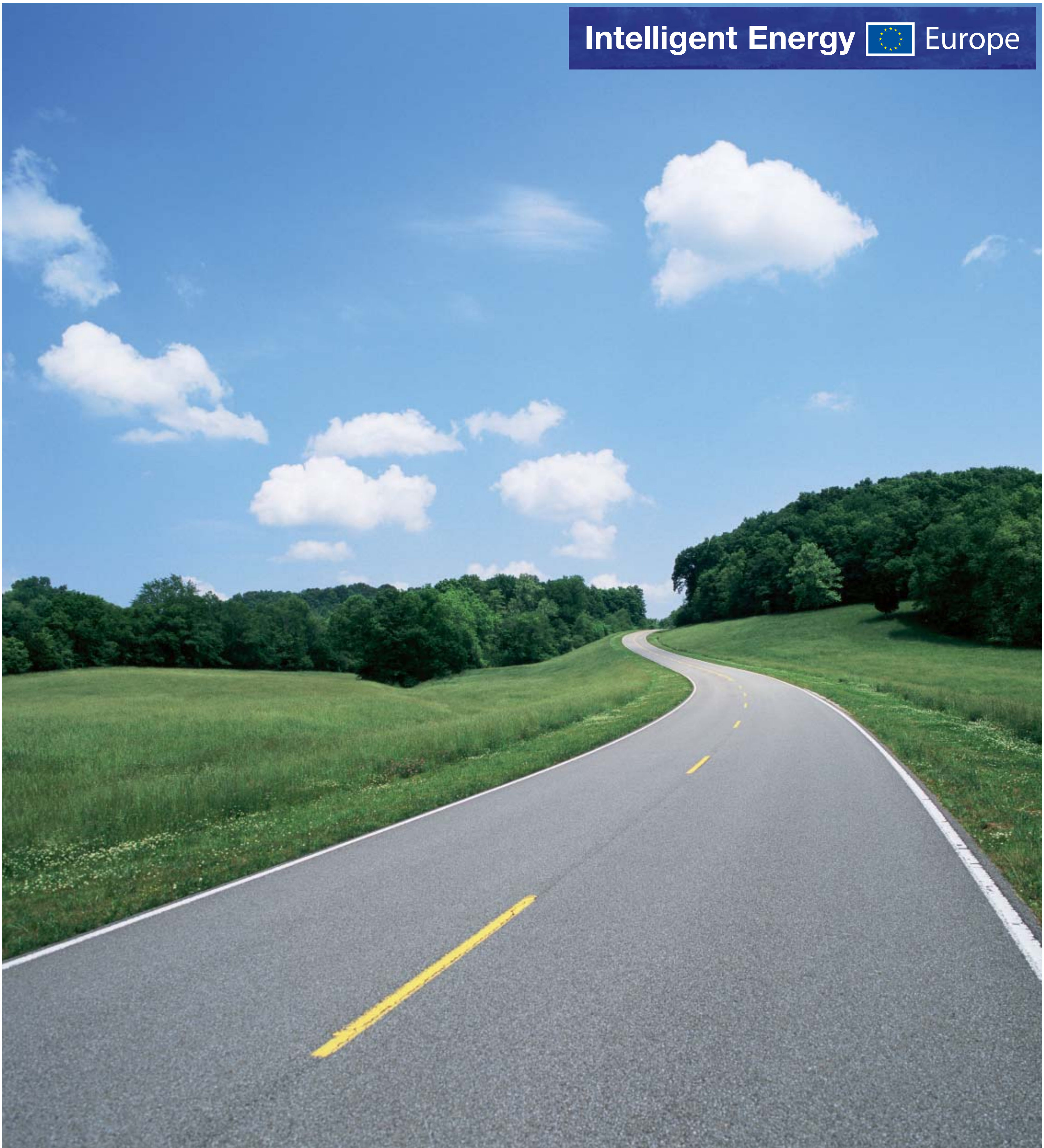
Intelligent Energy Europe



Eyes on the track, Mind on the horizon

From inconvenient rapeseed to clean wood: A European road map for biofuels

refuel

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A European road map for biofuels

March 2008

Executive summary

Biofuels production and consumption are growing rapidly at the moment. With this tempestuous short-term development comes the need for an integrated long-term vision for biofuels. REFUEL contributes to this vision formation. In this project, funded by the Intelligent Energy Europe programme, seven EU institutes of different backgrounds have analysed the prospects for biofuels in terms of resource potential, costs and impacts of different biofuels, effects of different policy strategies, and broader system impacts of biofuels. For this road map document, we applied our key tools and findings to the policy challenges of today.

