Optimizing the global environmental benefits of transport biofuels

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Scientific and Technical Advisory Panel

An independent group of scientists which advises the Global Environment Facility

OPTIMIZING THE GLOBAL ENVIRONMENTAL BENEFITS OF TRANSPORT BIOFUELS

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Optimizing the Global Environmental Benefits of Transport Biofuels

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DISCLAIMER

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ABOUT STAP

The Scientific and Technical Advisory Panel (STAP) comprises seven expert advisors supported by a Secretariat, who are together responsible for connecting the Global Environment Facility to the most up to date, authoritative and globally representative science.

The Global Environment Facility (GEF) unites 183 countries in partnership with international institutions, civil society organizations (CSOs) and the private sector to address global environmental issues, while supporting national sustainable development initiatives. An independently operating financial organization, the GEF provides grants for projects related to biodiversity, climate change, international waters, land degradation, and chemicals and waste.

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FOREWORD

"Bioenergy can play a critical role for [climate change] mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems."

"Commercially available liquid and gaseous biofuels already provide co-benefits together with mitigation options that can be increased by technology advances."

These statements, taken from the Summary for Policy Makers of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report – Mitigation (2014)[1], were approved by member governments at the 12th Session of IPCC Working Group III in Berlin, Germany, 7-11 April 2014.

Many countries encourage the development of biofuels (liquid and gaseous fuels derived from biomass, and the subject of this report) for their co-benefits. Biofuels can also enhance a country's long-term energy security, reduce dependence on imported oil products, promote economic and social development by providing livelihoods for the rural poor, and provide income for the nation as a whole. However, if adequate environmental and social safeguards are not in place, the production and use of biofuels in a given region can have perverse outcomes such as increased greenhouse gas (GHG) emissions and/or adverse impacts on the land, water, food supply or biodiversity. Therefore, when deciding whether to support a biofuels project, policy makers must carefully consider the trade-offs.

In this report, the Scientific and Technical Advisory Panel (STAP) recommends that the GEF and its Implementing Agencies support projects that sustainably produce and use first generation and/or advanced biofuels in place of petroleum derivatives (gasoline, diesel, kerosene). However, these biofuels must meet strict guidelines to ensure that overall benefits outweigh any economic, environmental or social costs. To that end, the STAP provides guidance on evaluating the risks and benefits of proposed biofuel projects.[2]

Where the impact of biofuels is found to be more positive than negative, the GEF can play an important role to overcome barriers to implementation. The STAP recommends a series of strategic entry points for the GEF in this regard, such as support for national mapping schemes and agro-ecological zoning; direct investment in innovative biofuels systems that provide multiple benefits; the creation or improvement of relevant research centers; capacity building programs for farmers, policy makers and other key stakeholders; and support for biofuels policies and programs where appropriate.

The "food versus fuel" debate should recognize that future bioenergy needs and land use must be planned together to help fulfill both environmental and social objectives, and meet the planet's growing demands for food, feed, fuel and fiber. Reducing GHG emissions to achieve the 2°C target for global temperature rise means considering all viable options, including the thoughtful and sustainable production and use of biofuels.

Rosina Bierbaum Chair, Scientific and Technical Advisory Panel	Ralph Sims Panel Member for Climate Change Mitigation	Annette Cowie Panel Member for Land Degradation

[1] http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf.

[2] The same principles of sustainable production also apply where biofuels are used for stationary applications such as fuel for small-scale electricity generating systems, lighting or cook stoves.

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ACRONYMS

ACCS	Assured Combinable Crops Scheme (UK)
AfDB	African Development Bank
BAU	Business as Usual
BOD	Biochemical Oxygen Demand
BSI	Bonsucro / Better Sugarcane Initiative
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
EROWI	Energy Return on Water Invested
FAO	Food and Agriculture Organization of the United Nations
GBEP	Global Bioenergy Partnership
GEA	Global Energy Assessment
GEF	Global Environment Facility
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
HVO	Hydrotreated (or hydrogenated) Vegetable Oil
IADB	Inter-American Development Bank
IFAD	International Fund for Agricultural Development
IMF	International Monetary Fund
iLUC	Indirect Land-Use Change
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability & Carbon Certification
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
LCA	Life Cycle Assessment
LUC	Land-Use Change
MSW	Municipal Solid Waste
NASA	National Aeronautics and Space Administration
NEPAD	New Partnership for Africa's Development
NGO	Nongovernmental Organization
OECD	Organisation for Economic Co-operation and Development
PIF	Project Identification Form
RED	Renewable Energy Directive
REN21	Renewable Energy Policy Network for the 21st Century
RFS	Renewable Fuel Standard
RSB	Roundtable on Sustainable Biomaterials
RSPO	Roundtable for Sustainable Palm Oil
RTRS	The Round Table on Responsible Soy
TRL	Technology Readiness Level
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice
STAP	Scientific and Technical Advisory Panel
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

Liquid biofuel production, using mainly food crops as feedstock, has increased rapidly in recent years. Liquid biofuels now supply around 2-3% of total transport fuels and many countries have developed biofuel blending mandates.[3] "Good" biofuels can enhance the environment, increase farm revenue and boost the security of energy supply. "Bad" biofuels can harm the environment, increase and destabilize food prices, heighten concern over food security and disrupt the lives of small farmers. The Global Environment Facility (GEF) can help overcome barriers to the development and deployment of "good" biofuels.

This report identifies and evaluates necessary conditions for the GEF's support of biofuel projects, and provides recommendations to the GEF Partnership. It outlines a strategic framework for supporting the supply of sustainable biofuels at scales that are significant to the global climate. It reconciles energy and food security challenges with local developmental needs and aspirations. Finally, it evaluates the growing controversy surrounding the sustainable production of biofuels and land-use competition.

Recognizing that biofuels can help stabilize atmospheric greenhouse gas (GHG) emissions, the GEF Council and GEF Secretariat should consider them within the mix of GHG mitigation options when balancing investment effort versus global environmental benefits.

The GEF Implementing Agencies and project proponents should use the GEF/UNEP/FAO/UNIDO biofuel guidelines (Franke *et al.,* 2013)[4] for *ex-ante* screening to assess the sustainability and social benefits of each biofuel project.

The GEF should assess all proposals to support transport biofuel projects to:

- ✓ ensure significant levels of GHG mitigation can be achieved, considering the full life cycle and emissions that result from direct and indirect land-use change
- ✓ minimize the risk of negative environmental impacts such as biodiversity loss, reduced water quality, competition for water supplies and worsened air quality
- ✓ promote positive, economic and social outcomes (including food and energy supply security and local employment).

The GEF should monitor each biofuel project to determine if it achieves the anticipated benefits, using criteria such as:

[3] REN 21 Global Status Report, 2014, lists 33 countries – Table R18 –and several others with targets – Table R15.

[4] Franke *et al.,* 2013. *Global Assessments and Guidelines for Sustainable Liquid Fuel Production in Developing Countries*. This is a joint GEF/UNEP/FAO/UNIDO project.

- ✓ net GHG emission impact
- ✓ ecosystem service impacts, including biodiversity
- ✓ food supply security impacts
- ✓ land-use changes (both direct and indirect), including deforestation
- ✓ negative and positive societal impacts.

The GEF should support:

- projects that sustainably produce and use first generation (conventional) and/or second generation (advanced) biofuels in place of petroleum derivatives (gasoline, diesel, kerosene) where they meet sustainability guidelines (Franke *et al*., 2013)[5]
- cost-competitive and near-market conventional and novel energy crops
- innovative and emerging technologies for new and sustainable[6] production systems
- institutional development that can help deploy biofuels and develop markets for them.

Overall, the GEF could help reduce the risks and costs for biofuel production, promote a faster transition to commercial viability, develop the market and regulatory conditions for promoting sustainable biofuel technologies and enable the positive development of biofuels as a climate mitigation option.

Biofuel projects *should* be supported when:

- net GHG mitigation benefits are anticipated, with minimal negative and potentially positive environmental and socio-economic outcomes
- energy crops, if grown, are located on currently low-yielding crop or pasture lands, or on abandoned, marginal or degraded lands
- energy crop production optimizes the use of fertilizers, pesticides and irrigation in ways that protect or enhance soil quality and minimize negative off-site impacts
- co-benefits are clearly evident, such as the co-production of livestock feed or efficient, low-carbon heat and power generation, or the avoidance of organic waste disposal
- biofuels are used domestically for multiple purposes, such as local transport fuels and rural energy services for powering irrigation pump engines and small-scale electricity generators, crop drying etc., or else exported only where countries support the development of local food and fuel markets

[5] Franke *et al.,* 2013. *Global Assessments and Guidelines for Sustainable Liquid Fuel Production in Developing Countries*. This is a joint GEF/UNEP/FAO/UNIDO project. http://www.unep.org/bioenergy/Portals/48107/publications/Global%20Assessment%20and%20Guidelines%20for%20Biofuels.pdf.

[6] "Sustainable", in this context, refers to those biofuels that offer economic, environmental and social benefits that outweigh any disbenefits.

- the interests of local rural communities are protected.

Biofuel projects *should not* be supported in *any* of the scenarios below:

- natural forests, wetlands or biodiversity-rich native grasslands are converted for energy crop production
- inefficient energy conversion technologies produce a negative net energy balance
- food crops are used for biofuel, unless the food product is in surplus or the biomass resource is a by-product (such as crop residues)
- smallholder farmers are disadvantaged, for example through unfavorable supply agreements or land acquisition for large-scale commercial biofuel production, especially for export biofuels.

A series of safeguards that avoid adverse environmental and social impacts of biofuel systems should be factored into the GEF project approval decision-making process (

Table 12). Any risks associated with biofuel production should be recognized and addressed in the project proposal.

Recommendations for the GEF Council and the GEF Secretariat

1. Support national policy frameworks and feasibility studies

As well as directly supporting sustainable biofuel production and processing facilities, the GEF should support projects that help develop national policy frameworks for the sustainable production of biofuels and conduct feasibility studies coupled with strategic environmental assessments. These projects must result in significant GHG reductions over the full life cycle (Section 4).

2. Promote rigorous monitoring and reporting

The GEF should encourage the use of a rigorous monitoring and reporting protocol with mandatory evaluations of biodiversity, land-use change, water use, local employment, food security, and direct and indirect GHG emissions (noting the complexity and uncertainties involved in estimating net GHG benefits).

3. Encourage innovation

Ideally, GEF projects would encourage innovative approaches that integrate new biofuel crop production into the agricultural landscape. These include introducing energy crops and plantations that provide ecosystem services such as reduced soil erosion, improved micro-climate and crop-

nutrient regulation for the benefit of food production, and reclamation of degraded lands (Section 3.4).

4. Support better land-use planning

GEF projects could also support improved land-use planning, including through the use of geospatial technologies and participatory mapping to help identify suitable locations for sustainable biofuel production. This type of "landscape approach" to land management considers multiple factors for biofuel feedstocks. These include the type and location of crop and forest residues; the plant species to be grown; the farm management and harvesting systems used for production; transport of the biomass to refineries, as well as of the biofuel to market; and the type and location of the production facilities (Section 3.3).

5. Build capacity

The GEF should support institutional capacity to provide assurance and accountability, such as through standards and certification (Table 10 and Box 5). Technology transfer and capacity development programs for conventional and advanced biofuels will need to disseminate sustainable land management and agricultural production practices (Section 3.4).

6. Develop and demonstrate flagship projects

"Flagship" sustainable conventional and advanced biofuel production systems should be developed and demonstrated, including field trials to assess water supply and demand, suitable crop rotations, and industrial pilot projects and prototypes (Table 10).

7. *Develop tailor-made approaches for different regions*

The environmental and socio-economic implications of biofuel production are specific to the location and production system. Therefore, the GEF should employ region-specific approaches based on economic status, technological advancement and the appropriate scale of biofuel production. It could support regional centers of excellence (Table 10) for applied research relating to the production of new crop varieties, agricultural stewardship, use of bio-waste products and integration of chemicals production into industrial processes.

Recommendations for GEF Implementing Agencies and project proponents

1. Support projects that provide net GHG benefits and avoid negative impacts

Projects demonstrating biofuel production systems, or their market development, which provide net GHG benefits and avoid adverse environmental and socio-economic impacts, would be worthy of support. Ideal biofuel projects would use agriculture and plantation forest residues or bio-wastes as feedstocks as these have a lower risk of negative direct and indirect effects than purpose-grown crops (Section 4.2).

2. Adopt a life cycle assessment approach

The initial soil and biomass carbon stocks, biomass production methods and processes to produce the biofuels affect GHG emission outcomes (Section 4). For this reason, a life cycle assessment (LCA) is recommended to determine the overall impacts of any proposed biofuel project. Since the accounting system and assumptions in the LCA affect the result, standard methods should be applied, following the ISO Standard 14040:2006[7] and ISO TS 14067 (Section 4). Quantification methodology and assumptions should be clearly stated and justified.

3. Support sustainable production practices

Both small- and large-scale ventures should support sustainable production practices and have no major adverse environmental or socio-economic impacts. Priorities include large-scale biofuel production systems coupled to smallholder co-operatives or farmer associations; small-scale bio-refineries; "drop-in" biofuels production systems[8]; efficient thermochemical conversion systems; and integrated options such as the co-production of biofuels with bio-polymers in a bio-refinery (Table 9). Higher priority should be given to projects using residues or bio-wastes, or with co-products that enhance economic viability; to those that meet local rural energy demands for transport and/or clean cooking fuels; and to those that provide additional co-benefits such as electricity and heat generation that reduce air pollution and thus improve human health.

4. Support other key strategic entry points

Other strategic entry points for the GEF Partnership include:

- national mapping schemes and agro-ecological zoning
- direct investment in innovative biofuel systems that provide multiple benefits
- creation or improvement of relevant research centers
- capacity building programs for farmers, policy makers and other key stakeholders

[7] ISO 14040: 2006, "Environmental Management Life cycle assessment: Principles and framework"; ISO 14044: 2006 "Environmental Management Life cycle assessment: Requirements and guidelines"; ISO/TS 14067 "Greenhouse gases - Carbon footprint of products – Requirements and guidelines for quantification and communication".

[8] "Drop-in" biofuels refer to hydrocarbon fuels produced from various biomass feedstocks that are compatible with diesel or gasoline fuels and can be easily blended and stored with existing infrastructure.

- biofuel policies and programs, where appropriate (Table 10).

1 Introduction

This report updates the global status of biofuels for transport and highlights major issues to consider when deciding whether to support specific biofuel projects. It forms the basis for recommendations to the GEF Partnership to support the supply of sustainable biofuels at national, regional and global scales and at volumes that are significant to the global climate within the context of a 2°C mitigation scenario.

Controversy continues around the sustainable production and use of biofuels. This has affected both the demand for GEF funding for biofuel projects and the circumstances under which it is appropriate to fund such projects. This report evaluates conditions under which the GEF could support transport-biofuel projects. Based on these conditions, the report recommends how the GEF Partnership could deliver a strategic framework for supporting the supply of sustainable biofuels; such a framework would reduce greenhouse gas (GHG) emissions, while improving energy and food security challenges and reconciling these with local needs and aspirations.

This report analyzes the criteria and background in potential project proposals that seek funding from the GEF. The geographic scope of the analysis, therefore, has two limitations. First, it is restricted to GEF recipient countries. Second, it only covers technology and supply pathways that involve one or more of market development, near commercial dissemination, capacity building, demonstration or pilot-level activities. It builds on methodologies in the GEF/UNEP/FAO/UNIDO (2013) report "*Global Assessments and Guidelines for Sustainable Liquid Biofuels Production in Developing Countries*" (Franke *et al.,* 2013) by providing a practical plan of implementation for the GEF at both project and programmatic levels (STAP, 2012).

The land required for growing biomass feedstocks is at the heart of the debate on the environmental and socio-economic effects of biofuel production. At the local level, biofuel projects can benefit local communities through job creation, improvement of local infrastructure, energy security, technological development, income growth and tax revenues. These types of co-benefits can justify proposing and/or supporting a particular project. For example, biogas is increasingly a co-product of palm oil production where anaerobic digestion is used to treat waste streams with high biological or chemical oxygen demand (BOD/COD) levels. The resulting biogas is used for co-generation of electricity within the mill, substantially reducing GHG emissions from the treated waste streams and displacing electricity derived from fossil fuels. Similarly, bagasse, a residue by-product from ethanol

or sugar production from sugarcane, can be used in combined heat and power (CHP) systems. Heat and electricity generated can be used in plants and any surplus power exported for rural electrification, including powering crop irrigation pumps.

In some cases, however, biofuel production projects can also have negative impacts. They can, for example, exclude local smallholders from farming the land. When they leverage foreign investments in rural areas, biofuels can also affect local communities negatively. Finally, expansion of biofuel production systems can damage the environment and food supply system. The scale of these risks depends on the magnitude and rate of expansion of new projects, their location, the way they are implemented and any impacts on the use of land, labor and availability of other natural resources (e.g. water, soil nutrients).

The synergies or trade-offs between the benefits gained and any negative impacts vary with each project proposal. Hence, this report covers wider sustainability issues, but maintains a focus on the GHG mitigation potential of biofuels. It recommends promoting biofuels when they are produced and used in a sustainable way and when synergy exists between food and energy supply systems.

1.1 Rationale for biofuels update

In 2007, the Scientific and Technical Advisory Panel (STAP, 2007)[9] stated that biofuels are a promising area for GEF support and suggested consideration of the inter-linkages of biofuels with climate change, biodiversity and rural development. Specifically, the STAP recommended:

- ✓ establishment of sustainability standards for biofuel projects
- ✓ demonstration of biofuel projects with proven substantial GHG reduction benefits
- ✓ demonstration of biofuel projects that integrate into existing food production and stimulate productivity growth by capturing synergistic opportunities
- ✓ exploration of the potential of second generation[10] biofuel technologies as and when they are ready.

Since that report, a large number of new scientific reports and academic papers have been released including:

1. The Intergovernmental Panel on Climate Change (IPCC) Working Group III contribution to the Fifth Assessment Report on mitigation of climate change (IPCC, 2014b)
2. IPCC's Special Report on Renewable Energy (IPCC, 2011)
3. Global Energy Assessment (GEA, 2012)

[9] See GEF/C.31/Inf.7 (May 21, 2007) entitled "Liquid Biofuels in Transport: Conclusions and Recommendations of the Scientific and Technical Advisory Panel (STAP) to the Global Environment Facility (GEF). http://www.globalbioenergy.org/uploads/media/0705_STAP_Biofuels_Recommendations_to_GEF_01.pdf.

[10] The terms "second generation" and "advanced" biofuels are used synonymously throughout this report.

4. International Energy Agency's Energy Technology Perspectives (IEA, 2012; IEA 2014).

These reports and the underlying research from many journal papers have highlighted a significant role for biofuels and other forms of bioenergy in the 2°C mitigation[11] scenario pathways to 2050 and beyond. In its 2°C (450 ppm CO_2 equiv.) scenario, for example, the GEA estimated that bioenergy for heat, power and biofuels would need to provide up to 139 EJ out of just over 1,000 EJ/yr of primary energy demand by 2100 (GEA, 2012) (Figure 1).

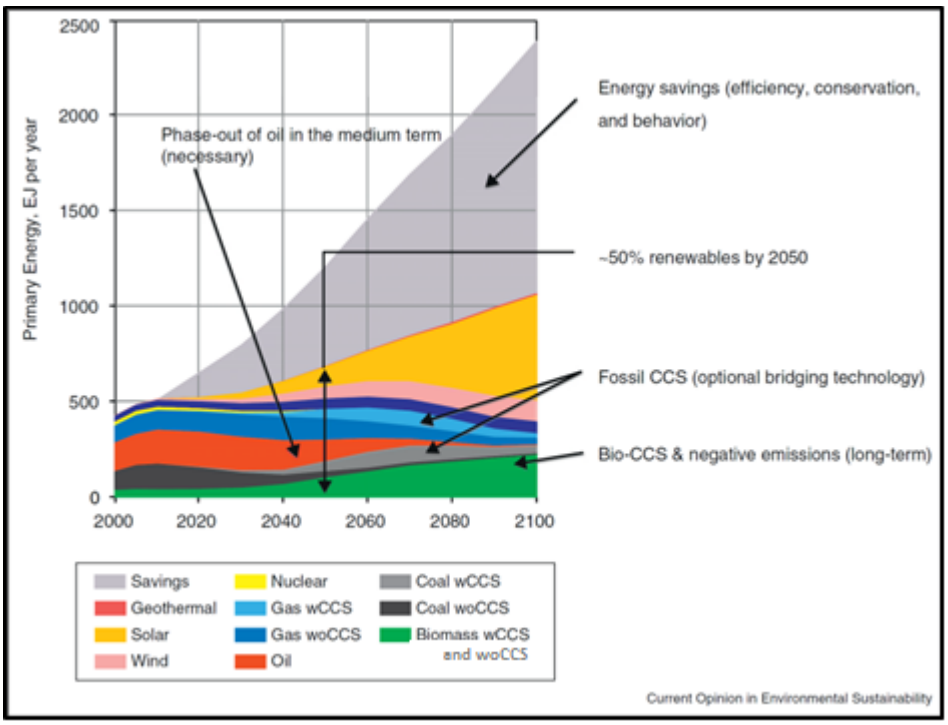


Figure 1: Example of an energy system transformation pathway required to meet 2°C global warming targets compared with a business-as-usual baseline.

Note: wCCS = with carbon dioxide capture and sequestration; woCCS = without carbon dioxide capture and sequestration
Source: GEA 2012; van Vuuren *et al.,* 2012.

Similarly, the IPCC 5th Assessment Report scenario database[12] confirmed the projected total transport final energy shares from biofuels will need to increase significantly to reach a 2°C future (Figure 2).

[11] In 2010, at the Cancun Climate Change Conference, Parties agreed to commit to a maximum temperature rise of 2 degrees Celsius above pre-industrial levels, and to consider lowering that maximum to 1.5 degrees in the near future (see http://unfccc.int/meetings/cancun_nov_2010/meeting/6266.php).

[12] Available at https://secure.iiasa.ac.at/web-apps/ene/AR5DB.

