and standards for allocation of GHG credits and to evaluate the avoided lifecycle GHG emissions. For example, in the Netherlands, four of five major biomass power producers consider obtaining emission permits as one of the major obstacles for further deployment of various biomass streams for electricity production. The main problem is that Dutch emission standards do not conform to EU emission standards. In several cases in 2003 and 2004, permits given by local authorities have been declared invalid by Dutch courts.

Harmonized support policies (e.g. on the EU level) and new national incentives for biofuels offer opportunities for formalizing and stabilizing international biofuel trade by guaranteeing greater overall demand. The EU Strategy for Biofuels, released in February 2006, calls for greater guarantee of supply and demand for biofuels through a framework of incentives for publicly and privately owned vehicle fleets, including city and private bus fleets with dedicated fuel supplies (which can be adapted easily to higher blends of biofuels), farm and heavy goods vehicles (which would receive continued tax exemptions), and fishing fleets and vessels (which offer a potential market for biodiesel). Towards a similar end, the Philippines and Thailand agreed in 2004 to strengthen bilateral and regional cooperation to promote biofuels by moving towards a regional standard for ethanol-blended gasoline and by pushing Association of Southeast Asian Nations (ASEAN) countries to encourage automobile manufacturers to make FFVs.

Logistical and economic barriers

Although generally most energy crops are difficult and expensive to transport, this is not an issue for liquid biofuels (e.g. ethanol, vegetable oils, biodiesel), as the energy density of these biofuels is relatively high. Various studies have shown that long-distance international transport by ship is feasible in terms of energy use and transportation costs (see below), but availability of suitable vessels and meteorological conditions (e.g. winter in Scandinavia and Russia) need to be considered. However, local transportation by truck (in both biomass-exporting and -importing countries) may be a high cost factor, which can influence the overall energy balance and total biomass costs. For example, in Brazil the cost of transport and lack of infrastructure can be a serious constraint for the expansion of new sugarcane plantations towards the centre-west region. Harbour and terminal suitability to handle large biomass streams can also hinder the import and export of biomass to certain regions. The most favourable situation is when the end user has a facility close to the harbour, avoiding additional transport by trucks. Furthermore, pipelines exist and are under construction in Brazil for ethanol transport. In addition, rail transport is used for fuels, for example in the USA. The lack of significant volumes of biomass can also hamper logistics. In order to achieve low costs, large volumes need to be shipped on a more regular basis. Only if this can be assured will there be forthcoming investment on the supply side (e.g. new biomass pellet factories), as these volumes will reduce costs significantly.

Risks and opportunities for market development

Some proponents of biofuels envision a future international biofuel trade that will develop over time into a real "commodity market" that secures supply and demand in a sustainable way – sustainability being a key factor for long-term security. However, a number of policy and institutional barriers exist that can cause market distortions and harm market entry for biofuels. In addition to the tariff and non-tariff barriers already discussed, other potential barriers include increased control of the biofuels market by the oil industry (which could lead to price manipulation) and lack of infrastructure to provide for use of biofuels in vehicles. Factors leading to unreliable supply and demand also create market uncertainty and could impede biofuel development. The economic barriers that these markets currently face include the following:

- Competition with fossil fuels on a direct production cost basis (excluding environmental and social externalities);
- Insufficient and/or inconsistent support policies promoting biofuels in many industrialized and some developing countries;
- Relatively immature and unstable markets that are perceived as too risky for agreeing on long-term or large-volume contracts.

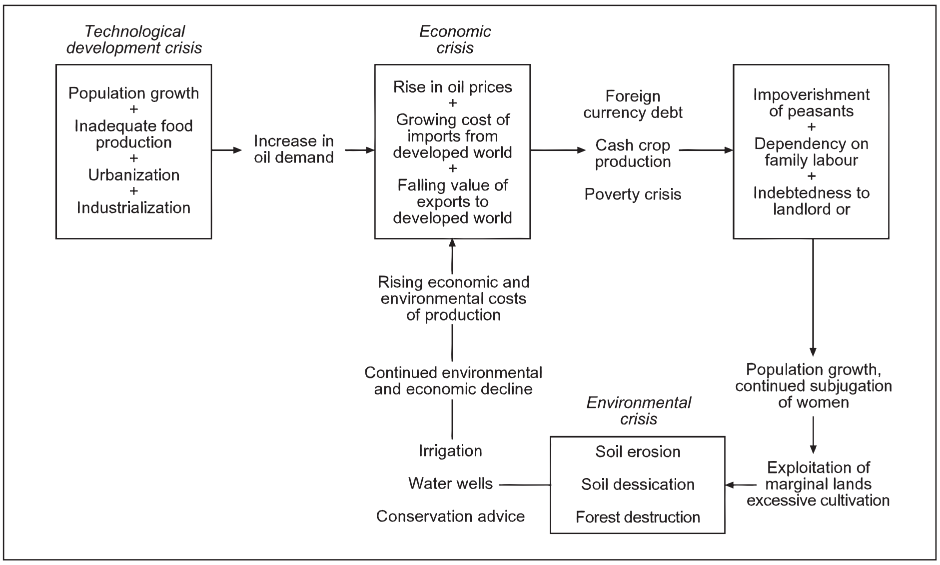
The biofuel market also remains vulnerable to factors outside the control of trade boards and financiers. First-generation biofuels are vulnerable to crop failures and market prices of food. Also, because they comprise such a tiny share of the global energy trade, they will continue to be price-takers in the short and medium term, meaning that prices of biofuels will mirror spikes and dips in oil prices. In response to these challenges, several mechanisms for reducing risks related to short-term imbalances in biofuel supply and demand are in the early stages of development. In May 2004, the New York Board of Trade took a step towards building institutional support for ethanol in the global market by negotiating an ethanol futures contract; as a result, ethanol is now traded under the symbol "XA". This backing from the New York Board – a well-established global futures and options market for internationally traded agricultural commodities – may provide both producers and consumers with a greater level of assurance that their price and quantity needs will be satisfied, attracting more capital to the ethanol industry. However, some have expressed concern that a lack of transparency in commodity trading could hinder the biofuel market.

Biofuel trade and sustainable development

Could the international biofuels trade really be a driver for sustainable development? Figure 13 depicts the relations that currently exist between economic growth and population growth, subsequent increasing demands for energy, trading balance of developing countries, and impacts on rural communities and subsequent environmental degradation. Many developing regions have ended up in a downward spiral similar to the scheme shown in Figure 13. Bioenergy is right in the middle of these relations. Modern biomass and bioenergy is not a silver bullet that can solve all these problems and could, when managed wrongly, even aggravate some of the problems mentioned. However, it seems to be one of the few available strategies and options that can, when implemented and developed in the right way and suited for regional conditions, reverse many of the downward trends.

The market size for bioenergy (virtually unlimited on an international scale), the fact that it can directly replace oil (through biofuels for transport), the possibilities for crop production with positive ecological impacts with respect to soil regeneration, the biodiversity and emissions of agrochemicals, and the fact that biomass production and supply chains can be operated fully in rural economies (in contrast to many other alternative energy options) – which maximizes the value added for this part of the economy – make it a potential backbone of broader sustainable development schemes. The inherent economic value of carbon-neutral renewable fuel on the world market may provide the economic engine for rural regions that now

Figure 13: The crisis of sustainability in developing countries



Source: Faaij and Domac (2006).

often lack any export possibilities to finance development and modernization of agriculture altogether. In doing so, the challenge will be about achieving the right balance between the need to expand access to modern sources of energy in rural areas of developing countries, and the opportunities that can arise from international trade and access to foreign markets.

For the stakeholders involved, such as energy companies, producers and suppliers of biomass for energy, it is important to have a clear understanding of the pros and cons of biomass energy. For example, investment in infrastructure and conversion facilities requires risk minimization of supply disruptions, in terms of volume, quality and price. More importantly, the long-term future of large-scale international biotrade must rely on an environmentally sustainable production of biomass for energy. This requires the development of criteria, project guidelines and a certification system, supported by international bodies. This is particularly relevant for markets that are highly dependent on consumer opinions, as is presently the case in western Europe. It is even more important for developing countries and rural regions to be aware of both the opportunities and the limitations of biofuels, which will be discussed in the following chapter, and to get involved in debate and collaboration for achieving sustainable development where it is most needed.

4. BIOFUELS AND SUSTAINABLE DEVELOPMENT

The relationship between biofuels and sustainable development is complex and varied. On the one hand, biofuels could improve energy security, support economic development, particularly in rural areas, and help in reducing GHG emissions associated with the transport sector. On the other hand, energy feedstock production could cause negative impacts on habitats, biodiversity, and water, air and soil resources. It could also lead to food security problems, increased land concentration, loss of rural employment, poor labour conditions, and increased social inequalities overall. Overall, the positive impacts of biofuels on sustainable development can vary significantly, depending on the type of energy crop utilized and the location and method of production. To highlight this, this chapter first discusses economic aspects of biofuels, such as energy diversification, trade balance and costs. Then it reviews the potential climate and environmental issues. Turning to social aspects, the chapter explores the likely impacts on agriculture markets and rural employment. Finally, the chapter concludes by discussing the "food-versus-fuel" debate.

4.1 Economic aspects

Energy diversification and improved trade balance

Although more a national security objective than an economic issue, a key strategic objective associated with biofuel promotion is the achievement of greater energy security through a diversified energy portfolio. Indeed, reduced reliance on imported oil was the main driver behind the earliest experiences with biofuels in Brazil, and it is a political priority in the two other large biofuel markets, the USA and the EU. Industrialized countries are facing an increased dependence on energy imports, particularly oil resources. In 2000 oil imports of OECD countries accounted for 52 percent of their energy requirements, but this is expected to rise to 76 percent by 2020. In addition, known oil reserves are limited in quantity, while global demand for oil is increasing fast due to large new economies such as those of China and India. All these factors, coupled with uncompetitive structures governing the oil supply (i.e. the Organization of the Petroleum Exporting Countries (OPEC) cartel), are fuelling high volatility of global oil prices, which in 2008 surpassed the psychological threshold of US$100 per barrel. The risky energy supply security situation affects mainly the transport sector, which is dependent almost completely on oil. Against this background, biofuels are considered the only direct alternative to oil use in road transport, which is available on a significant scale over the next 15 years. They are expected to improve energy security by increasing the diversity of fuel types and the regional origin of fuels.

In addition, heavy reliance on foreign energy sources means that countries have to spend a large proportion of their foreign currency reserves on oil imports. This is especially relevant for the poorest developing countries, where any saving of foreign currency would mean increased resources available for other urgent development needs. Almost all least developed countries are oil importers. For instance, crude oil imports to ACP countries were expected to increase to 72 percent of their requirements in 2005. In this context, domestic biofuel production offers an opportunity to replace oil imports and improve national trade balances. Since 1975, Brazil's ethanol programme has greatly reduced the country's oil imports. Given that oil imports were financed through external debt, reduced spending on imports has also reduced debt service costs. In all, it has been estimated that Brazil's external debt is approximately US$100 billion lower today than it would have been in the absence of its biofuels production. In other words, Brazil's external debt would be 50 percent higher today were it not for ethanol. The improved trade balance argument, however, encourages the introduction of protectionist measures against biofuel imports. In the EU, for example, some actors in the biofuel sector are criticizing the heavy dependence on imports that it might be creating. They argue that one of the primary reasons for the biofuel directive was to reduce dependence within the energy sector. Although currently it is easy to buy cheap bioethanol on the international market, there may be problems in the future when countries such as China start buying up huge amounts of this cheap energy.

Competitiveness

The biofuels industry has made dramatic improvements in reducing the cost of biofuels production. However, one of the biggest barriers to large-scale development of biofuels remains their higher economic costs compared with conventional fuels. Economic costs, however, tend to differ depending on the type of biofuel, the country of production and the technology used. Corn, for instance, is more expensive and produces less bioethanol per hectare than tropical crops such as sugarcane that are grown in many developing countries. Estimates show that bioethanol in the EU becomes competitive when the price of oil reaches US$70 a barrel, while in the USA it becomes competitive when the price reaches US$50–60 a barrel. With the technology currently available, EU-produced biodiesel breaks even at oil prices of about €90 per barrel (approximately US$135) (European Council for Automotive R&D, Conservation of Clean Air and Water in Europe, European

Commission Joint Research Centre 2006). Currently, only Brazilian ethanol producers can compete subsidy-free with conventional gasoline, with a break-even threshold of US$25–30 per barrel.

Costs of biofuel feedstocks are influenced especially by their yield, the land rent and the costs of labour. Influencing those factors is important for reducing biofuel production costs. Competition for land should be avoided due to its impact on land rental rates. Labour costs can be reduced by using plantation-like production systems and mechanization. The yield can be improved in many ways (e.g. crop development, production system, machinery), and continuous progress is observed. Other routes that could be followed in order to reduce the costs of biomass used for energy are the introduction of biomass production systems that have more than one function (multifunctional land use) and more than one output (multi-product plantations). Multi-product systems could have great similarities to commercial forestry or various forms of agriculture but could be optimized for new outputs. The potential and impacts of such systems on related markets deserve more research. Certainly, for large areas of the world, low-cost biomass can be produced in large quantities. Its competitiveness will depend to a large extent on the prices of oil, coal and natural gas.

The high oil prices recorded at the beginning of 2008 meant that biofuel production had become economically competitive in some parts of the world. Meanwhile, the increases in oil prices can also affect the competitiveness of biofuels, as an important component of biofuel production costs is the price of energy. The notable exception is Brazilian ethanol, due to the fact that bagasse, its plant residue, is burned for power generation. This is also true of next-generation fuels, if lignin co-generation is used to power the plant. It should be noted that increased consumption of biofuels is expected to lead to increased demand for biofuel feedstocks, leading in turn to an increase in the price of these feedstocks and the cost of biofuels. In the end, this will affect the competitiveness of biofuels, as it is difficult for producers to pass on any increases in these costs as biofuel prices tend to follow closely the price of petroleum-based fuels. It is unlikely that these costs will decline, given the ongoing structural changes affecting global agriculture markets.

Table 13 below shows examples of energy-cropping systems for different conditions determined by climate and land quality.

Table 13: Example of energy–cropping systems for different conditions determined by climate and land quality

	Tropical regions	Semi–arid conditions	Temperate climate
Arable land	Sugarcane; high–yielding woody crops and grasses	Cassava; woody crops; energy grasses	Miscanthus; willow; energy maize; cereals
Pasture land	Energy grasses	Managed grasslands	Switchgrass; miscanthus
Degraded/marginal land	Oil palm; longer–rotation trees	Jathropha oilseeds; longer–rotation trees (eucalyptus)	Poplars; grasses

4.2 Energy and climate aspects

Energy balance

Although biofuels are invariably described as "renewable" energy, their production typically involves the consumption of fossil fuels. Biofuels net energy balances – the ratio of energy contained in the final biofuel to the energy used to produce it – vary significantly, depending on the particular form of feedstock used, on the production method and on the conversion technology. Methods for calculating and accounting energy balances generally take into account all energy inputs associated with growing, harvesting and transporting the energy feedstock, as well as the energy required for processing the energy feedstock into a usable biofuel. In addition, methods should also account for energy payback associated with biofuels co-products – the so-called "co-product credit". Assumptions about inputs vary widely, and the value assigned to inputs as well as co-products affects the outcome.

