Executive Summary

Context

Global biofuel production has been increasing rapidly over the last decade, but the expanding biofuel 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.

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 for available land. 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 on second-generation biofuels so far have been undertaken only 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.

Second-generation biofuels: potential and perspectives

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, India and Thailand). Current IEA projections see a rapid increase in biofuel demand, in particular for second-generation biofuels, in an energy sector that aims on stabilising atmospheric CO_2 concentration at 450 parts per million (ppm).

The *World Energy Outlook 2009* (IEA, 2009a) *450 Scenario*[1] projects biofuels to provide 9% (11.7 EJ) of the total transport fuel demand (126 EJ) in 2030. In the *Blue Map Scenario*[2] of *Energy Technology Perspectives 2008* (IEA, 2008b) that extends analysis until 2050, 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 in the *Blue Map Scenario* is projected to occur in non-OECD countries, with China and India accounting for 19% of the total production.

Drivers for second-generation biofuel development

Ambitious biofuel support policies have recently been adopted in both the United States (with 60 billion litres of second-generation biofuel by 2022) and the European Union (with 10% renewable energy in the transport sector by 2020). Due to the size of the two markets and their considerable biofuel imports, the US and EU mandates could become an important driver for the global development of second-generation biofuels, since current IEA analysis sees a shortfall in domestic production in both the US and EU that would need to be met with imports (IEA, 2009b). Regarding second-generation biofuels, this shortfall could be particularly favourable for Brazil and China, where pilot plants are already operating and infrastructure allows for biofuel exports. In other countries, like Cameroon and Tanzania, the lack of R&D activities combined with poor infrastructure and shortage of skilled labour form considerable obstacles to being able to profit from second-generation biofuel demand in the EU and US in the near future.

Feedstock trade, however, could be an option for these countries to profit from a growing biomass market for second-generation biofuels outside their own borders, since requirements for financing and skilled labour are smaller. Biomass production could also attract foreign investment, and obtained profits could be invested into the rural sector, thereby helping develop feedstock cultivation and handling skills. However, constraints like infrastructure and smallholder interests might make domestic use of lignocellulosic feedstocks (*e.g.* for electricity production) more beneficial than their export.

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

To produce second-generation, considerable amounts of biomass have to be provided, which will require an analysis of existing and potential biomass sources well before the start-up of large-scale production. In recent studies, bioenergy potentials differ considerably among different regions; the main factor for large biomass potentials is the availability of surplus agricultural land, which could be made available through more intensive agriculture.

Expert assessments in the reviewed studies varied greatly, from 33 EJ/yr in 2050 (Hoogwijk *et al.*, 2003) assuming that mainly agricultural and forestry residues are available for bioenergy production. In the most ambitious scenario (Smeets *et al.,* 2007), the bioenergy potential reaches

[1] *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.*

[2] *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.*

roughly 1 500 EJ/yr in 2050. The scenario assumes availability of 72% of current agricultural land for biofuel production, mainly through increased yields and more intensive animal farming.

In the reviewed studies large potentials are often estimated in developing regions like Latin America or Sub-Saharan Africa, where agricultural productivity is currently low. Compared to the current situation 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 sustainably produce energy crops for second-generation biofuel production, mainly on underutilised pasture land. In many of the other countries (*e.g.* Cameroon, India, Tanzania, Thailand) significant investments in technological improvement, new infrastructure and capacity building are needed to increase the productivity and sustainability of the agricultural sector. This could allow dedicate agricultural land to second-generation feedstock production in the future.

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's development. Agricultural and forestry residues form a readily available source of biomass and can provide feedstock from current harvesting activities without need for additional land cultivation.