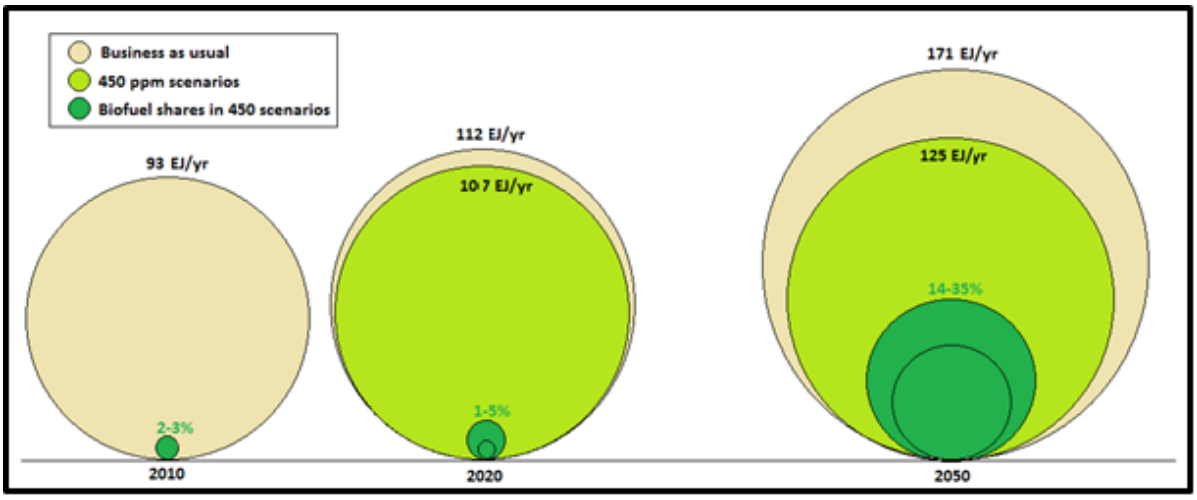


Figure 2: Total transport end-use energy demand in 2010, 2020 and 2050 under business-as-usual and 450 ppm CO_2-eq mitigation scenarios and the range (50 percentile to maximum) of shares of biofuels as projected in 2020 and 2050 in 127 mitigation scenarios.

Source: Data extracted from https://secure.iiasa.ac.at/web-apps/ene/AR5DB.

Multiple technological and behavioral pathways are possible to meet a 2° C target. Any scenario to reduce global carbon emissions, however, requires a substantial decrease in fossil fuel dependency coupled with an overall increase in renewable energies over the current century. Biofuels and bioenergy, across the diversity of implementation options, can contribute significantly to meeting this demand.

Biofuels can have direct, fuel-cycle GHG emissions that are typically 30–90% lower per kilometer traveled than those for gasoline or diesel fuels (IPCC, 2014b). However, in terms of life cycle assessment (LCA), carbon and energy-balance values, they continue to be a controversial option to mitigate climate change. National and regional policies (Table 1) are often designed to stimulate biofuel markets without specific actions to increase their production from sustainable resources. Adverse reaction to such biofuel policies around the world, and more broadly to bioenergy policies, is reflected in recent reports by nongovernmental organizations (NGOs) (e.g. RSPB, 2012) and policy assessment institutes such as the World Resources Institute (Searchinger *et al*., 2015). Environmental objections range from the capacity of the biosphere to cope with a significant new demand on net primary production (Krausmann *et al.,* 2013) to the scale of new land demand and the impacts of land-use change. Socio-economic concerns include competition for resources, time/labor, capital and land, and food security. As stated by José Graziano da Silva, Director-General of the Food and Agricultural Organization of the United Nations (FAO) at the Global Forum for Food and Agriculture in Berlin[13], "*We need to move from the food versus fuel debate to a food and fuel*

[13] 16 January 2015. http://www.fao.org/news/story/en/item/275009/icode/.

debate. There is no question: food comes first. But biofuels should not be simply seen as a threat or as a magical solution. Like anything else, they can do good or bad."

2 Biofuel status and policy context

In 2010, at the Cancun Climate Change Conference, Parties committed to a maximum temperature rise of 2°C above pre-industrial levels, and to consider lowering that maximum to 1.5°C in the near future. Major global research activities, however, have only begun to identify the scale of transformation required by the energy and land-use sectors to stabilize GHG emissions within that 2°C rise by 2050. Many global climate mitigation scenarios on future energy supplies highlight the continuing need for biofuels (GEA, 2012; IEA, 2011, 2012; IPCC, 2011, 2014b; REN21, 2014). They provide energy-dense, liquid fuels suitable for heavy goods trucks, as well as some rail, marine and aviation applications; the transport sector's need for biofuels is projected to grow rather than diminish.

Global business as usual (BAU) baseline emissions projections of 62 Gt CO_2/yr in 2050 must be reduced to about 14 GtCO_2/yr (IEA, 2012) for changes in the energy supply mix to reduce GHG emissions effectively. Current global emissions from the entire food supply chain are approximately 10 GtCO_2-eq/yr, or around 22% of total GHG emissions (FAO, 2011). The projected growth in population over the next 50 years combined with other pressures such as expected impacts from global climate change will further increase global food demand (Misselhorn *et al.,* 2012). Energy inputs will thus have to increase substantially above the current 93 EJ/yr (FAO, 2011). The agriculture/bioenergy nexus will therefore likely to be increasingly important (see Section 7).

2.1 Status of biofuel production, consumption, programs and targets

Biofuel production, and in particular ethanol, has increased significantly during 2000-12. In 2013, global biofuel production supplied around 117 billion l with an energy value of around 2.5 EJ: 87 billion l of ethanol, 26 billion l of biodiesel and 3 billion l of hydrotreated vegetable oils (REN21, 2014). This represented approximately 3.4% of global road transport fuels (2.3% of total transport fuels). The top five countries for bioethanol production are the US (50 billion l), Brazil (26 billion l), China (2 billion l), Canada (2 billion l) and France (1 billion l). For biodiesel, the US (5 billion l), Germany (3 billion l), Argentina (3 billion l), Brazil (2 billion l), France and Indonesia (2 billion l each), are the major producers (REN21, 2014). Other developing countries such as Thailand and Colombia have also initiated large biofuel programs (REN21, 2014).

Various projections have been published for the future supply and demand of biofuels globally, as well as for key countries and regions. Less than 3 EJ/yr of biofuels are consumed today, but this figure could increase by 10 times by 2050 (IEA, 2012). To stay on a 2°C pathway, the levels of biofuel use must keep rising after 2050 as fossil fuels are phased out (IEA, 2012; van Vuuren *et al.,* 2012).

2.2 National biofuel programs and policies

In 2013, around 40 countries or states had biofuel blending targets or mandates in place (Table 1). Brazil has promoted ethanol as a transport fuel for over 50 years, while Malawi has been blending ethanol into its gasoline pool since 1982 (COMPETE, 2007).

Table 1: Overview of national biofuel blending mandates and targets in place in 2013 and future proposals.

(B = biodiesel, B2 = 2% biodiesel blend; E = ethanol, E2 = 2% ethanol blend, etc.)

Country/region	*Current mandate/target*	*Mandate [M] or target [T]*	*Future mandate/target proposed*
Argentina	E5, B7, B10	M	n/a
Australia: New South Wales (NSW), Queensland (QL)	NSW: E6, B5; QL: E5 E4 and B2 in NSW	M	n/a
Belgium	E4 and B4		
Bolivia	E10, B2.5	T	B20 (2015)
Brazil	E18-25, E100, B5	M	n/a
Canada	E5 (up to E8.5 in 4 provinces), B2-B3 (in 3 provinces) National: E5 and B2 Provincial: E5 and B4 in British Columbia; E5 and B2 in Alberta, E7.5 and B2 in Saskatchewan; E8.5 and B2 in Manitoba; E5 in Ontario	M	B2 (nationwide)
Chile	E5, B5	T	n/a
China (9 provinces)	E10 (9 provinces)	M	n/a
Colombia	E8, E10, B10	M	B20
Costa Rica	E7, B20	M	n/a
Dominican Republic	n/a	n/a	E15, B2 (2015)
Ecuador	B5		
Ethiopia	E5		
European Union (Renewable Energy Directive)	5.75% biofuels*	T	10% renewable energy in transport**
Guatemala	E5		
India	E5, E10	M	E20, B20 (2017)
Indonesia	E3, B2.5	M	E5, B5 (2015); E15, B20 (2025)
Jamaica	E10	M	Renewable energy in transport: 11% (2012); 12.5% (2015); 20% (2030)
Japan	500 Ml/y (oil equivalent)	T	800 Ml/y (2018)
Kenya	E10 (in Kisumu)	M	n/a
Korea	B2	M	B2.5; B3
Malawi	B4, E10	M	E10 / E20
Malaysia	B5	M	n/a
Mexico	E2 (in Guadalajara)	M	E2 (in Monterrey and Mexico City)

Mozambique	n/a	n/a	E10 in 2012 -2015; E15 in 2016 – 2020; E20 form 2021, B5 (2015)
Norway	3.5% biofuels	M	5%; possible alignment with EU mandate
Nigeria	E10	T	n/a
Panama	E5	M	E7 (by April 2015); E10 (by April 2016)
Paraguay	E24, B1	M	n/a
Peru	E7.8, B2	M	B5
Philippines	E5, E10, B2, B5	M	B5, E10
South Africa	E2 and E5	n/a	2%
South Korea	B2.5		
Sudan	E5		
Taiwan	B2, E3	M	n/a
Thailand	B3, E5 and B5	M	3 Ml/d ethanol, B5; 9 Ml/d ethanol (2017)
Turkey	E2		
Ukraine	E5		E7 (2017)
United States	The RFS for 2013 was reduced to 49.21 billion l (13 billion gallons) of which 0.02 bln. is cellulosic-ethanol)	M	*National*: The Renewable Fuels Standard 2 (RFS2) requires 136 billion l (36 billion gallons) of renewable fuel to be blended annually with transport fuel (of which 60 bln. is cellulosic-ethanol) (2022).
Uruguay	B2, B5	M	E5 (2015), B5
Venezuela	E10	T	n/a
Vietnam	E5	n/a	50 Ml biodiesel, 500 Ml ethanol (2020)
Zambia	E15 and B5	n/a	E5, B10, E20 (2014)
Zimbabwe	E5		E10 and E15

2.3 Biofuel crops

Traditionally, solid biomass — as fuel wood, dung and crop residues — has been used as a source of energy for cooking and heating; more recently, it has also been used to generate heat and power. Liquid and gaseous biofuels are also produced from a range of biomass resources to provide mobility-related energy services. In recent years, agricultural food crops as feedstocks have largely driven the growth of biofuel production. Conventional sources of biomass feedstock include sugar, starch and oil crops; unconventional sources include ligno-cellulosic materials and algae.

Technically, biofuels can be produced from any organic material (Ruth, 2008). Based on the type of crops, cultivation practices and the process involved, however, biofuels are broadly classified into first generation (conventional) or second generation (advanced).

- First generation typically use the primary harvested component of oilseed rape (canola), *Jatropha*, oil palm and soya bean for biodiesel and corn, sugarcane, sugar beet, sweet sorghum, wheat and cassava for ethanol.
- Second generation typically use woody biomass (e.g. plantation forest residues, wood processing residues), vegetative grasses (e.g. switchgrass, elephant grass, napier grass,

Miscanthus), agricultural residues (e.g. sugarcane bagasse, straw, corn stover, cobs, empty oil palm fruit bunches, nut shells, rice husks) or algae.

2.3.1 First generation (conventional) biofuels

Almost all biofuel production is first generation and made from food crops; non-food feedstocks such as *Jatropha*, animal fats and recovered used cooking oils make only a small contribution. The current debate is largely focused on the environmental and socio-economic implications of large-scale use of first generation sugar, starch or oil crops (Table 2).

Table 2: Classification of biofuel types, their advantages and disadvantages, feedstocks process technologies and typical biofuel yields.

TECHNOLOGY	ADVANTAGES	DISADVANTAGES	BIOFUEL	TYPICAL FEEDSTOCK/PROCESS	TYPICAL YIELD
First Generation (conventional)	Simple and low-cost conversion technology. Can have lower GHG emissions, but not always. Valuable by-products.	Low yields. Large areas of arable land may be required for growing crops.	**Ethanol**	Sugarcane/ fermentation	5,000–8,000 l/ha.yr
				Corn/fermentation	2,000–4,000 l/ha.yr
				Sweet sorghum /fermentation	2,500–3,500 l/ha.yr
			Biodiesel	Palm oil/ transesterification	4,000–5,000 l/ha.yr
				Oilseed rape	1,000–1,500 l/ha.yr
				Jatropha / transesterification	1,000–1,500 l/ha.yr
				Soya bean/ transesterification	500–1,000 l/ha.yr
Second Generation (advanced)	GHG savings. Can use food wastes as feedstock. No food crop competition for land if residues used. Possible use of non-arable land for growing energy crops.	Pretreatment of ligno-cellulosic feedstock is costly. Advanced technology needs to be developed for more cost-effective conversion.	**Ethanol**	Ligno-cellulose / Biochemical hydrolysis /fermentation	110-300 l/dry tonne
				Ligno-cellulose/ thermochemical: gasification to syngas then Fischer Tropsch.	120-160 l/dry tonne
			Biodiesel	Ligno-cellulose/ thermochemical gasification to syngas then Fischer Tropsch.	75-200 l/dry tonne
				Vegetable oils/hydrogenated (HVO)	Similar to biodiesel produced from vegetable oils by transesterification as above.
Algal	Easy to cultivate algae. Versatile: can use wastewater, seawater. High growth rate. No food crop competition.	Energy consumption for cultivation of algae (mixing, filtration, centrifuging, etc.) Low lipid content. Contamination problem in open pond system.	**Biodiesel**	Micro- and macro-algae/thermo-mechanical or biochemical oil extraction.	90,000–100,000 l/ha.yr
			Bio-kerosene	Micro- and macro-algae / thermo-mechanical or biochemical oil extraction.	10,000–15,000 l/ha.yr

		High costs of photo-bio-reactor.			

Source: Mielkie, 2006; Fresco, 2007; Jongschaap *et al*., 2007; Sims *et al*., 2008; Langerveld *et al*., 2013, Dutta *et al.,* 2014.

Yields depend upon crop variety, soil quality, rainfall and irrigation, nutrient supplements and cultural practices. Many researchers, however, have suggested new technologies may help increase yields (IEA, 2006; FAO, 2008b; Staley and Bradley, 2008; FAO, 2012). In the meantime, food crops are likely to dominate biofuel production since the technologies are well established and a large production program with targets already exists. Key food crops for ethanol and biofuels are noted below.

Ethanol: Sugarcane dominates ethanol production in developing countries, providing the highest yields of around 7,000 l/ha.yr in Brazil with a global average of 5,000 l/ha.yr. Yield from corn is approximately 3,800 l/ha.yr in the US, whereas the global average is around 2,370 l/ha.yr (Table 2 and Table 3).

Table 3: Energy balances, productivity and GHG reduction potential compared with gasoline for a range of biofuel feedstocks based on life cycle assessment (LCA).

Feedstocks	Energy balance (output / input)	Typical productivity (l/ha.yr)	GHG reduction potential (based on US and EU legislation)
Wheat (EU)	2.0	2,500	16-69%
Corn (US)	1.4	3,800	0-38%
Sugar beet (EU)	2.0	5,500	52%
Sugarcane (Brazil)	9.3	7,000	61-91%
Sources: World Watch Institute (2006) and Macedo *et al.* (2008) for energy balance; MTEC, EU Commission, EPA and UNICA (2012) for productivity; and Macedo *et al.* (2004, 2008) for GHG balance. The same values were also recently presented by CTC (2012).			

Biodiesel: The dominant crop for producing biodiesel is oilseed rape in Europe and soya bean in Brazil and the US, both of which produce lower oil yields per hectare compared to oil palm, the dominant crop in Indonesia and Malaysia (Stone, 2007). However, oilseed rape and soya bean both produce a high value co-product of protein meal used for intensive animal production feed, soya milk, soya meat, etc., whereas empty oil palm bunches have only limited value as livestock feed. Oil palm provides the highest annual biodiesel yield (around 4,500 l/ha.yr) (Table 2). It is therefore increasingly popular for large-scale biodiesel production, although over 90% of palm oil is used for food, cosmetics and other non-fuel applications. Increasingly, *Jatropha* is grown as a biofuel crop in countries such as Tanzania and India (PISCES-FAO, 2009), although this is still a very minor crop in the biodiesel market worldwide. In addition, oil-producing trees such as castor bean and *Pongamia*

pinnata[14], as well as used cooking oil, are also used to produce biodiesel feedstock. Despite its status as a waste product, the logistics of collecting and processing used cooking oil are usually expensive, and not enough is produced to meet local diesel demand. However, the consumption of used cooking oil also keeps it out of the waste collection and treatment cycle, thus avoiding the associated environmental and economic costs.

2.3.2 Second generation (advanced) biofuels

Second generation biofuels are based on feedstock comprising ligno-cellulosic biomass such as woody biomass, grasses, agricultural residues (bagasse, husks, shells, straw, stalks, leaves) and forestry residues (small roundwood, branches, leaves, saw-dust, thinnings). These feedstocks, which are abundantly available, can be harvested at a much lower cost than first generation feedstocks (Sims *et al.,* 2008). Some crops that could be grown for biofuel production include perennial vegetative grasses, short-rotation willows, poplar, eucalyptus and algae (Worldwatch Institute, 2006; Li *et al.,* 2008). Some could become invasive species so caution is needed when introducing species into regions where they are not present (UNEP, 2009). Commercial demonstration of liquid biofuel production from ligno-cellulosic materials has only just begun (Janssen *et al.,* 2013).

2.3.3 Algal biofuels

Algae occur in two basic forms:

- micro-algae (single cell photosynthetically active cultures)
- macro-algae (large multi-cellular photosynthetic structures).

Relative to terrestrial biofuel feedstocks, algae can convert solar energy into fuels more efficiently, and some species can thrive in salt water systems. Algal biomass can be used to produce several bioenergy carriers, including starches for alcohols, lipids for diesel fuel surrogates and hydrogen for fuel cells. Algal technologies are advancing, with the ability to genetically optimize the production of targeted biofuels emerging as key (Beer *et al.,* 2009). The production systems for algae cultivation include simple “plastic bag” type systems, tanks, artificial pools, sewage treatment ponds, natural lakes and ocean-based systems.

There is no clear commercial or technical advantage between the biochemical and thermochemical processes (Section 5) for conversion of algae to biofuels. Neither route is yet fully commercial, although the thermochemical route has fewer technical hurdles since much of the technology is already proven (Sims *et al.,* 2008; Black *et al.,* 2011). Large research programs related to algae-based technologies are ongoing in the US, EU, India, Brazil, Japan, Canada, Australia and China. Micro-algae

[14] *Pongamia Pinnata* is known as Indian Beech in English, *Karanja* in Hindi and *Pongam* in Tamil. This plant has historically been used in India as a source of traditional medicines, animal fodder, green manure, timber, fish poison and fuel (Sangwan *et al.,* 2010).

systems have not been demonstrated at a sufficiently large scale, and biofuel production requires technological breakthroughs to become commercially viable (Demirbas, 2009; Jonker and Faaij, 2013; Smith *et al.,* 2014). The future of algae technologies remains uncertain and further investments in research and development are necessary to obtain the first commercial-scale plants. For example, in 2014, the US Department of Energy (USDOE) announced up to USD25 million in funding was available to reduce the cost of algal biofuels to less than USD1.30 per l (~USD5 / gasoline gallon equivalent) by 2019.[15]

3 Land for biofuels: area, demand, impacts and management

Land used for biofuel feedstock production remains a remarkably small share of total global agricultural land. The amount of land used to grow energy crops is estimated at 0.2% of the world's total land area of approximately 13 billion ha and 0.5-1.7% of global agricultural land (Ladanai and Vinterbäck, 2009). Estimates of future demand for land for biofuel production remain highly uncertain (RFA, 2008; Langeveld *et al*., 2013). For example, purpose-grown crops could contribute anywhere between 25 and 675 EJ/year in 2050 (Creutzig *et al.,* 2014) depending on the land required for food production and other commercial demands. Further, the current knowledge and models on land use are insufficient to accurately predict the impacts of increased demand on land for food, feed and fuel or the interaction between different cropping systems.

3.1 Land availability

About 4.5 Gha (30% of the world's land surface) is suitable to some extent for rain-fed agriculture (Table 4). Of this area, some 1.3 Gha are already under cultivation (FAO, 2012). Developing countries have some 2.8 Gha of land with potential for growing rain-fed crops at yields above an "acceptable" minimum level, of which nearly 0.97 Gha are already under cultivation. The gross land balance available of 2.9 Gha (4.5 – 1.6 Gha) of which 1.8 Gha is in developing countries, would therefore seem to provide significant scope for further expansion of agriculture, including land for bioenergy feedstock provision.

Based on FAO data, Slade *et al.,* (2011) summarized world land-use (Figure 3). FAO (2012) projected a 70 Mha net increase in the land required for food production by 2050. This assumed an expansion of 130 Mha in developing countries less a decline of 60 Mha in developed countries due to over-production, being out-competed for recreational land, and urbanization.

[15] See http://www.energy.gov/eere/articles/energy-department-announces-25-million-reduce-costs-algal-biofuels for more information.

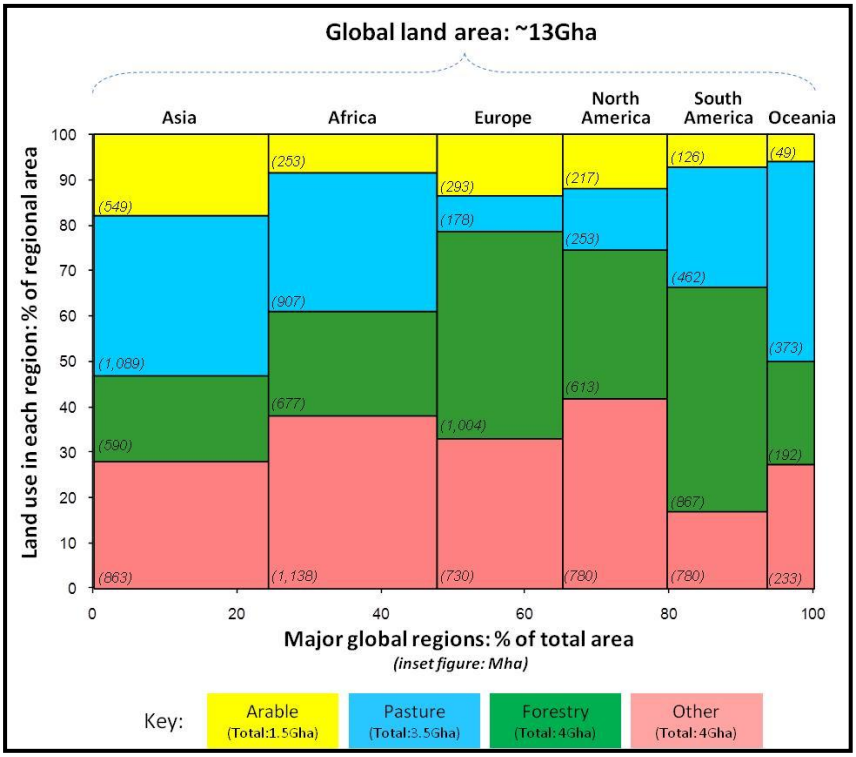


Figure 3: World land use showing breakdown of total land area into land uses (regional breakdowns in parentheses as Mha).

Source: (Slade *et al.,* 2011; based on FAO database).

Therefore, at the global level, land constraints or competition are considered unlikely to be the key determinant of either food or energy security, or for the provision of biomass for bioenergy (Table 4; FAO, 2012; Wise *et al*. 2014).

Table 4: Land with rain-fed crop production potential by region (million ha; FAO, 2012).