Among annual crops, tropical plants have the highest energy balance because they grow in more ideal conditions using sunlight and rain precipitations. They are often cultivated manually, using fewer fossil-fuel energy requirements and fewer chemical inputs of fertilizers and pesticides. Brazilian sugarcane ethanol, for instance, is deemed to be one of the most efficient forms of annual biofuel, with energy balance estimates to be about 8 units on average and 10 units in best cases (Fulton et al. 2004; Macedo et al. 2004). This can be explained by two key reasons: First, cane yields are high and require relatively low inputs of fertilizer, since Brazil has better solar resources and high soil productivity. Second, almost all conversion plants use bagasse (the residue that remains after pressing the sugar juice from the cane stalk) for energy, and many recent plants use co-generation (heat and electricity), enabling them to feed electricity into the grid. Therefore, net fossil energy requirements are near zero and in some cases could be below zero. In addition, less energy is required for processing because there is no need for the extra step of breaking down starch into simple sugars. With regard to biodiesel produced in tropical areas, studies find that the best average energy ratio is for palm-oil biodiesel, equal to 9 units, while soy and castor biodiesel have much lower energy balances, respectively 3 units and 2.5 units (Worldwatch Institute 2006).

Temperate biofuel production pathways are usually less efficient, although they have improved their energy performance in recent decades as agriculture practices have improved and fuel production mills have streamlined their operations. Most recent studies and reviews find a positive (though small) energy balance. Average estimates vary between 1.5 units for corn and 2 units for wheat and sugar beet-based ethanol. The lower energy balance for US corn is explained by the fact that cultivation requires higher quantities of petrochemical fertilizers and toxic pesticides and that the corn processing for bioethanol consumes fossil-fuel energy. For biodiesel, average energy balances range between 2.5 units for rapeseed and 3 units for sunflower-based biodiesel (Worldwatch Institute 2006). In the future, the energy cost of refining biofuels from lignocellulosic biomass is expected to exceed that of producing biofuels with conventional starch, sugar and oil. However, these lignocellulosic biofuels will bring with them greater quantities of residue bioenergy to use as processing energy.

Carbon balance

Biofuels can affect net carbon emissions in two main ways: by providing energy that can displace fossil fuels and by changing the amount of carbon sequestered in land (both below and above soil). Consequently, the net carbon balance depends on what would have happened otherwise – that is, both the amount and type of fossil fuel that would have been consumed, and the land use that would have prevailed. The majority of carbon lifecycle analyses carried out thus far look at grains and oilseed crops in North America and the EU. The exceptions are a study on sugarcane ethanol in Brazil, one on sugarcane ethanol in India and one on biodiesel from coconuts. Furthermore, most studies have looked at ethanol, biodiesel and ETBE. A limited number of studies have considered vegetable oil and biogas, DME and BTL fuels. There have been no studies to date on biodiesel from palm oil, cassava or oilseed plants such as jathropha and pongamia, or on pyrolysis oil diesel or hydrothermal upgrading (HTU) diesel.

Assuming the same system boundaries (e.g. no land-use changes and the same level of final output), the viability of biofuels as low-carbon replacements for oil generally depends less on the amount of energy required in production than on the type of energy used. Corn-derived ethanol, for example, may indirectly emit as much fossil carbon into the atmosphere as gasoline if the corn is grown with nitrogen fertilizers derived from petroleum sources; irrigated, harvested and delivered with vehicles run on conventional fuel; and processed using energy generated from coal. If, however, the corn is grown with manure or other natural fertilizers, harvested and delivered with biofuels, and distilled with renewable power, then the associated lifecycle emissions could drop to near zero. This highlights the importance of choice of feedstock, selection of refining processes, and careful planning and designing of the entire biofuel pathway, integrating it into the context of the biomass energy system.

Research on net emissions is far from conclusive, and estimates vary widely. According to Quirin et al. (2004), who reviewed more than 800 studies and analysed 69 of them in detail, the primary reasons for differing results are different assumptions made about cultivation, conversion or valuation of co-products. Larson (2005), who reviewed more than 30 lifecycle assessment studies for various biofuels, found that the greatest variations in results arose from the allocation method chosen for co-products, assumptions about nitrous oxide (N2O) emissions and soil carbon dynamics. In addition, GHG savings will vary from place to place – according to existing incentives for GHG reductions, for example. Furthermore, the advantages of a few biofuels (e.g. sugarcane ethanol in Brazil) are location-specific. As a result, it is difficult to compare between studies. However, despite these challenges, some of the more important studies point to several useful conclusions.

According to Larson (2005), conventional grain- and oilseed-based biofuels can offer positive (although modest) reductions in GHG emissions. The primary reason for this is that they represent only a small portion of the above-ground biomass. He estimates that, very broadly, biofuels from grains or seeds have the potential for a 20–30 percent reduction in GHG emissions per vehicle-kilometre, sugar beets can achieve reductions of 40–50 percent, and sugarcane (average in southeast Brazil) can achieve a reduction of 90 percent. Quirin et al. (2004) concluded that the GHG emissions balances of all biofuels considered are favourable compared with fossil-fuel counterparts. More specifically, they found that ETBE has advantages over all other biofuels; that whether ethanol is better than biodiesel depends on the feedstock used; and that biodiesel from rapeseed is favourable to pure rapeseed oil because the glycerine co-product can be substituted for technically produced glycerine. They considered both current and future vehicle technologies, used 2010 as their time reference, and looked only at studies that included methane, N_2O and CO_2. They further analysed impacts of all relevant agricultural sources (fertilizer production and emissions from field) and accounted for co-products.

It should be noted that a few studies stand out from the rest as they have reported *increased* emissions from biofuels relative to conventional petroleum fuels. For example, Pimentel (1991, 2001) has estimated that ethanol derived from corn results in a 30 percent increase in lifecycle GHG emissions over gasoline. Other studies reporting an increase are by Pimentel and Patzek (2005). They stand apart from the rest because they incorrectly assume that ethanol co-products should not be credited with any of the energy input (and thus associated emissions) in feedstock growing and fuel processing. They also include data that are out of date, do not represent the current agricultural and refining processes, or are poorly documented and thus cannot be evaluated fully.

The other notable exception is a series of studies by Delucchi (2005), who also found that biofuels from many of the current feedstock have higher lifecycle emissions than petroleum fuels. Delucchi (2005) includes co-products in his analysis and assumes that production processes will continue to become more efficient and will switch to low-emitting process fuels (such as renewable power). He continuously updates his model and data. His work differs from other studies primarily in that he includes a detailed accounting of the entire nitrogen cycle, uses comprehensive CO_2-equivalency factors (accounting for GHGs such as methane and N_2O

that various studies do not incorporate), and has a comprehensive and detailed accounting of land-use changes and resulting impacts on the climate. A study by Fargione et al. (2008) has found that land-use changes (both direct and indirect) can negatively affect the net carbon balances of biofuels, including the most efficient such as Brazilian ethanol (see Box 3).

BOX 3: EMISSIONS FROM LAND–USE CHANGE

When calculating the emissions from land-use change, two main categories are considered: direct and indirect conversion. Direct conversion refers to land that is converted directly from another use to agricultural land in order to grow biofuel feedstocks. In some cases site-specific data may be available, and in these instances relatively detailed calculations can be made for the direct impacts of biofuels production. When site-specific information is not available, a default value can be used based on conservative assumptions about how biofuels would likely be produced in the country in question.

Indirect conversion refers to the displacement of other land uses by biofuel production, which in turn encroaches on forested areas. For example, forests may be cleared for soy production because current soy fields are being converted to sugarcane production for biofuels. The likely impacts from indirect conversion have the potential to be large, but they are also much more difficult to quantify than direct conversion. Land-use activities may be displaced to other countries – for instance, as world soy prices increase in response to displacement of production in Brazil, additional production may arise elsewhere. Conversely, rising soy prices may result in non-soy crops displacing soy for some uses. Finally, responses may not be immediate, and tracking market responses over time means that the quantification of such impacts will need to rely on projections rather than historical information.

Source: Childs and Bradley (2007).

Ethanol

As mentioned earlier, there are significant variations in the findings of lifecycle GHG reductions associated with ethanol. In general, however, of all potential feedstock options, producing ethanol from corn results in the smallest decrease in overall emissions. Farrell et al. (2006) looked at six representative studies on corn-based ethanol production in the USA in order to compile estimates of primary fossil energy input/output ratios and net GHG emissions using consistent parameters. The study found that, depending on the study input parameters (such as energy embodied in farming equipment), switching from gasoline to corn ethanol yielded anywhere from a 20 percent increase in emissions to a 32 percent decrease. Their best estimate, with today's yields and technology, is that lifecycle emissions decline by only 13 percent. Delucchi (2005) estimates that emissions from corn ethanol can range from a 30 percent reduction to a 30 percent increase relative to those from petroleum fuels. Larson (2005) found that ethanol from wheat ranged from a 38 percent benefit to a 10 percent penalty.

Several studies have assessed the net emissions reductions resulting from sugarcane ethanol in Brazil, and all have concluded that the benefits far exceed those from grain-based ethanol produced in Europe and the USA. According to Fulton et al. (2004), for each unit of sugarcane ethanol produced in Brazil, only about 12 percent of a unit of fossil energy is required. As a result, CO_2 emissions calculated on a well-to-wheels basis are also very low, at about 10 percent of those of conventional gasoline. Finally, as mentioned above, Quirin et al. (2004) found that using ethanol to make ETBE results in even greater GHG savings than blending ethanol directly with gasoline. This is because ETBE replaces methyl tert-butyl ether (MTBE), which has relatively high energy demand, whereas ethanol replaces gasoline, which requires less energy for production than MTBE.

Biodiesel

The range of estimates for GHG emissions reductions from biodiesel is also large. Most studies show a net reduction in emissions, with waste cooking oil providing the greatest savings. The exception is Delucchi (2003), who estimates that biodiesel from soybeans will lead to significant emissions increases by 2015. Depending on assumptions (including land-use change), he believes that soy biodiesel could result in net emissions ranging from zero (relative to fossil fuels) to an increase of more than 100 percent. Other studies show major reductions in emissions from soybean diesel. Larson (2005) found that estimates for emissions reductions from soy methyl ester (SME) are similar to those for rapeseed methyl ester (RME), which provides a 15–65 percent reduction per vehicle-kilometre travelled. Again, varying results are due to different assumptions, as described above. Estimates for the net reduction in GHG emissions that are obtained from rapeseed-derived biodiesel in Europe range from about 40 percent to 60 percent compared with conventional automotive diesel. As with ethanol, however, these results are sensitive to several factors, including the use of the by-products and yields. If more of the by-product glycerine that results from biodiesel production is used for energy purposes, then the net emission savings would be higher. Biodiesel yields vary widely according to the conversion process, the scale of production and region, and the type of crop used.

Improving climate change impacts

In the future, there is the potential to further reduce GHG emissions associated with biofuels through a variety of means. These include improving yields with existing feedstock, improving process efficiencies and the deployment of new technologies and energy feedstocks. Table 14 shows the range of estimated possible reductions in emissions from wastes and other next-generation feedstock relative to those from current-generation feedstock and technologies.

Table 14: GHG emissions reduction impacts of second-generation biofuels per kilometre travelled, 2010–2015

Fuel	Feedstock/location	Process	Emissions change (%)
Diesel			
Biodiesel	Rapeseed (local)	Oil to FAME (transesterification)	–38
Biodiesel	Soybeans (local)	Oil to FAME	–53
Diesel	Biomass–eucalyptus (Baltic)	HTU bio-crude	–60
Diesel	Biomass–eucalyptus (Baltic)	Gasification/F–T	–108
Diesel	Biomass–eucalyptus (Baltic)	Pyrolysis	–64
DME	Biomass–eucalyptus (Baltic)	Gasification/DME conversion	–89
Gasoline			
Gasoline	Biomass–eucalyptus (Baltic)	Gasification/F–T	–104
Ethanol	Biomass–poplar (Baltic)	Enzymatic hydrolysis	–112
Ethanol	Biomass–poplar (Brazil)	Enzymatic hydrolysis	–112
Ethanol	Biomass–poplar (local with feedstock from Brazil)	Enzymatic hydrolysis	–101
Ethanol	Corn (local)	Fermentation	–72

Source: Worldwatch Institute (2006).

Improving yields and process efficiency

Over the past several decades, significant yield improvements have been achieved with a variety of crops, including sugarcane, corn, soybeans and oil palm, and advances are expected to continue. Yield increases are due to several factors, including breeding (particularly hybridization), genetic modification, better farming practices and farm conservation measures. As crop yields improve, the amount of land and other inputs required to produce a given amount of biofuel decline, generally reducing the climate impact. Advances in technology and process efficiencies also offer the potential for additional reductions in associated carbon emissions.

Improvements to date have been significant, as seen in both the USA and Brazil. Over the past 30 years, the US ethanol yield per bushel of corn has increased steadily, from less than 9 litres (2.4 gallons) per bushel in the 1970s to 9.8-10.6 litres (2.6–2.8 gallons) by the mid-2000s. This represents an efficiency increase of 8–16 percent. The position in this range depends on the starch content of the corn and the process efficiency. In Brazil, the improvements have been even more significant. Fulton et al. (2004) note that the ethanol yield from 1 tonne of sugarcane increased 23 percent between 1975 and 2002, from 73 litres per tonne in 1975 to 85 litres in 1995 and to 90 litres in 2002. The best values are 10–20 percent higher than average, and it is expected that these will become the average over the next several years.

According to other sources, the increase in yield, due to technological innovations and efficiency improvements, has been far greater. Nastari (2005) estimates a near tripling over the past 30 years, from about 2000 litres of ethanol per hectare of sugar cane in 1975 to 5000 litres in 1999 and 5900 litres in 2004, an average annual increase of 3.8 percent. Some put the current yield as high as 7000 litres per hectare under good conditions. In addition, the production of additional biofuel co-products can also reduce GHG emissions. In particular, renewable lignin from energy crops can reduce or eliminate the need for coal or gas required for processing, directly reducing GHG emissions. If excess electricity is available to feed into the local utility grid, offsetting fossil-generated power, then the resultant emissions reductions could be even greater. A study by the Dutch Energy Agency (NOVEM) and Arthur D. Little (ADL) estimated that lifecycle CO_2-equivalent emissions would decline significantly in many processes by the period 2010–15, with most pathways leading to high reductions relative to gasoline or diesel. In many cases, GHG emissions reductions would exceed 100 percent, due mainly to the use of biomass for process energy.

Developing second-generation energy feedstock and biofuels

Improvements in technologies and process efficiencies could bring about significant further reductions in emissions, but they will not be enough to change the relative benefit of given types of biomass and land-use change. Such improvements may not counterbalance the negative impacts of expanding feedstock supply and associated land use if they are not sited, selected, planted and managed in a sustainable manner. Thus, it is important to focus on new energy feedstocks such as short-rotation forestry and perennial grasses. These offer significant potential for further reducing the lifecycle emissions of biofuels while providing the added benefit of reducing the amount of land and other resources required for production. Such crops, if planted in place of annual crops or on degraded lands or unimproved pasture, can increase standing biomass growing above ground and the amount of biomass under ground and, hence, carbon sequestration. In addition, because these perennial energy crops generally require less fertilizer and less irrigation than other feedstock crops, they also reduce CO2 emissions associated with the final biofuel product more effectively. Finally, yields for miscanthus, switchgrass and other energy grasses are also expected to increase significantly. So far, energy crops such as switchgrass and poplar trees have not been bred intensively, and some experts believe that breeding could result in a doubling of their productivity.

The cellulosic conversion process for ethanol offers the greatest potential of reductions because feedstock can come from the waste of other products or from energy crops, and the remaining parts of the plant can be used for process energy. Typical estimates for GHG reductions from cellulosic ethanol (most of which come from engineering studies, as few large-scale production facilities exist to date) are in the range 70–90 percent relative to conventional gasoline. According to Fulton et al. (2004), the full range of estimates is far broader. Larson (2005) projects that future advanced cellulosic processes (to ethanol, Fischer–Tropsch diesel or DME) from perennial crops could bring reductions of 80–90 percent and higher. According to Fulton et al. (2004), net GHG emissions reductions can even exceed 100 percent if the feedstock takes up more CO_2 while it is growing than the CO_2-equivalent emissions released during its full lifecycle (e.g. if some of it is used as process energy to offset coal-fired power). Delucchi (2005), too, believes that next-generation feedstock (e.g. switchgrass, poplar) and processes can result in substantial reductions compared with petroleum fuels, assuming that all major production processes and the use of fertilizer inputs become more efficient, and that biomass is used as process energy.

Finally, another possible means of improving the GHG benefits of biofuels is carbon capture combined with storage. During the fermentation process, about half the biomass in sugar- and starch-rich sources is converted into ethanol; the remainder is converted into CO_2. With regard to Fischer–Tropsch diesel production, about half the carbon in the original feedstock can be captured before conversion of syngas to Fischer–Tropsch fuels. CO_2 capture and storage during these processes could allow for negative emissions per unit of energy produced on a lifecycle basis. Larson (2005) also projects that this option would enable reductions to exceed 100 percent.

4.3 Other environmental impacts

Sustained production of biofuel feedstocks on the same surface of land can potentially have considerable negative impacts with respect to soil fertility, water quality, nutrient leaching and biodiversity loss. These impacts are reviewed briefly below, highlighting the benefits of second-generation biofuels energy crops (perennial crops such as willow, misconstrues and switchgrass) over annual crops (planted and harvested each year, e.g. sugar beet, maize).

Water supply

Increased water use caused by the additional demand of new biofuel feedstocks can become an issue, particularly in semi-arid regions. For instance, concerns have been raised regarding the increased pressure on water resources because of large-scale corn production for ethanol generation in the USA. It should be noted that the choice of a certain energy crop can have a considerable effect on its water-use efficiency. Certain eucalyptus species, for example, have very good water-use efficiency when the amount of water needed per tonne of biomass produced is considered. But a eucalyptus plantation on a large area could increase the local demand for (ground)water and affect groundwater levels. However, improved land cover (as would be the case with biomass production systems) generally has a positive effect on water retention and microclimate conditions. Hydrological impacts should therefore always be evaluated at the local level.

A study by the International Institute for Applied Systems Analysis (IIASA) and World Energy Council (WEC) (1998) evaluated the expected demand for water in 11 world regions by 2025, taking into account increasing population and demand for food. Assuming that an acceptable water supply per capita would be around 2000 m^3/per capita/year, the Middle East and, to a lesser extent, parts of China and South Asia would face water constraints. For all other regions, water availability is not expected to become a major bottleneck. It should be noted that this is a very rough exercise, and on a regional level water availability can be a serious problem. More detailed assessments on national and regional levels are therefore necessary.

Water quality

The agricultural use of pesticides can further affect human health and ground- and surface-water quality, which consequently affects flora and fauna. Specific effects strongly depend on the type of chemical, the quantities used and the method of application. However, it should be noted that not all effects causing damage to flora, fauna and human health are well known or understood. Current experience with perennial crops (e.g. willow, poplar, eucalyptus) suggests that those crops meet very strict environmental standards. Compared with food crops such as cereals, application rates of agrochemicals per hectare are a factor of 5–20 lower for perennial energy crops (Faaij et al. 1998; Borjesson 1999).

The abundant use of fertilizers and manure in agriculture has led to considerable environmental problems in various regions in the world: nitrification of groundwater, saturation of soils with phosphate, eutrophication and contaminated drinking water. Also, the application of phosphates has led to increased flux of heavy metals into the soil. Energy farming with short-rotation forestry and perennial grasses also requires less fertilizer than conventional agriculture (Kaltschmitt et al. 1996). As with perennials, better nutrient recycling is obtained and, since nutrient-poor biomass is harvested, additional inputs are low. For example, the leaching of nitrogen related to willow cultivation can be about a factor of 2–10 less than for food crops. Willow farming is also able to meet very stringent standards for groundwater protection.

Erosion and recycling of nutrients

Erosion is a problem related to the cultivation of annual crops in many regions of the world. On the contrary, perennials help significantly to improve land cover compared with food crops. Also, during harvest, the removal of soil can be kept to a minimum, since the roots remain in the soil. In the USA, millions of hectares fall under the soil conservation programme and are currently covered by grasses. These spaces could provide very promising biomass production areas, since biomass production is combined with soil protection. Another positive characteristic of perennial crops compared with annual crops is that perennial crops form an extensive root system, which adds to the organic matter content of the soil. Generally, diseases (e.g. eel worms) are prevented and the soil structure is improved.

The use of plantation biomass will also result in the removal of nutrients from the soil that will have to be replenished in some way. Recycling of ashes proves feasible and returns crucial trace elements and phosphates to the soil. This is already a common practice in countries such as Sweden and Austria, where part of the ashes are returned to the forest floors. In Brazil, stillage, a nutrient-rich remainder of sugarcane fermentation, is returned to sugarcane plantations. During thermochemical conversion, nitrogen is lost, and this needs to be replenished. The use of artificial fertilizers is a straightforward option, but one could also consider the use of nitrogen-fixing plant species placed in between energy crops in order to meet the nitrogen needs of the crops.

Biodiversity loss

Biomass plantations are often criticized because the range of biological species that they support is much narrower than natural ecosystems. Although this is generally true, it is not always relevant. It would be relevant if a virgin forest were replaced by a biomass plantation, a situation that would certainly be undesirable. However, when plantations are established on degraded landscapes or on excess agricultural lands, then the restored lands are very likely to support a more diverse ecology compared with the previous situation. Degraded lands are plentiful: estimates by Hoogwijk (2004) indicate that, in developing countries, about 2 billion hectares of degraded land are "available". It would be desirable to restore such land surfaces even if just for purposes of water retention, erosion prevention and microclimate control.

A good plantation design includes setting aside areas for native flora and fauna and creating an area that fits in with the natural landscape. Doing so avoids many of the problems normally associated with monocultures. The presence of natural predators such as insects can also prevent an outbreak of pests and diseases. Altogether, however, this topic requires far more research and insights in which specific local conditions, species and cultural aspects are taken into account. Although appropriate landscaping and management of biomass production systems can reduce the risks of fires and diseases considerably, these two issues also deserve more specific attention when planning projects, policies and research.

4.4 Social aspects

Impacts on agriculture markets

Creating a market for biofuels as a way to increase the value of the world's farm products is an obvious plus for the agricultural economy as a whole. Global prices for agricultural commodities, including crops such as corn, wheat and cotton, have often fallen below the costs of production because government subsidies and policies in industrialized countries favour urban consumers over farmers, resulting in excess supply. Low agricultural prices have the greatest impact on small-scale grain and oilseed producers in developing countries, which are often unable to grow alternative crops or find other work.

Historically, biofuel programmes have served the purpose of providing farmers with both a larger market and a price support. In the early 1900s, the French government promoted ethanol production as a way to handle a decline in sugar-beet exports. Germany offered a subsidy to keep ethanol prices on a par with gasoline, largely to boost demand for domestic grain. In the USA, early fuel ethanol policies were established as a way to handle the surplus of grains, potatoes and sugar beets that resulted from agricultural exploitation of virgin western lands. Today, biofuel production still helps to maintain or increase the price of certain agricultural feedstock. In the USA, rising ethanol production has absorbed a steadily larger share of the country's corn crop, from 12 percent in 2004 to a predicted 18 percent for 2005–06, to a projected 20+ percent by 2012. This rising demand for corn feedstock for ethanol is expected to keep corn crop prices high. According to analysts at the University of Missouri, by 2012 increasing demand could raise the price of corn by an average of €0.11 (US$0.13) per bushel and increase net farm income by €246 million (US$298 million) per year.[6] Additional demand for corn would also raise the prices of sorghum and wheat by €0.07 and €0.05 (US$0.09 and US$0.06), respectively.

Within the EU, policymakers have developed a market for biodiesel in large part to support growers of oilseed crops. Limited by the Blair House Agreement, which restricts the amount of acreage that can be planted with oilseeds for food, farmers have instead planted rapeseed and sunflower seed for use in biodiesel fuel. The market has grown so rapidly that more than 20 percent of EU rapeseed is now sold for fuel. This market expansion has also caused rapeseed oil prices to reach new highs in the Rotterdam market. In Brazil, the advent of the Proálcool programme, designed to spur the domestic market for ethanol and to keep sugar prices high, led to an expansion of the land area planted for sugar cane that still continues today. Since about 50 percent of the country's sugar is converted into ethanol, the biofuel programme has effectively permitted a doubling of planted acreage, perhaps more, since most of the country's mills are integrated facilities that can hedge between sugar and ethanol and are less risky than sugar-only mills. High gasoline prices and increased demand for ethanol fuel in Brazil over the past few years has been a key factor in the rise in the global price of sugar to today's 10-year high.

Other countries are also pursuing biofuel programmes with the aim of expanding the market for agriculture crops. Australia's northern sugar growers have experienced a 20 percent drop in the price of their sugar despite high international prices between 1999 and 2004 and have turned to a domestic fuel ethanol programme to provide a more stable market. French wine growers are hoping that ethanol fuel production will help them cope with recent overproduction of food ethanol. Likewise, corn producers in South Africa are struggling with a glut of overproduction and are using these surpluses as collateral to finance the construction of eight ethanol facilities, creating a long-term additional market for the crop. Elsewhere, Thailand's ethanol blending mandate has already increased the price of cassava, and the government is reversing its sugarcane restriction policy to encourage more domestic production. In the Philippines, legislators have been planning to introduce a biodiesel-blending mandate to support the country's nearly 5 million coconut farmers and an ethanol mandate to help reverse shrinking acreage in the sugarcane industry.

A combination of the above-mentioned policies, production shortages and growing demand from emerging countries has led to higher prices for the most commonly used biofuel feedstocks (corn, sugarcane, rapeseed, palm oil) since 2006. According to the OECD, this trend will continue in the future. Additional demand for agricultural commodities due to increased biofuel use will have the strongest impact on sugar markets, with estimates of up to a 60 percent increase in price by 2014 (OECD and FAO 2007). In a conservative scenario that assumes that current levels of biofuels use will continue, vegetable oil prices are projected to increase by up to 20 percent and cereals by 4 percent. In a scenario that assumes sustained oil prices of around €50 (US$60) per barrel, the impact of additional biofuel production would increase the sugar price by an additional 4.2 percent and vegetable oils by an additional 4.3 percent.

Increasing biofuel production capacity as a way to take advantage of the changing availability of different feedstock sources is a good short-term response to fluctuations in commodity output and prices. However, as the markets for food, fuel and energy become increasingly intertwined, there may be risks as well. Agricultural surpluses could turn into regional shortages, pushing prices for biofuel feedstock and related commodities, including food crops, even higher. A study by the Center for International Economics suggests that ethanol substitution could harm some sectors of the rural economy. Using research from Australia, it concludes that mandating a 10–15 percent ethanol blend in gasoline would increase grain prices by up to 25 percent, adversely affecting the domestic livestock industry and weakening its export position.[7] More recently, the FAO estimates that developing countries' import bills will increase by 10 percent between 2007 and 2008 (FAO 2008).

While higher crop prices are clearly beneficial to some crop producers, other industries can suffer, in particular those that purchase agricultural feedstock. In Europe, the increased demand for biodiesel has caused shortages of rapeseed oil, sending makers of margarine, mayonnaise and salad dressing scrambling for alternative supplies. The Australian beef industry, wary of rising prices for feed grain, has warned that a grain-ethanol programme may lead to greater losses in meat exports than gains from avoided oil imports. In the USA, one study concluded that pig and poultry producers, along with operators of grain processing and exporting facilities, would lose out as more corn is diverted to ethanol.

Impacts on agricultural employment

In addition to the environmental benefits, rural economic development is a primary motivation for the promotion of biofuels. By generating greater demand for agricultural products, biofuel programmes have the potential to significantly increase employment in rural areas, especially when the cultivation involves small-scale farmers and the conversion facilities are located near the crop sources in rural areas. Research has found that the biofuel industry can generate more jobs per unit of output than the fossil fuel industry, sometimes at lower cost. The World Bank reports that biofuel industries require about 100 times more workers per joule produced compared with the fossil-fuel industry. In Brazil, for instance, the biofuels sector is a major employer, providing 1 million jobs in all, one-third of which are seasonal. This is more than the jobs created by fossil-fuel production. While working conditions on sugar plantations can be hard, sugarcane workers in the state of São Paulo on average receive wages that are 80 percent higher than the agricultural sector average and are roughly equal to the median wage in the service or industrial sectors (Worldwatch Institute 2006).

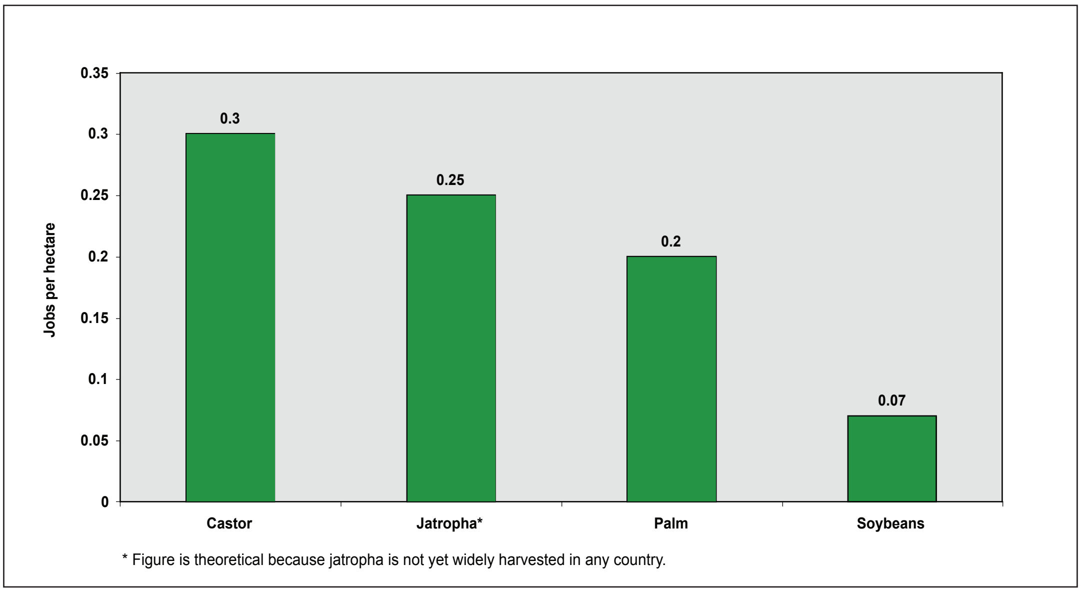
In the USA, the ethanol industry is credited with employing between 147 000 and 200 000 people, in sectors ranging from farming to plant construction and operation. In the EU, when biofuels reach 1 percent of the fuel supply, the industry is expected to have created 45 000–75 000 new jobs, mostly in agriculture. Even Germany's relatively capital-intensive biodiesel industry generates roughly 50 times more jobs per tonne of raw oil than does diesel production. Since the vast majority of employment in biofuel industries is in farming, transportation and processing, most of these jobs will emerge in rural communities. Biofuel production in other parts of the world can also create additional opportunities for family farmers and rural workers. In China, for instance, the liquid biofuel programme is predicted to create as many as 9 million jobs in the country, thus leading to significant increases in income generation and rural development. In sub-Saharan Africa, the World Bank estimates that a region-wide blend of ethanol – 10 percent of gasoline and 5 percent of diesel – could yield between 700 000 and 1.1 million jobs.