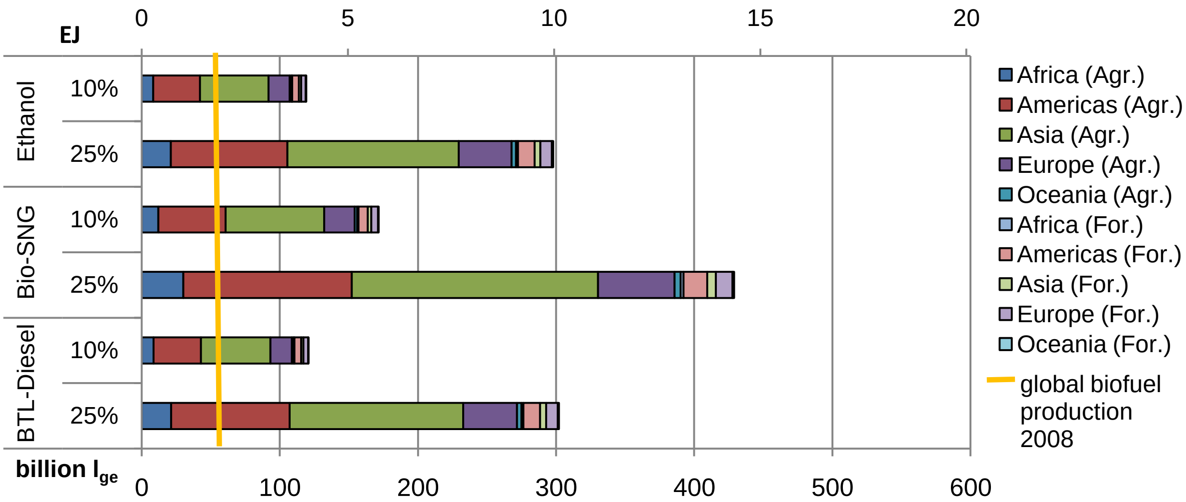
To assess the potential for lignocellulosic-residues, this study presents two scenarios in which 10% and 25% of global forestry and agricultural residues, respectively, are assumed to be available for biofuel production. The remaining residues could still be used for other uses, including fodder, organic fertiliser or domestic cooking fuel. The amount of residues is calculated on the basis of annual production data as indicated in the FAOStat database (FAOStat, 2009), using ratios of residue to main product (RPR) as indicated by Fischer *et al.* (2007). 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).

Results of IEA assessment[3] show that considerable amounts of second-generation biofuels could be produced using agricultural and forestry residues:

- **10%** of global forestry and agricultural residues in 2007 could yield 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. This means that second-generation biofuels could provide 4.2-6.0% of current transport fuel demand.
- **25%** of global residues in the agricultural and forestry sector could even produce around 300 billion lge (10.0 EJ) of BTL-diesel or lignocellulosic-ethanol, equal to 10.5% of current transport fuel demand. Bio-SNG 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 (Figure 1).

[3] 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).

Figure 1. 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 and forestry residues to be available for biofuel production.
Assumed conversion factors: BTL-Diesel – 217 lge/t_{DM}, Ethanol - 214 lge/t_{DM}, Bio-SNG – 307 lge/t_{DM}

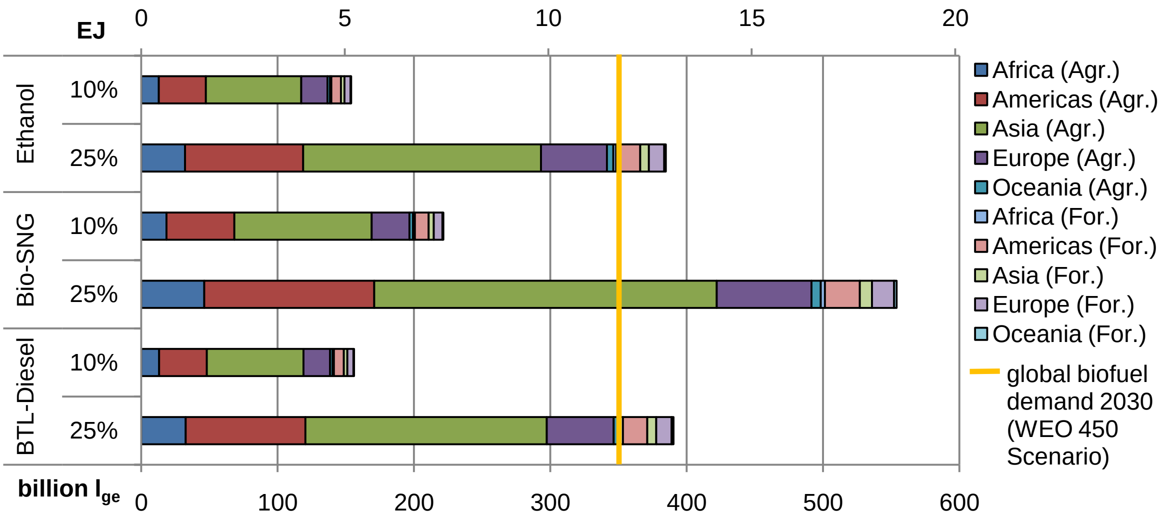
In 2030, compared to 2007, residue production increases by roughly 28% for crop sources and by 50% for roundwood:

- **10%** of global residues could then yield around 155 billion lge (5.2 EJ) BTL-diesel or lignocellulosic-ethanol, or roughly 4.1% of the projected transport fuel demand in 2030. The conversion to bio-SNG could even produce 222 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 45-63% of total projected biofuel demand (349 bn lge) in the WEO 2009 *450 Scenario*.
- **25%** of global residues converted to either LC-Ethanol, BTL-diesel or Bio-SNG could contribute 385-554 billion lge (13.0–23.3 EJ) globally (Figure 2). These amounts of second-generation biofuels are equal to a share of 10.3-14.8% of the projected transport fuel demand in 2030, and could fully cover the entire biofuel demand projected in the *WEO 2009 450 Scenario*.

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.

However, 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 still needed to assess the economic feasibility of collecting and pre-processing agricultural and forestry residues.

Figure 2. Theoretical second-generation biofuel production from residues in 2030



Amounts cannot be summed up. Each bar indicates biofuel yields using all available residues. "25%" and "10%" assume respective shares of agricultural and forestry residues to be available for biofuel production.
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Sustainability of second-generation biofuel production

So far, no experience with commercial production of second-generation biofuels 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

Financing of commercial second-generation biofuel plants (USD 125-250 million) should not be a problem in most of the studied countries (Brazil, China, India, South Africa, Mexico and Thailand), since foreign direct investment could be received in addition to domestic funding. However, for less developed countries like Cameroon and Tanzania, the required investment costs could be a bottleneck, since domestic funding possibilities are limited and 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. This is a particular challenge in the rural areas of the studied countries where poor infrastructure, as well as complex land property structure and the predominance of small land holdings increase the complexity of feedstock logistics (*e.g.* in Cameroon, India, South Africa and Tanzania).

The assessment of opportunity costs for residues from the agricultural and forestry sector is difficult due to the absence of established markets for these material flows. Data accuracy on costs is generally better when residues are used commercially (*e.g.* bagsse that is burned for heat and electricity production) than if they are used in the informal sector (*e.g.* as domestic cooking fuel, organic fertiliser or animal fodder). In cases where feedstock costs were indicated by local experts in the studied countries, they were often 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 indicated for Brazil, China, India, Mexico, South Africa and Thailand. Using the latest IEA production cost analysis, theoretical production costs for second-generation biofuels from straw or stalks are currently 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). This is still high compared to the reference gasoline price of USD 0.43/lge (*i.e.* oil at USD 60/bbl), but in the long term, technology improvement, higher conversion efficiencies and better transport logistics could bring costs close to the gasoline reference, if costs for feedstocks would remain stable.

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

		Feedstock price*	USD/lge	
oil price: USD 60/bbl		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
Assumed cost factors are: capital costs: 50% of the total production costs; feedstock is 35%; operation and maintenance (O&M), energy supply for the plant and others between 1-4% each.
Source: Based on IEA analysis presented in ***Transport, Energy and CO_2*** (IEA, 2009c)

Overall, production of second-generation biofuels based on agricultural residues could be beneficial to farmers, since it would add value to these by-products. 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 in Tanzania and Cameroon. However, these are the countries in which limited financing possibilities, poor infrastructure and a lack of skilled labour are currently constraining establishment of a second-generation biofuel industry.

Potential social impact

Job creation and regional growth will 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 varies depending on the feedstock choice. Use of dedicated energy crops will create jobs in the cultivation of the feedstock, whereas the use of residues will have limited potential to create jobs since existing farm labour could be used. The following conclusions regarding labour were found for the countries included in this study:

- Sufficient labour for feedstock cultivation and transport could be provided in all of the studied countries.
- Highly skilled engineers for the biofuel conversion 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).
- Significant capacity building would be required in Cameroon, Tanzania, and to a certain extent in Thailand, 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 and thus competition with current agricultural production. Except for Brazil (see section on environmental impact), data on land use in the studied countries is often poor and land use management strategies rarely exist. Displacement of smallholders might thus 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. An assessment of actual available land will be required to avoid that second-generation biofuel production from dedicated energy crops would cause the same negative social impact 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 provide an additional source of income in the agricultural and forestry sector with positive impact on local economies and rural development. However, constraints exist that increasing opportunity costs could affect farmers or rural population that is depending on residues as animal fodder or domestic fuel. 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 due to high production costs and the need for large-scale production facilities. Other bioenergy options like electricity production are technically less demanding and require less capital investment, and could thus be more effective in promoting rural development, as has been successfully demonstrated for instance 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 as well as 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. Currently available values indicate a high GHG mitigation potential of 60-120%[4], similar to the 70-110% mitigation level of sugarcane ethanol (IEA, 2008c) and better than most current biofuels. However, these values do not include the impact of land use change (LUC)[5] that can have considerable negative impact on the lifecycle emissions of second-generation biofuels and also negatively impact biodiversity.

To ensure sustainable production of second-generation biofuels, it is therefore 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

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

[5] *Two types of land use change exist: direct LUC occurs when biofuel feedstocks replace native forest for example; indirect LUC (iLUC) occurs when biofuel feedstocks replace other crops that are then grown on land with high carbon stocks.*

used for bioenergy crops. The following land-use issues and insights were found for the countries included in this study:

- Brazil is the only of the studied countries that has initiated a programme (*ZAE Cana*) to direct available land to the production of biofuel feedstock in order to stop deforestation and indirect land use change. The programme currently focuses on sugarcane, but it could also be applied to other biofuel feedstocks.
- In particular in India and Thailand, pressure on cropland is already so high that biofuel expansion requires careful planning.
- In South Africa, complex land ownership and the current insecurity about the government's land reform are the main constraints for the utilisation of some 3 Mha of land that have been identified as potentially available.

If residues are used as feedstock, the issue of iLUC is of less importance, since no additional land needs to be cultivated. This is also reflected in recent policies like the *California Low Carbon Fuel Standard*. 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, the cultivation of which can have a number of positive impacts:

- The year-round cover provided by perennial tree or grass species can increase the water retention capacity of the soil.
- Perennial plantations can also considerably reduce the impact of erosion through wind and water, which is a considerable benefit compared to annual feedstocks. This would be particularly advantageous on vulnerable soils like the loess plateau in China, or tropical soils in Thailand.
- Soil carbon stock can be increased through both roots and leaf litter.

However, there are drawbacks to using perennial tree or grass species:

- Little research on indigenous lignocellulosic crops has been undertaken in Asia or Africa. Therefore, 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 non-native species can become a severe threat for local biodiversity.

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 not returned to the field. The use of primary residues, however, could lead to nutrient extraction that has to be balanced with synthetic fertilisers to avoid decreasing productivity.

The access to freshwater is a growing concern in many of the studied countries (*e.g.* China, India, South Africa). Therefore, feedstock sources like agricultural and forestry residues that do not require irrigation should be given priority in these countries, and water requirements during the biofuel production process (*e.g.* 4-8 $l_{water}/l_{ethanol}$ for cellulosic ethanol) need to be considered carefully.

Conclusions

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 biofuels 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 technology 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 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.