	Total land surface area	**Total land with potential for cropping***	**Of which**		**Of which in use during 1999/2001**		**Unused as of 1999-2001** (a+b)–(c+d)	**Not suitable as too low-yielding ****	**Potential land area available for rain-fed agriculture**
			Prime land (a)***	**Good land** (b)	**Rain-fed land** (c)	**Irrigated land** (d)			
World	13 295	4 495	1 315	3 180	1 063	197	3 236	1 824	1 412
Developing countries	**7 487**	**2 893**	**816**	**2 077**	**565**	**138**	**2 190**	**1 227**	**963**
Sub-Saharan Africa	2 281	1 073	287	787	180	3	890	438	451
Latin America	2 022	1 095	307	788	137	15	943	580	363
Near East/North Africa	1 159	95	9	86	38	12	45	9	37
South Asia	411	195	78	117	85	55	55	43	11
East Asia	1 544	410	126	283	122	53	234	140	94
Other developing countries	70	25	9	15	2	0	23	16	7
Developed countries	**5 486**	**1 592**	**496**	**1 095**	**497**	**58**	**1 037**	**590**	**447**
Rest of the world	**322**	**11**	**3**	**8**	**2**	**0**	**8**	**7**	**1**

Source: Bruinsma (2011); FAO (2012).
*Crops considered: cereals, roots and tubers, sugar crops, grain legumes and oil-bearing crops.
**Suitability classes are defined according to attainable yields as a percentage of the maximum constraint-free yield as follows: VS=Very Suitable, 80-100%, S=Suitable, 60-80%, MS=Moderately Suitable, 40-60% mS=marginally Suitable, 20-40%, vmS=very marginally Suitable, 5-20%, NS=Not Suitable, <5%;
***Prime land = VS and Good land = S + MS.
Land at present under forest or urban build and not cultivated.

At the local level, increased demand for land for biofuels, as for other agricultural products, can stimulate both positive and negative land-use change effects on local communities. Positive effects include improved productivity and resilience, better access to clean water and increased income (Satolo and Bacchi, 2013). Negative effects include loss of access to land needed for subsistence, decreased access to water, increased food prices and detrimental impacts on biodiversity and ecosystem resilience (Section 0). Changed management practices, novel crops or over-extraction of biomass from land can increase pressures on land and soils, and advance degradation (Section 3.4).

3.2 Land requirement for biofuels

Assessing the net land area required for biofuel production involves a number of variables, including targets assumed for petroleum fuel substitution, biofuel crops selected, soil fertility, water availability, production practices, projected feedstock yields, market and policy incentives, conversion technologies, markets for co-products and evolution of alternate land uses. The projected land required for producing biofuels should be compared with that needed to meet food, livestock feed and fiber requirements, as well as the need to maintain ecosystem services and function. The land projected to be necessary to meet increased biofuels demand, rising from less than 3 EJ in 2010 to just over 30 EJ by 2050, would be about 100 Mha (IEA, 2011; Figure 4).

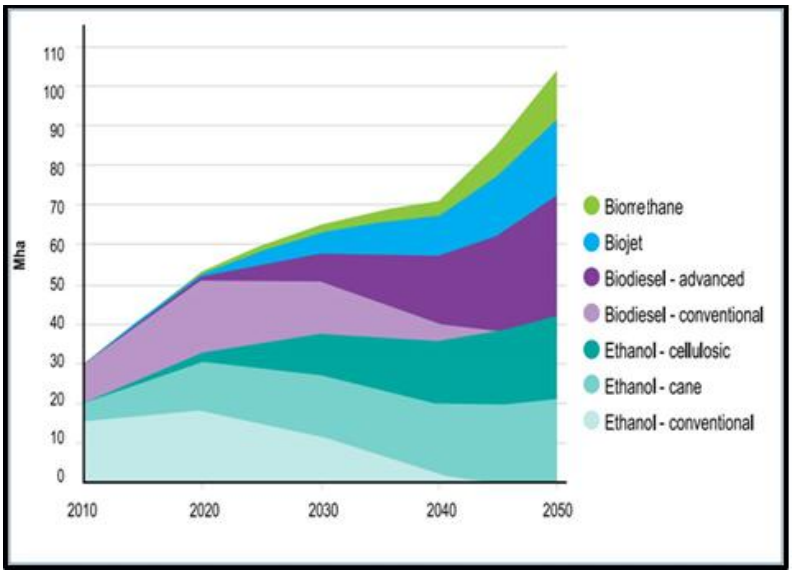


Figure 4: Land-use area projection for production of a range of biofuel types from 2010 to 2050.

Source: IEA, 2011.

Note: This is gross land demand excluding land-use reduction potential of co-products with the biofuel. It assumed 50% of advanced biofuels and biomethane will be produced in 2050 from 1 Gt of biomass supplied from wastes and residues. If more of this biomass could be used, then land demand for energy crops could be significantly reduced.

In 2005–07, about 12% of the total 13 Gha land surface (excluding "inland water") was used for arable land and land under permanent crops[16] (FAO, 2012). Therefore, the 100 Mha estimate of the land required for future projected biofuels production in 2050 represents less than 1% of total arable land area.

However, the growth in demand for land parallels an increase in biofuel production. Indeed, Murphy *et al.* (2011) estimated 650 Mha of land globally could be required to meet only 20-30% of IEA's calculated biofuel demand in 2050, representing over 4% of current global arable land. Langeveld *et al.* (2013), assessing the impacts of biofuel programs on major biofuel-producing countries, found that total direct land demand was 25 Mha in 2010. When co-products (primarily animal feeds) were included, however, the net land demand for biofuels alone dropped to 13.5 Mha.

Furthermore, when assessing actual land-use change impacts using empirical FAO land-use data, Langeveld *et al*. (2013) found the agricultural area in these countries had actually declined by 9 Mha. Another study suggests that, by 2030, less than 5% of the global arable area will likely be needed for biofuel crops (Woods *et al.,* 2015).

Clearly, due to future uncertainties, estimates vary greatly for the amount of land needed to support anticipated future demand for biofuels. Intensification to increase crop productivity would minimize competition for land, particularly in regions where yields are well below potential. In addition, ligno-cellulosic feedstocks from crop and forest residues, wood-processing wastes and the organic fraction of municipal solid waste (MSW) could be obtained with virtually zero or minimal impacts on land requirement. The use of second generation biofuels frees up land to be intensified in other ways; the penetration of advanced biofuels produced from ligno-cellulosic feedstocks reduces land intensity from around 20 Mha/EJ of total biofuels produced to 3 Mha/EJ in 2050 (IEA, 2011). Further, some grasses and tree crops could be grown on poorer or more vulnerable soils, although low productivity and higher feedstock and transport costs are likely to result.

Due to the complexity and uncertainties associated with land-use models, it is unrealistic to make a single projection of the land required for biofuel production. Only a range of potential area estimates is appropriate. Much of the impact depends on the effectiveness of national policies to

[16] Arable land is defined as land under temporary agricultural crops, temporary meadows for mowing or pasture, under market and kitchen gardens, and temporarily fallow (less than five years) (IEA, 2011). According to the FAO, arable land in 2008 accounted for 1.4 Gha of the 4.9 Gha global agricultural area worldwide.

generate incentives to choose highly productive crops and couple them to efficient supply chains for agriculture as a whole.

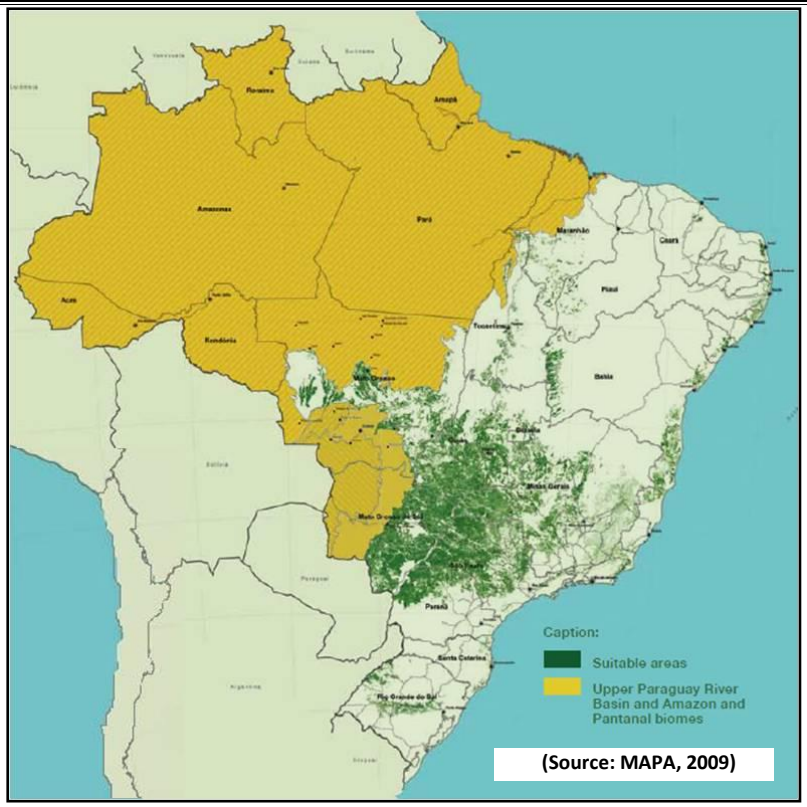
Many regions have constrained supplies of biomass residues and waste products due to limited area of crops grown, scale of production and/or competing uses. Therefore, to supplement the biomass resource available, dedicated cultivation of vegetative grasses or short-rotation forest crops may be required (Sims *et al.,* 2008). The land area then required will depend on the proportion of feedstock sourced in the form of residues and the yields of the dedicated energy crops.

3.3 Land-use planning

National and regional policy makers need to understand and mitigate local-level constraints and impacts. To that end, they require tools to map local resources in both space and time. Such a tool would both quantify the land area and track its evolving uses, including the protection of biodiversity-rich or vulnerable land. This type of "landscape approach" to land management is particularly useful if it considers multiple factors such as the type and location of plant species to be grown for biofuel feedstock; the farming and harvesting systems used for their production; transport to refineries, as well as of the fuel to market; and the type and location of production facilities (Dale *et al.,* 2010).

Policy makers could learn from practical examples of effective land-management tools. In Brazil, for instance, agro-ecological zoning has been used to direct sugarcane expansion onto low productivity pastureland, while intensifying production on remaining pasture land. This has minimized competition with food production and avoided deforestation (**Error! Reference source not found.**Box 2).

Box 1: The use of agro-ecological zoning to guide Brazil's bioethanol fuel expansion.



(Source: MAPA, 2009)

As a result of local concerns and the need to provide strategic direction for the expansion of biofuel production in Brazil from sugarcane, a pioneering effort was made to develop a national agro-ecological zoning tool and supportive legislation. Brazil's "Sugarcane Agro-ecological Zoning" was published as a legal framework in 2009 (MAPA Decree (Portaria) n. 333/2007, Presidential Decree n. 6961/2009; MAPA Normative Instruction n. 57/2009; Federal Law Project n. 6077/2009), with the work being coordinated by the Ministry of Agriculture, Livestock and Food Supply (MAPA *et al.,* 2009). Key aims of the zoning are to direct sugarcane expansion onto existing managed lands, particularly pastures; avoid forest areas; and avoid direct competition with food production. It also allows for the implementation and monitoring of reserve land in production areas such as buffer strips and biodiversity corridors as stipulated in Brazil's revised Forestry Code. The sugarcane zoning has now been followed by a zoning for oil palm (MAPA *et al*., 2010); Brazil has held workshops in a number of African countries to build capacity for agro-ecological zoning (Strapasson *et al.,* 2012).

3.4 Implications of biofuel expansion for land degradation

Land degradation processes are a major environmental concern, particularly in arid and semi-arid regions. Land degradation can result from deforestation, non-sustainable forest extraction, over-grazing by livestock, wild and managed fires, inappropriate crop choices and agronomic practices leading to soil erosion and the establishment of invasive species. Degraded or marginal lands require vegetation cover. This, in turn, requires soil, water and carbon/organic matter conservation practices to halt further land degradation and to aid restoration (Victoria *et al.*, 2012). Marginal lands are being targeted for biofuel production, particularly in semi-arid regions of South Asia, sub-Saharan Africa and Latin America.

In the context of land degradation, farmers' choices about what crops to grow and how they are cultivated will have long-term and far-reaching impacts on soil quality, water quality and biodiversity. Expansion of trade in biofuels derived from feedstocks produced on rural drylands, for example, could intensify biofuel production (i.e. increased mechanization, irrigation, use of chemicals, decreased fallow periods). This, in turn, could lead to further degradation and even

accelerate degradation on marginal lands. To mitigate these impacts, biomass production on small farms could be combined into larger farm units to meet the growing demands of global competitive markets. This strategy, however, could marginalize smallholder and subsistence farmers and force them on to poorer quality lands. That said, the use of cooperatives and small farmers' associations could increase their competitiveness and profits in such new markets.

Is it better to remove crop and forest residues or leave them in the soil? On the one hand, continuous removal of significant fractions of above-ground biomass for feedstocks may deplete soil nutrients (Karel *et al.,* 2005), thus exacerbating land degradation. Removing crop or forest residues normally left in the field after harvest for use in biomass feedstocks could reduce soil organic carbon content by up to 15% (Rajagopal *et al.,* 2007), and lead to loss of soil fertility. On the other hand, some crops, including sugarcane, produce a substantial amount of residues that remain in-field after harvesting. Indeed, volumes of crop residues have increased in Europe since most EU Member States banned the burning of straw and stubble under the Common Agricultural Policy (Kretschmer *et al.* 2012). As mechanical harvesting displaces manual labor, Brazil and other countries are phasing out the burning of sugarcane (which gave laborers easier and safer access to the cane). In the short term at least, removing up to half of in-field sugarcane residues left on the ground after harvest does not appear to adversely affect levels of organic matter in the soil, soil quality or the natural herbicide effect of the biomass cover (Hassuani 2005; CGEE, 2009).

Some perennial biofuel crops are being considered for marginal lands. Jongschaap *et al*. (2007) argued that, on a modest scale, *Jatropha* cultivation could help conserve soil water, reclaim soil and control erosion; it could also be used for living fences, firewood, green manure, local soap production, insecticides and medicine. However, scientific evidence is lacking to back claims that high oil yields combine with low soil fertility, low water use, low labor inputs and high tolerance to pests and diseases. The most critical gaps are the lack of improved varieties and availability of quality seeds of *Jatropha*, since it has not yet been domesticated as a crop with reliable performance over long periods. Continuing efforts are needed to improve the agronomy and management of this plant, which might help it become an efficient commercial energy crop. Caution is needed when assessing the potential promotion of novel crops grown on marginal or degraded lands. Sustainable land management practices should be promoted to maintain or enhance the chemical, biological and physical soil health (George and Cowie, 2011).

4 Climate change effects of biofuels

Greenhouse gases are emitted at all stages of the production and use chain for biofuels, as is the case for all agricultural and forestry products (FAO, 2011). Life cycle assessment (LCA) is commonly used to quantify the net GHG effects of bioenergy systems, but differences in the LCA methodology and assumptions can lead to variation in LCA results (Cherubini *et al*., 2009). The International Organization for Standardization (ISO) has published several LCA standards (ISO 14040 and 14044), and more recently ISO/TS 14067, that seek to improve consistency in the methods used for LCA and carbon footprint evaluation. The ISO standard on sustainability criteria for "bioenergy", which is under development, also applies a life cycle approach to quantifying climate change effects of bioenergy; it further elaborates the guidance provided in earlier standards for application to bioenergy systems.

Total climate forcing of bioenergy depends on many factors, including feedstock, site-specific climate and ecosystems, management conditions, production pathways, end uses and interdependencies with energy and land markets (Creutzig *et al.,* 2014). Therefore, for biofuels to contribute significantly to climate change mitigation, their implementation needs to result in a meaningful reduction in the use of fossil fuels in transport, coupled with a significant reduction in GHG emissions compared to the equivalent fossil fuel baseline.

To qualify as an "advanced biofuel" under its renewable fuel standard (RFS), for example, the US Environmental Protection Agency (EPA) requires life cycle GHG emission reductions of more than 50% compared to the baseline petroleum fuel it would replace. Full life cycle GHG emissions for gasoline and diesel are currently about 87g CO_2eq/MJ (JRC, 2013). Thus, to meet the 50% threshold, full life cycle GHG emissions from biofuels (including indirect emissions from land-use change) could not go beyond 43g CO_2eq/MJ. The scale, importance and potential to manage and mitigate these emissions are evaluated below.

4.1 GHG emissions from land conversion to biofuel production

Direct land-use change (LUC) takes place when crops used for bioenergy displace other crops, pastures or forests (Creutzig *et al.,* 2014). Ravindranath *et al.* (2009) estimated CO_2 emissions from first generation biofuel crops associated with land conversion at the global level. They envisioned that biofuels would replace 10% of petroleum fuel for transport in 2030 (Table 5). The method of estimation of CO_2 emissions involved the following steps:

- Estimating demand for diesel and gasoline for the transport sector based on international energy outlook projections for 2030 (EIA, 2008)
- Assessing land area required for production of biodiesel and ethanol to meet 10% of the projected diesel and gasoline demand of the transport sector in 2030
- Estimating potential CO_2 emissions from land conversion for different land category conversions, for different biodiesel and ethanol crops, and for mean annual CO_2 emissions per hectare due to land conversions (based on Fargione *et al.,* 2008). Emissions resulting from land-use change were arbitrarily averaged over 30 years (Table 5). The UK's PAS2050 standard (BSI, 2011) averages land-use change emissions over 20 years, but a longer period was chosen here to account for longer assumed life-times for biofuel conversion plants and associated cropping systems.

Table 5: Mean annual emissions (Mt CO_2/yr) from land-use change.

Regions	**Emissions from land-use conversion to a single oil crop that enables substitution of 10% of total global diesel demand by biodiesel in 2030.**			**Emissions from land-use conversion to a single starch or sugar crop that enables substitution of 10% of global gasoline demand by ethanol in 2030.**		
	Jatropha	Oil Palm	Soya bean	Corn (maize)	Sugarcane	Sweet sorghum
OECD	273	436	569	359	110	183
Non OECD	264	421	550	347	106	177
World	537	857	1 119	706	216	360

Notes: Mean annual CO_2 emissions were estimated from the area of original land use converted to the selected biofuel crop under each scenario multiplied by the associated CO_2 emission factor considered over the 30 year period: grassland to *Jatropha* 3.1 tCO_2/ha.yr; tropical forest to oil palm 17.4 tCO_2/ha.yr; grassland to soya bean, 3.1 tCO_2/ha.yr; abandoned crop land to corn, 4.1 tCO_2/ha.yr; grassland to sugarcane, 3.1 tCO_2/ha.yr; grassland to sweet sorghum, 3.1 tCO_2/ha.yr.
Emissions were averaged over 30 years under a scenario of producing biofuels used for transport in 2030 as a result of land conversion to a biofuel crop; this is assumed to meet all of projected fuel demands to substitute 10% of total global diesel or total gasoline fuels.

Source: Ravindranath *et al.,* 2009.

CO_2 emissions from land conversion were estimated by considering six conversion scenarios and by using the total area required for each crop (Ravindranath *et al.,* 2009) (Table 5). The calculations included carbon fluxes associated with changes to above- and below-ground biomass stocks and soil carbon for transitions from grassland, tropical forest and abandoned cropland to biofuel cropping. To substitute 10% of total gasoline and 10% of diesel project demand, the CO_2 emissions from land conversion alone ranged from about 750 Mt CO_2 (grassland to *Jatropha* plus grassland to sugarcane) to 1,800 Mt CO_2 (grassland to soya bean plus abandoned land to corn). A business-as-usual scenario would generate emissions of 840 Mt CO_2.

Estimates for the biofuel-based land-use change emissions in Table 5 do not account for emissions from cultivation, indirect land conversion, transport of the biomass, rebound effect[17] and processing

[17] The "rebound effect" refers to indirect market-induced effects on fossil fuel consumption arising from changes in price due to the expansion of biofuels. Due to the rebound effect, one unit of biofuel may displace less than one unit of fossil fuel. Estimates of rebound vary widely, suggesting that a unit of renewable energy may displace between 0 and 1.6 units of electricity generated by fossil fuels in different situations, with the factor generally less than 1.0 (e.g. York, 2012; Rajagopal and Plevin, 2013).

of the biofuels, which together could increase emissions by 20-90%, 170 to 760 Mt CO_2 (Thow and Warhurst, 2007). To minimize land conversion emissions, energy crops should be cultivated on agricultural or pasture lands, preferably those used sub-optimally, rather than in areas where native vegetation dominates (see, for example, Davis *et al.,* 2013).

Careful planning is needed to ensure land-use change from direct biofuel expansion enhances rather than degrades terrestrial carbon stocks**Error! Reference source not found.**. In analyzing carbon stocks and payback periods for biofuel production in Brazil (Table 6), House *et al.* (2012) showed the importance of detailed land classification and carbon stock data for estimating carbon impacts of land-use change. In Brazil, the expansion of sugarcane to produce ethanol as a transport fuel has historically involved transfer of land use between different types of cropland, and from pastureland (Nassar *et al.,* 2011). Establishing sugarcane on *cerrado* (savanna land) can result in losses of 3 to 18 tC/ha (11 to 66 tCO_2/ha) depending on whether sugarcane residues are burned or left in-field to decay. Replacement of degraded pasturelands or corn/cotton croplands with sugarcane can lead to an increase of 10 to 29 tC/ha (based on Amaral *et al.,* 2008 and Macedo, 2010 for above-ground biomass and soil carbon down to 20 cm). The resulting carbon payback times range from over 700 years to immediate (where biofuel-induced land-use change enhances net carbon stocks). It is now clear there are good and bad biofuel production systems and options for expanding supply. Overall, however, the scientific community remains conflicted about the net impacts of a significant expansion of biofuel production (IPCC, 2014a). It is impossible to estimate the global scale of biofuel production that could occur before it inflicted significant negative impacts on global ecosystems or communities (indirect effects).

Table 6: Change in carbon stocks from land-use-change conversions, and estimated payback periods after land is converted to sugarcane or soyabean production in Brazil.

	Carbon stocks:[b] selected values above and below ground		**Change[c] to degraded pasture**	**Change to unburned sugarcane**	**Change to soya bean cropland**	**Sugarcane ethanol payback[d]**	**Soya bean biodiesel payback**
	1,000tC/km^2		1,000tC/km^2	1,000tC/km^2	1,000tC/km^2	Years	Years
Tropical forest	16.6	60.9	–12.4	–9.7	–11.1	51	728
Degraded pastureland	4.2	15.5	n/a	2.7	1.3	immediate	immediate
Cultivated pastureland	5.9	21.5	–1.6	1.0	0.4	immediate	24
Soya bean cropland	5.5	20.1	–1.3	1.4	n/a	immediate	0.0
Corn cropland	4.4	16.1	–0.2	2.5	1.1	immediate	immediate
Cotton cropland	4.0	14.7	0.2	2.9	1.5	immediate	immediate
Cerrado (savanna)	7.2	26.2	–2.9	–0.3	–1.7	1	109
Campo limpo (grassland *cerrado*)	8.0	29.5	–3.8	–1.2	–2.6	6	168
Cerrado (woodland / forest savanna)	8.7	31.7	–4.4	–1.8	–3.2	9	208

Burned sugarcane	5.4	19.7	–1.1	1.5	0.1	immediate	immediate
Unburned sugarcane	6.9	25.2	–2.7	n/a	–1.4	0	92

[a]n/a = not applicable. [b]Carbon stocks for "tropical forests" from Stickler *et al.* (2007). All other carbon stocks from Amaral *et al.,* 2008 (all at 0–20 cm depth). [c]Calculated change in carbon stock in vegetation and soils when moving from existing land cover to the stipulated land cover. Negative values denote a loss of stock on the land or emissions to the atmosphere. Carbon gain on the land or net uptake from the atmosphere is shown in bold. [d]Payback times for bioenergy conversions are calculated based on typical emission and savings factors for the two different bioenergy conversion pathways, fuel ethanol and biodiesel and change in carbon stocks as shown.
Source: House *et al.,* 2012.

4.2 Indirect GHG emissions from land-use conversions

Indirect land-use change (iLUC) occurs when land is converted to cropland or pasture somewhere on the Earth to replace a fraction of crops displaced by cultivation of biomass crops (Searchinger *et al.,* 2008; Creutzig *et al.,* 2014). Several studies have highlighted that direct and indirect land conversion can dominate the GHG implications of biofuel production (OECD, 2008; OECD-FAO, 2008; IPCC, 2014a). Estimates of emissions from land-use change range from -80g to 450 CO_2eq/MJ for biodiesel and from -90 to 270 g CO_2eq/MJ for ethanol supply chains (IPCC, 2014a).

The growing demand for biofuels in both industrialized and developing countries will require bringing new land into biofuel feedstock production. Searchinger *et al.* (2008) reported an increase in total GHG emissions when biofuel crops were grown in the US, due mainly to indirect land-use changes. Gibbs *et al.* (2008) used a database of crop locations, yields, vegetation and biomass estimates to calculate carbon payback times under different scenarios of future crop yields, biofuel technologies and petroleum sources. They concluded that displacement of tropical ecosystems through promotion of biofuels would lead to net carbon emissions for decades; at the same time, production of biofuels on degraded or cultivated land would lead to carbon savings. Biofuels expansion to date has occurred mostly over pasture, agricultural or marginal areas (i.e. already occupied lands such as in the US, Brazil, Argentina, Canada and EU, which represent the majority of biofuels production worldwide), and rarely over natural vegetation (Box 2).

Box 2: Biofuels and deforestation in Brazil.

The hypothesis that biofuels expansion to date could be indirectly affecting deforestation rates in Brazil (the Amazon Forest) is inconsistent with observed trends in deforestation (Strapasson *et al.,* 2012). Sugarcane expansion in recent decades in the Brazilian State of São Paulo, which is responsible for more than 60% of national ethanol production, occurred mainly over pasture and crop lands (Egeskog *et al.*, 2014). However, despite less pasture area, the production of beef and milk in this state has substantially increased in the same period due to livestock intensification, yield growth and adoption of best practices. In addition, while ethanol production expanded, the deforestation rate has been significantly reduced over the last decade (INPE, 2014). Land demand for biofuels increased by between 10 and 20,000 ha between 2000 and 2010 compared to an increase in agricultural land area of 8.9 Mha (Langeveld *et al.*, 2013). Overall, there is no strong evidence of a causal link between biofuels production and deforestation in Brazil.

Nonetheless, such risks, such as deforestation in Indonesia for oil palm plantations, have to be considered in future expansion. Fargione *et al.* (2008) introduced the concept of "carbon debt" from biofuel production, which indicates tonnes of CO_2 resulting from land conversion (some including iLUC) to be offset by biofuel-substituting fossil fuels. Carbon debt could also be understood as the number of years of biofuel production required to offset the total CO_2 emissions arising from land conversion. Natural vegetation or pre-conversion land use, and carbon (soil and biomass) density of the land, influences the net CO_2 benefit (which reflects use of new land for biofuel production).

Among conventional "first generation" crops assessed by Fargione *et al.* (2008), carbon debt would be highest for converting peat land to oil palm (~3,500 tCO_2/ha[18]) followed by converting tropical rainforest to soya bean (~750 tCO_2/ha) and using palm oil for biodiesel production (~700 tCO_2/ha). Conversion of grassland to corn (maize) and *cerrado* to sugarcane would lead to a net carbon debt of ~140 and ~170 tCO_2/ha respectively.

The carbon debt is very low for conversion of abandoned croplands, which have low carbon densities. Conversion of marginal cropland could have no net CO_2 debt (Danielsen *et al.*, 2008). Estimates by Fargione *et al.* (2008) did not include CO_2 emissions from biofuel production; conversion processes and the carbon debt included only the biofuel component and excluded co-products such as animal feeds (e.g. soya meal and dry distillers grain with solubles [DDGS]). If these components are included in the calculations, the carbon debt is lower for many of the land conversion systems, particularly when using co-product biomass residues as feedstocks (e.g. sugarcane bagasse) for combined heat and power generation (CHP).

Sugarcane-ethanol and palm oil-biodiesel have been found to be the best feedstocks for carbon savings if traditional lands (i.e. conventional areas used for agricultural or livestock) or marginal lands are converted for biofuel production. However, Lapola *et al.* (2010) reported that iLUC could considerably compromise the GHG savings if forests are converted to pasture and/or cropland.

Potential iLUC effects generate a great deal of speculation and concern. The agricultural dynamics are so complex that available models can only provide uncertain and inaccurate information to estimate such effects (Akhurst *et al.,* 2011; Langeveld *et al.,* 2013). More recent estimates of iLUC are much lower than the original figures published by Searchinger *et al.* 2008 (Figure 5). The quantification, attribution and management of iLUC remain complex and controversial, especially in

[18] 1,000 tC/km^2 as in Table 4 equates to 36 tCO_2/ha.

the current globalized food market (IPCC, 2014a). However, precautionary public policies could reduce or avoid iLUC effects in several ways: using energy crops with higher yields; expanding biofuels onto under-used or marginal areas; using agro-ecological zoning and sustainable public policies for guiding new investments into favorable lands; and promoting capacity building and technology transfer in developing countries (Lynd and Woods, 2011; Strapasson *et al.,* 2012).

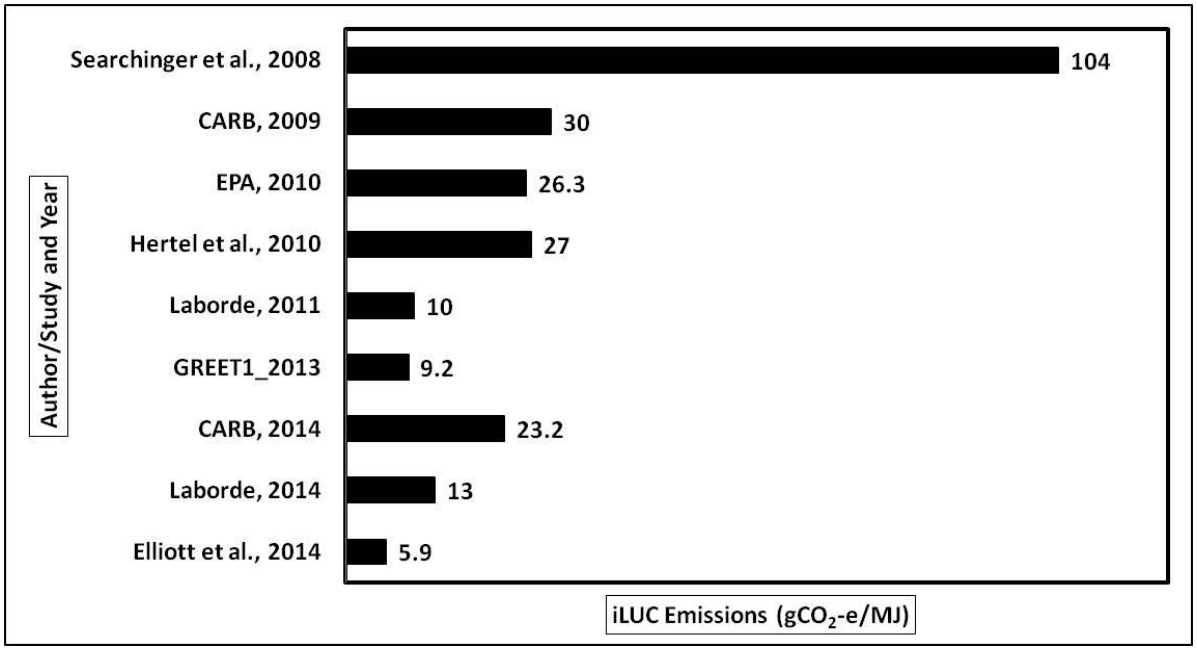


Figure 5: Estimates from several studies of indirect land-use change (iLUC) emissions for corn-based ethanol (based on Agricone).

Indirect land conversions could be a function of multiple, complex and inter-related drivers, particularly deforestation. Using linked economic and terrestrial bio-geochemistry models, researchers have evaluated direct and indirect effects of possible land-use changes from an expanded global cellulosic bioenergy program on GHG emissions over the 21st century (Melillo *et al*., 2009). The analysis predicts that iLUC will be responsible for up to two times more carbon loss than direct LUC. However, due to the predicted increase in nitrogenous fertilizer use, nitrous oxide emissions could be more important than carbon losses in terms of overall global warming potential. Other studies have shown a decrease in the estimated impact of LUC (including iLUC) due to a more detailed inclusion of the supply chain dynamics and co-products (Wicke *et al.,* 2012) and a better understanding of the use of wastes and residues as feedstocks for bioenergy.

While modeling iLUC and resulting emissions is highly uncertain and impossible to quantify, several strategies can minimize risk (Wicke *et al.,* 2012). For example, feedstocks from residues and wastes, as well as yield increases, carry minimal risk. Feedstocks produced on under-used or marginal lands can also be sustainable so long as proper safeguards are in place (Section 10.3). Capacity building for

land-use planning and enforcement in areas likely to be affected by either direct or indirect LUC may be the best strategy to reduce negative effects over the long term.

In summary, indirect land-use change (iLUC) could potentially threaten GHG savings gained through biofuels; however, strategies have been developed to minimize the risk of iLUC (Cherubini *et al*., 2009; Wicke *et al.,* 2012; Langeveld *et al.,* 2013).

4.3 GHG implication of co-products

Production of many biofuel crops leads to co-products such as straw, bagasse, corn stover, soya meal, oil seed cake, rape meal, glycerine, distillers grains and sugar-beet pulp. For soya bean, the biofuel is often a by-product of producing the more valuable protein meal. These co-products have numerous potential applications, including for livestock feed and as biomass feedstock for electricity and heat generation. Incorporation of the co-products will have mostly positive implications for net GHG emissions. Croezen and Brouwer (2008) and Langeveld *et al.* (2013) indicated that co-products have a significant positive impact on land-use requirements for biofuels and net GHG benefits. The scale of the effects will depend upon the substitution adopted in the co-product life cycle analysis (for example, including an assessment of the nutrient balance of different feed types).

4.4 Nitrous oxide (N_2O) emissions

N_2O is produced from N compounds in soil (derived from chemical fertilizers, animal wastes or organic matter) through denitrification and nitrification processes – the relative importance of each varying between soil types, soil moisture and temperature levels, and N source. Using nitrogen-based fertilizers for biofuel production, particularly in marginal lands, could potentially increase N_2O emissions, which have a global warming potential about 300 times higher than CO_2 (IPCC, 2007a, 2014a). Thus, cultivation of biofuel feedstocks with nitrogenous fertilizer may reduce the net GHG benefit of biofuels.

Bates *et al.* (2008) and Crutzen *et al.* (2007) concluded that N_2O emissions from soil could be a significant source of GHG emissions for first generation biofuel crops. Therefore, to quantify life cycle GHG emissions, N_2O emissions and other gases must be included with estimates of CO_2 emissions. In addition, the GHG LCA of biofuels (from field to wheel) and of fossil fuels (from well to wheel) must be compared fairly. Specifically, emissions per kilometer traveled rather than per MJ of energy consumed would account for energy density and engine performance improvements. The GEF should recommend incorporation of LCA into performance assessment and in due-diligence evaluations, which is now standard practice, including reporting of all assumptions.

4.5 GHG implications of second generation biofuels

A review of LCA that focused on GHG emissions concluded that very few studies have assessed net GHG benefits from second generation biofuel production based on ligno-cellulosic feedstocks (OECD, 2008). The review concluded that production routes of ethanol and biodiesel based on ligno-cellulosic feedstocks provide net GHG reductions between 60% to more than 120%.[19] More recent studies support these conclusions, including work by the European Union's Joint Research Centre (JRC, 2013) and the IPCC's Bioenergy Annex to its 5th Assessment Report (IPCC, 2014a).

Replacing gasoline or diesel with biofuels can actually reduce total GHG emissions by more than 100%: when heat and electricity co-produced from residual biomass also replace fossil fuels, it creates an additional emissions benefit. FAO (2008b) estimates conservatively that second generation biofuels offer total emission reductions by 70-90% compared to diesel and gasoline; this estimate excludes CO_2 emissions from land conversion. Production of second generation cellulosic feedstocks, which are often perennial crops, can reduce the GHG emissions since it requires less nitrogenous fertilizer and minimum tillage compared to conventional cropping systems (Robertson *et al.,* 2008).

[19] This is possible where biomass by-products are used for heat and power supply to displace fossil fuels.

5 Biodiversity consequences of biofuel production

The Convention on Biological Diversity (CBD) has summarized the potential positive and negative impacts of biofuel production on biodiversity (Box 3). The nature of the impact depends on the land category converted (directly and indirectly) for biofuel feedstock production, biodiversity status of the land before conversion, the biofuel crop and cultivation/land management practices. FAO (2008b) and Sala *et al.* (2009) stated how increased biofuel production could have negative implications on biodiversity due to: (i) habitat conversion and loss; (ii) agricultural intensification; (iii) invasive species; and (iv) pollution.

Box 3: Convention on Biological Diversity (CBD) summary of impacts of biofuel production on biodiversity.

The Convention on Biological Diversity (CBD) has expressed concerns over the effects of biofuel production on biodiversity and recommends scientific research to assess both positive and negative impacts of specific projects. In its recommendations related to biodiversity and biofuel production, the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) noted the following: (SBSTTA Recommendation XII/7).

Positive implications of biofuel production on biodiversity and human well-being, where the production and use processes are associated with:

- reduction of the consumption of fossil fuels
- decrease in land use for agricultural purposes associated with the increase in energy outputs per area
- change in agricultural production leading to reduced management inputs, increase in crop diversity, restoration of degraded lands, reduction in the application of pesticides and fertilizers, reduction in water used for irrigation and increased water use efficiency of crops
- decreasing land abandonment and decreasing conversion of agricultural land to other uses
- increase of the income-base for farmers and forest owners and improvement of employment opportunities in rural areas
- reduction of GHG emissions derived from the use of liquid biofuels.

Biofuel production and use can have adverse effects on biodiversity and human well-being, including where the production process and use are associated with:

- Loss, fragmentation and degradation of valuable habitats such as natural and semi-natural forests, grasslands, wetlands and peat lands and other carbon sinks, their biodiversity components and the loss of essential ecosystem services and leading to increases in GHG emissions due to these changes
- Competition for land managed for the production of alternative crops, including land managed by indigenous and local communities and smallholder farmers, and competition for the commodity prices potentially leading to food insecurity
- Increased water consumption, increased application of fertilizers and pesticides, increased water pollution and eutrophication, soil degradation and erosion
- Uncontrolled cultivation, introduction and spread of genetically modified organisms
- Uncontrolled introduction and spread of invasive alien species
- Emissions from burning biomass and potential adverse effects on human health.

(i) ***Habitat conversion and loss***: Agricultural production sometimes involves the expansion of managed land into natural forests, peat lands, grasslands, wetlands and marginal or abandoned lands. Production of feedstocks for biofuels also presents this risk. According to the CBD (2008), many biofuel crops are well suited for tropical areas. De Vries *et al.* (2007) suggested that grasslands

could be the primary target for biofuel expansion in many regions. The conversion of marginal or degraded lands could also have adverse implications for biodiversity (Robertson *et al.,* 2008). However, biofuel production only affects biodiversity when it uses wastes or residues that involve significant land-use change.

(ii) ***Agricultural intensification***: Commercial large-scale biofuel plantations are based on monocultures with low genetic diversity. This genetic uniformity may increase susceptibility to pests and diseases. Studies have reported that energy plantations have lower biodiversity compared to natural forests; plantations, for example, have only a fraction of fauna, including birds, mammals, and bats (Danielsen *et al*., 2009). Thus, plantation expansion into native vegetation is not compatible with enhancing or maintaining biodiversity (Stone, 2007). Biodiversity corridors and multi-species planting, however, can enhance the biodiversity of existing plantations. Careful integration of ligno-cellulosic, perennial crops with conventional agricultural crops provides an option to integrate biomass production with the "sustainable intensification" of agriculture to feed the world's growing population (Godfray *et al.,* 2010; Woods *et al.,* 2010; Murphy *et al.,* 2011; Alongi *et al.,* 2013).

(iii) ***Invasive Species***: Taxa that invade or are introduced into areas outside their natural ranges can have large negative impacts on biodiversity. Non-native species and genotypes have put native species at greater risk of extinction, altering both the composition of ecological communities and ecosystem processes (Sala *et al.,* 2009). Some species identified for biofuel production are also potential invaders outside their native range. These include switchgrass (*Panicum virgatum L.*), which is native to most of North America east of the Rocky Mountains and now pursued by California and the Pacific Northwest (Barney and DiTomaso, 2008). Further, habitat changes associated with biofuel production are likely to increase the risk of invasion by non-native taxa. Projections for climate change will heighten the risk still further, increasing the likelihood of the establishment, growth, spread and survival of invasive species (Chown *et al.,* 2012; IPCC, 2014c). Whether these habitats are clear-cut in large or small patches, or selectively harvested for particular species, any form of disturbance will bring invasion risks (Davis *et al.*, 2000).

(iv) ***Pollution***: Many biofuel crops rely on intensive management. Therefore, large-scale commercial biofuel production from crops or residues will normally require fertilizers (mainly nitrogen, phosphorus and potassium) and pesticides. These are likely to impact on terrestrial and aquatic biodiversity. Over-use of fertilizers could pollute water with nutrients, leading to eutrophication of water resources. This, in turn, could lead to changes in habitat and functioning of aquatic ecosystems (Carpenter *et al.,* 1998; Martinelli and Filoso, 2008).

Drivers negatively affecting biodiversity may occur simultaneously and interact with one another in an additive, synergistic or antagonistic fashion. For example, the use of marginal land for biofuels may directly impact on native biodiversity. At the same time, it can create source populations for invasive species that then spill over to impact conserved land (Sala *et al.,* 2009).

5.1 Biodiversity consequences of second generation biofuels

Ligno-cellulosic crops do not normally demand high levels of nutrient addition. Donner and Kucharik (2008), however, suggested that even perennial crops such as switchgrass may require moderate to high doses of fertilizer to maximize productivity. In the long term, most cellulosic feedstocks are expected to be generated from dedicated perennial crops. This long rotation would reduce the need for tillage after the original establishment phase. Cellulosic crops can be grown as mixes of more complex species, including native poly-cultures for conservation and biodiversity benefits (Robertson *et al.*, 2008).

Alongside fewer GHG emissions, biofuel production using sustainable practices involving high diversity mixtures of native grassland perennials offers a range of ecosystem services. With low agro-chemical inputs, these systems could have positive implications for biodiversity, especially where they mimic native grasslands.

Expanded biofuel production would have a range of potential impacts on biodiversity depending on the region, biofuel crop and production practices (Sala *et al.,* 2009). The use of vegetative grasses for expanding advanced biofuel production, for example, will likely have less impact on biodiversity than if oil palm, soya bean or corn replaced tropical forests or grasslands. The implications of biofuel production from first and second generation crops are less well understood, requiring further research. Biofuel production on abandoned land, formerly intensively used agricultural land or moderately degraded land may benefit biodiversity depending on the production system (UNEP, 2009).

6 Effects of biofuels on water

Food production in many tropical countries is subject to water stress and declining ground water levels; increasing demand and climate change impacts may exacerbate the problem. Some biofuel crops can require irrigation for higher yields. Thus, biofuel production could have adverse implications for water availability for food production, especially in water-deficit areas. On the farm, it takes 850 l of water to produce 1 l of ethanol from corn, compared to 1,300 l of water to produce 1 l of ethanol from sugarcane (FAO, 2008b). Additional water is required for biofuel processing.

Mulder *et al.* (2010) examined the role of water by calculating the energy return on water invested (EROWI) in the harvested biomass from irrigated crops (Table 7). Any given crop has a large range (e.g. between 70-350 l of water/MJ of biomass energy for corn). Water usage varied from crop to crop, including for ligno-cellulosic crops where the EROWI tended to be higher than for first generation crops.

Table 7: Water usage and energy return on water investment (EROWI) and net EROWI for biomass energy technologies.

Biofuel/feedstock	Water usage (l/MJ)	EROWI (kJ/l)	Net EROWI (kJ/l)
Biodiesel	-	-	-
Rapeseed oil	100-175	10-5.7	5.7-3.3
Ethanol	-	-	-
Sugarcane	38-156	26-6.5	23-5.7
Sugarbeet	71-188	14-5.3	7.8-2.9
Corn	73-346	14-2.9	3.9-0.81
Ligno-cellulosic	-	-	-
Ethanol	11-171	91-5.8	71-4.5
Methanol	11-138	91-7.2	53-6.2

Source: Mulder *et al.,* 2010.

Water scarcity, rather than land scarcity, may prove to be a key limiting factor for biofuel production in many regions (FAO, 2008b). Gerbens-Leenes *et al.* (2009) estimated the water footprint[20] of bioenergy feedstocks and their processing. Many crops used for biofuel production such as sugarcane, palm oil and corn have relatively higher requirements for water extracted from groundwater or dams. Thus, they can be grown under irrigated conditions or in regions with high rainfall, which reduces or excludes the need for irrigation.

Extensive cultivation of biofuel crops for commercial purposes may lead to competition for water between biofuel production and food production, particularly in countries with limited fresh water resources (Peña, 2008; Royal Society, 2008). Water-scarce regions need to consider carefully the matching of biofuel crops to local water resources, and competing demands for water. For example, even though *Jatropha* is a drought-resistant crop requiring at least 300 millimeters (mm) of rain annually, production of seeds is low at these levels; four times this amount of rain needed each year for good production (Wetlands International, 2008).

[20] The water footprint (WF) of a product is defined by Gerbens-Leenes *et al.* (2009) as "the volume of freshwater used for production at the place where it was used. In general, the actual water content of products is negligible compared with their WF, and water use in product life cycles are dominated by the agricultural production stage. The WF consists of 3 components: the green WF, the blue WF and the grey WF. The green WF refers to rainwater that evaporated during production, mainly during crop growth. The blue WF refers to surface and groundwater for irrigation evaporated during crop growth. The grey WF is the volume of water that becomes polluted during production, defined as the amount of water needed to dilute pollutants discharged into the natural water system to the extent that the quality of the ambient water remains above agreed water quality standards."

In addition, climate change may influence precipitation and evaporation patterns. This, in turn, affects factors such as local water availability, river discharge and seasonal availability of water (Arnell *et al.,* 2011). Climate change is likely to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions. This will intensify competition for water among agriculture, ecosystems, human settlements, industry and energy production, thereby affecting regional water, energy and food security (IPCC, 2014c).

7 Food security

On the one hand, the development of biofuels may lead to opportunities to generate income and expand agricultural production technologies in developing countries, improving the purchasing power of farmers and decreasing vulnerability to price shocks for food and energy (Ewing and Msangi, 2009). On the other hand, a shift of areas traditionally used for food production for producing biomass crops could increase food prices and create new — or exacerbate existing — food security problems by pricing consumers out of the market. This "food vs fuel" dilemma is thought to be most intense in areas that are most vulnerable to food insecurity, in particular the arid and semi-arid countries of Africa. The dilemma is further complicated when projected global climate change scenarios and the potential impacts on Africa and other food-insecure areas of the world are taken into account.

OECD/FAO (2010) estimated that sub-Saharan Africa and Latin America (excluding Brazil) accounted for only about 0.07% and 1%, respectively, of the global biofuel production during 2007-09, whereas projections for 2019 show slight increases to 0.08% and 1.09%. Other experts predict that future global demand for biofuels will provide significant opportunities for African exporters. This, along with the high price of fuel and rising domestic demand in Africa, may lead to an increase in the production of biofuel feedstocks, possibly contributing to increased food insecurity (Mitchell, 2011).

From 1970 to 2010, per capita world food production grew by 17%; in Africa, it fell 10% as population growth outstripped agricultural output, which remained relatively stagnant. Therefore, when considering options to expand low GHG biofuel production, perhaps the most important contemporary issue is the perceived competition with food production. Biofuel feedstock production is likely to affect food security both directly and indirectly. In terms of direct effects, the focus for biofuel production is likely to shift to developing countries in the coming years due to the lower costs of production and labor, lower effective land rents and lower processing costs (Worldwatch Institute, 2006). According to several reviews (Bates *et al*., 2008; FAO, 2008a; Mitchell, 2008; Peña,

2008; Chakravorty *et al.,* 2014), the growing demand for biofuels feedstock apparently contributed to rising food prices; this, in turn, threatened food security for many developing countries, even though other variables (e.g. oil price, trade barriers, dollar volatility, droughts, food stock variations) have been primarily responsible for higher food prices worldwide (ISO, 2009). More recently, the assumed correlation between increasing biofuel production and consumption, and increased food prices, has been called into question. Baffes and Dennis (2013) concluded "that most of the [food] price increases are accounted for by crude oil prices (more than 50 percent), followed by stock-to-use ratios and exchange rate movements, which are estimated at about 15 percent each. Crude oil prices mattered most during the recent boom period because they experienced the largest increase."

Biofuels can have varying effects on food prices. For instance, corn-based ethanol affected grain prices that peaked in 2008, but sugarcane had no discernable impact on them (ISO, 2009). The Partners for Euro-African Green Energy (PANGEA, 2012) also showed the US and EU biofuel mandates have had no impact on food prices in sub-Saharan Africa. They also noted that biofuels can help reduce risks in least developing countries caused by high volatility of international food prices, as well as improve and balance the local agricultural market.

In many regions of the world, such as Africa and South Asia, crop yields are lower than could be expected based on soils and climate. For example, FAO data on six field crops from 1961-2005 showed the rate of average annual percent yield increases was declining, with African cereal yields remaining around 1.5 t/ha (UNCEA, 2009). In such regions, biofuel production, if accompanied by agricultural intensification leading to increased crop yields, may not lead to any adverse implications for food security. Further, commercial biofuel production may increase farmers' income, generating capital to invest in agricultural practices (such as irrigation and land development) and livestock sectors; this, in turn, could increase crop yields.

Agricultural intensification in Asia and Africa could hold the key for making land available for biofuel production. The global crop land area required for agricultural production may grow substantially, however, due to a strong increase in meat consumption worldwide, among other factors. In that case, displacement effects, land conversion and related direct and indirect impacts may be challenging; they could still be avoided through wide adoption of robust production standards for biofuels (UNEP, 2009; UNEP/FAO/GEF, 2013).

The production of biofuels can lead to other positive impacts on food security. The steep cost of transporting fertilizers to the farm, for example, means that African farmers typically pay two to six times the global cost of fertilizers. This is a major obstacle to increasing production (Mitchell, 2011;

Accenture, 2013). Local biofuel production, if cost competitive with petroleum fuels, could help reduce transport costs (although fuel costs are a small share of the total costs). This would, in turn, reduce vulnerability to volatile fossil fuel prices.

Secure, affordable and reliable energy inputs to food production systems are also a prerequisite to stabilizing and then increasing local food production and the resilience of long-term markets for that production (FAO, 2011). Yields of staple crops such as corn, rice, groundnuts and sorghum in the rural areas of developing countries are 30% to 60% lower than the global average. If the growing populations in these countries are to eat nutritious and safe foods, yields of staples urgently need to increase through improved management, new gene stocks, additional nutrients and, where practical, irrigation. Judicious use of fertilizers can produce large yield increases.

Finally, energy inputs are critical to enhance food supply chains for tillage, irrigation, harvesting, drying, storage (decreasing wastage, spoilage and contamination), pre-processing, transport and cooking (FAO, 2011). In addition to their transport applications, biofuels are used in all parts of the food supply chain. As a result, in countries vulnerable to food insecurity, Lynd and Woods (2011) suggest that any new biofuel project should demonstrably support local food security through provision of energy products to the food supply chain. Therefore, where feasible, biofuels production should primarily support food production with new GEF projects, preferably contributing to, and being integrated with, the local agribusiness chain.

8 Typology of biofuel technologies that can deliver GHG benefits

The expansion of biofuels to replace fossil fuels generates both direct effects (from the supply chain and use of the biofuel) and indirect effects (primarily due to changes in local and international markets [Figure 6]). Thus, innovations to maximize the life cycle GHG benefits of biofuels can occur throughout the direct supply chain for biofuels or in closely associated supply chains and markets affected by biofuel expansion (Pacini and Strapasson, 2012). These innovations in specific biofuel technologies and supply chains can be characterized by:

- impacts of direct land-use change (positive and negative depending on site and mechanism) with land management innovation (e.g. no-till, minimum-tillage, precision agriculture, organic production schemes, plant genetic improvements), crop development and breeding (often linked to management options)
- greater efficiency in logistics, storage, transport and conversion systems, often linked to changes in biomass quality achieved through innovative approaches outlined above, but also in areas

such as bio-refining, co-production of heat and electricity and associated investment requirements for high pressure/high temperature facilities

- novel end-use technologies, such as new engine design (e.g. hybrid vehicles, fuel cells), new fuel delivery systems (e.g. pipelines, coastal tankers)
- consequential "indirect" impacts such as displacement of existing production, integrated land management perspectives, impacts on food security (both positive and negative).

Commercially-produced biofuels need to meet national and international norms and standards for diesel, gasoline and aviation fuels. These standards may constrain the feedstocks, conversion technologies and even the ultimate size of the market. For example, the fraction of ethanol or biodiesel that can be blended into gasoline or diesel respectively is often limited to meet fuel quality specifications or to ensure specific combustion conditions occur in an engine. In the US, the maximum ethanol blend in gasoline (i.e. the blend ratio that would not require technical adaptation in conventional vehicles) is set at 10%$_{vol}$, the so-called "blend wall". To overcome these technical limitations, novel biofuels based on oxygen-free, hydrocarbon molecules are being developed that meet existing fuel specifications, the so-called "drop-in" biofuels.

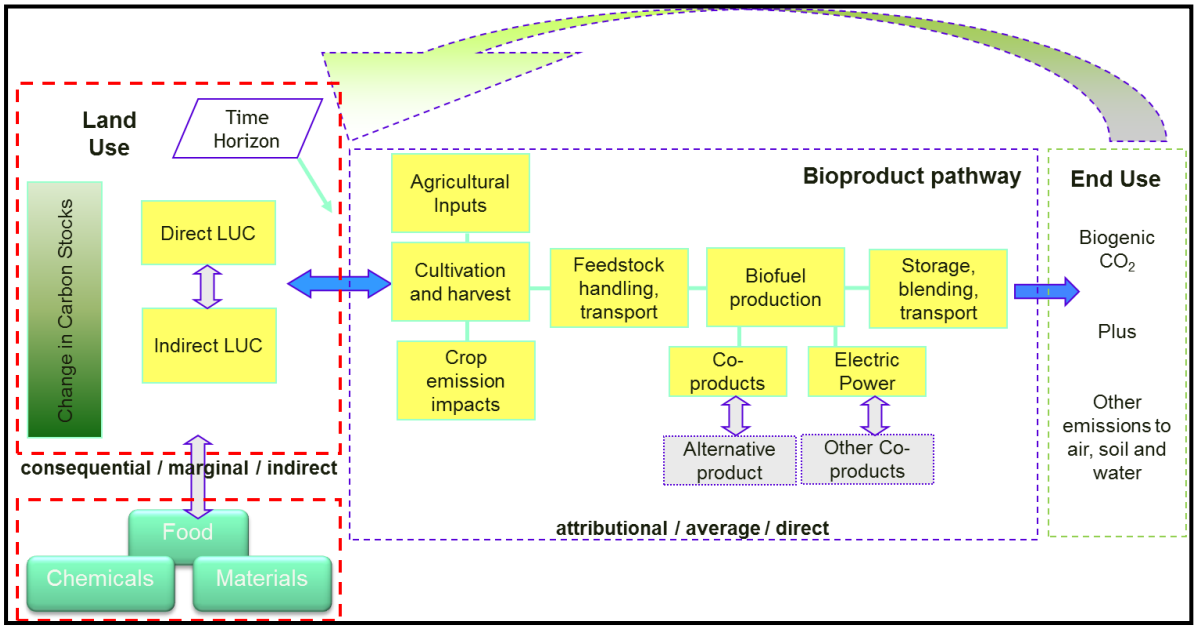


Figure 6: System boundary of a generic biofuel life cycle, identifying processes that should be considered when conducting LCA for GHG emissions.
Source: Tarka-Sanchez *et al.*, 2012.

Despite these limitations, potential biofuel projects cover a very wide range of crop, conversion technologies and end-fuel options that depend highly on site, climate, soils, demographics,

infrastructure (including technological status of vehicles and road infrastructure and markets), technology R&D and implementation capacity.

At a national and sub-national level, the choice of crop, feedstock, conversion system and end fuel is context-sensitive, but broad categories can be developed based on the pre-existing prevailing crops grown and transport infrastructure in place.

Biomass conversion technologies can be broadly characterized as thermochemical and/or biological pre-treatment and conversion. In practice, both types are often used in an integrated conversion facility, which are often poly-generation facilities (also known as "bio-refineries") that co-produce biofuels, electricity, heat and sometimes other chemicals. As such, integration can be a critical element to the cost-effective co-production of a food product (e.g. crystalline sugar in an annexed ethanol/sugar mill). Similar outcomes are seen in large-scale biodiesel production plants such as palm-oil mills, which treat organically-rich effluent streams with anaerobic digestion systems and use the resulting biogas to provide heat to process the palm oil and generate electricity to power the plant with any surplus exported to the grid. Examples of supply chains in the different donor-recipient regions appear in Table 8 and Table 9 (based on Lane, 2012; Bacovsky *et al.,* 2013).

Table 8: Selected example of biofuel supply chains by region and commercialization status.

Commercialization state	Region	Selected technology supply chain options (and leading companies)
Dissemination	Africa	Microbial ligno-cellulosic ethanol systems Novel catalysis for biodiesel production
	Latin America	Advanced gasification/pyrolysis, ligno-cellulosic ethanol (CTBE, CTC, Petrobras, Mascoma); sugarcane diesel (Amyris); irrigated oil palm, *Jatropha* without toxins (Embrapa, Brazil)
	S&SE Asia	Advanced gasification/pyrolysis (India, IISc); algae ethanol (Bankchak Petroleum, Thailand); biochemical from glycerine (GlycosBio, Malaysia; Vinythai, Thailand); biobutanol (GreenBiologics, China); aviation biofuels (Sinopec, China; Wilmar, Indonesia)
Demonstration	Africa	*Jatropha* biodiesel Straight/pure vegetable oil (oil palm residues in Ghana, Sierra Leone) Integrated food/biofuel production systems at small to medium scale (groundnut biodiesel R&D just starting; Afrinut, Malawi for aflatoxin control)
	Latin America	Bio-refinery pilot plant and bagasse-to-ethanol technologies (CTBE, Petrobras, GraalBio, Brazil); indigenous oil palms (Embrapa, Brazil); sugarcane plantation with one-bud technology (Syngenta, Brazil)
	S&SE Asia	Ethanol and electricity from municipal waste (LanzaTech, India) or industrial gases (LanzaTech, China)
Diffusion	Africa	Sugarcane to ethanol with enhanced bio-electricity production e.g. Malawi, Sierra Leone, Zimbabwe, Mozambique, Sudan and Kenya; *Jatropha* biodiesel (as part of the Mali multi-purpose platform project, also Malawi BERL project) Advanced/clean cook-stoves fueled by ethanol
	Latin America	Soya bean, oil palm and animal fat biodiesel; cassava and sugarcane ethanol. Sugarcane bagasse for cogeneration in the ethanol mill. Biogas from animal wastes, sewage treatment and landfills
	S&SE Asia	Palm oil biodiesel, cassava, and sugarcane ethanol, including molasses; biogas from animal wastes and sewage treatment

Table 9: Type, typology and assumptions for sustainable biofuels production.

Biofuel type	Typology of option	Conditions/assumptions
Diesel substitution/ replacement options	Soya production for animal feed with co-production of oil for biodiesel	Give preference for production systems that enhance soil organic matter (e.g. through no-till or minimum tillage technologies) and improve land productivity. Ensure that crop production will not expand onto protected areas.
	Jatropha on waste/ degraded lands	Whenever possible, stimulate production on degraded/ marginal lands, but remain aware of risks of lower yields. High, and often sustained, investment is required to restore productive quality of the soils.
	Community-scale oil palm production	Promote projects that involve (at least partially) small farmers in the production chain, e.g. by integrating them into a feasible industrial scale. The oil palm expansion has to be on degraded or agricultural lands, preferably through agro-ecological zoning (AEZ) schemes and never on protected areas or peat soils.
	Hydrotreated vegetable oil (HVO)	The hydrogenation of pure or used vegetable oils allows the resulting drop-in biofuel to be easily blended with existing diesel and aviation fuels. Concerns: large-scale nature and rapidity of scale-up disconnected to feedstock supply issues.
	Micro algal systems	Preferred technology for waste/contaminated water treatment. Niche applications, but promising area for research and development.
	Gasification + Fischer Tropsch	The resulting bio-oil can be co-fed into an oil refinery with crude oil. Supporting projects based on sustainable biomass. Likely to be large to very large scale.
Gasoline substitution/ replacement options	Ethanol production	Large-scale ethanol plants should preferably involve (at least partly) local farmers, e.g. through the integration of smallholder producer cooperatives. The production system should whenever possible maximize use of residues (e.g. bagasse, vinasse) in the production chain and minimize environmental impacts. Novel crops such as sweet sorghum should be considered, particularly if smallholder farmers are involved. The risks of such novel cropping systems should also be considered carefully.
Aviation biofuels	Algal/*Jatropha/* starch/sugars	Investments in research, development and demonstration (RD&D) based on efficient crops in terms of energy and carbon balances.
Drop-in fuels	Butanol/biofene/HVO	
	FT-diesel, gasoline & naptha (BTL)	

Huge resources, both human and financial, are being invested to develop ligno-cellulosic decomposition and biofuel synthesis technologies in the US and Europe. But significant doubt exists about whether these technologies will become fully commercial in 5, 10 or even 20 years. In part, the emergence of shale oil and tight gas has reduced the price for fossil fuels and made it more challenging to develop biofuel technology and bring it to market (Burnham *et al*., 2011). Technological innovation for biofuel production spans the entire range from blue-sky research to large-scale commercial. The GEF should assess project proposals, particularly if medium-to-large scale, against internationally accepted "technology readiness levels" as developed by NASA, and should be TRL 5 or higher (Figure 7).

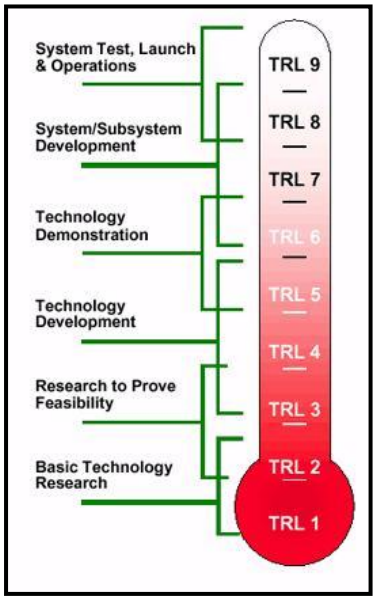


Figure 7: An indication of the technology readiness levels (TRL) achieved during the development of a new technology.
Source: NASA, 1995.

Biofuel conversion technologies such as fermentation and distillation for ethanol production and extraction, as well as esterification technologies, are commercially available and technically viable. However, they are sensitive to national policies supporting biofuels or fossil fuels. Chum *et al.,* (2015) provide a detailed review of biofuel conversion technologies by highlighting the very recent emergence of advanced biofuel conversion technologies. They state that "many process configurations are [now] being tested in pilot and demonstration stages around the world."

Box 4: Processing technologies for second generation biofuels.

Conversion of cellulosic material to biofuels involves breaking down the biomass to release the sugars effectively locked in the complex ligno-cellulosic structures, followed by a range of processes to convert the sugars to biofuels. The ligno-cellulosic structure can be broken down through three different processes (Sims *et al.,* 2008; Black *et al.,* 2011; House *et al.,* 2012):

- **Enzymatic** processes, based on enzymes and micro-organisms, are used to convert cellulosic and ligno-cellulosic components of the feedstock to sugars before their fermentation to produce ethanol or alternative fuel molecules. An indicative biofuel yield through biochemical route (enzymatic hydrolysis ethanol) is in the range of 110 – 300 l (average 200 l) per dry tonne of feedstock.
- **Acidic** processes, which use acid hydrolysis instead of, or in conjunction with, enzymes as described above.
- **Thermochemical** processes, include thermal decomposition using pyrolysis or gasification technologies to produce bio-oils or a synthesis gas (mainly $CO + H_2$); from this, a wide range of long carbon-chain biofuels can be produced called biomass-to-liquids (BTL). An indicative yield of synthetic diesel through the processing of syngas in the Fischer Tropsch (FT) reaction, ranges from 75 to 200 l per dry tonne of feedstock, while syngas-to-ethanol ranges from 120 to 160 l per dry tonne. Drop-in biofuels can be produced by catalytically synthesizing syngas and using hydrogen to remove oxygen; the long hydrocarbon-chain molecules must be similar or identical to those of gasoline and diesel. The derived fuels are often chemically and physically identical to the fossil analogues.

Over the coming decades, the deployment of biofuels at large scale will involve an increasingly wide range of feedstocks (crops, residues and wastes) and an equally broad range of conversion

technologies. (

Pathway ingredient	Fuel widely available today in Europe	No vehicle modification needed	Mass blend option	Refueling infrastructure available now	Significant potential contribution to EU 2020 GHG targets	Significant potential to reduce EU 2030 GHG emissions
	G: Sold and widely available Y: Sold but not widely available R: Fuel not commercially available	G: None Y: Yes but not likely to be significant R: Significant	G: Yes Y: Starting to expand beyond niche areas R: Limited to niche areas	G: Infrastructure already exists Y: Some modification needed R: Significant modification needed	G: Yes R: Limited contribution based on ramp-up potential	G: Yes R: Limited contribution based on ramp-up potential
E10 or equivalent oxygenate blend wall	Y	G	G	G	G	G
E20 or equivalent oxygenate blend wall	R	Y	G	Y	R	G
E25/E30 or equivalent oxygenate blend wall	R	R	G	R	R	R
E85	Y	R	R	R	R	R
LC* gasoline drop-in	R	G	G	G	R	G
B7	G	G	G	G	G	G
B10-30	Y	R	R	R	R	R
ED95 in modified diesel HDVs	Y	R	R	R	R	R
LC* diesel drop-in	R	G	G	G	R	G
Hydrotreated/co-processed oils and fats	Y	G	G	G	G	G
Biogas	Y	R	Y	R	G	G

*LC = ligno-cellulose G = green; Y = yellow; R = red

Figure 9; IEA, 2011). A wide array of technical issues (e.g. fuel specifications and engine technology capabilities) and non-technical issues (e.g. availability of feedstocks, public acceptability and innovation timelines) affect the potential market development and deployment of the different biofuel options. Ethanol for gasoline displacement/blending, and biodiesel for diesel displacement/blending are limited; their chemical and physical characteristics differ from their fossil analogue in ways that limit their overall share in fossil fuel blends (

Pathway ingredient	Fuel widely available today in Europe	No vehicle modification needed	Mass blend option	Refueling infrastructure available now	Significant potential contribution to EU 2020 GHG targets	Significant potential to reduce EU 2030 GHG emissions
	G: Sold and widely available Y: Sold but not widely available R: Fuel not commercially available	G: None Y: Yes but not likely to be significant R: Significant	G: Yes Y: Starting to expand beyond niche areas R: Limited to niche areas	G: Infrastructure already exists Y: Some modification needed R: Significant modification needed	G: Yes R: Limited contribution based on ramp-up potential	G: Yes R: Limited contribution based on ramp-up potential
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E20 or equivalent oxygenate blend wall	R	Y	G	Y	R	G
E25/E30 or equivalent oxygenate blend wall	R	R	G	R	R	R
E85	Y	R	R	R	R	R
LC* gasoline drop-in	R	G	G	G	R	G
B7	G	G	G	G	G	G
B10-30	Y	R	R	R	R	R
ED95 in modified diesel HDVs	Y	R	R	R	R	R
LC* diesel drop-in	R	G	G	G	R	G
Hydrotreated/co-processed oils and fats	Y	G	G	G	G	G
Biogas	Y	R	Y	R	G	G

*LC = ligno-cellulose G = green; Y = yellow; R = red

Figure 9), at least until engine technologies change.

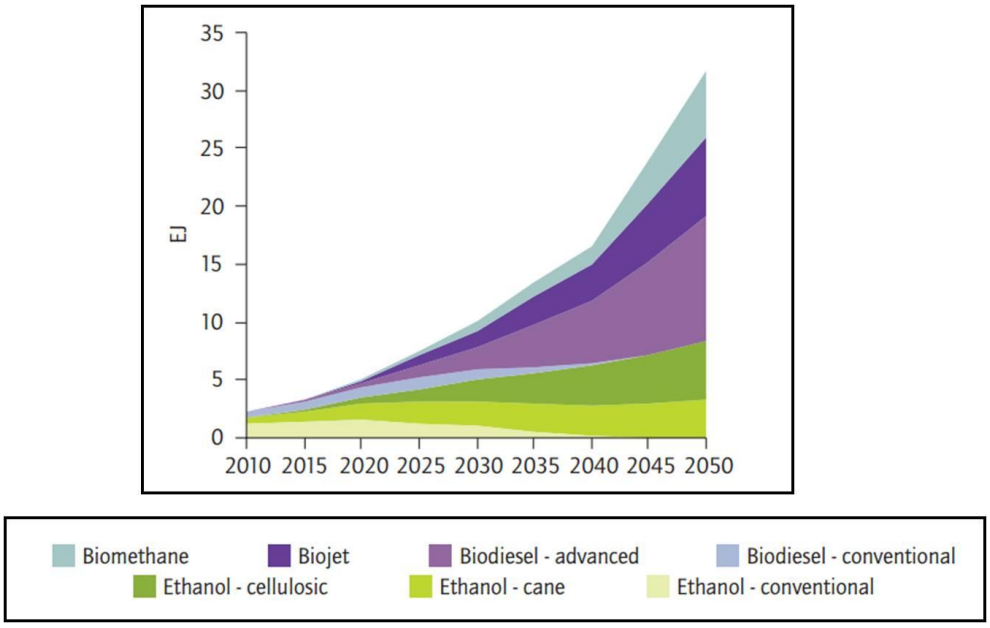

Figure 8: Global production of a range of biofuels in 2010 and forecast production out to 2050.

Source: IEA, 2011.

Technological innovations are overcoming the limitations of conventional biofuels to enable the production of drop-in biofuels (Karatzos *et al.*, 2014). Hydrotreated vegetable oil (HVO) can be regarded as near-commercial (TRL 9; Figure 7). Other options such as Fischer-Tropsch diesel and upgraded pyrolysis oils (TRL 5 or 6) still require further research and development to reduce costs. Entirely novel fuels and supply pathways are also being developed (e.g. algal oils, TRL 6 or 7).

Pathway ingredient	Fuel widely available today in Europe	No vehicle modification needed	Mass blend option	Refueling infrastructure available now	Significant potential contribution to EU 2020 GHG targets	Significant potential to reduce EU 2030 GHG emissions
	G: Sold and widely available Y: Sold but not widely available R: Fuel not commercially available	G: None Y: Yes but not likely to be significant R: Significant	G: Yes Y: Starting to expand beyond niche areas R: Limited to niche areas	G: Infrastructure already exists Y: Some modification needed R: Significant modification needed	G: Yes R: Limited contribution based on ramp-up potential	G: Yes R: Limited contribution based on ramp-up potential
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E20 or equivalent oxygenate blend wall	R	Y	G	Y	R	G
E25/E30 or equivalent oxygenate blend wall	R	R	G	R	R	R
E85	Y	R	R	R	R	R
LC* gasoline drop-in	R	G	G	G	R	G
B7	G	G	G	G	G	G
B10-30	Y	R	R	R	R	R
ED95 in modified diesel HDVs	Y	R	R	R	R	R
LC* diesel drop-in	R	G	G	G	R	G
Hydrotreated/co-processed oils and fats	Y	G	G	G	G	G
Biogas	Y	R	Y	R	G	G

*LC = ligno-cellulose G = green; Y = yellow; R = red

Figure 9: Implementation characteristics of different biofuel-vehicle roadmap options in the European Union.

Source: E4tech, 2013.

9 Barriers to adoption of biofuel projects and areas for GEF support

Project developers and national implementation bodies experience a wide range of barriers when attempting to develop biofuel projects, including:

- technology risk (lack of understanding of development stage of individual technological components across all segments of a production and supply chain)
- lack of capacity for land-use planning and tools for managing incumbent land tenure
- lack of "an integrated energy system strategy" between the heat, electricity and transport energy sectors (GEA, 2012)
- lack of finance for small-scale projects
- differing levels or absence of supporting infrastructure and markets
- short-term outlook and perspectives of policy and financing.

Different funding organizations can help technologies move through the innovation cycle from basic research, piloting and demonstration to market entry (Figure 10). The GEF plays a unique role by supporting innovative and risky investments to stimulate environmental mitigation and adaptation markets in recipient countries, while not directly supporting research. Selecting a promising crop, conversion technology and end-use option to fund a specified biofuel supply chain in a recipient country is complex and may be controversial. The GEF will most likely support projects as they exit the pilot (pre-commercial) stages and enter the commercialization-to-market entry stages. Section 8 reviewed methods for classifying the state of technological development for specific conversion technologies. This section reviews the barriers to financing biofuel projects and discusses opportunities for the GEF to help support the development and implementation of modern biofuel supply chains.

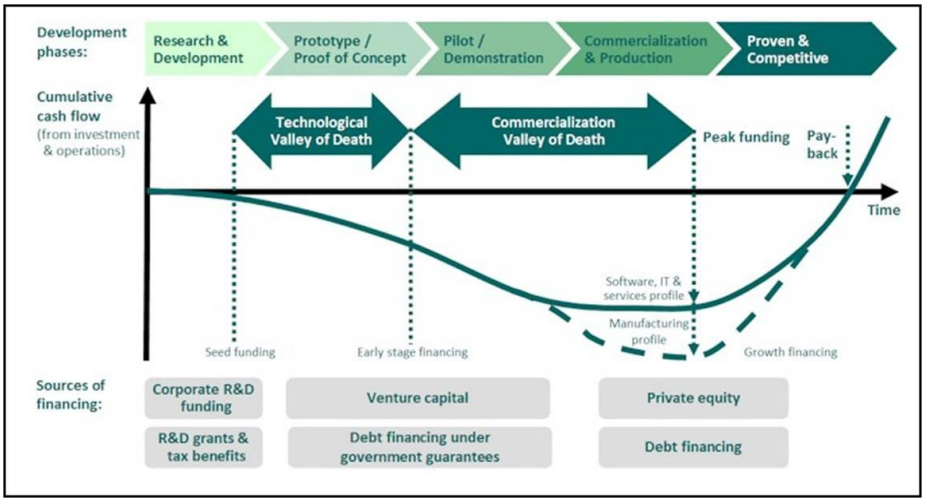

Figure 10: Typical financial investment shares over the development of an innovative and new technology as it moves from early research to market entry having passed through the "valley of death" where many technologies flounder.

Note: IPO = initial public offering

Source: Energy Transitions Group BV, 2013. http://www.energytransitiongroup.com/vision/greengrowth.html

9.1 Financing transformational scales of biofuel production

While major investments will occur in the energy supply industry over the coming decades, costs and financing are a major challenge for the expansion of biofuels industries in developing countries. To avoid exceeding the agreed 2°C target, global investments in combined energy efficiency and supply will need to increase to between US$1.7–2.2 trillion per year compared to present levels of about US$1.3 trillion per year (about 2% of current world gross domestic product), including end-use components (GEA, 2012). Shah *et al.* (2013) estimated that up to $2 trillion per year will be needed to cover additional costs incurred through deployment of carbon abatement technologies (including biofuels) to meet a 2°C carbon mitigation target pathway by 2050. In their *Low Carbon Scenario*, biofuels provide nearly half of the transport energy demand by 2050, with investment in biofuels needed to increase rapidly to displace fossil fuels. Very large scales of investment can favor equally large-scale projects, which may marginalize local communities and smallholder farmers. Historically, economies of scale and the physical properties of fossil fuels have lent themselves to such very large-scale operations and investments (e.g. for mines, oil wells and refineries). Renewable energy technologies tend to operate at much smaller scales, harvesting a diverse range of lower density energy carriers, including biomass, wind and solar.

For biofuels specifically, economies of scale apply particularly for feedstock production and supply that can account for up to 70% of overall costs. Bio-refining technologies are emerging that enable the feedstock biomass to be processed into different product streams. Some fractions may have very high value, but low- volume markets; others, such as energy products, have low value, but high-volume markets. Such technologies also enable access to lower-cost feedstocks (e.g. solid wastes, crop and forest residues) that can make smaller-scale bio-refineries economically feasible and challenge conventional-scale economies when applied to biofuels (Chum *et al.,* 2011). Bio-refining will also affect the economies of scale for conventional supply chains with a tendency to increase capital costs rather than operating costs. Overall, the combination of lower-cost feedstocks and access to higher-value markets is expected to favor smaller-scale bio-refineries. However, clear, low-risk investment and business models are yet to emerge.

Approximately US$500 billion needs to be invested annually in the renewable energy sector between 2030 and 2050 to avoid exceeding a 2°C global temperature rise (REN21, 2014; GEA, 2012);

biofuels account for between US$25–$50 billion of the total investment. Given this challenge, the biofuel sector must be able to deploy US$5–$10 billion of new capacity per year. To that end, the GEF could help develop and direct the sector's investment in capacity building and deployment of sustainable feedstock production systems and supply chains that deliver maximum rates of carbon abatement.

Considerable institutional barriers block delivery of this level of investment, which will be needed mainly in the poorer rural areas of developing countries. From an energy security and energy access perspective, biofuels can provide a low-cost but high-risk option for expanding energy supplies in these areas. The GEF could play a major role in helping deliver the institutional capacity needed to supply this scale of financing and the training involved. For example, partnerships with local governments for promoting new clusters of biofuels production could become catalysts to future business and bring investment to rural areas, particularly in developing countries.

Among a large variety of biofuel projects the GEF could support, critical financing obstacles exist. These affect deployment at scales needed to transform a sustainable biofuels industry from pilot, demonstration and niche commercial activities into one of sufficient scale to be commoditized (Figure 10). Achieving such commodity status requires more countries to produce, export and import biofuels to create robust global markets. Lessons can be learned from Brazil's long-running sugarcane ethanol program; it progressed from a niche national energy security program to a globally competitive, large scale and resilient industry over three decades and now produces fuel-ethanol as a global commodity. Securing this transition from a protected local production and supply industry into a globally competitive one has taken policy persistence and technological innovation. The importance of generating local innovation capacity was highlighted by Furtado *et al.* (2011), using the Brazilian cane ethanol system as an example. "*Brazil's success with sugarcane cannot be understood as based solely on a natural comparative advantage, but as a result of efforts that culminated in a positive trajectory of technological learning, relying mostly on incremental innovations.*" The GEF should evaluate the technological and institutional capacity required to enable such "incremental innovation" over time and how best it can support this capacity development.

GEF biofuel projects could support win-win collaborations between countries with long-term biofuels experience (e.g. Brazil, US, Malawi) and countries with substantial land availability and favorable soil and climate conditions (e.g. Angola, Mozambique, South Sudan, Nigeria, Colombia, Argentina). This could include technical assessments to identify the main bottlenecks such as legislation, tax systems, business models, production chains, storage systems and infrastructure. Developing local biofuel programs, as well as leap-frogging the biofuels' learning curve, are

challenges. Current research and development focuses on lowering biofuel costs, GHG emissions, land and water resource needs, and improving compatibility with fuel distribution systems and vehicle engines. Policy priorities need to be aligned with these R&D objectives, as well as with other policies addressing climate, agriculture, forestlands and international trade (Peña, 2008).

Biofuels are often characterized by long and complex supply chains of the feedstock. Monitoring and verification throughout the supply chain are required to ensure that modern energy services go hand-in-hand with environmental and social co-benefits. This is particularly the case for innovative biofuel supply chains where basic sustainability metrics are not well established. Given the need for quality-assured and scalable production, the commoditization of ethanol, such as in Brazil and the US, is leading to new standards, independent certification schemes, reductions in price volatility and risk to biofuel supplies.

For all these reasons, in addition to supporting biofuel production projects using specific crops and conversion technologies, sustainable public and private investment in developing countries is needed to support areas indirectly tied to the biofuel production projects, over the short, medium and long-terms. A non-exhaustive list of strategic areas for GEF investment is provided in Table 10.

Table 10: Strategic themes for GEF funding support for biofuels to help overcome barriers to widespread adoption.

Strategic themes	Description
National mapping schemes	Support the preparation and implementation of agro-ecological zoning in developing countries to guide biofuel expansion in harmony with agriculture and nature conservation objectives. Mapping tools can help the sustainable expansion of biofuels, by avoiding deforestation or competition with food production, when guiding further public policies involving financing, environmental license and new tax system schemes (Strapassson *et al.,* 2012).
Energy crops	Promote investment in projects with high-efficient crops with agronomic technologies already available. Sugarcane-based ethanol and palm-based biodiesel are examples, but in some market niches other crops can also be viable. These include the use of dedicated energy crops (vegetative grasses and short and long rotation forestry crops, as well as crop residues and by-products).
Regional centers of excellence	Create new research centers on biofuels, or improve existing centers of excellence, in selected developing countries to promote applied research related to the production of new crop varieties, agricultural stewardship, waste use (e.g. plant breeding, biomass decomposition, vinasse, molasses, crop residues and animal fats), integrated industrial process, among other key areas. Such centers will also act as hubs for private sector investment.
Capacity building	Promote capacity building programs for farmers and policy makers and technology transfer and extension support schemes. The viability of biofuels production depends to a large extent on the scale of application. Therefore, to preserve the livelihoods of small farmers and integrate them into a medium/large-scale bio-refinery scheme, they should be mobilized through collective schemes, such as farmers' cooperatives and associations. The creation of a "cooperative culture" depends on capacity building programs, regulation and supportive contracts, which should be implemented *in loco* and include issues regarding cooperatives' establishment, structures and management.
Policy guidance	Support the development of biofuels policies such as the preparation of reports, guidelines and training programs that may help elaborate a legal framework; sustainability monitoring against agreed standards; market regulation; financing; tax system; mapping tools; stock management; blending schemes; logistics; and infrastructure. Many countries want to start biofuels

	programs, but have no support for preparing strategic overarching policies to assure stable and transparent rules for investors that benefit society. They could benefit from solutions applied in countries with longer experiences in biofuels (e.g. Brazil, Argentina).
Demonstration projects	Develop and demonstrate “flagship” sustainable conventional and advanced biofuel production systems, including field trials to assess water supply and demand, suitable crop rotations, and industrial pilot projects and prototypes.

Box 5: Sustainable biofuel production standards.

The environmental and socio-economic implications of biofuel production are specific to location and production systems, but adverse effects can be kept to a minimum through the development and enforcement of sustainable biofuel production criteria and standards. Biofuels have attracted the attention of the UN Framework Convention on Climate Change (UNFCCC), the Convention of Biological Diversity (CBD), the Food and Agriculture Organization (FAO) and the International Union for Conservation of Nature (IUCN), as well as the EU, US and many other countries. Some international initiatives (e.g. the Global Bioenergy Partnership – GBEP; the International Organization for Standardization – ISO; Roundtable for Sustainable Biomaterials – RSB; Roundtable for Sustainable Palm Oil – RSPO; the International Energy Agency – IEA/Bioenergy Tasks) and individual countries are developing sustainable biofuel production norms, policies and guidelines.

While globally relevant principles and criteria for assessment can be defined, indicators for sustainability may have to be region- and even country-specific. Efforts to develop sustainable biofuel criteria and standards include sustainability criteria under the UK's Renewable Transport Fuels obligation, the score card system of the Inter-American Development Bank (IADB) and the EU Renewable Energy Directive (RED). In June 2007, a Roundtable on Sustainable Bioenergy (RSB), now called the Roundtable on Sustainable Biomaterials, was convened to address the sustainability issue of biofuels. In adopting its RED in 2009, the EU committed to sustainable biofuel production with the adoption of sustainability criteria to monitor competition with land and water for food crops and to limit the GHG emissions from land conversion. The directive applies in EU countries and their biofuels trading partners (EU RED Directive, 23 April 2009).

The US has also revised the Environmental Protection Agency's bill on sustainable biofuel production standards (Renewable Fuel Standard 2). The bill confirms that support for sustainable production should not compete with land and water for food, or add to net GHG emissions. Internationally, the United Nations Environment Programme (UNEP), supported by the GEF, commissioned a study (*Global Assessments and Guidelines for Sustainable Liquid Biofuels Production in Developing Countries*) and a complementary assessment tool (*Biofuel Greenhouse Gas Calculator*). The study addressed issues such as life-cycle energy and GHG assessment, economics, social/food security and pricing, as well as overall environmental impacts (Franke *et al.*, 2013, also UNEP, 2011). The tool identified and assessed sustainable systems for the production of liquid biofuels both for transport and stationary applications (Franke *et al*., 2013). It can be used to screen existing projects against sustainability criteria and to assess an existing project's overall sustainability performance. IUCN has also developed sustainability criteria for biofuel production focusing on implications for biodiversity, and discourages biofuel production that involves conversion of land-use systems rich in biodiversity. The GBEP[1] has also developed sustainability criteria (GBEP, 2011) and indicators, and along with UNEP, FAO and GEF (GBEP, 2014), jointly produced guidelines for policy makers, procedures and tools to assess sustainable bioenergy development, including trade-offs between different policy objectives. See Table 11 for a list of the main international standards and norms for sustainability assessment that evaluate biofuel production and use.

Table 11: List of main sustainability assessment standards and guidelines for assurance and certification of biofuels and of biomass feedstocks used in their production.

Standard or Guideline	Reference Source	Comments
Roundtable on Sustainable Biomaterials (RSB)	http://rsb.epfl.ch/files/content/sites/rsb2/files/Biofuels/Version%202/PCs%20V2/10-11-12%20RSB%20PCs%20Version%202.pdf	Standard for assurance and certification of sustainable biofuels production and processing.
Inter-American Development Bank Sustainable Energy and Climate Initiative (SECCI) and its Biofuels Sustainability Scorecard (IDB)	http://www.iadb.org/scorecard/	Assesses the economic viability of biofuels and bioenergy development.
International Sustainability & Carbon Certification (ISCC)	http://www.iscc-system.org/en/	Standard to reduce the risk of un-sustainable biofuel production and for use as a proof of GHG emissions of biofuels on a life cycle basis.
Roundtable on Sustainable Palm Oil (RSPO)	http://www.rspo.org/?q=search/node/standard	Standard to promote the growth and use of sustainable palm oil through cooperation within the supply chain.
The Round Table on Responsible Soy (RTRS)	http://www.responsiblesoy.org	Promotes responsible soy (soya bean) production. Standard on development
Bonsucro / Better Sugarcane Initiative (BSI)	http://www.bonsucro.com/	Standard to reduce negative social and environmental impacts of sugar cane production
UK Assured Combinable Crops Scheme (ACCS)	http://assurance.redtractor.org.uk/rtassurance/farm/crops/cr_about.eb	Agricultural standard; part of an initiative with a wider reach than simply biofuel feedstocks, but modified to include biofuels under UK's RTFO. Includes wheat and rape seed-based biofuels.
IPCC guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use.	http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html	Provides guidelines for calculating the greenhouse gas emissions and carbon stock changes from land use/land-use change.
Global Bioenergy Partnership (GBEP)	http://www.globalbioenergy.org/	Establishes environmental criteria and indicator for biofuels. GBEP is an official initiative (i.e. governmental approach) that involves the main biofuels-producing countries and UN institutions.
International Organization for Standardization (ISO)	www.iso.org	Developing standard on sustainability criteria for bioenergy. Once developed, this ISO standard would allow existing (and future) assurance and certification standards to operate under a common, quality assured, baseline.

10 Guidelines for GEF support of sustainable biofuels

10.1 Principles to guide GEF strategy for biofuels

Using the following five principles from STAP (2012), five principles are outlined to help the GEF develop a strategy for supporting sustainable biofuels

Principle 1: Define common goals with differential delivery approaches, taking into account differing geographies and levels of national development. Focus on rapidly urbanizing economies to enable deep emissions reductions, while supporting energy access.

Biofuel supply chains that co-produce food and fuel, and supply reliable and locally value-added transport fuels to rapidly urbanizing economies, will deliver mitigation, adaptation and increased resilience to food supply chains in these countries if carefully implemented.

Energy crops that need to be processed rapidly (e.g. oil palm, sweet sorghum and sugarcane), require the biofuel conversion industry to be near the plantation fields; otherwise, the raw material will deteriorate, reducing competitiveness. Thus, the producing country could process and use raw materials domestically, and export any excess as an industrialized biofuel product with added value, such as ethanol or biodiesel. This also stimulates rural development and supports small cities in the interior through biofuels agro-industries, generating income and new jobs locally. To an extent, it also helps control urban migration.

In addition, some conversion plants (mills) can use the biofuel processing residues (e.g. sugarcane bagasse or empty palm fruit bunches) to generate heat and electricity with surplus electricity exported to the grid. This power can support energy access in the rural areas of developing nations. Agro-ecological zoning programs can guide expansion onto suitable areas in harmony with the rural development objectives of poor regions. Therefore, some schemes can catalyze a series of social, environment and economic benefits from developing biofuels programs (i.e. by meeting common goals with different delivery approaches).

Principle 2: Enhance leverage of available global climate financing.

By linking food and energy security, agricultural development and financing to climate change mitigation, biofuel projects could leverage funding through careful coordination with public investors (regional development banks) and private companies (multinationals, entrepreneurs). Such investment would need to be coordinated within integrated regional and national development frameworks (e.g. energy security and agricultural development roadmaps of the New Partnership for Africa's Development [NEPAD]; under FAO's Integrated Food and Energy Systems program). This

type of integrative approach would avoid the conflicting outcomes that arise when energy, food and climate security aims are targeted in isolation.

Biofuel projects are eligible for several initiatives related to both mitigation and climate financing. More communication is needed between international funding institutions, such as the GEF, World Bank, International Monetary Fund (IMF), African Development Bank (AfDB), Brazilian Development Bank (BNDES), International Fund for Agricultural Development (IFAD), Common Fund for Commodities (CFC), German Agency for Technical Cooperation (GTZ) and the Japan International Cooperation Agency (JICA). These institutions could leverage the results of biofuels initiatives in developing countries by joining efforts and reducing risks for financing programs. Further regulations in the carbon market through the UNFCCC — such as alignment with the Clean Development Mechanism — could also help promote sustainable biofuels in developing countries.

Principle 3: Promote biofuels production, where the necessary economies of scale are based on sustainable issues and are in harmony with the interests of local communities.

Conventional biofuel supply chains deliver co-benefits of energy (biofuels, electricity and heat) or food/feed production. Biofuels can maximize the merits of lower-value residues, by-products and waste streams of food production supply chains. In so doing, they enable more local retention of revenue/values, even when export demand is driving feedstock production. However, the GEF should take care to adequately consider smallholder and subsistence farmers in associated supply chains. To that end, it should consider specific support for small-scale farmers, or transitional strategies for new livelihoods.

As production increases, most biofuels industries decrease marginal costs due to technological advantages in processing larger volumes. Eventually, with increasing costs to transport raw material and diminishing returns from processing technology, it becomes cheaper to build another factory elsewhere. With the exception of some market niches or under strong state protection, small stand-alone biofuels businesses are vulnerable to failure due to lack of market economies over the medium and long terms, especially after a market crisis. Assembling small farmers and local industries through cooperatives, associations and joint ventures can achieve the necessary economy of scale for biofuels. Therefore, biofuels industries usually benefit from having multiple facilities with good infrastructure interconnecting them to reach “critical mass”.

Principle 4: Account for climate risk and ensure the resilience of GEF climate mitigation projects.

Biofuel production can provide alternative markets for spoiled, damaged or contaminated food products and residues/wastes from integrated food-fuel supply chains, and increase the economic resilience of these supply chains. Any consideration of novel energy crops (such as perennial energy

grasses, short or long rotation forests) should quantify and value their role in landscape-level management for carbon stocks, nutrient interception and cycling, biodiversity and fiber provision.

Genetic improvements of energy crop varieties and enhancing germplasm storage nurseries of strategic cultivars can help increase the resilience of agricultural fuels for unexpected changes in local climate, e.g. longer droughts and variable seasons brought on by global climate change. Climate-zoning approaches based on GIS technologies can help alleviate such risks; they can guide the agricultural financing sector to stimulate production only in areas with low climate risk.

Principle 5: Assure transparency, accountability and global learning.

National to global level sustainability assurance and voluntary certification schemes (based on a framework of principles, criteria and indicators) have been developed specifically for biofuels. These include detailed monitoring, measurement and assessment standards and protocols, which have been deployed for large- and small-scale projects. Similar schemes for other commodities (from food, fiber, biochemicals to oil, gas and coal) could minimize distortion of global markets for sustainable products. However, the potential misuse of sustainable biofuels initiatives as non-tariff barriers to protect regional markets, motivated by local lobbies, should be avoided. Strategic and integrative guidance from the GEF to business makers, local organizations and governments would be extremely useful in delivering global low carbon markets for these products.

Biofuel projects supported by international funding sources should be used for global learning. To promote transparency, information could be available online, and stakeholders could be engaged in a representative dialogue. Participation of NGOs, national universities and local governments can also help to promote transparency and accountability, as well as to avoid local corruption, exploitation of people and over-use of natural resources. Sharing international experiences and funding support for technology transfer would accelerate sustainable biofuel production in developing countries.

10.2 Guidance for development and assessment of sustainable biofuel projects

What biofuel technology, scale of implementation, supply chains, capacity building, and enabling and supporting activities should the GEF support? When evaluating and balancing the potential positive and negative impacts of proposed biofuel programs and projects as outlined above, multiple institutional, financial and spatial scales of application for biofuels should be considered.

Proposals for biofuel projects could be screened simply and rapidly to provide constructive feedback to project proponents. This initial assessment should consider potential impacts of the project in the following areas:

- ✓ net GHG emission impact
- ✓ ecosystem service impacts, including biodiversity
- ✓ food supply security impacts
- ✓ land-use changes (both direct and indirect), including deforestation
- ✓ negative and positive societal impacts.

Where projects are deemed high risk and/or large-scale, proponents should be encouraged to report their progress against specified sustainability criteria as defined in voluntary standards and indicators (Section 9**Error! Reference source not found.**). These could be augmented by using the *Global Assessments and Guidelines for Sustainable Liquid Biofuel Production in Developing Countries* (Franke *et al.,* 2013, particularly for large-scale projects in sensitive areas. The GEF should also support national-level capabilities such as zoning, biotechnology and financing (Table 10) to help overcome the barriers discussed in Section 9.

10.3 Safeguards for demonstrably sustainable biofuel projects

The main environmental impacts of biofuels are related to land use, land-use change effects and biomass feedstock production, which have consequences for GHG emissions, food and energy security, forest conservation and afforestation (see Sections 3 to 7).

Rapid and large-scale expansion of biofuels worldwide could exacerbate emissions from land-use change and increase food insecurity risks. Under certain conditions, however, biofuel developments can contribute toward land rehabilitation, infrastructural investment and sustainable development for local communities. They can also be a tool to manage food stocks and, therefore, volatility in domestic food prices. For instance, investments in new biofuel supply chains usually help improve general support infrastructure, as well as local energy access and safe food storage. Perhaps counter-intuitively, the Brazilian biofuel program has deployed systems that have integrated production of different crops and residues, often for electricity generation. This has stimulated new local investment in food crops and production. In so doing, it highlights that while large-scale biofuel production systems are widely believed to compete with food production, the opposite can also occur.

Still, the associated intensification of agricultural (and forestry) production systems through biofuel programs can have negative environmental consequences. Therefore, some key safeguards should be put in place before investing in any biofuel project (

Table 12). Once these safeguards are established, the GEF should assess projects against economic and social indicators before committing funds.

Table 12: Safeguards for demonstrably sustainable biofuel projects.

Main effects	Assumptions
GHG emissions and environmental protection	• Energy crops should demonstrate the ability to produce biofuels with a full life-cycle GHG reduction threshold, preferably of more than 50% emissions reductions compared to reference fossil fuels, also under LCA. • Biofuels expansion should not occur over protected areas or native ecosystems. • Large-scale (e.g. 50 million l per year or more) biofuel plants should be implemented only after an environmental impact assessment (EIA), which should include a water-use/quality assessment.
Food security and energy balance	• In food-insecure countries, biofuel projects should demonstrate a positive net impact on local food security by assessing and mitigating impacts on local food production and access to food (Lynd and Woods, 2012).
Energy security	• Projects should demonstrate increased local provision and access to energy services and have a positive energy balance (preferably output/input >2). High productivity crops and efficient conversion systems can minimize the land area necessary for biofuels production per energy unit delivered.
Social impacts	• Projects should ensure the biofuel project will not cause negative impacts on local communities and that instead enhance local land tenure, avoid competition for local food production and enhance energy service provision, particularly for cooking. • Projects should integrate stakeholder consultations to avoid potential conflicts of interest.

11 Conclusion and Recommendations

Biofuel production can yield net GHG benefits with minimal negative and potentially positive environmental and socio-economic outcomes. This is especially true when energy crop areas are expanded onto currently low-yielding crop or pasture lands, or on abandoned or degraded lands. To ensure maximum benefits, energy crop production should be based on best practices that optimize the use of synthetic fertilizers, pesticides and irrigation in ways that protect or enhance soil quality.

The co-benefits of biofuels should be clearly identified. Ideally, biofuels should primarily be used locally for multiple purposes, such as to provide rural energy services and transport fuels. Alternatively, they could be exported for use as transport fuels but only where the revenue from such markets can be used to support the development of local food and energy markets for the benefit of biofuel-producing communities. A biofuel project should sufficiently protect the interests of local rural stakeholders.

Clearly, the GEF should *not* support projects that involve:

- the conversion of natural forests, wetlands or biodiversity-rich native grasslands
- the use of inefficient energy conversion technologies, (i.e. where the resulting biofuels have a negative net energy balance)
- the use of food crops for biofuel feedstocks (unless the food product is in surplus or any food crop co-products and residues are the biomass resource)
- the acquisition of significant shares of land from smallholder farmers for large-scale commercial biofuel production, especially for export biofuels.

Recommendations for GEF support for biofuels are specifically aligned with the five principles for supporting GHG mitigation as outlined in *Climate Change: A Scientific Assessment for the GEF* (STAP, 2012) (Annex 1). The GEF – 6 strategy for whole system, integrated approaches directly applies to biofuels. Without such a systems-level approach, it would be difficult to evaluate individual biofuel projects against the global environmental benefits required by the GEF. Specific recommendations for the GEF Council and the GEF Secretariat are discussed throughout the paper and in the Executive Summary.

Given global energy trends — such as increased demand for energy services in developing countries, irreversible global climate change and the pressing need for energy security — bioenergy will clearly need to be included in future low-carbon energy systems. The GEF is ideally positioned to help support future development of biofuel projects that significantly reduce GHG emissions, that

minimize the risk of negative environmental and social impacts, and that promote positive environmental, economic and social outcomes.

References

Accenture (2013). *Food for Thought: Unlocking the Economic Potential of Sub-Saharan Africa by Addressing Food Security*. http://www.accenture.com/za-en/Pages/insight-unlocking-sub-saharan-africa-food-security.aspx.

Akhurst, M., Kalas, N., and Woods, J. (2011). Synthesis of European Commission biofuels land use modelling. *Science Insights for Biofuel Policy*. March 2011 (1). LCA^{works} and Porter Institute, Imperial College London, UK.

Alongi, S., Berndes, G., and Woods, J. (2013). Integration of bioenergy systems into UK agriculture – new options for management of nitrogen flows. *Biomass and Bioenergy* 54:219–226.

Amaral, W.A.N., Marinho, J. P., Tarasantchi, R., *et al.* (2008). Environmental sustainability of sugarcane ethanol in Brazil. In: Zuurbier, P. and van de Vooren, J. (eds.), *Sugarcane Ethanol: Contributions to Climate Change Mitigation and the Environment.* Wageningen: Wageningen Academic Publishers, 113–138.

Arnell, N.W., Van Vuuren, D.P., and Isaac, M. (2011). The implications of climate policy for the impacts of climate change on global water resources. *Global Environmental Change* 21:592–603.

Bacovsky, D., Ludwiczek, N., Ognissanto, M., *et al*. (2013). Status of advanced biofuels demonstration facilities in 2012. *A Report to IEA Bioenergy Task 39*. Report, T39-P1b, 18 March 2013.

Baffes, J., and Dennis, A. (2013). Long-term drivers of food prices. *Policy Research Working Paper* 6455. World Bank, Washington, D.C.

Bailey, R. (2013): *The Trouble with Biofuels: Costs and Consequences of Expanding Biofuel Use in the United Kingdom.* Chatham House, London. http://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy%2C%20Environment%20and%20Development/0413pp_biofuels.pdf.

Barney, J.N., and DiTomaso, J.M. (2008). Nonnative species and bioenergy: Are we cultivating the next invader? *Bioscience* 58(1):64–70.

Bates, J., Howes, P., Dent, C., *et al.* (2008). Review of indirect effects of biofuels. *AEA Energy & Environment*. ED43654. Renewable Fuels Agency, UK. http://www.globalbioenergy.org/uploads/media/0806_AEA__Review_of_indirect_effects_of_biofuels.pdf.

Beer, L.L., Boyd, E.S., Peters, J.W., *et al.* (2009). Engineering algae for biohydrogen and biofuel production. *Current Opinion in Biotechnology* 20:264–271.

Black, M.J., Whittaker, C., Hosseini, S.A., *et al.* (2011). Life cycle assessment and sustainability methodologies for assessing industrial crops, processes and end products. *Industrial Crops and Products* 34(2):1332–1339.

Bruinsma, J. (2011*). The Resource Outlook to 2050: By How Much Do Land, Water and Crop Yields Need to Increase by 2050?* Paper presented to: Expert Meeting on How to Feed the World in 2050, held 24-26 June 2009. Food and Agriculture Organization of the United Nations (FAO),

Economic and Social Development Department, Rome. ftp://ftp.fao.org/agl/aglw/docs/ResourceOutlookto2050.pdf.

BSI (2011*). Guide to PAS 2050. How to Assess the Carbon Footprint of Goods and Services*. British Standards Institution, London. ISBN 978-0-580-64636-2.

Burnham, A., Han, J., Clark, C.E., *et al.* (2011). Life-cycle greenhouse gas emissions of shale gas, natural gas, coal, and petroleum. *Environmental Science & Technology* 46(2):619–627.

CARB (2014). *iLUC Analysis for the Low Carbon Fuel Standard (Update).* March 2014. California Air Resources Board, Sacramento, California.

CARB (2009). *Staff Report: Proposed Regulation to Implement the Low Carbon Fuel Standard.* March 2009. California Air Resources Board, Sacramento, California.

Carpenter, S.R., Cararo, N.F., Correll, D.L., *et al.* (1998). Non-point pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8:559–568.

CBD (2008*). Biodiversity and Agriculture – Draft Findings of the Ad Hoc Technical Expert Group on Biodiversity and Climate Change*. London, 17–21 November 2008, Convention on Biological Diversity. http://www.cbd.int/doc/meetings/cc/ahteg-bdcc-01/other/ahteg-bdcc-01-findings-en.pdf.

Cerri, C.E.P., Easter, M., Paustian K., *et al.* (2007). Predicted soil organic carbon stocks and changes in Brazilian Amazon between 2000 and 2030. *Agriculture, Ecosystems and Environment* 122(1):58–72.

CGEE. (2009). *Bioethanol combustível: uma oportunidade para o Brasil*. NIPE/Unicamp & CGEE Centro de Gestão e Estudos Estratégicos, Brasília. http://www.nipe.unicamp.br/2013/docs/publicacoes/bioetanol-combustivel-uma-oportunidade-para-o-brasil.pdf.

Chakravorty, U., Hubert, M.H, Moreaux, M., *et al.* The long run impact of biofuels on food prices. April 2014. *CESifo Working Paper Series* 3876. http://ssrn.com/abstract=2104053.

Cherubini, F., Bird, N.D., Cowie, A., *et al.* (2009). Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Resources, Conservation and Recycling* 53:434–447.

Chown, S.L., Huiskes, A.H.L., Gremmen, N.J.M., *et al.* (2012). Continent-wide risk assessment for the establishment of nonindigenous species in Antarctica. *Proceedings of the National Academy of Sciences of the United States of America*, 109(13):4938–4943.

Chum, H., Nigro, F., McCormick, R., *et al.* (2015). Conversion technologies for biofuels and their use. In: *Bioenergy & Sustainability: Bridging the Gaps*. Scientific Committee on Problems of the Environment (SCOPE), Paris. http://bioenfapesp.org/scopebioenergy/index.php.

Chum, H., Berndes, G., Dhamija, P., *et al.* (2011). In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., et al. (eds). *Bioenergy. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, UK and New York, N.Y.

COMPETE. (2007). *Report on National Policies on Biofuels Sector Development in Sub-Saharan Africa*. Prepared by Jumbe, C., Msiska, F., and Mhango, L. for the Food Agriculture and Natural Resources Policy Analysis Network (FANRPAN) to WIP-Renewable Energies, Germany. Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semiarid Ecosystems – Africa (COMPETE) project, European Union. www.compete-bioafrica.net.

Croezen, H., and Brouwer, F. (2008). *Estimating Indirect Land Use Impacts from By-Products Utilization.* CE Delft, AEA Technology, The Netherlands. http://www.ce.nl/art/uploads/file/08_4723_30.pdf.

Creutzig, F., Ravindranath, N.H., Berndes, G., *et al.* (2014). Bioenergy and climate change mitigation: An assessment. *Global Change Biology Bioenergy.* 24 July.

Crutzen, P.J., Mosier, A.R., Smith, K.A., *et al*. (2007). N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics.* 7:11191–11205. www.atmos-chem-phys-discuss.net/7/11191/2007/.

CTC (Centro de Tecnologia Canavieira or Sugarcane Technology Centre). (2012). Presentation by Gustavo Leite at "Sugar and Ethanol Summit, Brazil Day: a Quantum Leap in Productivity and Sustainability"; 28 June 2012. Promoted by Datagro and the Brazilian Ministry of External Relations. Institute of Directors (IoD), London.

Dale, V.H., Kline, K.L., Wiens, J., *et al.* (2010). Biofuels: Implications for land use and biodiversity. *Biofuels and Sustainability Reports.* January. Ecological Society of America, Washington, D.C.

Danielsen, F., Beukema, H., Burgess, N.D., *et al.* (2008). Biofuel plantations on forested lands: Double jeopardy for biodiversity and climate. *Conservation Biology* 23(2):348–358.

Davis, M.A., Grime, J.P., and Thompson, K. (2000). Fluctuating resources in plant communities: A general theory of invisibility. *Ecology* 88:528–534.

Davis, S.C., Boddey, R.M., Alves, B.J.R*., et al.* (2013). Management swing potential for bioenergy crops. *Global Change Biology Bioenergy* 5(6):623–638.

de Fraiture, C., Giordano, M., and Liao, Y. (2008). Biofuel and implications for agricultural water use: Blue impacts of green energy. *Water Policy* 10(1):67–81.

De Vries, B.J.M., van Vuuren, D.P., and Hoogwijk, M.M. (2007). Renewable energy sources: Their global potential for the first half of the 21st century at a global level: An integrated approach. *Energy Policy* 35(4):2590–2610.

Demirbas, A. (2009). Progress and recent trends in biodiesel fuels. *Energy Conversion and Management* 50(1):14–34.

Donner, S.D. and Kucharik, C.J. (2008). Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. *Proceedings of the National Academy of Sciences* 105(11):4513–4518.

Dutta, K., Daverey, A., and Lin, J-G. (2014). Evolution retrospective for alternative fuels: First to fourth generation. *Renewable Energy* 69:114–122.

E4tech. (2013). A harmonised auto-fuel biofuel roadmap for the EU to 2030. *Final Report*. November. E4tech, London. http://www.e4tech.com/PDF/EU_Auto-Fuel-report.pdf.

Egeskog, A., Freitas, F., Berndes, G., *et al.* (2014). Greenhouse gas balances and land use changes associated with the planned expansion (to 2020) of the sugarcane ethanol industry in Sao Paulo, Brazil. *Biomass and Bioenergy* 63:280–290.

EIA (2013). Independent Statistics and Analysis. Biofuels online database. Energy Information Administration, Washington, D.C. www.epa.gov.

EIA (2008). International Energy Outlook 2008. Energy Information Administration, Department of Energy, Washington, D.C. http://www.eia.gov/forecasts/ieo/.

Elliot, J., Sharma, B., Best, N., *et al.* (2014). A spatial modeling framework to evaluate domestic biofuel-induced land use changes and emissions. *Environmental Science and Technology* 48(4):2488–2496.

EPA (2010). Renewable Fuel Standard Program (RFS2). *Regulatory Impact Analysis*. Assessment and Standards Division, Office of Transportation and Air Quality. U.S. Environmental Protection Agency, Washington, D.C.

Escobar, J.C., Lora, E.S., Venturini, O.J., *et al*. (2009). Biofuels: Environment, technology and food security. *Renewable and Sustainable Energy Reviews* 13(6-7):1275–1287.

Ewing, M., and Msangi, S. (2009). Biofuels production in developing countries: Assessing tradeoffs in welfare and food security. *Environmental Science & Policy* 12:520–528.

FAO. (2012). World agriculture towards 2030/2050: The 2012 revision. Alexandratos, N., and Bruinsma, J. *ESA Working Paper* 12-03. Food and Agriculture Organization, Rome. http://www.fao.org/docrep/016/ap106e/ap106e.pdf.

FAO. (2011). "Energy-smart" food for people and climate. *Issue Paper*. Food and Agriculture Organization, Rome. http://www.fao.org/docrep/014/i2454e/i2454e00.pdf.

FAO. (2008a). *The State of Food and Agriculture in Asia and the Pacific Region*. Rap Publication. Food and Agriculture Organization, Bangkok.

FAO. (2008b). *The State of Food and Agriculture: 2008*. Food and Agriculture Organization, Rome.

FAPRI. (2008). *U.S. Baseline Briefing Book. Projections for Agricultural and Biofuel Markets*. Food and Agriculture Policy Research Institute, Columbia, Missouri.

Fargione, J., Hill, J., Tilman, D*., et al*. (2008). Land clearing and the biofuel carbon debt. *Science* 319:1235–1238.

Fischer, G. and Prieler, S. (2010). Impacts of biofuel expansion on world food systems and the environment. *Elobio WP5: Assessment in Biofuel Policy Impacts in Food and Feed Markets*. www.elobio.eu/fileadmin/elobio/user/docs/D5.2_5.3.pdf.

Franke, B., Reinhardt, G., Malavelle, J., *et al.* (2013). *Global Assessments and Guidelines for Sustainable Liquid Biofuels. A GEF Targeted Research Project*. 29 February 2012. Global Environment Facility, Heidelberg/Paris/Utrecht/Darmstadt.

Fresco, L.O. (2007). *Biomass for Food or Fuel: Is there a dilemma?* Rabobank, University of Amsterdam, the Netherlands.

Furtado, A.T., Scandiffio, M.I.G., and Cortez, L.A.B. (2011). The Brazilian sugarcane innovation system. *Energy Policy* 39(1):156–166.

GBEP. (2014). Global Bioenergy Partnership (GBEP) Toolkit. http://www.globalbioenergy.org/toolkit/en/ (Accessed: 6 August 2014).

GBEP. (2011). *The Global Bioenergy Partnership (GBEP) Sustainability Indicators for Bioenergy*. First edition. Food and Agriculture Organization, Rome. http://www.cleanenergyministerial.org/Portals/2/pdfs/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf.

GEA. (2012). *Global Energy Assessment – Toward a Sustainable Future.* Cambridge University Press, Cambridge, UK and New York, NY and the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

George, B.H. and Cowie, A.L. (2011). Bioenergy systems, soil health and climate change. In: Singh, B., Cowie, A.L., and Chan, K.Y. (eds.) *Soil Health and Climate Change*. *Soil Biology* 2011(29):369–397.

Gerbens-Leenes, P.W., Hoekstra, A.Y., and Van der Meer, T. (2009). The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply. *Ecological Economics* 68:1052–1060.

Gibbs, H.K., Johnston, M., Foley J.A., *et al*. (2008). Carbon payback times for crop-based biofuel expansion in the tropics: The effects of changing yield and technology. *Environmental Research Letters* 3. 034001. IOP Electronic Journals.

Global Calculator. (2014). Global Calculator Project, a joint initiative by UK Department of Energy and Climate Change (DECC, project lead), the European Institute of Innovation and Technology (EIT Climate-KIC), Imperial College London, London School of Economics (LSE), Energy Research Institute (ERI China), EY (India), Climact (Brussels), and World Resources Institute (WRI). www.globalcalculator.org.

Gnansounou, E., Dauriat, A., Villegas, J., *et al*. (2009). Life cycle assessment of biofuels: Energy and greenhouse gas balances. *Bioresource Technology* 100(21):4919–4930.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., *et al.* (2010). Food security: The challenge of feeding 9 billion people. *Science* 327(5967):812–818.

Goldemberg, J., and Guardabassi, P. (2009). Are biofuels a feasible option? *Energy Policy* 37(1):10–14.

GREET1_(2013). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. Argonne National Laboratory, Argonne, Illinois.

GRFA (2010). Press release: Global ethanol production to reach 85.9 billion litres in 2010. Global Renewable Fuels Alliance, Toronto. http://globalrfa.org/news-media/global-ethanol-

production-to-reach-859-billion-litres-in-2010-global-renewable-fuels-alliance-releases-2010-biofuels-production-forecast.

GSI (2008). Biofuels – At What Cost? Government support for ethanol and biodiesel in China. Global Subsidies Initiative, International Institute for Sustainable Development (IISD), Geneva.

Hassuani, S.J. (2005). *Biomass Power Generation: Sugar Cane Bagasse and Trash*. Centro de Tecnologia Canavieira (CTC) and United Nations Development Programme (UNDP), Piracicaba, Brazil. http://www.sucre-ethique.org/IMG/pdf/CTC_energy_-_biomass_1_.pdf.

Havlik, P., Schneider, U.A. Schmid, E., *et al.* (2011). Global land-use implications of first and second generation biofuel targets. *Energy Policy* 39:5690–5702.

Hertel, T., Golub, A.A., Jones, A.D., *et al.* (2010). Global land use and greenhouse gas emission impacts of U.S. maize ethanol: Estimating market-mediated responses. *Biosciences* 60(3):223–231.

Hoogeveen, J., Faurès, J.M., and Van de Giessen, N. (2009). Increased biofuel production in the coming decade: To what extent will it affect global freshwater resources? *Irrigation and Drainage* 58(S1):S148–Sd160.

House, J.I., Bellarby, J., Böttcher, H., *et al.* (2012). Chapter 7. Mitigating climate risks by managing the biosphere. In: Cornell, S.E., Prentice, C.I., House, J.I., *et al.* (eds.) *Understanding the Earth System.* August. Global Change Science for Application, Cambridge University Press, Cambridge, UK and New York, NY. http://www.cambridge.org/9781107009363.

IEA. (2014). *Energy Technology Perspectives.* International Energy Agency, Organisation for Economic Co-operation and Development, Paris. http://www.iea.org/etp/.

IEA. (2012). *Energy Technology Perspectives.* International Energy Agency, Organisation for Economic Co-operation and Development, Paris. http://www.iea.org/etp/.

IEA. (2011). *Technology Roadmap: Biofuels for Transport*. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

IEA. (2010). *IEA Roadmap 2010*. International Energy Agency, Organisation for Economic Co-operation and Development, Paris. http://www.iea.org/roadmaps/.

IEA. (2006). *World Energy Outlook 2006*. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

INPE. (2014). Projeto PRODES: Monitoramento da Floresta Amazônica por Satélite. Brazilian National Institute for Space Research (INPE). http://www.obt.inpe.br/prodes/index.php.

IPCC. (2014a). Agriculture, forestry and other land use (AFOLU). Chapter 11. In: *Mitigation of Climate Change in IPCC Fifth Assessment Report (AR5). Appendix on Bioenergy: Climate Effects, Mitigation Options, Potential and Sustainability Implications*. Intergovernmental Panel on Climate Change Geneva, Switzerland.

IPCC. (2014b). *Mitigation of Climate Change: Technical Summary in IPCC Fifth Assessment Report (AR5).* Intergovernmental Panel on Climate Change, Geneva. http://www.ipcc-wg3.de/.

IPCC (2014c). *Impacts, Adaptation, and Vulnerability: Summary for Policy Makers in IPCC Fifth Assessment Report (AR5).* Intergovernmental Panel on Climate Change, Geneva. http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf.

IPCC. (2011). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Edenhofer, O., Pichs-Madruga, R., Sokona, Y., *et al*. (eds). Cambridge University Press, Cambridge, UK and New York, NY.

IPCC. (2007a). Changes in atmospheric constituents and radiative forcing. Chapter 2. In: *The Physical Science Basis in IPCC Fourth Assessment Report (AR4).* Intergovernmental Panel on Climate Change, Geneva. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2.html.

IPCC. (2007b). *Mitigation of Climate Change: Technical Summary in IPCC Fourth Assessment Report (AR4).* Intergovernmental Panel on Climate Change, Geneva. http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ts.html.

ISO. (2009). *Sugarcane Ethanol and Food Security*. MECAS(09)07. International Sugar Organisation, London. http://www.sugaronline.com/shop_products/view/52356.

Janssen, R., Turhollow, A.F., Rutz, D., *et al*. (2013). Production facilities for second generation biofuels in the USA and the EU – current status and future perspectives. *Biofuels, Bioproducts, & Biorefining* 7(6):647–665.

Jonker, J.G.G., and Faaij, A.P.C. (2013). Techno-economic assessment of microalgae as feedstock for renewable bio-energy production. *Applied Energy* 102:461–475.

JRC. (2013). *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context: WELL-TO-TANK*. Joint Research Centre. Ispra, Italy.

Jongschaap, R.E.E., Corré, W.J., Bindraban, P.S., *et al.* (2007). Claims and Facts on *Jatropha curcas* L.: Global *Jatropha curcas.* Evaluation, Breeding and Propagation Programme, Plant Research International, Wageningen, the Netherlands. http://edepot.wur.nl/41683.

Karatzos, S., McMillan, J.D., and Saddler J.N. (2014). The potential and challenges of drop-in biofuels, *IEA Bioenergy* Task 39. July. http://task39.org/files/2014/01/Task-39-Drop-in-Biofuels-Report-FINAL-2-Oct-2014-ecopy.pdf.

Krausmann, F., Erb, K-H., Gingrich, S., *et al.* (2013). Global human appropriation of net primary production doubled in the 20th century. *PNAS* 110(25):10324–10329.

Kretschmer, B., Allen, B., and Hart, K. (2012). *Mobilising Cereal Straw in the EU to feed Advanced Biofuel Production*. Report for Novozymes. Institute for European Environmental Policy, London.

Laborde, D. (2011). Assessing the land use change consequences of European biofuel policies. *Final Report* October. International Food Policy Research Institute, Washington, D.C.

Laborde, D., Padella, M., Edwards, R., *et al.* (2014). *Progress in estimates of iLUC model with Mirage Model.* Report EUR 26106 EN. Joint Research Centre, Ispra, Italy.

Ladanai, S., and Vinterbäck, J. (2009). Global potential of sustainable biomass for energy. *Technical Report* 013. Swedish University of Agricultural Sciences Department of Energy and Technology, Uppsala.

Lane, J. (2012). The Top 10 Advanced Biofuels and Biorefining companies in Asia. 3 September 2012. www.biofuelsdigest.com (Accessed 9 July 2013).

Langeveld, J.W.A., Dixon, J., van Keulen, H., *et al.* (2013). Analyzing the effect of biofuel expansion on land use in major producing countries: Evidence of increased multiple cropping. *Biofuels, Bioproducts & Biorefining.* 8(1):49–58.

Lapola, D.M., Schaladach, R., Alcamo, J., *et al*. (2010). Indirect land-use changes can overcome carbon savings from biofuels in Brazil, *PNAS* 107(8): 3388–3393.

Laurance, W. (2007). Switch to corn promotes Amazon deforestation. In: Letters, *Science* 318(5857): 1721.

Li, Y., Horsman, M., Wu, N., *et al.* (2008). Biofuels from microalgae. *Biotechnology Progress* 24(4):815–820.

Lynd, L.R., and Woods, J. (2011). Perspective: A new hope for Africa. *Nature* 474:S20–S21.

Macedo, I.C. (2010). Biofuels and sustainability: Brazilian developments, international expansion. Contribution to *Sustainable Biofuels: Recent developments, International Opportunities*. 16 November 2010. Chatham House seminar in collaboration with the Embassy of Brazil and the Imperial College Seminar. Chatham House, London.

Macedo, I.C., Seabra, J.E.A., and da Silva, J.E.A.R (2008). Greenhouse gas emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. *Biomass and Bioenergy* 32:582–595.

Macedo, I.C., Leal, M.R.L.V, and da Silva, J.E.A.R. (2004). *Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil*. The Wilson Center. www.wilsoncenter.org/sites/default/files/brazil.unicamp.macedo.greenhousegas.pdf.

MAPA, Embrapa, MMA, *et al*. 2010. *Palm Oil Agro-ecological Zoning.* Government of Brazil Sustainable Oil Palm Production Program. National coordination group: Campello, T., Brandão, S.M.C., Strapasson, A.B., *et al*. 2010. Casa Civil (Presidency of Republic's Chief Office). Legal framework of the oil palm agro-ecological zoning: Presidential Decree 7.172/2010, Bacen Resolution 3.852/2010, Federal Law Project 7.326/2010. Maps and GIS database edited by Embrapa Soils. Brasília, Brazil.

MAPA, Embrapa, Conab, *et al.* 2009. *Sugarcane Agro-ecological Zoning*. National Coordination Group: Strapasson, A.B., Caldas, C.J., Manzatto, C.V., *et al*. Booklet and video. Casa Civil (Presidency of Republic's Chief Office), Brasilia, Brazil. Publications of the Government of Brazil: Presidential Decree 6.961/2009; Portaria MAPA Ministerial Decree no. 333/2007 and Normative Instruction 57/2009; Bacen Resolution 3.813/2009 and Resolution 3.814/2009; Federal Law Project 6.077/2009. Maps and GIS database edited by Embrapa Soils**.** Brasília, Brazil.

Martinelli, L.A., and Filoso, S. (2008). Expansion of sugarcane ethanol production in Brazil: Environmental and social challenges. *Ecological Applications* 18(4):885–898.

Mayrand, K., Paquin, M., and Dionne, S. (2005). *From Boom to Dust? Agricultural Trade Liberalization, Poverty, and Desertification in Rural Drylands: The Role of UNCCD*. Unisféra International Centre, Montreal.

Melilio, J.M., Reilly, J.M., Kicklighter, D.W., *et al.* (2009). Indirect emissions from biofuels: How important*? Science* 4(326):1397–1399.

Menichetti, E., and Otto, M. (2009). Energy balance and greenhouse gas emissions of biofuel from a product life-cycle perspective. In: Howarth, R.W., and Bringezu, S. (eds.) *Biofuels: Environmental Consequences and Interactions with Changing Land Use*. Cornell University, Ithaca.

Mielke, T. 2007. *Oil World Annual 2007*. Oil World, Hamburg.

Misselhorn, A., Aggarwal, P., Ericksen, P., *et al*. (2012). A vision for attaining food security. *Current Opinions in Environmental Sustainability* 4:7–17.

Mitchell, D. (2011). *Biofuels in Africa: Opportunities, Prospects, and Challenges*. World Bank, Washington, D.C.

Mulder, K., Hagens, N., and Fischer, B. (2010). Burning water: A comparative analysis of the energy return on water invested. *AMBIO* 39(1):30–39.

Murphy, R., Woods, J., Black, M., *et al*. (2011). Global developments in the competition for land from biofuels. *Food Policy* 36(1):52–61.

Nassar, A.M., Harfuch, L., Moreira, M.M., *et al.* (2011). *Simulating Land Use and Agriculture Expansion in Brazil: Food, Energy, Agro-industrial and Environmental Impacts.* Instituição Sede, Instituto de Estudos do Comércio e Negociações Internacionais (ICONE), São Paulo.

NASA (1995). *Technology Readiness Levels. A White Paper*. 6 April. National Aeronautics and Space Administration, Washington, D.C. http://www.hq.nasa.gov/office/codeq/trl/trl.pdf.

O'Connell, D.O., and Haritos, S.V. (2010). Conceptual investment framework for biofuels and biorefineries research and development. *Biofuels* 1:201–216.

OECD. (2008). *Biofuel Support Policies. An Economic Assessment*. Organisation for Economic Co-operation and Development, OECD Publishing, Paris.

OECD/FAO. (2010). *OECD-FAO Agricultural Outlook 2008*. Organisation for Economic Co-operation and Development, OECD Publishing, Paris. http://www.oecd.org/site/oecd-faoagriculturaloutlook/.

Oladosu, G., Kline, K., Uria-Martinez, R., *et al.* (2011). Sources of corn for ethanol production in the United States: A decomposition analysis of the empirical data. *Biofuels, Bioproducts & Biorefining* 5: 640–653.

Pacini, H., and Strapasson, A. (2012). Innovation subject to sustainability: The European policy on biofuels and its effects on innovation in the Brazilian bioethanol industry. *Journal of Contemporary European Research* 8(3):367–397.

PANGEA. 2012. Who's Fooling Whom? The real drivers behind the 2010/2011 food crisis in sub-Saharan Africa. *Report* October 2012. Partners for Euro-African Green Energy (PANGEA), Brussels.

Peña, N. (2008). *Biofuels for Transportation: A Climate Perspective*. Pew Center on Global Climate Change, Washington, D.C.

Pimental, D., Marklein, A., Toth, M.A., *et al.* (2009). Food versus biofuels: Environmental and economic costs. *Human Ecology* 37(1):1–12.

PISCES-FAO. (2009). *Small-Scale Bioenergy Initiatives: Brief Description and Preliminary Lessons on Livelihood Impacts from Case Studies in Asia, Latin America and Africa*. Practical Action Consulting. Policy Innovation Systems for Clean Energy Security (PISCES) and Food and Agriculture Organization (FAO) ftp://ftp.fao.org/docrep/fao/011/aj991e/aj991e.pdf.

Plevin, R.J., Delucchi, M.A., and Creutzig, F. (2013). Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers. *Journal of Industrial Ecology* 18(1):73–83.

Rajagopal, D., Sexton, S.E., and Zilberman, D. (2007). Challenge of biofuel: Filling the tank without emptying the stomach? *Environmental Research Letters* 2:9.

Rajagopal, D., and Plevin, R.J. (2013). Implications of market-mediated emissions and uncertainty for biofuel policies. *Energy Policy* 56:75–82.

Ravindranath, N.H., Manuvie, R., Fargione, J., *et al.* (2009). Greenhouse gas implications of land use and land conversion to biofuel crops. In: Howarth, R.W. and Bringezu, S. (eds.) *Biofuels: Environmental Consequences and Interactions with Changing Land Use.* Cornell University, Ithaca.

REN21. (2014). *Renewables 2014 Global Status Report.* Renewable Energy Policy Network for the 21st Century (REN21). REN21 Secretariat, Paris. http://www.ren21.net.

RFA. (2008). *Changing the Climate: Ethanol Industry Outlook 2008*. Renewable Fuels Association, Washington, D.C.

Righelato, R. and Spracklen, D.V. (2007). Carbon mitigation by biofuels or by saving and restoring forests? *Science* 317(5840):902.

Robertson, G.P., Dale, V.H., Doering, O.C., *et al*. (2008). Sustainable Biofuels Redux. *Science* 322(5898):49–50.

Rosillo-Calle, F. (2012). Food versus fuel: Toward a new paradigm–the need for a holistic approach. *International Scholarly Research Network (ISRN) Renewable Energy* 2012 (Article ID 954180):15 pages.

Royal Society. (2008). Sustainable biofuels: Prospects and challenges. *Policy document* 01/108. Royal Society, London.

RSPB. (2012). *Dirtier than Coal? Why Government Plans to Subsidise Burning Trees are Bad News for the Planet.* Royal Society for the Protection of Birds, The Lodge, Bedfordshire. http://www.rspb.org.uk/Images/biomass_report_tcm9-326672.pdf.

Ruth, L. (2008). Bio or bust? The economic and ecological cost of biofuels science & society. *European Molecular Biology Organization* 9(2):130–133.

Sala, O.E., Sax, D., and Leslie, H. (2009). Biodiversity consequences of increased biofuel production. In: Howarth, R.W. and Bringezu, S. (eds.) *Biofuels: Environmental Consequences and Interactions with Changing Land Use.* Cornell University, Ithaca.

Sangwan, S., Rao, D.V., and Sharma, R.A. (2010). A review on *Pongamia Pinnata (L.) Pierre*: A great versatile leguminous plant. *Nature and Science* 8(11):130–139.

Satolo, L., and Bacchi, M. (2013). Impacts of the recent expansion of the sugarcane sector on municipal per capita income in São Paulo State. *ISRN Economics* 2013 (Article ID 828169):14 pages.

SBSTTA 12. (2007). Recommendation XII/7 – Biodiversity and Biofuel Production. Secretariat, Convention on Biological Diversity (CBD), Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), Paris. http://www.cbd.int/recommendation/sbstta/default.shtml?id=11466.

Scharlemann, J.P.W. and Laurance, W.F. (2008). How green are biofuels? *Science* 319(5859):43–44.

Searchinger, T., and Heimlich, R. (2015). *Avoiding Bioenergy Competition for Food Crops and Land.* World Resources Institute, Washington, D.C.

Searchinger, T., Heimlich, R., Houghton, R.A., *et al.* (2008). Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319(5867):1238–1240.

Shah, N., Vallejo, L., Cockerill, T., *et al.* (2013). *Halving Global CO_2 by 2050: Technologies and Costs.* Imperial College, London. http://www3.imperial.ac.uk/climatechange/publications/collaborative/halving-global-co2-by-2050.

Siangjaeo, S., Gheewala, S.H., Unnanon, K., *et al.* (2011). Implications of land use change on the life cycle greenhouse gas emissions from palm biodiesel production in Thailand. *Energy for Sustainable Development* 15:1–7.

Sims, R.E.H., Taylor, M., Saddler J., *et al.* (2008). *From 1st to 2nd Generation Biofuel Technologies: An Overview of Current Industry and RD&D Activities – Extended Executive Summary.* Organisation for Economic Co-operation and Development/International Energy Agency, Paris.

Slade, R., Saunders, R., Gross, R., *et al.* (2011). *Energy from Biomass: The Size of the Global Resource – An Assessment of the Evidence that Biomass can make a Major Contribution to Future Global Energy Supply*. Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre, London.

Smith P., Bustamante, M., Ahammad, H., *et al.* (2014). Agriculture, forestry and other land use (AFOLU). In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY.

Stanford Woods. (2014). *Biofuels Ideas*. Institute for the Environment, Stanford Woods Institute for the Environment, Stanford, US.

STAP. (2012). Climate Change: A Scientific Assessment for the GEF. Ravindranath, N.H., Sims, R.E.H., Ürge-Vorsatz, D., *et al*. (eds.). Scientific and Technical Advisory Panel to the Global Environment Facility, Washington D.C.

STAP. (2007). *Liquid Biofuels in Transport: Conclusions and Recommendations of the Scientific and Technical Advisory Panel (STAP) to the Global Environment Facility (GEF)*, Washington, D.C. 21 May 2007 GEF/C.31/Inf.7.

Stickler, C., Coe, M., Nepstad, D., *et al*. (2007). *Readiness for REDD: A Preliminary Global Assessment of Tropical Forested Land Suitable for Agriculture*. Woods Hole Research Center, Falmouth, US. www.whrc.org/resources/publications/pdf/WHRC_REDD_crop_suitability.pdf.

Staley, B.C. and Bradley, R. (2008). *Plants at the Pump: Reviewing Biofuels' Impacts and Policy*. World Research Institute, Washington, D.C.

Stone, R. (2007). Can palm oil plantations come clean? *Science* 317(5844):1491.

Strapasson, A.B., Ramalho-Filho, A., Ferreira, D., *et al.* (2012). Agro-ecological Zoning and Biofuels: The Brazilian experience and the potential application in Africa. In: Johnson, F.X., and Seebaluck, V., (eds.) *Bioenergy for Sustainable Development and International Competitiveness - the Role of Sugar Cane in Africa.* Routledge (Taylor and Francis Group), Earthscan Book. 48-65.

Thow, A., and Warhurst, A. (2007). *Biofuels and Sustainable Development*. Maplecroft Report, UK.

Tarka-Sanchez, S., Woods, J., Akhurst, M., *et al.* (2012). Accounting for indirect land use change in the life cycle assessment of biofuel supply chains. *Journal of the Royal Society Interface* 9(271):1105–1119.

Tilman, D., Socolow, R., Foley, J.A., *et al.* (2009). Energy. Beneficial biofuels—the food, energy and environment trilemma. *Science* 325(5938):270–271.

UNCEA. (2009). *Economic Report on Africa 2009. Developing African Agriculture through Regional Value Chains.* United Nations Economic Commission for Africa, Addis Ababa. http://www.uneca.org/publications/economic-report-africa-2009.

UNEP. (2011). *Biofuels Vital Graphics: Powering a Green Economy*. United Nations Environment Programme (UNEP)/GRID-Arendal, Paris. http://www.unep.org/climatechange/mitigation/Portals/93/documents/Bioenergy/VBG_Ebook.pdf.

UNEP. (2009). *Towards Sustainable Production and Use of Resources: Assessing Biofuels.* Working Group on Biofuels of the International Panel for Sustainable Resource Management, United Nations Environment Programme, Paris.

UNEP/FAO/GEF. (2013). *Global Assessments and Guidelines for Sustainable Liquid Biofuel Production in Developing Countries.* United Nations Environment Programme (UNEP), Food and Agriculture Organization (FAO) and Global Environment Facility (GEF),

Heidelberg/Paris/Utrecht/Darmstadt. http://www.unep.org/bioenergy/Portals/48107/publications/Global%20Assessment%20and%20Guidelines%20for%20Biofuels.pdf.

UNICA, Sugarcane Industry Association. 2012. How can Brazil contribute to the sustainability of the European sugar/ethanol sector? Presented by Géraldine Kutas at the *Sugar and Ethanol Summit, Brazil Day: A Quantum Leap in Productivity and Sustainability*; promoted by Datagro and the Brazilian Ministry of External Relations. Institute of Directors (IoD), 28 June 2012, London.

van Vuuren, D.P., Nakicenovic, N., Riahi, K., *et al.* (2012). An energy vision: The transformation towards sustainability — interconnected challenges and solutions. *Current Opinion in Environmental Sustainability* 4:18–34.

Victoria, R., Banwart, S., Black, H., *et al.* (2012). The benefits of soil carbon: Managing soils for multiple economic, societal and environmental benefits. Chapter 2. In: *UNEP Year Book 2012: Emerging Issues in our Global Environment*. UNEP, Nairobi. www.unep.org/yearbook/2012.

Wetlands International. (2008). *Biofuels in Africa. An assessment of risks and benefits for African wetlands.* Wetlands International, Wageningen, the Netherlands. http://www.unido.org/fileadmin/user_media/UNIDO_Header_Site/Subsites/Green_Industry_Asia_Conference__Maanila_/GC13/Wetlands.pdf.

Wicke, B., Verweij, P., van Meijl, H., *et al*. (2012). Indirect land use change: Review of existing models and strategies for mitigation. *Biofuels* 3(1):87–100.

Wise, M., Dooley, J., Luckow, P., *et al.* (2014). Agriculture, land use, energy and carbon emission impacts of global biofuel mandates to mid-century. *Applied Energy* 114:763–773.

Worldwatch Institute. (2006). *Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century – Extended Summary*. German Federal Ministry of Food Agriculture and Consumer Protection. Worldwatch Institute, Washington, D.C.

Woods, J., Lynd, L.R., Batistella, M., *et al.* (2015). Land and Biomass. Chapter 1. In: *Bioenergy & Sustainability: Bridging the Gaps*. Scientific Committee on Problems of the Environment (SCOPE), Paris. http://bioenfapesp.org/scopebioenergy/index.php.

Woods, J., Williams, A., Hughes, J.K., *et al*. (2010). Energy and the food system. *Philosophical Transactions of the Royal Society B* 365(1554):2991–3006.

York, R. (2012). Do alternative energy sources displace fossil fuels? *Nature Climate Change* 2(6):441–443.

Zah R., Böni H., Gauch, M., *et al.* (2007). *Life Cycle Assessment of Energy Products: Environmental Assessment of Biofuels (Executive Summary).* EMPA, Bern.