Such massive jobs programmes are possible because biofuel production can be very labour-intensive. However, it is not clear whether biofuels will produce enough jobs to compensate for the losses being brought about by industrialized agriculture. Much of the early expansion of Brazil's sugarcane area, especially in the northeast, occurred as large plantation owners took over smaller-scale farms. This often created violent social tension that led to an increase in unemployment and landlessness in the region. In recent projections, total employment in Brazil's sugarcane industry is expected to decline gradually, largely because of the trend towards mechanical harvesting (Worldwatch Institute 2006). In the USA, despite an expanding ethanol industry, the farming population of the Midwest has been shrinking for decades and is now one-third of what it was in 1940. The need to lower the production costs of biofuels offers considerable incentives for the wide-scale adoption of high-technology and less labour-intensive production practices. For instance, the cultivation of some energy crops such as soy is linked to highly mechanized large-scale cultivation practices with very little impact on rural labour. While there are some cooperatives of small-scale soya producers, a key factor for their long-term viability is whether they can organize themselves in such a way that will enable them to achieve economies of scale.

In developing countries, many agricultural jobs are seasonal, making it difficult for workers to maintain steady employment in any one area. Sugarcane in particular has an ugly history of exploiting temporary workers. To address this problem, some plantation owners in Brazil now provide labourers with off-season work, planting and preparing for the next harvest. This has helped to raise the wages of sugarcane workers above those of other agricultural sectors, but the disparity between wealthy plantation owners and labourers remains striking and subject to continuing criticism. It should be noted, though, that seasonality of jobs is not related directly to disparity of wealth. In industrialized countries, even though full-time farmers are more likely to be tending the land, they are also typically tenants rather than owners. Some 40 percent of US farmers currently rent their land and facilities. As such, they are unlikely to benefit from higher corn prices – as corn prices increase, so will land renting rates – nor are they likely to have enough capital to participate in the value-adding process of converting corn into ethanol.

Compared with other biofuel feedstock, labour-intensive oilseed crops may be more suitable for a process of sustainable and equitable job creation. (See Figure 15 for a comparison of the labour intensity of different oilseed crops in Brazil.) Because oil seeds often must be harvested manually, large owners who can purchase advanced harvesting machinery have fewer advantages. Moreover, since the process of converting plant oils into biodiesel is fairly straightforward and can happen at relatively low temperatures and pressures, it can often be done on a smaller scale. Thus, feedstock that is labour-intensive rather than capital-intensive, and the production of biodiesel rather than ethanol, may be the most promising options for supporting poor farmers and for providing liquid fuel in remote areas. Livelihoods could also improve because of the positive impacts on land restoration associated with crops such as jathropha. Becker and Francis (2003) argue that, once the jathropha trees establish themselves and fertilize the soil, their shade can be used for intercropping shade-loving vegetables such as red and green peppers and tomatoes, which would provide additional income for the farmers.

Figure 14: Labour intensity of selected oilseed crops in Brazil



Source: Kaltner et al., Jones

Finally, it should be noted that the overall impact on employment and wealth will depend, to a large extent, on the ability of the countries not only to grow the feedstocks but also to be able to convert them into biofuel. However, the tariff escalation system prevailing in many industrialized countries may well encourage developing countries to export the feedstocks and the unprocessed crude oil and molasses while the final conversion takes place in the importing country, thus causing them to miss out on some of the positive impacts of biofuels (Dufey 2006).

The gender dimensions of bioenergy

In many developing countries, where much energy use comes from traditional forms of biomass, women are responsible for securing energy for household needs and producing crops. The collection of traditional fuels for cooking such as wood and charcoal consumes a considerable amount of time that otherwise could be devoted to other, more productive activities. It is estimated that women spend threefold more time transporting fuel and water compared with men (IUCN 2007).

In addition, traditional fuels are associated with serious health problems among women and children linked to their exposure to harmful indoor airborne pollutants. Studies have shown that in certain developing countries exposure to internal pollution from fossil fuels causes more deaths among women and children than malaria and tuberculosis combined (UNDESA 2007). Consequently, developments in bioenergy have the potential to benefit women if well planned; yet if gender and poverty considerations are not incorporated into bioenergy policies and practices, then the livelihoods of women and their families could be threatened (IUCN 2007).

Using modern forms of bioenergy including wood pellets or ethanol gel in stoves can contribute substantially to improving air quality and health, especially for women and children in rural areas, while freeing up time for women to devote to income-generating activities. Women can also participate in productive activities related to energy crops. For example, in western Africa, women use the jathropha-based oil to produce shea butter and jathropha seeds are used to produce soap.

A gender perspective must be mainstreamed into planning and policymaking on bioenergy, in order to ensure that the concerns and needs of both men and women are taken into account (IUCN 2007). In this regard, it has been suggested that developing countries should give priority to feedstocks and production models that maximize opportunities for male and female small farmers (Oxfam International 2008).

4.5 The "food-versus-fuel" debate

When considering rapid increases in biofuel production, concerns have been raised that crops that would otherwise become food might instead become fuel, leaving the world's poorest inhabitants malnourished (Worldwatch Institute 2006). International cereal prices have risen sharply in the past year. By the end of March 2007, prices of wheat and rice were about twice their levels of a year earlier, while those of maize were more than one-third higher (FAO 2008). As a consequence, prices of basic foods have soared in domestic markets across the world, leading to social unrest in countries in Asia, Africa, Latin America and the Caribbean. It has been suggested that biofuels are the main factor of the latest increases in the cost of basic staples, causing some of the recent food crises around the world. In principle, other things being equal, the additional demand of biofuels can be expected to put upward pressures on the prices of soft commodities currently used to make them. However, a closer look at this situation suggests that there are a number of factors that have affected cereal prices over the past year, some of which are cyclical or shorter-term and induce volatility into the market and others longer-term and structural in nature.

First, adverse weather conditions, possibly associated with global climate change, have negatively affected agricultural production worldwide. For instance, Australia, normally the world's second-largest wheat exporter, has recently suffered an epic drought, which has had significant impacts on its crop output. Following lower-than-expected harvests, reductions in stocks have put upward pressure on prices due to the induced volatility and higher risk premium that lower stocks imply. In this context, an influx of speculative investment may have contributed to recent price rises. Second, growing demand from emerging economies has increased demand for agriculture commodities. For instance, in China and India, a growing number of people are consuming meat and dairy products. Since it takes about 700 calories' worth of animal feed to produce a 100-calorie piece of beef, this change in diet increases the overall demand for grains. Third, higher oil prices have an impact on the agriculture industry. According to the UK Sustainable Development Commission, an increase in oil price from US$50 to US$100 a barrel could cause an increase in production costs, causing a 13 percent increase in commodity prices for crops and a 3–5 percent increase in livestock products. Finally, in a context of strained world grain markets, rising biofuel production, mainly in the USA, has contributed to the overall price volatility of agricultural commodity prices, most notably on the maize market.

In the short term, food price increases may hurt consumers in countries that are net food importers. The cost of cereal imports in the poorest countries is expected to increase 56 percent in 2007–08, following an already significant increase of 37 percent in 2006–07. In poor and food-deficient African countries, the cost of cereal imports is expected to soar by 74 percent (FAO 2008).

Faced with higher food prices, many people, especially in the world's poorest countries, tend to consume fewer high-value goods such as meat and dairy products. Although food demand is relatively inelastic, studies show that, for every 1 percent increase in the price of food, consumers in developing countries decrease their consumption by three-quarters of 1 percent, compared with only one-third of 1 percent in industrialized countries. In the longer term, however, access to food could be enhanced for many of the world's 800 million undernourished people by boosting overall agricultural production. Under certain conditions, commodity price increases could offer a new opportunity for farmers and farm labourers by reversing the historically low levels of investment in agriculture and agricultural research that have slowed down improvements in productivity, with a negative impact on agricultural output potential. Additionally, if biofuel programmes end up absorbing much of the surplus crop production in industrialized countries, then they could spare farmers in the developing world from commodity "dumping" and artificially low prices.

However, it should be noted that higher crop prices do not automatically translate into better conditions for farmers or rural communities; for instance, they can raise the price of inputs for the meat- and agricultural-processing industries. Economic benefits can also fail to trickle down to the poorest participants in an agricultural economy. Generally, poor farmers are more likely to benefit if biofuel production is done in a small-scale, labour-intensive manner that keeps them employed and able to afford food. The alternative is large plantations of monocultures controlled by wealthy producers, who could drive farmers off their land without providing new opportunities. In Brazil, where the early years of the Proálcool programme led to regional food scarcities in the northeast, the government now embraces biodiesel and specifically encourages poverty reduction from biodiesel industry activities. By providing families of labourers with a new market for their tree oil crops, the government aims to improve the economic conditions that would otherwise lead to hunger.

In the future, markets for cellulosic biofuel feedstock offer a promising opportunity to reduce direct competition between food and biofuels. Farmers could preserve the sugary, starchy or oily components of the plant for food and sell the fibrous components as fuels. By adding value to agricultural residues, farmers may be able to benefit while also selling food at a lower price. Yet even cellulosic feedstocks can put pressure on food supplies, particularly if enormous demand for biofuels strains the limits of agricultural potential and productive land. The likelihood of such tension will depend on a variety of factors, including the ability of agronomists and farmers to further raise agricultural yields, the overall size of the human population, the extent to which calorie-intensive meat and dairy products dominate diets, and the fuel efficiency of peoples' lifestyles.

These factors notwithstanding, the central cause of food scarcity in the world today is and will likely remain the realities of economic inequality and inadequate food distribution. Since the very poorest people are unable to afford food when prices are set by wealthier consumers, the most immediate question is whether biofuels will help to reduce some of these inequalities.

5. BIOFUEL SUSTAINABILITY CERTIFICATIONS[8]

As discussed in the previous chapter, not all biofuels are equal, with some being more environmentally and socially sound than others. As biofuels are increasingly consumed and traded internationally, mechanisms are needed to assure both policymakers and consumers that the biofuels they are promoting and using result in significant GHG emissions reductions and are produced using the most sustainable methods. Setting sustainability standards and establishing certification schemes are strategies increasingly popular for achieving these objectives. This chapter reviews ongoing initiatives to design sustainability schemes for biofuels and explores the associated links with WTO rules. Then it discusses the limits of sustainability certification and proposes ways to overcome these limits.

5.1 Ongoing sustainability certification initiatives

Governmental initiatives

Over the past few years, a number of governments have sought to establish sustainability standards and certification schemes for biofuels, including Germany, the Netherlands and the UK in Europe and California in the USA. Some of these efforts greatly overlap, but they are all broadly consistent in their core aims, which are promoting a reduction in GHG emissions and addressing the environmental and social impacts associated with biomass production. Among these initiatives, the UK's RTFO has perhaps gone the furthest in developing operational standards, which are entered into force in April 2008. However, this and other European schemes will be replaced by an EU-wide certification system that is currently being discussed by the EU and is expected to enter into force in 2010.

Germany

In Germany, the 2007 Biofuel Quota Law, setting mandatory biofuel blending targets, mandated the government to develop sustainability standards for biofuels. In December 2007, the Decree on Biomass Sustainability lay down specific sustainability requirements for the production of biomass feedstocks, the sustainable use and protection of habitats, and the reduction of GHG emissions. More specifically, in order to qualify for the governmental quota and financial support, biofuels will be required to demonstrate at least a 40 percent reduction in lifecycle GHG emissions, including emissions from land-use change.

To operationalize the above requirement, the German Decree includes default values in GHG savings for a number of common biofuel production chains. Suppliers have the option of either using the default values or undertaking an independent certification of the actual GHG emissions reduction resulting from their operation. This option is particularly attractive for companies using efficient production processes and, more importantly, that can demonstrate that biofuel feedstock production is not resulting in direct land-use changes. Given that conversion of grazing land or woods into arable land could lead to significant carbon release, land-use changes can have major impacts on GHG balances of biofuels. For instance, it is estimated that Brazilian ethanol would not be able to meet the minimum GHG saving requirement due to its land-use change impacts (Fritsche and Hunecke 2006). Following EU internal market rules, the German Decree was notified to the European Commission, which in March 2007 decided to put the process on hold in order to avoid various EU countries implementing different sustainability standards.

The Netherlands

Following sustainability concerns regarding increasing biofuels imports, in 2006 the Dutch government established the Sustainable Production of Biomass Taskforce, which produced a set of criteria and a testing framework for sustainable biomass production for both biofuels and electricity and heat production (Cramer et al. 2007). The framework identified the following six sustainability themes: GHG emissions; competition with food and other applications; biodiversity; environment; prosperity; and social wellbeing. For each of these criteria, indicators and reporting requirements were developed. For example, the taskforce requires that biomass use results in a GHG emissions reduction of 50–70 percent for electricity and 30 percent for transport applications. These thresholds are dynamic and will be updated according to technological developments.

The Dutch testing framework makes a distinction between, on the one hand, the information that can be obtained only at the regional or national level (the macro-level) and, on the other hand, the evidence that bioenergy suppliers will be required to submit in order to be eligible for public financial support and to meet blending mandates. The government will be responsible for monitoring the macroeconomic impacts of biomass production, including land-use changes, deforestation and biodiversity loss, changes in food and land prices, property relations and food security impacts. Research suggests that many of the existing agriculture and forestry standards, such as Forest Stewardship Council (FSC), Roundtable for Sustainable Palm Oil (RSPO), Roundtable on Sustainable Soy (RTRS) and International Federation of Organic Agriculture Movements (IFOAM), partially cover the Dutch sustainability requirements for biodiversity, environment and social wellbeing (except integrity), but that GHG emissions, competition with food and other applications are not covered. In October 2007, the Dutch government announced that palm oil will be excluded from the renewable energy incentive scheme because of its current unsustainable production methods.

The UK

In November 2005, the UK announced the introduction of the RTFO, which places a legal requirement on transport fuel suppliers to ensure that a specified percentage of their overall fuel sales are from a renewable source. The obligation entered into force in April 2008 with targets for 2.5 percent (by volume) of renewable fuels to be supplied in the first year, rising to 5 percent in 2010–11. A carbon and sustainability reporting scheme forms an integral part of the RTFO, and both environmental and social criteria and indicators have been proposed based on an analysis of existing standards to achieve maximum consistency. The enforcement of the sustainability reporting requirements is based on the so-called "meta-standard approach", which seeks to make maximum use of existing standards where these exist; to stimulate existing initiatives such as RTRS and the Better Sugarcane Initiative (BSI); and to harmonize criteria in the long term (Dehue et al. 2007).

Furthermore, the UK government has defined expected levels of reporting for the period 2008-11 and the various permissible chain-of-custody methodologies. Biofuels suppliers are required to provide monthly and annual carbon and sustainability reports to the RTFO administrator. The UK reporting guidelines call for suppliers to employ independent auditors to verify the veracity of their carbon and sustainability reports. An independent international certification body could perform the same function. Pilot projects to test the feasibility of the proposed certification standards had also been finished by October 2007. Based on the lessons learned in the pilot and in the public consultation associated with the process, final reporting requirements and technical guidelines were issued at the end of 2007, with mandatory reporting in April 2008 (Dehue et al. 2007).

The EU

In January 2007, the European Commission – the EU executive body – tabled a new energy policy for Europe, proposing two binding targets for 2020: a 20 percent share of renewable energy and a 10 percent share of biofuels. To translate these policy targets into legislation, the European Commission published the Renewable Energy Directive in January 2008, which includes the awaited biofuels sustainability rules that will determine the structure and composition of biofuels usage in the EU for the following decades. In its rules, the Commission set a default value of 35 percent of GHG savings, which biofuels must achieve in order to count for the EU's biofuel target. Second-generation biofuels are incentivized as they are each counted twice for the EU biofuels targets. Biofuels producers have until April 2013 to meet these targets. Additionally, the regulation bans the use of biofuels that use feedstocks grown on land with the status of "recognised high biodiversity value" in or after January 2008. The Commission has provided default GHG emissions values for the most typical biofuel production chains. According to the Commission's calculations, wheat ethanol has no GHG savings if produced using lignite as process fuel. However, if wheat ethanol uses straw as the process fuel, then the GHG savings jump to 67 percent. Palm oil also has a huge variation in emissions savings of between 16 and 60 percent, depending on the production process. On the other hand, sugarcane ethanol fared best of all the conventional biofuels, with GHG savings of 74 percent.

Another relevant initiative is the 2007 revision of the EU's Fuels Quality Directive, which contains a proposal requiring fuel suppliers to measure the lifecycle GHG emissions (i.e. production, transport and use) for the fuels they supply in the EU as of 2009, and to reduce these emissions by 1 percent per year from 2011 to 2020. It therefore also has an effect on biofuel lifecycle emissions, being a strong incentive for the best-performing biofuels. However, during the debate in September 2007 in the European Parliament, concerns were raised against these proposals, as it was argued that they would conflict with similar rules being drawn up by the Commission on the Renewable Energy Directive. At the beginning of 2008, the European Council – the body representing European governments – decided to set up an ad-hoc committee to draft a set of sustainability criteria that would be common to both the revised Renewable Energy Directive and the Fuels Quality Directive. This proposal will be discussed by the European institutions during 2008 with the aim of finalizing and approving an overall system by mid-2009.

California

In 2006, California adopted the Warming Solution Act, which fixed ambitious GHG emissions reduction targets and requested the California Air Resources Board (CARB) to elaborate a mandatory reporting system for GHG emission reductions. To this end, the Low Carbon Fuel Standard (LCFS) imposes a reduction of at least 10 percent in GHG emissions from transportation fuels by 2020. After a technical study, the LCFS was included in the State Alternative Fuels Plan, a public programme to increase the production and use of renewable fuels in the state. The implementation schedule is being analysed by the CARB, and the regulatory process to implement the standard was scheduled to be completed by December 2008.

The California Standard is limited to GHG emissions and does not include other sustainability criteria. The approach is based on the UK standard and applies the same lifecycle assessment methodology to calculate the "carbon intensity" of the biofuel. Fuel suppliers have to comply with the standard in order to commercialize fuels in California. The main mechanism for reporting is the annual self-reporting of fuel sales. The fuels with GHG emissions above the standard will pay a fee proportional to the exceeded GHG emissions and the fuel volume. On the contrary, fuel performing beyond the standard will benefit from emission reduction credits. After certification of a fuel supplier, an auditing process by third parties of the supplier and of licensed certifiers is foreseen to verify compliance with the standard and the certification process.

Non-governmental initiatives

At the global level, a number of international agencies and non-governmental groups have undertaken a wide range of initiatives on biofuels sustainability with different levels of maturity. While all of these efforts contribute to the stimulation and advancement of the policy debate on the sustainability of biofuels, better international coordination between initiatives seems desirable. This would not only prevent proliferation of certification schemes but also improve overall coherence and efficiency of international efforts aimed at developing an internationally harmonized sustainability standard for biofuels. Some of the major initiatives include the following:

- *The Roundtable on Sustainable Biofuels* (RSB) is a stakeholder initiative led by the Swiss École Polytechnique Fédérale de Lausanne (EPFL) Energy Centre. This group seeks to develop sustainability standards for biofuels that are simple, generic, adaptable and efficient. They produced broad principles at the end of 2007 and draft criteria in mid-2008.

- *The Global Bioenergy Partnership* (GBEP), coordinated by the FAO headquarters, is a political forum for promoting bioenergy. The Secretariat seeks to encourage the production, marketing and use of "green" fuels, with particular focus on developing countries. It will help members to identify and implement projects for sustainable bioenergy development and support the formulation of guidelines for measuring reductions in greenhouse gas emissions by the use of biofuels (GBEP 2007).

- *The Roundtable for Sustainable Palm Oil* (RSPO) is a multi-stakeholder group of organizations, producers and industries that represent the entire supply chain of palm oil and biofuel production. The group developed a set of principles and criteria for sustainable palm oil production, including ecological, social, economic and more general criteria. They are studying the supply chain in order to establish whether a track-and-trace standard would be a viable option for the industry.

- *The Roundtable on Sustainable Soy* (RTRS) has as one of its objectives the development and promotion of criteria for the production of soy on an economically viable, socially equitable and environmentally sustainable basis. In September 2007, a technical working group started to develop the RTRS principles, criteria and its verification system (RTRS 2006).

- A similar initiative started for sugarcane with the establishment of the *Better Sugarcane* Initiative (BSI). One of the aims of the BSI is to determine principles and to define globally applicable performance-based standards for "better sugarcane" with respect to its environmental and social impacts.

- A number of companies seek to develop their own biomass certification systems. The Dutch power utility Essent, for instance, has developed the *Green Gold Label* (GGL), in cooperation with Peterson Bulk Logistics and Control Union Certifications. Started in 2002, this scheme defines criteria for the sustainable use of forest and agriculture products used in the company power plants.

5.2 Certification and international trade law

Certification schemes and labelling programmes fall within a grey area of the WTO rules. The TBT Agreement requires that regulations (mandatory) and standards (voluntary) should not create unnecessary trade obstacles and prohibits discrimination between domestic products and foreign products (the "national treatment principle") and between products from different WTO members, called the "most favoured nation principle" (MFN) (Bauen et al. 2005). The MFN and national treatment obligations apply only if two products are "like", which is determined on a case-by-case basis by four criteria: properties, nature and quality of the product; tariff classification; consumers' tastes and habits; and product end use. Environmental trade measures that distinguish between products based on their production processes and methods (PPMs) that do not influence the physical characteristics of a product may violate the TBT obligations (Wessels et al. 2001). This is important to consider, as criteria related to sustainable biomass certification are likely to be based on non-product-related criteria. Howse and van Bork (2006) argue that, the more remote distinguishing criteria are from features that consumers can associate with a particular product, then the more probable that the products themselves are considered to be "like".

At present, the applicability of the TBT Agreement that is based on non-product-related PPMs is unclear. Jurisprudence is not conclusive, and authoritative authors are divided on the subject (Zarrilli 2006). The Appellate Body in the Asbestos Case has interpreted jurisprudence in the setting of PPM-based regulatory requirements, emphasizing that regulatory distinctions may be drawn between products found to be "like", provided that the distinctions in question do not systemically disadvantage imports over domestic products (Zarrilli 2006).[9] Also, the complainant would have to establish that the "like" imported product has been afforded less favourable treatment than the domestic product (Howse and van Bork 2006). The jurisprudence is, for instance, applicable in measures relating to post-import environmental impacts. Measures to minimize overall impacts of a fuel throughout its lifecycle on global carbon emissions do not seem to interfere with local or domestic policies as it relates to global environmental problems (Howse and van Bork 2006).

In this respect, the prime requirement in almost all current initiatives to meet GHG or energy targets is the expectation that biofuels from developing countries will be able to meet these criteria. For example, case studies on the sustainability of ethanol production from sugarcane in São Paulo, Brazil, show that GHG emission reduction potentials of 80 percent can be achieved (Smeets et al. 2006). Under current practices in São Paulo state, GHG reduction levels of, for example, 30–50 percent (the reduction level used by Dutch government for criteria on GHG reduction) can be met easily, and a disadvantage in importing Brazilian ethanol products to European countries is therefore not likely. The feasibility of other criteria, such as labour circumstances, can differ largely on local scale and can be assessed only on a case-by-case basis.

The latter example also relates to the General Agreement on Tariffs and Trade (GATT), which states few exceptions that may justify *environment-related measures* on products and the use of necessary measures to ensure that these standards are met, even though they violate the general principles of GATT. These exceptions are justified when it is necessary to protect human, animal or plant life or health or if relating to conservation of exhaustible natural resources. This is if such measures are made effective in conjunction with restrictions on domestic production or consumption (Bauen et al. 2005). Air is considered to be an exhaustible resource, and the argument of adequate supply of sustainable biofuels within this context also has plausibility (Howse and van Bork 2006). Also stated in GATT is the "National Security Exception", which permits the taking of necessary measures in the protection of a country's national interest. It is acknowledged that energy security is a vital dimension of national security in general (Howse and van Bork 2006). No provisions exist within WTO agreements to link trade with social issues and labour standards, and any attempt to make such linkages has so far been met with opposition. However, the International Organization for Standardization (ISO) has established the Working Group on Social Responsibility, with the task of publishing the ISO26000 standard on guidelines for social responsibility in 2008 (Bauen et al. 2005).

The Code of Good Practice (Annex 3 of the TBT Agreement) provides disciplines for standardizing bodies, including those related to transparency, for preparing, adopting and applying standards (Wessels et al. 2001). Members should use international standards where appropriate, but the TBT Agreement does not require members to change their levels of protection as a result (Fritsche and Hunecke 2006). Based on previous concerns and debates in the 1990s regarding the use of the Code, especially with reference to voluntary eco-labelling schemes, it was agreed that there should be an open market for all certification schemes; no political action to diminish the trade of uncertified products; and no inclusion of the origin of the timber on the label in order to avoid discriminatory action against specific regions (FASE-ES and Carbon Trade Watch 2003).

5.3 Certification implications for development

There is a concern that biomass certification can become an obstacle to international trade and cause trade restrictions due to proposed sustainability criteria. For instance, measures to ensure conformity may act as powerful non-tariff barriers (especially for developing countries) if they impose costly, time-consuming tests (Zarrilli 2006). In addition, sustainability requirements for biofuel feedstocks may be stricter than those applying to the same crops used for food and feed markets (Cramer et al. 2007). A brief discussion of the main development issues related to biofuel sustainability certification follows.

Stakeholders' involvement

For successful implementation of a biofuels certification system, it is crucial that all concerned stakeholders are involved in the process of the development of sustainability certification and that a broad consensus about basic underlying principles is found. While expert judgement can flag the issues, alert the stakeholders to major concerns and provide methodologies for measuring, evaluating and monitoring the different aspects, experts should not unilaterally decide which sustainability criteria to include and how to prioritize them. Where strict specific criteria and indicators are difficult to establish because of differing opinions of stakeholders, the use of "process indicators" that show continuous improvement may help to facilitate progress. To a large extent, the judgement of local stakeholders, including primary processors and workers in the field, is crucial in order to account for local specific circumstances and needs that could affect, for instance, monitoring of the sustainability criteria (ProForest 2006). Stakeholders' involvement in ongoing certification initiatives is, however, still limited and often starts too late in the process (Ortiz 2006). The main reason for these participation failures is that the selection of consulted groups is often arbitrary, tending to include the most influential actors but neglecting local groups. Also, people without access to modern communication channels, such as people living in rural areas, are often not informed. Other limitations mentioned are the gap of "technical expertise" between certifiers or specialists and the local population and, in case questions or problems are raised, the lack of budget in the certification assessment to include more detailed studies (FASE-ES and Carbon Trade Watch 2003).

Costs of sustainability certification

Issues of cost and payment are critical to the success of sustainability certification, particularly when seeking participation of smaller-scale producers in developing countries (Worldwatch Institute 2006). In a brief review of the literature assessing cost ranges of existing certification systems, Van Dam et al. (2007) found that additional costs for complying with strict sustainability criteria can be substantial, in the range of 8–65 percent, although incidentally also a slight cost reduction was reported. Costs for the certification process itself and the chain of custody are, in the case of large-scale operations, much lower, in the range 0.1–1.2 percent; however, for small-scale farmers, this number may be much higher. Costs are strongly related to the scale of operation, the strictness of the sustainability criteria, the number of sustainability criteria and the expertise required to check them adequately.[10] For instance, Zarrilli (2006) mentions that developing countries have traditionally encountered difficulties in getting certificates issued by their domestic certification bodies and recognized by the importing countries. They often need to rely on expensive services provided by international certification companies.

In addition, many biomass types (especially non-pretreated, bulky biomass) already have a relatively low economic value. For example, in Finland, one lorry of forest chips (40 tonnes) residues is sold for about €800 at the power-plant gate. For such streams and small-scale production, extra costs for sustainability certification could potentially become prohibitive. Compliance with the biofuel sustainability certification should be feasible and should not result in high additional costs. It is recommended as much as possible to make a link with existing certification systems in order to limit administrative burdens and costs (Cramer Commission Report 2006).

Proliferation of certification schemes

Past experience shows that proliferation of different certification initiatives and the resulting confusion for consumers has hampered market efforts to develop meaningful sustainability certification systems in ecotourism, organic foods and even wood products. According to FASE-ES and Carbon Trade Watch (2003), for instance, the open market for FSC certification has transferred the responsibility for "combating environmental and social crime from governments to consumers faced with hundreds of eco-labels, the vast majority of which are a result of opportunistic product marketing". This competition has led some certifiers to apply in a vague and lax way the FSC-standards, such as including vague formulations that criteria have to be fulfilled «within a certain timeframe» after the certificate had been issued. This competition has led some certifiers to lax application of FSC-standards, such as including vague formulations that criteria have to be fulfilled "within a certain timeframe" after the certificate had been issued. This has resulted in negation of the possibilities of the system. FASE-ES and Carbon Trade Watch (2003) also mentions that certifiers often have commercial relationships through direct contracts with the certification client, which results in an interest of the certifiers in a positive assessment that weakens its objectivity. The Worldwatch Institute (2006) recommends that a proliferation of standards, differing from one country or region to another, has to be avoided through the promotion of an international harmonization of sustainability certification criteria and systems.

Sustainability criteria and indicators

While there is a growing consensus on the broad principles to be addressed by sustainability certification, there is less clarity and experience on how to translate these principles into operational criteria and indicators that can be cost-effectively verified on the ground. Despite their specificity, criteria and indicators should be flexible enough to be adapted to diverse regional conditions and circumstances. These should also be simple to enforce without generating high additional costs. Pilot studies are needed to generate experience in these issues. In addition, the development of new methodologies to measure particular impacts, particularly in regard to indirect land use (the so-called leakage effects), is highly recommended.

For a detailed discussion of the implementation issues related to sustainability criteria and indicators, see Worldwatch Institute (2006).

Monitoring and verification systems

Monitoring procedures and robust verification systems are needed in order to implement reliable and effective biofuel sustainability certification. Their establishment can be complex, however, due to the variety of energy feedstocks and production methods (monocultures, small scale, different crops), national context (legislation, stakeholders, national view on sustainability) and environmental vulnerabilities (drought, fire, soil) (Both Ends 2008). For instance, non-governmental organizations (NGOs) have indicated in several cases that the frequency of field visits is often too low, but if stricter monitoring is required, this will also have an impact on the costs and feasibility of verification (ProForest 2006). More insight is needed on compliance with monitoring and verification systems (Both Ends 2008). Project Group Sustainable Production Bio-mass (2006) recommend that a biomass certification system must be based on a track-and-trace system, in which the traceability of biomass is guaranteed. However, the guarantee of complete traceability in the short term can be difficult, making transition periods necessary.

Needs of small producers

Smallholders, often operating with limited resources and technical skills, may lack the capacity, including knowledge and financial resources, to implement necessary changes required for transition to sustainability certification (ProForest 2006). The changes may be, without transition periods, too complicated for smaller companies. There is a risk that only larger producers can fulfil these new demands in a short time, which involves a risk for market disturbance as only a few producers can offer certified feedstock resulting in artificial high prices (Maris 2006). Using existing agriculture certification systems in the development of a specific biofuels certification system, at least for the short term, may be a strategy to promote the involvement of smaller producers. While existing systems may not cover all the required criteria, this could limit the risk for market disturbance. Including extra criteria in a certification system can then be achieved over a longer period by mutual consultation (Maris 2006). It is recommended to pair a certification scheme with assistance and incentives (Worldwatch Institute 2006) and to look for possibilities for group certification to guarantee that small producers are not excluded (Cramer et al. 2007).

Indirect environmental and social impacts

Sustainability certification systems generally focus their scope on specific biofuels production projects and do not capture wider macroeconomic impacts and associated environmental and social impacts. Addressing the latter usually requires national and regional land-use planning, which is often missing in producing countries. In addition, although legislation might be in place, a weak enforcement system may remain a problem. For instance, Smeets et al. (2006) mention in a study on the sustainability of Brazilian bioethanol that environmental and land-use legislation and regulations often lack effective implementation and enforcement. Council for Regulatory Environmental Modeling (2006) also acknowledge this issue and mention that a lack of land-use planning can increase risks for local food security and leakage effects. Lack of land certification is another concern, limiting the position of local communities. As well as sustainability certification, additional measures at international and national level will be required, both to support the costs of effective enforcement of environmental regulations and to provide financial incentives for promoting forest and biodiversity conservation programmes and activities.

6. CONCLUSIONS AND RECOMMENDATIONS

Extensive analysis has been completed in recent years on the technological, environmental and social aspects of biofuel production and trade. This paper aimed to provide a short overview of existing analyses, with a view to identifying the potential opportunities and limitations associated with large-scale biofuel production and drawing out relevant lessons for policymakers, businesses and civil society. This study concludes that, if developed correctly, biofuels have the potential to help diversify energy resources and reduce overall GHG emissions associated with transportation. Alternatively, if not developed correctly, they could intensify the threat of global climate change and result in significant social impacts. As a result, the sustainable development benefits of biofuels are neither intrinsic nor automatic but depend on the timing and framing of their development and on the overall policy and financial incentives. The analysis leads to the following conclusions:

- *Long-term sustainable potential of bioenergy and biofuel production is uncertain and requires further analysis.* In theory, the technical biomass potential could be large enough to supply between one-third and two times the current global energy demand by 2050 without competing with food production. In practice, however, to what extent and how rapidly humanity can realize this potential is uncertain, as it would require major efforts such as a significant improvement in agriculture efficiency in developing countries, including livestock production and optimal integration of biomass and food production systems. More research is needed on the interactions between different land uses such as bioenergy, food and materials production – i.e. of competition for resources and of synergies between different uses. This would improve the understanding of what is a socially and environmentally sound threshold for biofuel use.

- *First-generation biofuels produced in temperate regions (the EU, North America) offer lower carbon and environmental benefits.* Research on net carbon emissions is far from conclusive, and estimates vary widely, in part due to different methodological assumptions for energy sources used for processing and treatment of co-production. Although they have improved in recent decades, grain-based biofuels produced in Europe and North America often offer low GHG gains, have negative impacts on water, soil and biodiversity, and remain expensive compared with gasoline and diesel, even at high oil prices. Furthermore, they can only be produced on higher-quality farmland in direct competition with food production. Sugarcane-based ethanol production and to a certain extent palm oil and jathropha oilseeds are notable exceptions to this given their high production efficiencies and lower costs. However, land-use change, and in particular deforestation, to allow for tropical biofuel cultivation can make a significant difference in lifecycle GHG emissions, and in the worst cases can negate GHG savings. Research is therefore needed to improve data on GHG fluxes from land-use change, which today can be very uncertain. There is also a need to harmonize GHG methodologies for transport fuels and to fill gaps in the existing body of lifecycle studies. More analyses that cover the range of biofuel feedstocks and pathways relevant to developing countries are needed (e.g. including biodiesel from palm oil or jathropha).

- *Risks of indirect land-use change are poorly understood but can be significant and should be incorporated into estimates of GHG emissions.* As well as direct land-use impacts, increased biofuel cultivation can lead to indirect land-use changes with negative climate and environmental impacts. For instance, biofuels could displace agriculture or livestock production so there is land-use change elsewhere to accommodate the lost food or cattle production. Indirect land-use changes, also called "leakage effects", with resulting loss of carbon-rich habitats, could partially or totally negate the climate benefits gained through biofuel use. Leakage in the context of biomass trade could entail an unwanted shift of activities from the area of biofuel consumption to another area where it leads to negative effects on the environment. There is a need for clear guidance on how the risks of indirect land-use change can be assessed and how they may be incorporated into estimates of GHG savings in order to attain a more accurate picture of the full impacts of biofuel production on the global climate.

- *The development of second-generation biofuels is required to maximize environmental and social benefits.* In the future, next-generation technologies –advanced cellulosic technologies, in particular – offer the potential to maximize energy and GHG benefits and to reduce the risk of competition with food production. Assuming oil prices remain high, it will be possible to achieve negative CO_2-abatement costs in the process, while also providing a host of other environmental and social benefits. Government policies should focus on commercializing these advanced technologies and driving down their costs as rapidly as possible in those cases in which they appear to be efficient and sustainable in the long term. The use of energy feedstocks such as jathropha could minimize potential conflicts between food and feed production, as these non-edible crops are not in direct competition with food uses and can be produced on land unsuitable for conventional food crops.

- *Sustainability certification of biofuels is a critical tool to deliver sustainable development benefits.* As biofuels are increasingly promoted around the world as part of national and regional sustainable development strategies, sustainability standards and certification regulations need to be developed that include criteria for reducing GHG emissions and promoting environmentally and socially sound production methods. Certification should be developed through an open, transparent and non-discriminatory process, taking into account local conditions in which all concerned stakeholders are represented effectively. Support is needed to improve small-scale producer capacity to play an active role in the development of biofuel certification, particularly producers from developing countries. In addition, incentives supporting biofuel development should be proportional to the actual environmental and social benefits. Among the policies reviewed, applying technology-neutral "low-carbon standards" may result in more energy and environmental gains than simple renewable fuel mandates and could help to promote the development of more efficient second-generation biofuel technology.

- *Sustainable trade of biofuel should be promoted through a reduction of tariff and non-tariff barriers.* While there is a great potential for sustainable trade between industrialized and developing countries, this is currently limited by tariff and non-tariff barriers. If trade is restricted or made more expensive by tariffs, then the utilization of resources will be economically unprofitable, leading to higher costs for society as a whole and to higher prices for consumers. The Doha Round should provide a unique opportunity to deliver tariff cuts for sustainably produced biofuels. Meanwhile, the adoption and application of sustainability certification to the production of biofuels should not create new non-tariff barriers.

GLOSSARY

Anaerobic digestion: The breakdown of organic matter under conditions of low air or oxygen supply.

Atomization: The conversion of a vaporized sample into atomic components.

Biodiesel: Fuel derived from biological sources that can be used instead of petroleum-derived diesel in diesel engines. Biodiesel is created through the process of transesterification.

Biodiversity: The full range of natural variety and variability within and among living organisms, as well as the ecological and environmental complexes in which they occur. It encompasses multiple levels of organization, including genes, species, communities and ecosystems.

Bioenergy: Energy derived from any biological material that can be used as fuel. This fuel is burned or converted in systems that produce heat, electricity and power.

Bioethanol: Alcohol biofuel produced by yeast fermentation and distillation of starch or sugar crops found in corn, sugar beet and sugarcane.

Biofuel: Fuel made from renewable biological sources, including ethanol, methanol and biodiesel. Common biofuel sources are corn, soybeans, flaxseed, rapeseed, sugarcane, palm oil and rice.

Biomass: Plant material such as wood, grains, agricultural waste and vegetation that can be used as an energy source.

Biomass gasification combined cycle (BIG-CC): Process in which biomass is converted into gas for use as a fuel. Studies are currently being conducted to see how BIG-CC can be used more feasibly and reliably in alternative power plants.

Biomass to liquid (BTL): A multistep process that creates liquid biofuels from biomass. Three current BTL processes include the Fischer–Tropsch process, pyrolysis and catalytic depolymerization, which uses heat and catalysts to separate diesel from organic waste.

Carbon sequestration: The capture and storage of carbon that prevents it from being released into the atmosphere. Carbon sequestration usually occurs in carbon sinks, reservoirs that absorb carbon dioxide and sequester it from the atmosphere.

Catalyst: Substance that increases the rate of a chemical reaction without being consumed or produced by the reaction.

Cellulose: Complex carbohydrate polymer commonly found in plant cell walls.

Cellulosic ethanol: Ethanol fuel produced from cellulose. It requires an extra processing step of cellulosis, which breaks down cellulose into sugars.

Circulating fluidized bed (CFB): A bed of small solid particles suspended and kept in motion by an upward flow of a fluid or gas. The bed is continuously renewed by circulating solids with a gas stream in a controlled way. CFBs generally have high capacity and efficiency.

Co-generation: An energy system that consumes a fuel to produce electricity and thermal energy in the form of steam or hot air.

Combined heat and power (CHP): A form of energy generation in which the waste heat from electricity generation is passed through a second cycle to extract further energy from the heat.

Digestor: Instrument that breaks down organic material into sugar in the process of digestion.

Dimethyl ether (DME): Colourless gaseous ether commonly used as an aerosol spray propellant and in conjunction with propane to lower temperature to –60°C.

Dry distillers' grains with solubles (DDGS): By-product from which bioethanol can be produced. DDGS can be fed to cattle to replace protein supplement and corn.

Energy balance: The difference between the energy produced by 1 kg of fuel (e.g. biodiesel, petroleum, uranium) and the energy needed to produce it (e.g. extraction, transportation, refining).

Ester: Compound formed from the reaction between an acid and an alcohol. In esters of carboxylic acids, the –COOH group of the acid and the –OH group of the alcohol create a –COO– linkage.

Esterification: The chemical process of combining an acid and an alcohol to form an ester.

Ethyl tertiary butyl ester (ETBE): A bioethanol-based gasoline component designed to enhance combustion and reduce exhaust emissions.

Evapotranspiration: The combination of evaporation from free water surfaces and the transpiration of water from plant surfaces to the atmosphere.

Exajoules (EJ): 1018 joules. The joule is the SI (Système International) unit of energy measuring heat, electricity and mechanical work.

Fatty acid methyl ester (FAME): Ester created by an alkali-catalysed reaction between fats or fatty acids and methanol. The molecules in biodiesel are primarily FAMEs, usually obtained from vegetable oils by transesterification.

Fischer-Tropsch (FT) process: A catalysed chemical reaction in which synthesis gas is converted into liquid hydrocarbons. The process produces biodiesel from natural gas and syngas or from gasified coal or biomass.

FT diesel: Diesel made using the Fischer–Tropsch process.

Gasification: The conversion of solid material such as coal into a gas for use as a fuel.

Gasohol: A mixture of gasoline and ethanol derived from fermented agricultural products containing at least 9 percent ethanol.

Glycerine: The liquid by-product of biodiesel production. It is used in the manufacture of dynamite, cosmetics, liquid soaps, inks and lubricants.

Hemicellulose: A carbohydrate polysaccharide that is similar to cellulose and found in the cell walls of many plants.

Hydrolysis: The decomposition of organic compounds by an interaction with water.

Lignin: Energy-rich material contained in biomass that can be used for boiler fuel.

Lignocellulose: The bulk of plant material, consisting principally of lignin, cellulose, hemicellulose and extractives.

Liquefaction: Converting coal into synthetic liquid fuel similar in nature to crude oil or refined products such as gasoline.

Methyl tertiary butyl ether or Methyl tert-butyl ether (MTBE): An ether compound added to gasoline to provide oxygen and enhance complete combustion. It is currently being phased out of California's gasoline.

Municipal solid waste (MSW): Solid waste generated by householders, commercial establishments, industrial offices and canteens not regulated as a residual or hazardous waste.

Oxygenate: A gasoline fuel additive containing hydrogen, carbon and oxygen. The oxygen content promotes more complete combustion of gasoline, which reduces tailpipe emissions of carbon monoxide.

Petajoule (PJ): 1015 joules. The joule is the SI (Système International) unit of energy measuring heat, electricity and mechanical work.

Pyrolysis: One method of converting biomass into biodiesel through the use of heat.

Rape methyl ester (RME): A suitable substitute for mineral diesel in existing compression-ignition engines. It is an alternative transport fuel made from rapeseed oil.

Saccharification: The process of converting a complex carbohydrate such as starch or cellulose into fermentable sugars such as glucose or maltose.

Second-generation biofuels: Biofuels produced from biomass or non-edible feedstock. The definitions for this term vary.

Short-rotation coppice (SRC): An energy crop whose woody solid biomass is used in applications such as heating and electric power.

Straight vegetable oils (SVO) or pure plant oil (PPO): Pure vegetable oil, as opposed to waste vegetable oil, used to fuel diesel engines. It is not a by-product of other industries and therefore its prospects for fuel use are not limited by the capacity of other industries.

Syngas: A mixture of carbon monoxide (CO) and hydrogen (H_2). It is the product of high-temperature gasification of organic material such as biomass and can be used to synthesize organic molecules such as synthetic natural gas or liquid biofuels such as synthetic diesel (via the Fischer–Tropsch synthesis process).

Tail Oil: A dark, odorous liquid that is a by product from the sulfate process of paper and pulp manufacturing

Tonne of oil equivalent (toe): Amount of energy released by burning one tonne of crude oil, approximately 42 GJ.

Transesterification: Process to prepare vegetable oil into diesel fuel, which mixes methanol (50 percent excess) and sodium hydroxide (100 percent excess) with the vegetable oil. Removing the glycerol yields the biodiesel and a mixture of methylated fatty acids and methanol.

Waste vegetable oil (WVO): Oil that is left over after the frying of food and other uses. It is used as a feedstock for the production of biodiesel and competes with some already established uses.

SOURCES

BiobasedNew.com. Glossary of Terms. http://www.biobasednews.com/glossary/10.

Biodiesel International. Biodiesel Glossary. http://www.biofuels-news.com/

Earth 911. Product Stewardship Glossary. http://earth911.org/product-stewardship/

Ethanol: Fueling America's Future. Glossary. http://www.drivingethanol.org/

IGreenHouse. Carbon Market Glossary. http://www.igreenhouse.com.au/?page_id=12.

Nordic Pure: AC and Furnace Filters. Glossary. www.nordicpure.com

National Safety Council. Environmental Health Center: Glossary. http://california.nsc.org

Stanford University. Electrical Technical Glossary. www.stanford.edu/group/Power-Systems/

NOTES

1. This section is based largely on the "Biofuel" section of the World Energy Outlook (IEA 2006).

2. Good statistics on the global international trade in biofuels are not yet available. Although for some markets (pellets, ethanol) separate overviews exist, no comprehensive overview is available on global biomass trade. Such an overview, however, is deemed highly relevant for market actors and policymakers. Determining international traded biofuel volumes is difficult for a number of reasons. First, many biomass streams are traded for material purposes, but they end up in energy production. Second, biomass streams can have several final applications, for example palm oil (feedstock for biodiesel or for food applications) or ethanol (as transportation fuel or as feedstock for the chemical industry). Third, some biomass fuels such as wood pellets and bio-ETBE are recorded in aggregated form by foreign trade statistics; for example, wood pellets are recorded under the same code with wood waste in the EU's trade statistics, thus making it difficult to asses the volume.

3. Data about fuel ethanol trade are imprecise due to various potential uses of ethanol (fuel, industrial or beverage use) and also because of the lack of proper codes for biofuels in the (HS) System (UNCTAD 2006).

4. Fuel ethanol is traded under HS code 2207, which covers denatured and undenatured alcohol. Both can be used as fuel ethanol, but denatured ethanol is often used as a solvent (UNCTAD 2006); in this case a material (the removal of which is expensive) is added to ethanol to make it undrinkable (Rosillo-Calle and Walter 2006). From the 6 Gl of ethanol traded in 2005, 4.7 Gl (almost 80 percent) corresponded to undenatured ethanol with at least 80° strength (F.O. Licht 2006). Trade of denatured ethanol, which corresponded to 20 percent of the traded volume in 2005, remained basically unchanged during the period 2000–04 (UNCTAD 2006). Based on F.O. Licht (2006) data, it is possible to identify the origin of 5.5 Gl exported in 2005 and the destination of 4.5 Gl imported (roughly 92 percent and 75 percent of the volume traded, respectively).

5. Larger biodiesel production is due to the deficit in EU diesel production, a direct consequence of the ongoing shift of the EU car fleet from petrol to diesel.

6. In contrast, increased ethanol production results in more production and lower prices of corn by-products. Soybean meal prices are reduced by 10 percent.

7. Potential savings from averted petroleum and diesel imports, valued at around €1.08 billion (US$1.3 billion), would be offset by losses in livestock exports valued at around €1.74 billion (US$2.1 billion). They would also be offset by the additional cost of importing grain to make up for diverted feedstock, estimated at €314.2 million (US$380 million).

8. This chapter draws extensively from van Dam (2006).

9. How this jurisprudence applies to biofuels and related feedstock is still an open debate, as the jurisprudence is looked at on a case-by-case basis. A specific characteristic of the Asbestos Case is that it showed a physical difference between products, as the presence of asbestos can cause cancer (health aspect).

10. Sustainability certification could result in two types of additional cost: First, the extra costs associated with meeting sustainability criteria for the production and transport of biomass (e.g. measures against soil erosion or an additional wastewater treatment facility); second, costs for monitoring the compliance with the sustainability criteria and the physical traceability of the product, including for instance the costs of field studies by a certifier or sampling the energy feedstock during loading and unloading.

REFERENCES

Bauen, A., Howes, J., Chase, A., Woods, J., Tipper, R., Inkinen, A., Lovell, J. (2005). "Feasibility Study on Certification for a Renewable Transport Fuel Obligation", ECCM 80, final report, E4Tech, Imperial College London, London, UK.

Becker, K., Francis, G. (2003). "Jatropha Plantations on Degraded Land", working paper, Workgroup Multifunctional Plants – Food, Feed, Industrial Products, University of Hohenheim, Hohenheim, Germany.

Borjesson, P. (1999). "Environmental Effects of Energy Crop Cultivation in Sweden", Biomass and Bioenergy 16: 137–170.

Both ENDS (2008). "Agrofuels and Land Distribution: Towards a Rights Based Approach to Food Security", Both ENDS Policy Note, Amsterdam, the Netherlands.

Childs, B., Bradley, R., in conjunction with Goldman Sachs, Center for Environmental Markets (2007). "Plants at the Pump: Biofuels, Climate Change, and Sustainability", World Resources Institute (WRI), Washington, DC, USA.

Cornland, D., Johnson, F. X., Yamba, F., Chidumayo, E.N., Morales, M., Kalumiana, O., Chidumayo, S.B.M. (2001). "Sugarcane Resources for Sustainable Development: A Case Study in Luena, Zambia", Stockholm Environment Institute, Stockholm, Sweden.

Council for Regulatory Environmental Modeling (2006). "Dutch Import of Biomass-Producing Countries' Point of View on the Sustainability of Biomass Exports", Council for Regulatory Environmental Modeling (CREM) report no. 06.885. BothENDS, Stichting Natuur en Milieu, COS Nederland, Núcleo Amigos da Terra (NAT), Vitae Civilis Institute, Biodiversity Foundation Kehati, Sawit Watch, Social Economic Institute (INRISE), Bogor Agricultural University, Media Indonesia Group-Daily Research and Development, Gwynne Foster CREM BV, Amsterdam, the Netherlands.

Cramer Commission Report (2006). London, UK.

Cramer, J., Wissema, E., de Bruijne, M., Lammers, E., Dijk, D., Jager, H., van Bennekom, S., Breunesse, E., Horster, R., van Leenders, C., Wonink, S., Wolters, W., Kip, H., Stam, H., Faaij, A., Kwant, K., Hamelinck, C., van den Heuvel, E., DehuE, B., Bergsma, G., Croezen, H., Kampman, B., Vroonhof, J., Junginger, M., Smeets, E., Dornburg, V., Maris, J., Prose, M., Joost Kessler, J., Sielhorst, S. (2007). "Eindrapport van de projectgroep 'Duurzame productie van biomassa'", Ministerie van Economische Zaken (Dutch Ministry of Economic Affairs), The Hage, the Netherlands, March 2007.

Dahl, J., Broechner-Andersen, M., Hanh, B., Vinterbäck, J., Erkkilä, A., Grecka, K. (2005). "Wood Pellets: A Growing Market in Europe", 14th European Biomass Conference, 17–21 October 2005, Paris, France.

Damen, K. (2001). "Future Prospects for Biofuel Production in Brazil: A Chain Analysis Comparison of Ethanol from Sugarcane and Methanol from

Dehue, B., Meyer, S., Hamelinck, C. (2007). " Towards a Harmonised Sustainable Biomass Certification Scheme", ECOFYS, Utrecht, the Netherlands.

Delucchi, M.A. (2003). "A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials", Institute of Transportation Studies, University of California, Davis, CA, USA.

Delucchi, M.A. (2005). "A Multi-Country Analysis of Lifecycle Emissions from Transportation Fuels and Motor Vehicles", Institute of Transportation Studies, University of California, Davis, CA, USA, www.its.ucdavis.edu/publications/2005/UCD-ITS-RR-05-10.pdf.

Dufey, A. (2006). "Biofuels Production, Trade and Sustainable Development: Emerging Issues", International Institute for Environment and Development (IIED), London, UK.

EC (2006). "Communication from the Commission: An EU Strategy for Biofuels", COM(2006)34 final, no. 28, European Commission, Brussels, Belgium.

European Council for Automotive R&D (EUCAR), Conservation of Clean Air and Water in Europe (CONCAWE), European Commission Joint Research Centre (JRC) (2006). "Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context", A joint study by EUCAR, CONCAWE and JRC, version 2b.

EurOberv'ER (2007). "State of Renewable Energies in Europe", 7e Report, EurObserv'ER. In the scope of "EurObserv'ER" Project which groups together Observ'ER, Eurec Agency, Erec, Eufores, Institut Jozef Stefan, with the participation of IEO/EC BREC. Paris, France.

Faaij, A., Domac, J. (2006). "Emerging International Bio-Energy Markets and Opportunities for Socio-Economic Development", Energy for Sustainable Development X(1): 7–19.

Faaij, A., Hamelinck, C. (2002). "Long Term Perspectives for Production of Fuels from Biomass: Integrated Assessment and RD&D Priorities", 12th European Conference on Biomass for Energy, Industry and Climate Protection, 17–21 June 2002, Amsterdam, the Netherlands.

Faaij, A., Meuleman, B., Turkenburg, W., van Wijk, A., Bauen, A., Rosillo-Calle, F., Hall, D. (1998). "Externalities of Biomass Based Electricity Production Compared to Power Generation from Coal in the Netherlands", Biomass and Bioenergy 14(2): 125–147.

FAOSTAT (2006). Food and Agriculture Organization of the United Nations, http://faostat.fao.org/

Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P. (2008). "Land Clearing and the Biofuel Carbon Debt", Science 319: 1235–1238.

Farrell, A.E., Plevin, R.J., Turner, B.T., Jones, A.D., O'Hare, M., Kammen, D.M. (2006). "Ethanol Can Contribute to Energy and Environmental Goals", Science 311(5760): 506–508.

FASE-ES and Carbon Trade Watch, Transnational Institute (2003). "Where the trees are a desert - Stories from the ground", FASE-ES, TNI, Amsterdam, the Netherlands.

Fischer, G., Schrattenholzer, L. (2001). "Global Bioenergy Potentials through 2050", Biomass and Bioenergy 20(3): 151–159.

F.O. Licht (2006). Licht's World Ethanol and Biofuels Report. Vol.4, Tunbridge, Wells, UK.

Food and Agricultural Organization (FAO) (2008). "Crop Prospects and Food Situation", Food and Agricultural Organization, Rome, Italy, www.fao.org/docrep/010/ai465e/ai465e00.htm.

Fritsche, U., Hunecke, K. (2006). "Sustainability Standards for Bioenergy", Oko institut, Darmstadt, Germany, commissioned by WWF Germany.

Fulton, L., International Energy Agency (IEA) (2004). "Biofuels for Transport: An International Perspective", Office of Energy Efficiency, Technology and R&D, OECD/IEA, Paris, France.

Global Bioenergy Partnership (GBEP) (2007). "A Review of the Current State of Bioenergy Development in G8 + 5 countries", Global Bioenergy Partnership, Food and Agriculture Organization (FAO), Rome, Italy, ftp://ftp.fao.org/docrep/fao/010/a1348e/a1348e00.pdf.

Global Subsidies Initiative (2007). "Biofuels: At What Cost? Government support for ethanol and biodiesel in selected OECD countries", International Institute for Sustainable Development (IISD), Winnipeg, Canada.

Hamelinck, C.N., Faaij, A., (2006). "Outlook for Advanced Biofuels", Energy Policy 34(17): 3268–3328. Elsevier, St.Louis, USA.

Hamelinck, C.N., Van Hooijdonk, G., Faaij, A., (2006). "Ethanol from Lignocellulosic Biomass : Techno-Economic Performance in Short-, Middle-, and Long-term", Biomass and Bioenergy, 28(4): 384-410.

Hansson, J., Berndes, G., (2006). "The Prospects for Large-Scale Import of Biomass and Biofuels into Sweden: A Review of Critical Issues", Energy for Sustainable Development X(1): 82–94.

Hamelinck, C.N., Voogt, M., Joosen, S., de Jager, D., Palmers, G., Shaw, S., Cremer, C. (2002). "PRETIR, Implementation of Renewable Energy in the European Union until 2010", report executed within the framework of the ALTENER programme of the European Commission, DG-TREN, ECOFYS BV, 3E, Fraunhofer-ISI, Utrecht, the Netherlands.

Haverkamp, J. and Parker, L. (2007). Governments must act to boost trade in biofuels. Bioenergy Business. Found online on 13.03.2008 at URL: www.bioenergybusiness.com/index.cfm?section=features&action=view&id=10786

Hazell, P.P.R.K. (2006). "Bioenergy and Agriculture: Promises and Challenges", the International Food Policy Research Institute (IFPRI), Washington, DC, USA.

Hoogwijk, M. (2004). "On the Global and Regional Potential of Renewable Energy Sources", Copernicus Institute, Utrecht University, Utrecht, the Netherlands.

Hoogwijk, M., Faaij, A., van den Broek, R., Berndes, G., Gielen, D., Turkenburg, W. (2003). "Exploration of the Ranges of the Global Potential of Biomass for Energy", Biomass and Bioenergy 25(2): 119–133.

Hoogwijk, M., Faaij, A., Eickhout, B., de Vries, B., Turkenburg, W. (2005). "Potential of Biomass Energy out to 2100, for Four IPCC SRES Land-Use Scenarios", Biomass and Bioenergy 29(4): 225–257.

Hoogwijk, M., Faaij, A., de Vries, B., Turkenburg, W. (2008). "Global Potential of Biomass for Energy from Energy Crops under Four GHG Emission Scenarios, Part B: The Economic Potential", Biomass and Bioenergy, in press.

Howse, R., van Bork, P. (2006). "WTO Disciplines and Biofuels: Opportunities and Constraints in the creation of a Global Marketplace", IPC discussion paper. International Food and Agricultural Trade Policy Council, Washington, DC, USA.

Indexmundi (2006). "Online Database: Agricultural Commodities - Production, Consumption, Exports, and Imports", Retrieved: 21 July 2006 from www.indexmundi.com/en/commodities/agricultural/.

Intergovernmental Panel on Climate Change (IPCC) (2000). IPCC Special Report on Emission Scenarios. Intergovernmental Panel on Climate Change. A Special Report of IPCC Working Group III. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC) (2007). "Climate Change 2007: Mitigation", in Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A.

International Energy Agency (IEA) (2006). "World Energy Outlook 2006", OECD/IEA, Paris, France.

International Energy Agency (IEA) (2007). "Biofuels Production", IEA, Energy Technology Essentials 2, Paris, France.

International Food and Agricultural Trade Policy Council (2006). "Summary of Rationale and Main Legal Points Raised in October 2006 IPC Discussion Paper, 'WTO Disciplines and Biofuels: Opportunities and Constraints in the Creation of a Global Marketplace'", IATP, Washington D.C., USA.

International Union for the Conservation of Nature (IUCN) (2007). "Gender and Bioenergy". IUCN, Gland, Switzerland. www.genderandenvironment.org/admin/admin_biblioteca/documentos/Factsheet%20 BioEnergy.pdf.

Italian Ministry for the Environment and Territory, Imperial College London, Itabia, E4tech (2005). "Global Bioenergy Partnership: White Paper", Global Bioenergy Partnership, Rome, Italy, www.globalbioenergy.org/fileadmin/user_upload/docs/WhitePaper-GBEP.pdf.

Johnson, F., Seebaluck, V., Watson, H., Woods, J. (2006). "Bio-Ethanol from Sugarcane and Sweet Sorghum in Southern Africa: Agro-Industrial Development, Import Substitution and Export Diversification", in Linking Trade, Climate Change and Energy. International Centre for Trade and Sustainable Development (ICTSD), Geneva, Switzerland.

Jönsson, M. (2007). "Trade Aspects of the Biofuels Sector", report no. 119-0109-2007. Swedish National Board of Trade, Stockholm, Sweden.

Junginger, M., Faaij, A., Koopmans, A., van den Broek, R., and Hulscher, W., (2001). "Setting Up Fuel Supply Strategies for Large Scale Bio-energy Projects – A Methodology for Developing Countries", Biomass and Bioenergy 21(4): 259-275.

Junginger, M., Faaij, A. (2006). "Sustainable International Bioenergy Trade: Securing Supply and Demand", IEA Bioenergy Task 40. International Energy Agency, Paris, France.

Kaltner, F., Azevedo, G., Campos, I., Mundim, A. (2005). "Liquid Biofuels for Transportation in Brazil: Potential and Implications for Sustainable Agriculture and Energy in the 21st Century", Fundação Brasileira para o Desenvolvimento Sustentável, Rio de Janeiro, Brazil.

Kaltschmitt, M., Reinhardt G.A., Stelzer T. (1996). "LCA of Biofuels under Different Environmental Aspects", Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), University of Stuttgart, Stuttgart, Germany.

Koplow D. (2006). "Biofuels—at What Cost? Government Support for Ethanol and Biodiesel in the United States", Global Subsidies Initiative of the International Institute for Sustainable Development (IISD), Geneva, Switzerland.

Larson, E.D. (2005). "A Review of LCA Studies on Liquid Biofuel Systems for the Transport Sector", in Energy for Sustainable Development, 10 (2): 109-126, 2006.

Lobe, J. (2007). "Promise of Biofuels Boom is Overrated, Report Says", IPS News, 25 October 2007.

Macedo, I.D.C., Leal, M.R.L.V., Da Silva, J.E.A.R. (2004). "Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil". Secretariat of the Environment of the State of São Paulo, Brazil, www.unica.com.br/i_pages/files/pdf_ingles.pdf.

Maris (2006). Personal communication with J. Maris, Control Unions, about status GGL system and possible implications for the implementation of a biomass certification system.

Nakicenovic, N., Grubler, A., McDonald, A. (eds.) (1998). "Global Energy Perspectives". Cambridge University, Cambridge, UK.

Nastari, P. (2005). "1975–2005/Etanol Combustível Balanço e Perspectivas: Tendências para o Uso de Etanol – 'Etanol Combustível: Balanço e Perspectivas'".

National Development and Reform Commission (2007). "The Outline of the Eleventh Five-Year Plan for National and Economic Social Development of the People's Republic of China", Beijing, China, http://en.ndrc.gov.cn/hot/t20060529_71334.htm.

Organisation for Economic Co-Operation and Development (OECD) and Food and Agriculture Organization (FAO) (2007). "Agricultural Outlook 2007–2016", OECD, Paris, France and FAO, Rome, Italy.

Oxfam International (2008). "Another Inconvenient Truth: How Biofuel Policies are Deepening Poverty and Accelerating Climate Change", briefing paper, Oxfam International, Oxford, UK.

Pimentel, D. (1991). "Ethanol Fuels: Energy Security, Economics, and the Environment", Journal of Agricultural and Environmental Ethics 4: 1–13.

Pimentel, D. (2001). "The Limitations of Biomass Energy", in Encyclopedia of Physical Science and Technology, Academic Press, San Diego, USA : 159-171.

Pimentel, D., Patzek, T.W. (2005). "Ethanol Production Using Corn, Switchgrass, and Wood: Biodiesel Production Using Soybean and Sunflower", Natural Resources Research 14(1): 65-75.

ProForest (2006). "Developing a Mechanism for Palm Oil Traceability from Plantation to End User, Annex 6 Draft Chain of Custody Procedures for Pilot Testing". Proforest commended by the Rountable on Sustainable Palm Oil (RSPO), Oxford, UK.

Project Group Sustainable Production Bio-mass (2006). "Criteria for Sustainable Bio-mass Production". Final Report. The Netherlands.

Quirin, M., Gärtner, S.O., Pehnt, M., Reinhardt, G.A. (2004). "CO2 Mitigation through Biofuels in the Transport Sector, Status and Perspectives, Main Report". Institute for Energy and Environmental Research, Heidelberg, Germany, www.ufop.de/downloads/FVV_IFEU_Study_engl.pdf; www.ifeu.org/landwirtschaft/pdf/co2mitigation.pdf.

REN21 (2008). "Renewables 2007 Global Status Report". Renewable Energy Policy Network for the 21st Century Secretariat, Paris, France and Worldwatch Institute, Washington D.C, USA.

REN21 (2007). "Renewables 2008, Global Status Report". Renewable Energy Policy Network for the 21st Century Secretariat, Paris, France, Worldwatch Institute, Washington, DC, USA.

Renewable Fuels Association (2008). "Ethanol Facts: Trade." Renewable Fuels Association Resource Center. www.ethanolrfa.org/resource/facts/trade/.

Rodrigues, D., Ortiz, L., (2006). "Case Study Sugar Can Ethanol from Brazil: Sustainability of Ethanol from Brazil in the Context of Demanded Biofuels Imports by the Netherlands". Friends of the Earth, London, UK.

Rogner, H.H. (2000). "Chapter 5, Energy Resources", in World Energy Assessment: Energy and the Challenge of Sustainability, Goldemberg, J. (ed.), United Nations Development Programme (UNDP), United Nations Department of Economic and Social Affairs (UN-DESA) and World Energy Council (WEC), New York, USA.

Rosillo-Calle, F., Walter, A. (2006). "Global Market for Bioethanol: Historical Trends and Future Prospects", Energy for Sustainable Development X(1): 20–32.

Rossi, A., Lambrou, Y. (2008). "Gender and Equity Issues in Liquid Biofuels Production: Minimizing the Risks to Maximize the Opportunities". Food and Agriculture Organization, Rome, Italy.

Roundtable on Responsible Soy (RTRS) (2006). "Objectives and background of the Roundtable on Responsible Soy", Buenos Aires, Argentina, www.responsiblesoy.org/eng/index.htm.

Smeets, E., Junginger, M., Faaij, A., Walter A.C., Dolzan, P., (2006). "Sustainability of Brazilian Bio-ethanol", Universiteit Utrecht Copernicus Institute, Department of Science, Technology and Society and University of Campinas, the Netherlands.

Smeets, E., Faaij, A. (2007). "Bioenergy Potentials from Forestry to 2050: An Assessment of the Drivers that Determine the Potentials", Climatic Change 81: 353–390.

Smeets, E., Junginger, M.W., Faaij, A., Lewandowski, I., Turkenburg, W. (2007). "A Quickscan of Global Bio-Energy Potentials to 2050", Progress in Energy and Combustion Science 33(1): 56–106.

Swaan (2006). "Presentation on BioEnergy Opportunities 2006, Technology Trade Mission", Follow-up Workshop on "Wood pellets".

UK Department of Trade and Industry (DTI) (2003). "Technology Status Review and Carbon Abatement Potential of Renewable Transport Fuels in the UK", report B/U2/00785/REP. Department of Trade and Industry, London, UK.

United Nations Conference on Trade and Development (UNCTAD) (2006). "The Emerging Biofuels Market: Regulatory, Trade and Development Implications", Geneva, Switzerland, New York, USA.

United Nations Department of Economic and Social Affairs (UNDESA) (2007). "Small-Scale Production and Use of Liquid Biofuels in Sub-Saharan Africa: Perspectives for Sustainable Development", UNDESA, New York, USA.

Upton, S. (2006). "Press Release: Biofuels – At What Cost?", Global Subsidies Initiative, International Institute for Sustainable Development (IISD), Winnipeg, Canada, 25 October 2006, www.iisd.org/media/2006/oct_25_2006.asp on 19 August 2008.

US Department of Agriculture USDA (2007). "Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?", report for the Economic Research Service, US Department of Agriculture, May 2007. www.ers.usda.gov/Publications/FDS/2007/05May/FDS07D01/fds07D01.pdf.

van den Broek R., (2000). "Sustainability of Biomass Electricity Systems" (PhD thesis), Utrecht University, Department of Science Technology and Society, Utrecht, the Netherlands.

van Dam, J., Junginger, M., Faaij, A., Jürgens, I., Best, G., Fritsche, U., (2007). "Overview of Recent Developments in Sustainable Biomass Certification", International Energy Agency (IEA) Bioenergy Task 40, Paris, France.

Van Sark, W., Patel, M., Faaij, A. (2006). "The Potential of Renewables as a Feedstock for Chemistry and Industry", in Renewable-Based Technology: Sustainability Assessment, Chapter 2, Dewulf, J., van Langenhove, H. (eds.), John Wiley & Sons, USA.

Volpi, G. (2006). "Soya is not the Solution to Climate Change", The Guardian, London, UK, 16 March.

Walter, A., Dolzan, P., Piacente, E. (2006). "Biomass Energy and Bioenergy Trade: Historic Developments in Brasil and Current Opportunities", IEA Bioenergy Task 40 Country report for Brazil, available at www.bioenergytrade.org.

Walter, A., Rosillo-Calle, F., Dolzan P.B., Piacente E., Borges da Cunha K. (2007). "Market Evaluation: Fuel Ethanol", Task 40 Sustainable Bio-energy Trade: Securing Supply and Demand (Deliverable 8), State University of Campinas (Unicamp), Campinas, Brazil.

Wessels, C.R., Cochrane, K., Deere, C., Wallis, P., Willmann, R. (2001). "Ecolabelling and International Trade Law Implications: Product Certification and Ecolabelling for Fisheries Sustainability", FAO Fisheries Technical Paper 422, Food and Agricultural Organization, Rome, Italy.

Worldwatch Institute (2006). "Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century". German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), Worldwatch Institute, Washington, DC, USA.

Zarrilli, S. (2006). "The Emerging Biofuels Market: Regulatory, Trade and Development Implications". United Nations Conference on Trade and Development (UNCTAD), Geneva, Switzerland.

SELECTED ICTSD ISSUE PAPERS

Agricultural Trade and Sustainable Development

Value Chains and Tropical Products in a Changing Global Trade Regime. By Charles Mather. Issue Paper No. 13. May 2008

Trade Effects of SPS and TBT Measures on Tropical and Diversification Products. By Anne-Celia Disdier, Belay Fekadu, Carlos Murillo, Sara A. Wong. Issue Paper No. 12. May 2008

Tropical and Diversification Products Strategic Options for Developing Countries. By Santiago Perry. Issue Paper No. 11.March 2008

Implications of proposed modalities for the Special Safeguard Mechanism: a simulation exercise. Issue Paper No.10 Raul Montemayor, November 2007

Trade and Sustainable Land Management in Drylands. Selected Issue Briefs, 2007.

A Comparison of the Barriers Faced by Latin American and ACP Countries' Exports of Tropical Products.Issue Paper No. 9 by Jean-Christophe Bureau, Anne-Celia Disdier and Priscila Ramos, 2007.

South-South Trade in Special Products. Issue Paper No.8 by Christopher Stevens, Jane Kennan and Mareike Meyn, 2007.

Competitiveness and Sustainable Development

Looking for a meaningful Duty Free Quota Free Market Access Initiative in the Doha Development Agenda. By David Laborde. Issue Paper No.4, 2008

Impact of Origin Rules for Textiles and Clothing on Developing Countries. By Munir Ahmad. Issue Paper No.3, 2007

Special and Differential Treatment for Small and Vulnerable Countries Based on the Situational Approach. Issue Paper No. 2 by Werner Corrales-Leal, Felipe Baritto, and Sarah A. Mohan, 2007.

Basic Concepts and Proposals on the use of Policy Spaces in Trade-supported Strategies for Sustainable Development. Issue Paper No. 1 by Werner Corrales-Leal, 2007.

Dispute Settlement and Legal Aspects of International Trade

Trading Profiles and Developing Country Participation in the WTO Dispute Settlement System. Issue Paper No. 6 by Joseph Francois and Henrik Horn, 2008.

Developing Countries, Countermeasures and WTO Law: Reinterpreting the DSU against the Background of International Law Issue Paper No. 5 by Andrea Bianchi and Lorenzo Gradoni, 2008.

Does Legal Capacity Matter? Explaining Dispute Initiation and Antidumping actions in the WTO. Issue Paper No. 4 by Marc L. Busch, Eric Reinhardt and Gregory Shaffer, 2008.

Compliance and Remedies against Non-Compliance under the WTO System: Towards A More Balanced Regime for All Members. Issue Paper No. 3 by Virachai Plasai, 2007.

Access to Justice in the WTO: The Case for a Small Claims Procedure, A Preliminary Analysis. Issue Paper No. 2 by Håkan Nordström and Gregory Shaffer, 2007.

Appeal Without Remand: A Design Flaw in the WTO Dispute Settlement System. Issue Paper No. 1 by Joost Pauwelyn, 2007.

Fisheries, International Trade and Sustainable Development

Fisheries, Aspects of ACP-EU Interim Economic Partnership Agreements: Trade and Sustainable Development Implications Issue Paper No.6, by Liam Campling, 2008

Fisheries, International Trade and Sustainable Development.Policy Discussion Paper, by ICTSD, 2006.

Aquaculture: Issues and Opportunities for Sustainable Production and Trade. Issue Paper No. 5 by Frank Asche and Fahmida Khatun, 2006.

Market Access and Trade Liberalisation in Fisheries. Issue Paper No. 4 by Mahfuz Ahmed, 2006.

Trade and Marketplace Measures to Promote Sustainable Fishing Practices. Issue Paper No. 3 by Cathy Roheim and Jon G. Sutinen, 2006.

Fisheries Access Agreements: Trade and Development Issues. Issue Paper No. 2 by Stephen Mbithi Mwikya, 2006.

Intellectual Property Rights and Sustainable Development

The Global Debate on the Enforcement of Intellectual Property Rights and Developing Countries. Issue Paper No.22, by Carsten Fink and Carlos M. Correa. 2009

Intellectual Property and Competition Law Issue Paper No.21, by Carlos M. Correa, 2007.

Intellectual Property Provisions in European Union Trade Agreements: Implications for Developing Countries. Issue Paper No. 20 by Maximiliano Santa Cruz S., 2007.

Maintaining Policy Space for Development: A Case Study on IP Technical Assistance in FTAs. Issue Paper No. 19 by Pedro Roffe and David Vivas with Gina Vea, 2007.

New Trends in Technology Transfer: Implications for National and International Policy. Issue Paper No. 18 by John H. Barton, 2007.

Trade in Services and Sustainable Development

Maritime Transport and Related Logistics Services in Egypt, by Ahmed F. Ghoneim, and Omneia A. Helmy, Issue Paper No 8, December 2007

Opportunities and Risks of Liberalising Trade in Services in Pakistan, By Abid A. Burki, Issue Paper No 7, December 2007

Regulatory Principles for Environmental Services and the General Agreement on Trade in Services, by Massimo Geloso Grosso, Issue Paper No 6, December 2007

Opportunities and Risks of Liberalising Trade in Services in Mozambique, by Alberto Teodoro Bila, Eduardo Mondlane, Hélder Chambal and Viriato Tamele, Issue Paper No 5, December 2007

Opportunities and Risks of Liberalizing Trade in Services in Tanzania, by Daima Associates Limited, National Consultant, Issue Paper No.4, December 2007

Trade and Sustainable Energy

Climate Change and Trade on the Road to Copenhagen Policy Discussion Paper, 2009.

Trade, Climate Change and Global Competitiveness: Opportunities and Challenge for Sustainable Development in China and Beyond, Selected Issue Briefs No.3 by ICTSD, 2008.

Intellectual Property and Access to Clean Energy Technologies in Developing Countries: An Analysis of Solar Photovoltaic, Biofuel and Wind Technologies. Issue Paper No. 2 by John H. Barton, 2007.

Climate, Equity, and Global Trade. Selected Issue Briefs No. 2, 2007.

The WTO and Energy: WTO Rules and Agreements of Relevance to the Energy Sector. Issue Paper No. 1 by Julia Selivanova, 2007.

Linking Trade, Climate and Sustainable Energy. Selected Issue Briefs, 2006.

These and other ICTSD resources are available at http://www.ictsd.org

ICTSD's Programme on Agricultural Trade and Sustainable Development aims to promote food security, equity and environmental sustainability in agricultural trade. Publications include:

- Value Chains and Tropical Products in a Changing Global Trade Regime. Issue Paper No. 13 by Charles Mather
- Trade Effects of SPS and TBT Measures on Tropical and Diversification Products. Issue Paper No. 12 by Anne-Célia Disdier, Belay Fekadu, Carlos Murillo and Sara A. Wong
- Tropical and Diversification Products Strategic Options for Developing Countries. Issue Paper No. 11 by Santiago Perry, 2008
- Implications of Proposed Modalities for the Special Safeguard Mechanism: A Simulation Exercise. Issue Paper No. 10 by Raul Montemayor, 2007
- Trade and Sustainable Land Management in Drylands. Selected Issue Brief, 2007.
- A Comparison of the Barriers Faced by Latin American and ACP Countries' Exports of Tropical Products. Issue Paper No. 9 by Jean-Christophe Bureau, Anne-Celia Disdier and Priscila Ramos, 2007.
- South-South Trade in Special Products. Issue Paper No.8 by Christopher Stevens, Jane Kennan and Mareike Meyn, 2007.
- The ACP Experience of Preference Erosion in the Banana and Sugar Sectors: Possible Policy Responses to Assist in Adjusting to Trade Changes. Issue Paper No.7 by Paul Goodison, 2007.
- Special Products and the Special Safeguard Mechanism: Strategic Options for Developing Countries. Issue Paper No. 6 by ICTSD, 2005.
- Lessons from the Experience with Special Products and Safeguard Mechanisms in Bilateral Trade Agreements. Issue Paper No. 5 by Carlos Pomareda, forthcoming.
- Methodology for the Identification of Special Products (SP) and Products for Eligibility Under Special Safeguard Mechanism (SSM) by Developing Countries. Issue Paper No. 4 by Luisa Bernal, 2005.
- Special Products: Options for Negotiating Modalities. Issue Paper No. 3 by Anwarul Hoda, 2005.
- Tariff Reduction, Special Products and Special Safeguards: An Analysis of the Agricultural Tariff Structures of G-33 Countries. Issue Paper No. 2 by Mario Jales, 2005.
- The New SSM: A Price Floor Mechanism for Developing Countries. Issue Paper No. 1 by Alberto Valdés and William Foster, 2005.

For further information, visit www.ictsd.org.

ABOUT ICTSD

Founded in 1996, the International Centre for Trade and Sustainable Development (ICTSD) is an independent non-profit and non-governmental organization based in Geneva. By empowering stakeholders in trade policy through information, networking, dialogue, well-targeted research and capacity building, the centre aims to influence the international trade system such that it advances the goal of sustainable development.