The EU is in the process of setting out an ambitious development of biofuels until 2020. Given the current shaping of this policy, analyses in REFUEL indicate that a mix of conventional (1st generation) biofuels is probably the most cost-effective way to meet these ambitions. Meeting the target would not compromise EU food & feed production, and it would not require any conversion of EU nature reserves into agricultural land. However, when we reconsider the policy drivers for biofuels, it remains questionable whether such a development is the best answer to the underlying motivation for biofuels: such a mix leads to only modest reductions of greenhouse gases, creates minor opportunities for a competitive and innovative new industry, and requires extensive tracts of land. The latter issue becomes especially important if we need to go to higher biofuels shares by 2020 or later, or if biomass demand from other sectors increases substantially as well.

A biofuels target share alone does not seem to induce the development of biofuels that best respond to the drivers for biofuels policy. Therefore, we defined and analysed several 'policy packages' that are built up on a specific policy perspective for biofuels, e.g. climate mitigation or energy security. It appears that all of these policy packages lead to improved competitiveness of 2nd generation biofuels, and an introduction of these fuels before 2020. The earlier they are introduced, the better the 2020 biofuels mix meets the drivers behind the policy push for biofuels. Furthermore, an early start leads to earlier cost reductions in conversion technology due to learning effects. There are several ways to enhance advanced biofuels, given these perspectives. Specific targets for 2nd generation may be the easiest, but other packages may have comparable effects.

When developing a policy strategy for biofuels, it appears clearly that the risk profile of 2nd generation biofuels differs fundamentally from that of 1st generation biofuels. The introduction of the related perennial cropping systems faces barriers, possibly increased by a strong initial demand for conventional (1st generation) feedstock. Furthermore, the high investment costs for 2nd generation production plants lead to a higher vulnerability for market volatilities. A policy aiming at the introduction of 2nd generation biofuels should take these differences into account. As for feedstock supply policy, points of attention are research on cultivation practices of perennial crops, and adaptation of the EU Common agricultural policy and spatial policies in order to accommodate these crops. Other relevant issues are cross-sector policy harmonisation and the enhancement of lignocellulosic markets able to absorb large-scale supply chains. In order to reduce the initial risks for 2nd generation biofuel production installations, stepping stones may be created by finding synergies with biomass co-firing for power generation (preparing stable feedstock supply) and by integration of plants in district heating systems (output diversification).

When stimulating biofuels, the wider perspective of biomass use in the entire energy economy is essential. The optimal allocation of biomass over applications like power, heat and biofuels is subject to many factors. Application in heat and power is often mentioned as most cost-effective in terms of greenhouse gas emission reduction, but the attractiveness of biomass in each sector strongly depends on the expected competitiveness of alternative options in the different sectors. Common feature is that lignocellulosic bioenergy feedstocks provide the best opportunities. The food-fuel competition effect is also lower for these feedstocks, although competition for the best soils may still occur. With their substantial feedstock potentials, the Central and Eastern European countries currently develop a conventional biofuels industry rapidly. Biofuels policies aiming at introduction of the 2nd generation would need to pay specific attention to this region. Finally, we specify some common environmental criteria for any type of feedstock production.

As any integrative study with a long-term horizon, our statements are subject to the limitations of the approaches we applied, and sensitive to unexpected external developments. Concise remarks on this can be found at the end of this report; more extensive information can be obtained from the different detailed studies that underlie it. They can be found on www.refuel.eu.

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1. Biofuels: the need for a long-term strategy

Energy use in the transport sector is one of the most challenging dossiers in the EU energy domain. Transport is projected to maintain its solid growth rate, inducing several environmental impacts, greenhouse gas emissions being one of them. Furthermore, the transport sector solely depends on oil, the fossil resource for which energy security issues are the most urgent.

In the short- to mid-term, two options can contribute substantially to reducing the environmental and energy security impacts in transport: improved energy efficiency and biofuels. Both options are particularly interesting since they also provide the opportunity to create innovative sustainable technologies, improving competitiveness of EU industry and creating export opportunities.

Biofuels are liquid or gaseous fuels made from biological feedstock, such as agricultural crops and residues, forestry and wood-processing by-products or organic wastes (see Box 1 for further definitions). Compared to other sustainable transport options, such as the electric or fuel-cell powered vehicle, biofuels have the advantage that they can be applied without any fundamental changes in fuel distribution and end use: most biofuels can be blended with gasoline or diesel and used with only minor changes to fuelling points and vehicles.

Table 1: Biofuels, their feedstock and their classification into 1^{st} and 2^{nd} generation.

Feedstock			Classification	Biofuel: Biodiesel	Bioethanol	FT-Diesel	Bio-DME	Bio-SNG
Energy crops	Lignocellulosic crops	Woody plants 1)	2^{nd}		X	X	X	X
		Herbaceous plants 2)	2^{nd}		X	X	X	X
	Oil crops	Rapeseed	1^{st}	X				
		Sunflower	1^{st}	X				
	Sugar crops	Sugar beet	1^{st}		X			
		Sugar cane	1^{st}		X			
	Starch crops	Wheat	1^{st}		X			
		Maize	1^{st}		X			
		Triticale	1^{st}		X			
		Sweet sorghum	1^{st}		X			
Residues	from agriculture	Digestible	1^{st}		X			X
		Non-digestible (straw)	2^{nd}		X	X	X	X
	from forestry		2^{nd}		X	X	X	X
	from wood industry		2^{nd}		X	X	X	X
Waste	Organic waste	Used oils/fats/fatty acids	1^{st}	X				

1) Short rotation forestry: poplar, willow, eucalypt
2) Perennials: miscanthus, switch grass, reed canary grass
1^{st} First generation of biofuels
2^{nd} Second generation of biofuels

EU biofuels production and consumption today

The major biofuel producing regions today are Brazil, the USA and the EU. In the first two, bioethanol (from sugar cane and corn, respectively) dominates the market, in the EU biodiesel from rapeseed. Between the different EU member states, significant differences occur, in terms of production volumes and in the ratio between biodiesel and bioethanol production. The production of biofuels is currently concentrated in a limited number of member states: Germany, France, Spain, Italy and Sweden cover more than 80% of total production. In recent years, biofuel consumption grew tempestuously (see Figure 1), reaching an approximate 1,5% share of EU gasoline and diesel demand in 2006.

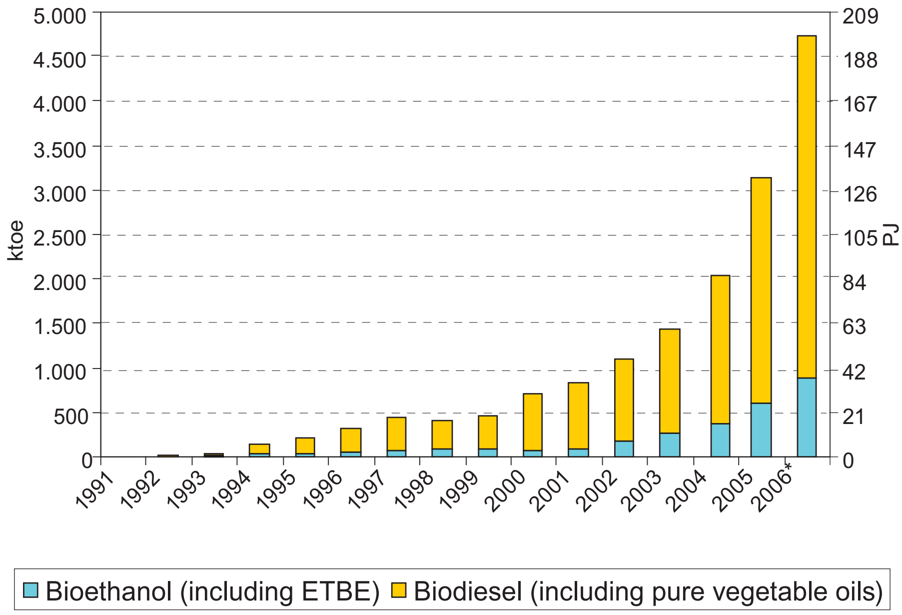


Figure 1: Biofuels consumption in the EU27 1991-2006. Source: IEA, Eurobserv'ER.

High expectations, challenging issues

For 2010, the EU biofuels directive has set an indicative target of 5,75%, which will probably induce further growth in the near term. Furthermore, the European Commission has proposed a 10% binding target for all member states to be reached by 2020. However, with the increasing growth rates and ambition levels, the societal debate on biofuels is also becoming increasingly strong. Issues like feedstock availability, competition with food, environmental impacts and implementation issues can strongly influence the long-term perspectives for biofuels. Particularly in the domain of biofuels-induced deforestation, and related greenhouse gas emissions, today's knowledge is controversial and research is ongoing. These issues are highly important for the biofuels sector since negative new findings may reduce public support, change policy preferences and thereby deprive the sector of its licence to produce. Furthermore, a pathway vision is needed that is both ambitious for biofuels and explicit in its treatment of their drawbacks, aiming at a responsible development.

Box 1: Biofuels and other definitions for this report

Conventional biofuels, or 1st generation biofuels, are fuels made out of biomass, of which worldwide large quantities have been produced so far and for which the production process is considered 'established technology'.

Biodiesel is a substitute of diesel and is produced through transesterification of vegetable oils, and residual oils and fats. With minor engine modifications, it can serve as a full substitute as well.

Bioethanol (conventional) is a substitute of gasoline. It is a full substitute for gasoline in so-called flexi-fuel vehicles. It is derived from sugar or starch through fermentation. Bioethanol can also serve as feedstock for ETBE which blends more easily with gasoline.

Biogas, or biomethane, is a fuel that can be used in gasoline vehicles with slight adaptations. It can be produced through anaerobic digestion of liquid manure and other digestible feedstock.

Advanced biofuels, also referred to as 2nd generation biofuels, are carbon-based fuels that are produced by innovative processes for which commercial utilization is still under development. They are derived from lignocellulosic materials mainly.

Bioethanol (advanced) is a substitute of gasoline. It is a full substitute for gasoline in so-called flexi-fuel vehicles. With hydrolysis, sugars are extracted from lignocellulosic feedstock, after which the sugars are fermented into ethanol.

Fischer-Tropsch diesel, FT-diesel, or BtL (Biomass-to-Liquids) is a full substitute of diesel. Lignocellulosic biomass is gasified to produce syngas which is in turn transformed into liquid hydrocarbons, mostly diesel and kerosene.

Bio-SNG (Synthetic Natural Gas) is a fuel that can be used in gasoline vehicles with slight adaptations. Lignocellulosic biomass is gasified to produce syngas which is in turn transformed into methane.

Bio-DME (Dimethyl Ether) is a fuel that can be used in diesel vehicles with slight adaptations. Lignocellulosic biomass is gasified to produce syngas which is in turn transformed into DME.

Transport costs are the direct costs associated which the transport of resources, intermediate products or biofuels, excluding the distribution costs of biofuels, see distribution costs.

Distribution costs are the direct costs for distributing produced biofuels from a storage facility to the filling stations.

Sugar crops are feedstock for conventional bioethanol production. Typical resources are sugar beet and sugar cane.

Starch crops are feedstock for conventional bioethanol production. Typical resources are cereals.

Oil crops and used fats/oils are feedstock for conventional biodiesel production. Typical resources are sunflower, rapeseed, palm oil, cooking waste and animal fats.

Lignocellulosic materials are a collection of feedstocks for advanced biofuels, either through hydrolysis and fermentation (bioethanol) or through gasification (Fischer-Tropsch biodiesel, bio-DME and bio-SNG). Typical resources are short rotation forestry crops (poplar, willow and eucalyptus), perennial grasses (miscanthus, switch grass and reed canary grass) and residues from the wood industry, from forestry and from agriculture.

REFUEL: a long-term road map for biofuels

The REFUEL project tries to contribute to such responsible development. In this project, we have addressed many of these issues, in order to provide and integrate knowledge that allows the discussions on biofuels to reach a higher level. We applied our key findings, models and tools to today's challenges relating to biofuels, and integrated them into this road map document. It is not a road map sensu stricto: We do not indicate what e.g. the appropriate target levels for 2020 or beyond should be, as we are not in the driver's seat when it comes to policy making. But we do analyse what the general implications might be of the policies under discussion today (Chapter 2).
Furthermore, we indicate what policies are conceivable, when e.g. the climate change or energy security benefits are considered key for biofuels. And we analyse what developments in biofuels may be expected when specific policies are adopted along these priorities (Chapter 3). Doing so, we also came across several issues related to policy making that most futures for biofuels have in common (Chapter 4), across some more strategic and system-oriented issues (Chapter 5). Since all analytical work simplifies the complexities of the world, we discuss the limitations of the approach we've taken, and also sum up the external factors to which our statements are most sensitive (Chapter 6).
Finally, the annex contains a short 'model catwalk', indicating the key characteristics of the methods, models, and tools we developed and applied in REFUEL.
The detailed REFUEL reports that form the basis of this road map can be found on
www.refuel.eu/publications

2. The EU 2020 objective and biofuels potentials

The EU is in the process of setting out an ambitious development of biofuels until 2020. