International Energy Agency

SUSTAINABLE PRODUCTION OF SECOND-GENERATION BIOFUELS

Potential and perspectives in major economies and developing countries

Extended Executive Summary

INFORMATION PAPER

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INTERNATIONAL ENERGY AGENCY

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Extended Executive Summary

CONTEXT

Biofuels currently provide approximately 1.5% of global transport fuel, as a result of rapidly increasing production over the last decade. Led by Brazil and followed by China and Thailand as the largest non-OECD producers, emerging- and developing countries produce roughly 40% of the total global supply of biofuels.

However, this rapidly growing industry has recently raised important concerns. In particular, the sustainability of many first-generation biofuels – which are produced primarily from food crops such as grains, sugar cane and vegetable oils – has been increasingly questioned over concerns such as reported displacement of food-crops, effects on the environment and climate change. It has been shown that some biofuels have low net life-cycle benefits in terms of CO_2 and other emission reductions compared to conventional fossil fuels. Some studies have argued that the CO_2 impact of certain biofuels can be even higher than those of fossil fuels, if land use change is taken into account, although the result depends strongly on the specific biofuel chain and kind of land use change.

In general, there is growing consensus that if significant emission reductions in the transport sector are to be achieved, biofuel technologies must become more efficient in terms of net lifecycle greenhouse gas (GHG) emission reductions while at the same time be socially and environmentally sustainable. It is increasingly understood that most first-generation biofuels, with the exception of sugar cane ethanol, will likely have a limited role in the future transport fuel mix.

The increasing criticism of the sustainability of many first-generation biofuels has raised attention to the potential of so-called second-generation biofuels. Depending on the feedstock choice and the cultivation technique, second-generation biofuel production has the potential to provide benefits such as consuming waste residues and making use of abandoned land. In this way, the new fuels could offer considerable potential to promote rural development and improve economic conditions in emerging and developing regions. However, while second-generation biofuel crops and production technologies are more efficient, their production could become unsustainable if they compete with food crops or conservation areas. Thus, their sustainability will depend on whether producers comply with criteria like minimum lifecycle GHG reductions, including land use change, and social standards.

Research-and-development activities so far have only been undertaken in a number of developed countries and in some large emerging economies like Brazil, China and India. The aim of this study is, therefore, to identify opportunities and constraints related to the potential future production of second-generation biofuels and assess the framework for a successful implementation of a second-generation biofuel industry under different economic and geographic conditions. Therefore, eight countries have been analysed in detail: Mexico, four major non-OECD economies (Brazil, China, India and South Africa), and three developing countries in Africa and South-east Asia (Cameroon, Tanzania and Thailand). The study further assesses the potential of agricultural and forestry residues as potential feedstock for second-generation biofuels. The results of this study help answer, what contribution second-generation biofuels from residues could make to the future biofuel demand projected in IEA scenarios, and under which conditions major economies and developing countries could profit from their production.

Although the study focusses solely on second-generation biofuels, it is acknowledged that certain first-generation biofuels can offer potential benefits for developing countries. However, these aspects, as well as technical issues have been discussed in a number of previous publications (*e.g.* IEA, 2008a).

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SECOND-GENERATION BIOFUELS: POTENTIAL AND PERSPECTIVES

Status quo of second-generation biofuels

The production of first-generation biofuels is in an advanced state with mature technologies and relatively well-understood processing and production pathways. Some emerging countries have successfully implemented a first-generation biofuel industry (*e.g.* Brazil, China, Thailand, Indonesia, and Colombia). On the contrary, second-generation biofuels are not yet produced commercially, but a considerable number of pilot and demonstration plants have been announced or set up in recent years, with research activities taking place mainly in North America, Europe and a few emerging countries (*e.g.* Brazil, China and India).

Projections for future demand of biofuels

IEA projections see biofuels, in particular second-generation, as one of the key technologies to decarbonise the future transport sector. The *World Energy Outlook 2009* (IEA, 2009a) *450 Scenario*[2] analyses how future energy demand could evolve up to 2030, if countries take co-ordinated action to restrict the global temperature increase to 2°C. Under such CO_2-constrained conditions, biofuels provide 9 % (11.7 EJ) of the total transport fuel demand (126 EJ) in 2030, with roughly 7 EJ of this being second-generation biofuels. In this scenario, biofuels are one of the most important technologies to reduce transport emissions, after improved efficiency and plug-in hybrids and electric vehicles.

Another IEA work extends analysis to 2050: the *Blue Map Scenario*[3] of *Energy Technology Perspectives 2008* (IEA, 2008b) targets 50% reduction in global CO_2-emissions by 2050. In this scenario, biofuels provide 26% (29 EJ) of total transportation fuel (112 EJ) in 2050, with second-generation biofuels accounting for roughly 90% of all biofuel. More than half of the second-generation biofuel production is projected to occur in major economies and developing countries with China and India accounting for 19% of the total production. Another 35% would take place in other developing countries, underlining the importance of further research on framework conditions for second-generation biofuel production outside the OECD region.

Drivers for second-generation biofuel development

Biofuel development has mainly been driven by ambitious support policies in developed regions (*e.g.* United States, Canada, and the European Union). Brazil, China, India, South Africa, Thailand, and others have also adopted support policies for biofuels. Both the United States and the European Union have recently adopted ambitious new biofuel support policies, which, due to the size of the two markets and their considerable biofuel imports, could become an important driver for the global development of second-generation biofuels. With many first-generation biofuels facing severe criticism regarding their sustainability, the EU and the US, as well as some other countries, have also started to redraft their biofuel policies in order to ensure sustainable production and minimum lifecycle GHG emission reductions.

With a steadily increasing second-generation biofuel quota in the United States (60 billion litres in 2022) and increasingly stringent sustainability criteria in both the US and EU, both regions' demand for second-generation biofuels imports is expected to increase. This is because the IEA's *Medium Term Oil Market Report* (IEA, 2009b) projects that the domestic biofuel production in these two regions will most likely not be sufficient to meet the adopted mandates. The projected shortfall could give a drive to second-generation biofuel production outside the United States and European Union, promoting exports from emerging and developing countries. In the medium-term, this could be particularly favourable for Brazil and China where pilot plants are already operating and infrastructure allows for biofuel exports.

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[2] *This scenario models future energy demand in light of a global long-term CO_2 concentration in the atmosphere of 450 parts per million (ppm), which would require global emissions to peak by 2020 and reach 26 Gt CO_2-equivalent in 2030, 10% less than 2007 levels. The total global primary energy demand would then reach 14 389 Mtoe (604 EJ) in 2030.*

[3] *This scenario models future energy demand until 2050, under the same target as the WEO 450-Scenario (i.e. a long-term concentration of 450ppm CO_2 in the atmosphere). Global primary energy demand in this scenario reaches 18 025 Mtoe (750 EJ) in 2050.*

In other developing countries, mandates in the United States and the European Union are not expected to drive second-generation biofuel development in the near future. The lack of second-generation biofuel R&D activities combined with poor infrastructure and a shortage of skilled labour are currently significant obstacles; considerable investment would be required to improve these situations, as is currently the case in Cameroon and Tanzania. Therefore, feedstock trade might be a feasible option for these countries, since it is less capital intensive and can be undertaken with existing capacities. Foreign investment in land for feedstock production could offer an option for developing countries to profit from the growing biomass market for second-generation biofuel production outside their borders, provided that transport infrastructure is suitably developed. Profits could be invested in the rural sector to improve infrastructure and the overall economic situation, and at the same time to develop skills for feedstock cultivation and handling.

However, there are still risks that small landholders' interests are ignored when large investments are undertaken by foreign companies and this concern needs to be carefully addressed through sound policy regulations. Furthermore, only certain feedstocks with high energy density (*e.g.* woody biomass or coffee shells), are suited for long-distance transportation. Poor infrastructure in many developing countries and little experience with biomass production and supply form significant barriers for feedstock trade and can prevent international trade in many cases. Considering this situation, many countries may find it more beneficial to use the available biomass domestically – for example, to increase access to electricity in rural areas.

As a next step, cooperation on R&D at a scientific level would be needed in many emerging and developing countries to build capacity for second-generation biofuel production. In Brazil, for example, research collaboration funded by the European Union's Seventh Research Framework Programme has been set up between a large enzyme producer and the Brazilian Centro de Tecnologia Canavieira. Besides exchange of knowledge and capacity building, technology access is ensured through such cooperation, an important factor to implement a sound second-generation biofuel industry in the future.

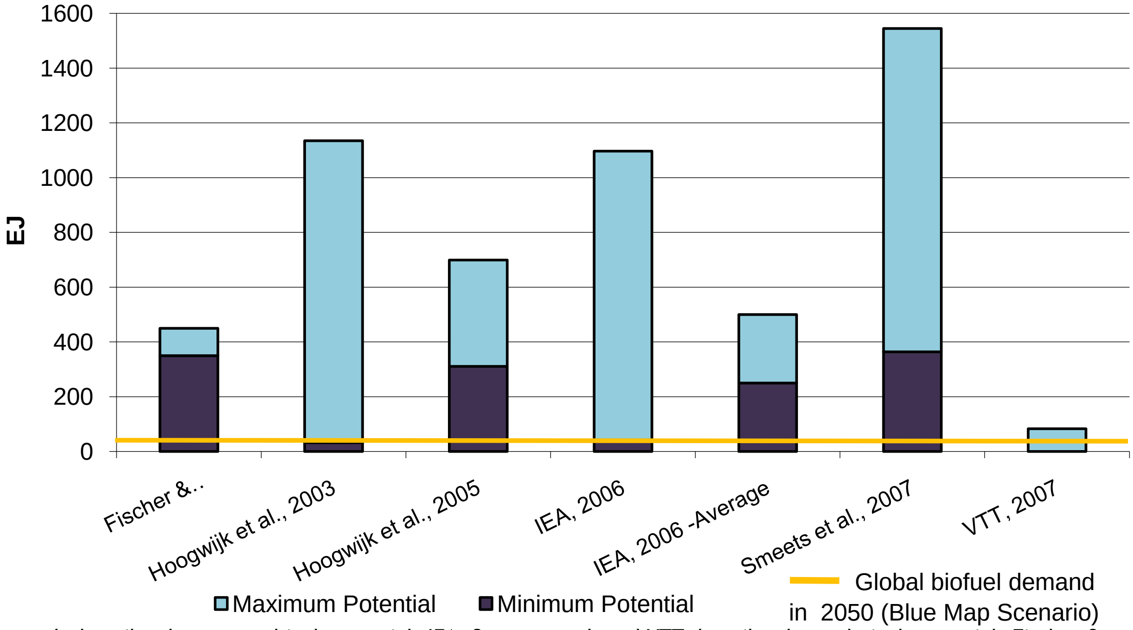
Review of global bioenergy potentials and perspectives for second-generation biofuel production

To produce second-generation biofuels once the technology becomes commercially viable, considerable amounts of biomass have to be provided. This will require an analysis of existing and potential biomass sources well before the start-up of large-scale second-generation biofuel production. To assess land resources potentially available and respective biomass potentials, a number of recent studies on biomass potentials have been reviewed. The review shows under what conditions large amounts of biomass could be produced, as well as where improvements are needed to increase second-generation biofuel feedstock production in emerging and developing countries.

Bioenergy potentials differ considerably among different regions and depend on the set of assumptions used in the scenarios. The major assumption that influences the biomass potential is the availability of land. Land availability depends on the size of the world population, diet, and in particular on the productivity and intensification of the agricultural sector. Expert assessments varied greatly. The lowest (Hoogwijk *et al.*, 2003) estimated a bioenergy potential of only 33 EJ/yr in 2050. In this scenario, no agricultural land can be made available for biomass production and therefore agricultural and forestry residues are the main source for bioenergy production.

In the most ambitious scenario (Smeets *et al.,* 2007), bioenergy potentials increase considerably to around 1 500 EJ in 2050. The indicated 1 500 EJ could cover ten times bioenergy demand in 2050 (150 EJ) projected in the IEA Blue Map Scenario. In particular, in developing regions like Sub-Saharan Africa, the Caribbean and Latin America, as well as the Commonwealth of Independent States (CIS) and the Baltics, large potentials are estimated due to these regions' currently low-productivity of agriculture which is assumed to significantly improve over time. Technological development, increased yields and more intensive animal farming would free vast areas of agricultural land suitable to the production of biomass. However, such an approach would require higher inputs of fertiliser and irrigation water, which are concerns regarding the sustainability of the measures.

Figure 1. Estimates of global bioenergy potentials for 2050 vary widely



Hoogwijk *et al.* describe the geographical potential; IEA, Smeets *et al.* and VTT describe the technical potential; Fischer & Schrattenholzer the economical potential.

Compared to the current circumstances in the eight countries in the project, some of the expert scenarios reviewed appear very ambitious. Brazil currently seems to be the only country with considerable potential to produce second-generation biofuel feedstocks sustainably, mainly on underutilised pasture land. In many of the other countries (*e.g.* Cameroon, India, Tanzania, Thailand) the productivity and sustainability of the agricultural sector would have to increase considerably in order to dedicate agricultural land to second-generation feedstock production. Attaining this important objective would require investment in technological improvement, new infrastructure, including roads and energy supply, and capacity building in the agricultural sector. In the short-term these improvements would help to revitalise rural economies and could allow for sustainable biomass production with additional income opportunities in the long term.

Potential contribution of lignocellulosic residues for production of second-generation biofuels

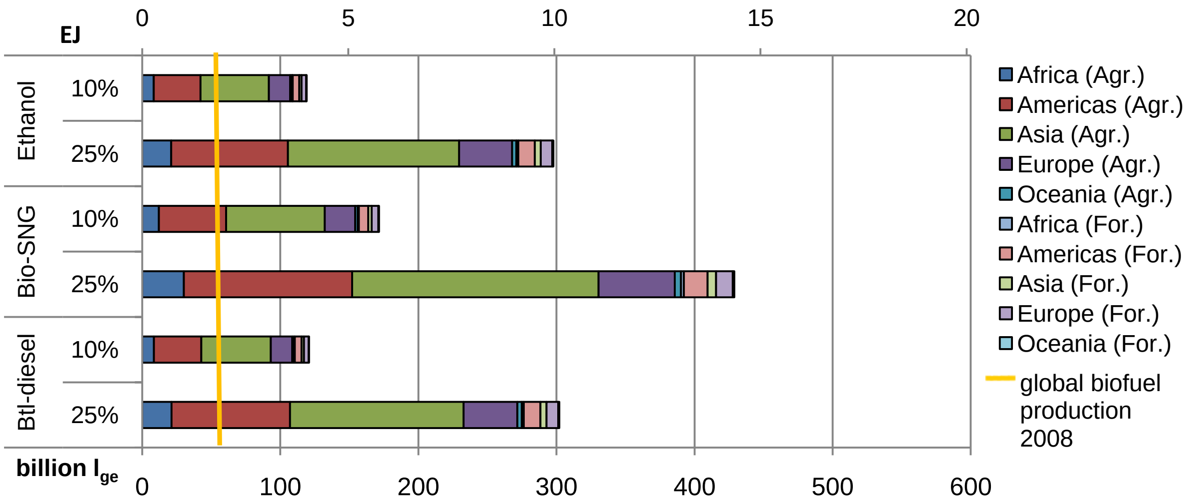
The constraints related to the availability of additional land suggest that second-generation biofuel industries should focus on currently available feedstock sources in the initial phase of the industry. Agricultural and forestry residues form a readily available source of biomass and can provide feedstock from current agricultural and forestry activities without need for additional land cultivation.

To assess the amount of residues that can be used sustainably, data on global crop and roundwood production from the FAOStat database (FAOStat, 2009) were used. Ratios of residue to main product (RPR) were used to calculate the amount of residue that is theoretically produced in the agricultural and forestry sector on the five continents. In order to ensure sustainability, previous studies often assumed that 25% of the residues could be used for bioenergy production. Compared to the findings from some of the eight country profiles in this study, this estimate seems to be optimistic in many cases. In India, as well as in South Africa, the availability of most residues was estimated at around 10% by local experts, due to competing uses like fodder, fertiliser or domestic cooking fuel. Therefore, a second calculation of biofuel yields was undertaken, assuming that only 10% of the residues can be used sustainably without competing for traditional uses.

Results of IEA assessment[4] show that considerable amounts of second-generation biofuels could be produced using agricultural and forestry residues. Assuming the availability of 10% of global forestry and agricultural residues in 2007, around 120 billion lge (4.0 EJ) of BTL-diesel or lignocellulosic-ethanol and up to 172 billion lge (5.7 EJ) of bio-SNG could theoretically be produced. This means that second-generation biofuels could provide 4.2-6.0% of current transport fuel demand.

If 25% of global residues in the agricultural and forestry sector could be made available, second-generation biofuel production could reach around 300 billion lge (10 EJ) of BTL-diesel or lignocellulosic-ethanol, equal to 10.5% of current transport fuel demand. Dedicating all 25% of the residues to the production of bio-SNG (Figure 2) could contribute an even greater share: 14.9 % or 429 billion lge (14.4 EJ) globally if a sound distribution infrastructure and vehicle fleet were made available. As a result, five to seven times the current biofuel volumes could be produced, without occupying any arable land.

Figure 2. Theoretical second-generation biofuel production from residues in 2007



Amounts cannot be summed up. Each bar indicates biofuel yields using all available residues. ”25%“ and ”10%“ assume respective shares of agricultural (agr.) and forestry (for.) residues to be available for biofuel production.
Assumed conversion factors: BTL – 217 lge/t_{DM} , Ethanol - 214 lge/t_{DM}, Bio-SNG – 307 lge/t_{DM}

In 2030, compared to 2007, residue production increases by roughly 28% for crop sources and by 50% for roundwood. If 10% of these global residues would be converted to BTL-diesel or lignocellulosic-ethanol, around 155 billion lge (5.2 EJ) or roughly 4.1% of the projected transport fuel demand[5] in 2030 could be produced. The conversion to bio-SNG could even produce 221 billion lge (7.4 EJ), or around 5.8% of total transport fuel. This means that second-generation biofuels using 10% of global residues could be sufficient in meeting between 45-63% of total projected biofuel demand (349 billion lge) in the WEO 2009 *450 Scenario*. These results underline the potential contribution of agricultural and forestry residues to meet growing demand for transport fuel and help to reduce global emissions in this sector.

Obviously, assuming a greater availability, the use of 25% of global residues would lead to much higher amounts of biofuels and could contribute roughly 385 billion lge (13.0 EJ) globally if the residues were converted to BTL-diesel or lignocellulosic-ethanol, respectively. This is equal to a share of 10.3% of the projected transport fuel demand in 2030. Converting all of the available residues into bio-SNG could yield around 554 billion lge (18.6 EJ), or roughly 14.8 % of total transport fuel, assuming that respective distribution infrastructure and vehicle fleet would be in place. This is more than the projected biofuel demand in 2030. Thus, total biofuel production could

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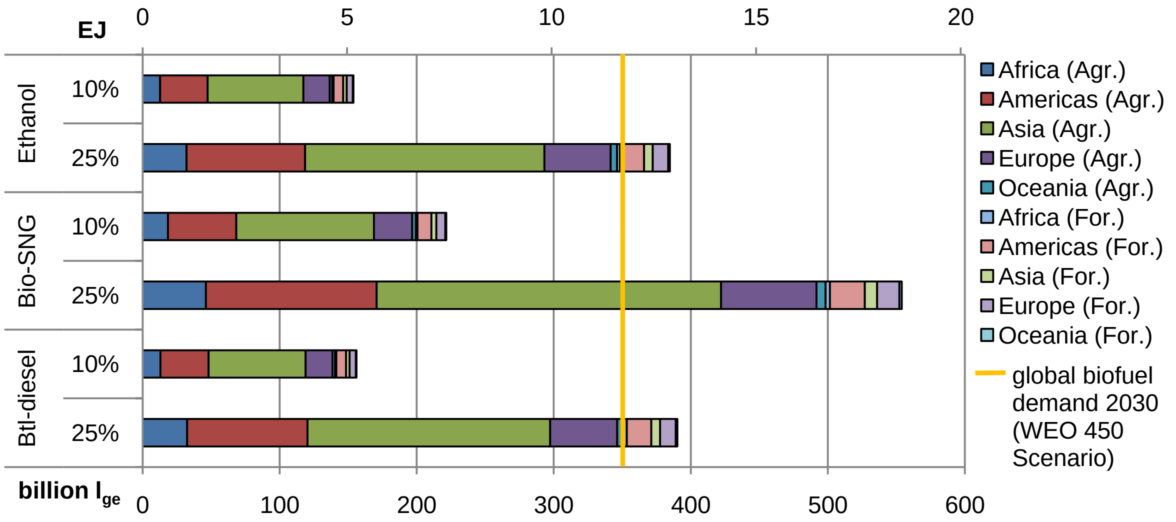
[4] *To assess available residues in 2030, increases in agricultural production (1.3%/yr) and roundwood consumption (1.1%/yr) were adopted from the FAO (2003).*

Average biofuel yields (based on IEA, 2008a) applied are: 214 lge/ton dry matter (t_{DM}) for cellulosic-ethanol and 217 lge/t_{DM} for biomass-to-liquid (BTL) diesel, 307 lge/t_{DM} for bio-synthetic natural gas (bio-SNG).

[5] *Total transport fuel demand in 2030 is 125.7 EJ (2 994 Mtoe), provided by Oil: 105.4 EJ (2 510 Mtoe); Biofuels: 11.7 EJ (278 Mote); Electricity: 5.1 EJ (122 Mtoe), Gas: 3.4 EJ (82 Mtoe) and other 0.1 EJ (3 Mtoe).*

even increase above the projected level in the *WEO 2009 450 Scenario* without occupying any additional agricultural or forestry land. Considering that roughly two-thirds of the potential is located in developing countries in Asia, Latin America and Africa, including these countries in the development of new technologies will be especially important.

Figure 3. Theoretical second-generation biofuel production from residues in 2030



<u>Amounts cannot be summed up</u>. Each bar indicates biofuel yields using all available residues. "25%" and "10%" assume respective shares of agricultural (agr.) and forestry (for.) residues to be available for biofuel production.
Assumed conversion factors: BTL – 217 lge/t_{DM} , Ethanol - 214 lge/t_{DM}, Bio-SNG – 307 lge/t_{DM}

Since the agricultural sector in many developing countries differs significantly from that in the OECD, a better understanding of material flows is a key aspect to ensure the sustainability of second-generation biofuel production. More detailed country and residue-specific studies are needed to assess the economic feasibility of collecting and pre-processing agricultural and forestry residues.

SUSTAINABILITY OF SECOND-GENERATION BIOFUEL PRODUCTION

Even if expectations regarding the sustainability of second-generation biofuels are high, the new technologies represent an industry for which no experience with commercial production yet exists. In particular, in developing countries it will be a challenge to balance large-scale industrial development with small-scale local value chains, which would be required to ensure environmental, economical and social sustainability.

Potential economic impacts

To set-up a commercial second-generation biofuel plant with a capacity around 100 Ml/yr, large investment volumes in the range of USD 125-250 million are currently required. Most of the selected countries (Brazil, China, India, South Africa, Mexico and Thailand) have already set up bioenergy projects of this scale. While some of these projects are financed from domestic resources, these countries also receive considerable amounts of foreign direct investment. For less developed countries like Cameroon and Tanzania, the required investment costs could be a bottleneck, since domestic financing resources are limited. Foreign investment would thus be needed to successfully implement a second-generation biofuel industry, but significant administrative and governance problems may considerably reduce the willingness of foreign companies to undertake large investments in these countries.

The large biomass demand (up to 600 000 t/yr) for a commercial second-generation biofuel plant requires complex logistics systems and good infrastructure to provide biomass at economically competitive costs. In particular, in the rural areas of the studied countries, poor infrastructure is one of the biggest challenges for biomass supply. Complex land property structure and the predominance of small land holdings increase the complexity of feedstock logistics even more in some countries (*e.g.* in Tanzania, Cameroon, South Africa, and India).

Residues from the agricultural and forestry sector are often considered to have no economic value, but in fact many are already used in one way or another in the countries studied for this report. Therefore opportunity costs occur depending on the current use of the material. In Brazil, for instance, bagasse is burnt to provide heat and electricity for the production plant and the national grid; whereas in China, straw is commercially used to produce heat and power. In these cases, opportunity costs can be assessed with good accuracy. In other cases, residues are used in the informal sector, for example as animal fodder in subsistence farming or as fuel for domestic cooking and heating, as in Cameroon, India, South Africa and Tanzania. The absence of established markets for these material flows makes it difficult to assess actual opportunity costs.

One important finding is that in cases where feedstock costs were indicated by local experts in the studied countries, they were reasonably small compared to dedicated energy crops. Thus residues are an economically attractive feedstock for second-generation biofuel production. Comparably low feedstock prices in the range of USD 1-8/GJ were given for Brazil, China, Mexico, and South Africa. Current production costs for second-generation biofuels based on the latest IEA cost estimates are presented below. In the analysis, capital costs account for 50% of the total production costs; feedstock is 35% of the total cost; and operation and maintenance (O&M), energy supply for the plant and others factors account for 1-4% each.

Based on IEA analysis[6] in *Transport, Energy and CO_2* (IEA, 2009c), second-generation biofuels from dedicated energy crops could currently be produced at costs of USD 0.84-0.91/lge. Using straw or stalks, theoretical production costs for second-generation biofuels are in the range of USD 0.60-0.79/lge in South Africa and up to USD 0.86/lge in India and China (Table 1). Compared to the reference gasoline price of USD 0.43/lge (*i.e.* oil at USD 60/bbl), these costs are still high. If the oil price would rise to USD 120, the gap between gasoline costs and the biofuel production costs indicated above would narrow and ethanol could in some cases be produced at a lower cost than gasoline. Furthermore, technology improvement, higher conversion efficiencies and better transport logistics could reduce production costs by roughly one third in the long term and biofuel production costs could then come close to the gasoline reference. One uncertainty, however, is the opportunity costs for residues. Due to the expected increasing demand for bioenergy and biomaterials, costs for feedstocks are likely to increase.

Table 1. Theoretical production price for second-generation biofuels in selected countries

oil price: USD 60/bbl		Feedstock price*	USD/lge	
		USD/GJ	**Btl-diesel**	**lc-Ethanol**
Woody energy crops	global (IEA analysis)	5.4	0.84	0.91
Straw/stalks	China	1.9 - 3.7	0.66 - 0.79	0.68 - 0.85
	India	1.2 - 4.3	0.62 - 0.80	0.63 - 0.86
	Mexico	3.1	0.74	0.79
	South Africa	0.8 - 3.1	0.6 - 0.74	0.6 - 0.79
	Thailand	2.0 - 2.8	0.67 - 0.72	0.67 - 0.77

*Note that feedstock prices reflect assumptions by local experts and might vary regionally
Source: Based on IEA analysis presented in ***Transport, Energy and CO_2*** (IEA, 2009c)

With regard to the domestic economy, production of second-generation biofuels based on agricultural residues could be beneficial to farmers, since it would add a value to these by-products. More profit could thus be obtained from the cultivated area if sufficient amounts of residues were available. This could reduce the necessity to support farmers and smallholders in countries where the agricultural sector is struggling and investment is urgently needed, such as Tanzania and Cameroon. However, these are the countries in which limited financing possibilities, poor infrastructure and a lack of skilled labour is currently constraining establishment of a second-generation biofuel industry.

[6] *In the applied model, an oil price of USD 60/bbl is assumed and conversion efficiencies, transport and other costs based on current state of the art are used. Note that complex transport logistics and increased demand for feedstocks could increase the feedstock costs and thus the total biofuel costs in some regions.*

Potential social impact

Job creation and regional growth would probably be the most important drivers for the implementation of second-generation biofuel projects in major economies and developing countries. The potential for creation of jobs along the value-chain of second-generation biofuels could help to increase rural employment and welfare. If dedicated energy crops are used as second-generation feedstock, jobs will be created in the cultivation of the feedstock; however, for residue production, existing farm labour could be used, which could extend employment periods after the harvesting season.

Neither feedstock cultivation nor transport requires skilled labour and thus sufficient labour could be provided in all of the studied countries. The biofuel conversion, however, requires highly skilled engineers which, among the countries studied, are only abundant in Mexico and in the large emerging countries with experience in other energy industries or first-generation biofuel production (*i.e.* Brazil, China, India, South Africa). In Cameroon, Tanzania, and to a certain extent in Thailand, human capital is a bigger constraint, and significant capacity building would be required to successfully adopt second-generation biofuel technologies.

A large constraint regarding the social impact of feedstock production is the occupation of arable land for energy crop cultivation. In the studied countries, except for Brazil (see environmental impact), data on land use are often poor and land use management strategies rarely exist. Competition for scarce cropland resources can be a critical point in some regions, when it comes to cultivation of dedicated energy crops. The African Biodiversity Network (ABN, 2007) pointed out that displacement of smallholders might occur if large-scale land acquisition is not planned carefully. This is a concern particularly in Africa (*e.g.* Cameroon and Tanzania), where land ownership is often not secured. In cases where no accurate land use data are available, an assessment of actual available land will be required. If this is not done, second-generation biofuel production could cause the same negative social impacts as some first-generation biofuel projects. These concerns are comparably small for the utilisation of agricultural and forestry residues as second-generation biofuel feedstock.

The use of residues could furthermore provide an additional source of income in the agricultural and forestry sector with positive impact on local economies and rural development. However, constraints exist whereby increasing opportunity costs for agricultural and forestry residues could lead to income losses for traditional buyers of these materials and affect poor farmers who cannot afford alternative fodder for their cattle. Therefore, more research on regional markets has to be undertaken to evaluate the potential social impacts of increased competition for agricultural and forestry residues.

The use of second-generation biofuels to provide energy access in rural areas seems currently unlikely. High production costs and the need for large-scale production facilities are considerable disadvantages compared to other bioenergy options. Many developing countries would need to develop export possibilities for second-generation biofuels in order to benefit. However, given that domestic energy supply is lacking in many rural areas, the use of residues for electricity and heat production, as well as the use of first-generation biofuels in generators, could be more beneficial to those countries. Since these technologies are technically less demanding and require less capital investment, they could be more effective in promoting rural development, as has been successfully demonstrated in China, India, Tanzania and Cameroon.

Potential environmental impacts and GHG balances

The environmental impact of second-generation biofuel production varies considerably depending on the conversion route, the feedstock and site-specific conditions (climate, soil type, crop management, etc.).

An important driver for biofuel promotion is the potential to reduce lifecycle CO_2 emissions by replacing fossil fuels. It is therefore important to ensure that cultivation and production of second-generation biofuels produce less CO_2 than the replaced fossil fuel. Since no commercial production yet exists, data on lifecycle emissions of second-generation biofuels only refer to demonstration and pilot plants. They are therefore not necessarily representative for large-scale production.

Currently available values indicate a high GHG mitigation potential of 60-120%[7], similar to the 70-110% mitigation level of sugarcane ethanol (IEA, 2008c). This analysis does, however, not consider the impact of land use change (LUC) on the lifecycle emissions of second-generation biofuels. Recent studies suggest that cultivation of biofuel feedstock can release considerable amounts of GHG, if it involves the conversion of land with high carbon stock (*e.g.* tropical peat forest, native grasslands, and others). This land use change can be direct, for example, if biofuel feedstocks replace native forest, or indirect, if biofuel feedstock cultivation replaces other crops, which are then grown on land with high carbon stocks. This so-called indirect land use change (iLUC) can also have a severe impact on biodiversity if valuable ecosystems are destroyed to grow the replaced crops.

If second-generation biofuels are to be produced sustainably, it is important to assess and minimise potential iLUC caused by the cultivation of dedicated energy crops. This deserves a careful mapping and planning of land use, in order to identify which areas (if any) can be potentially used for bioenergy crops. In the studied countries, Brazil is the only country so far that has initiated a programme (*ZAE Cana*) to direct available land to the production of biofuel feedstock. The programme aims to stop deforestation and avoid negative impacts through direct or indirect land use change. Though it currently focuses on sugarcane, it could also be applied to other biofuel feedstocks and form a major step towards a sustainable land use for biofuel production.

In the other countries, only poor data on abandoned land is available. In particular in India and Thailand, pressure on cropland is already so high that biofuel expansion requires careful planning. In South Africa on the other hand, some 3 Mha of land have been identified as potentially available, but land ownership is complex and the current insecurity about the government's land reform is a main constraint for the utilisation of this land.

If residues are used as feedstock, the issue of (i)LUC is of less importance, since no additional land needs to be cultivated. Recent policies like the *California Low Carbon Fuel Standard* reflect this since no emissions from iLUC are included in the default lifecycle emission values for biofuels from residues. The use of residues for biofuel production could only cause iLUC when current use (*e.g.* as fodder or fuel wood) is replaced by crops that are grown on additional land.

Impact on soil, water and biodiversity

Feedstock plantations for second-generation biofuels are usually perennial tree or grass species. Therefore, the plantations provide year-round soil cover and require less soil preparations than annual crops. The permanent cover can considerably reduce the impact of erosion through wind and water and increases the water-retention capacity. For example, on vulnerable soils like the loess plateau in China, or tropical soils in Thailand, such energy crop plantations could contribute to reduce advancing degradation with both environmental and social benefits. Furthermore, the soil carbon stock can be increased through both roots and leaf litter.

However, so far most energy crop varieties (*e.g.* willow, pine and switchgrass) are developed in OECD countries and little research is undertaken in Asia or Africa to develop indigenous lignocellulosic crops. Since crop breeding takes decades, constraints exist to prevent potentially invasive crop species from being introduced to these regions when biomass demand for second-generation biofuel production increases. Experiences in South Africa and other countries show that such non-native species can become a severe threat for local biodiversity.

There are also negative aspects related to the use of pesticides and fertiliser. Though these inputs are expected to be lower than for conventional biofuel feedstocks (*e.g.* maize, canola), they can cause negative impact on freshwater reserves and potential acidification of soils.

The use of residues is bound by different constraints, since biomass is taken away from the site rather than added. Using secondary residues as feedstock is expected to have only little negative impact on the environment, since these residues are usually disposed at the processing site and not returned to the field. Primary residues on the other hand, are often left on the field where they act

[7] *An improvement higher than 100% is possible because of the benefits of co-products (notably power and heat.)*

as fertiliser. Their removal could thus lead to nutrient extraction that has to be balanced with synthetic fertilisers to avoid decreasing productivity. This consequence should be considered carefully in order to avoid negative environmental as well as social and economic impacts.

Since access to freshwater is a growing concern in many countries, in particular India, China and South Africa, feedstock sources that do not require irrigation like agricultural and forestry residues, should be given priority in these countries. However, certain amounts of water are required in the biofuel production process. According to Hargrove (2007), water requirements for lignocellulosic-ethanol, are expected to lie between 4-8 litre water per litre biofuel. This is slightly more than for first-generation ethanol production (2-4 $l_{water}/l_{ethanol}$), mainly due to additional conversion steps in the production process. However, this is a small amount compared to the total water demand for feedstock cultivation.

CONCLUSIONS

Based on the analysis undertaken for this project and the particular findings from eight country studies, the global resource potential for the future sustainable production of second-generation biofuels looks promising. However, significant differences exist between regions and countries regarding biomass availability and necessary framework conditions for participation in this future industry.

On a global level, previous studies on biomass potential suggested that between 10% and 300% of current global energy consumption could be produced with much of the biomass coming from developing regions and emerging economies. Based on the findings of the eight country profiles conducted for this study, some of these previous projections seem to be very ambitious – especially considering the high share of currently cultivated land and the steadily increasing population in some countries (*e.g.* in India and Thailand). Therefore, the potential availability of land dedicated to energy crops for the production of second-generation biofuels may be limited and requires careful assessment: more research on available land resources is clearly needed in many countries.

Agricultural and forestry residues, on the other hand, could offer the solid potential for biofuel production, with some constraints regarding competition with current uses (*e.g.* as fodder, organic fertiliser), especially in countries with subsistence farming (Cameroon, India, South Africa, Tanzania). Furthermore, the possible environmental impact on soil nutrients, carbon and water quality require careful consideration.

Considerable amounts of second-generation biofuels could be produced from available agricultural and forestry residues. Assuming a conservative value of only 10% availability of global agricultural and forestry residues for second-generation biofuel production, there should be enough feedstock remaining for traditional uses. BTL-diesel for instance could cover around 50% of the projected biofuel demand, or 5% of the total transport fuel needs in 2030 in an energy scenario where considerable emission reductions are a priority (WEO 2009 *450 Scenario*). This represents significant potential considering that no additional land would be required to produce these amounts.

The potential to use available residues in the agricultural and forestry sector to produce second-generation biofuels underscores the need for technology development. In the short term, this is likely to take place in developed countries and some large emerging economies like Brazil, China and India, where sufficient financing and R&D capacities can be provided. For other developing countries like Cameroon and Tanzania, however, second-generation biofuels have only limited potential to promote sustainable development in the near future. Until the new technologies are commercially available, developing countries could revitalise rural economies by investments into rural infrastructure, agricultural production and improved energy supply (*e.g.* rural electrification). Different bioenergy systems could play an important role in this regard by providing access to cheap and clean domestic energy with significant potential to improve productivity and the overall standard of living in rural communities. This includes the use of biogas in China and India, several options at the village level in Thailand, a more efficient use of bagasse in Tanzania, and saw-mill residues in Cameroon for the generation of heat and power.

The assessment of sustainable biomass potential and the evaluation of benefits of different bioenergy options, including first-generation biofuels, are important steps to increasing rural energy access. Investments to help build capacities in the field of feedstock supply and handling can create favourable conditions to set up a second-generation biofuel industry. This way, countries that are currently not able to produce second-generation biofuels could profit from new technology and market opportunities once the technology is commercially available. Another key point is to enhance collaboration both with developed countries and amongst developing countries to build capacities in the field of second-generation biofuels and to ensure technology access.

Key messages from this study:

- There is a considerable potential for the production of second-generation biofuels. Even if only 10% of the global agricultural and forestry residues were available in 2030, about half of the forecasted biofuel demand in the *World Energy Outlook 2009 450 Scenario* could be covered – equal to around 5% of the projected total transport fuel demand by that time.
- To ensure a successful deployment of second-generation biofuel technologies requires intensive RD&D efforts over the next 10-15 years.
- The technical development will mainly take place in OECD countries and emerging economies with sufficient RD&D capacities like Brazil, China and India.
- In many developing countries, the framework conditions needed to set up a second-generation biofuel industry are not currently sufficient. The main obstacles that need to be overcome include poor infrastructure, lack of skilled labour and limited financing possibilities.
- Investments in agricultural production and infrastructure improvements would promote rural development and can significantly improve the framework for a second-generation biofuel industry. This will allow developing countries to enter second-generation biofuel production once technical and costs barriers have been reduced or eliminated.
- The suitability of second-generation biofuels for countries' respective needs has to be evaluated against other bioenergy options. This should be part of an integrated land use and rural development strategy, to achieve the best possible social and economic benefits.
- Capacities should then be built slowly but continuously in order to avoid bottlenecks when the new technologies become technically available and economically feasible. To ensure tehnology access and transfer, co-operation on RD&D between industrialised and developing countries as well as among developing countries should be enhanced.
- Agricultural and forestry residues should be the feedstock of choice in the initial stage of the production, since they are readily available and do not require additional land cultivation.
- More detailed research is still needed to ensure that second-generation biofuels will provide economic benefits for developing countries. This research includes a global road map for technology development, an impact assessment of commercial second-generation biofuel production, and improved regional data on available land. Additionally, more case studies could enable further analyses of local agricultural markets, material flows, and specific social, economical and environmental benefits and risks in developing countries.

Research gaps and next steps

It is still too early to fully assess the potential social, economic, and environmental impacts of large-scale second-generation biofuel production in practice. The following research steps are suggested to understand better the potential and impact of second-generation biofuels in developing countries and emerging economies:

- Creation of a global road map for second-generation biofuels, to enable governments and industry to identify steps needed and to implement measures to accelerate the required technology development and uptake.
- Set-up of pilot and demonstration plants outside the OECD in order to develop supply chain concepts, assess feedstock characteristics, and analyse production costs in different parts of the world.
- Collection of field data from commercial second-generation biofuel production from residues to better understand impacts on agricultural markets and the overall economic situation in developing countries.
- Improved data accuracy on sustainably available land in developing countries to determine the potential for dedicated energy crops.

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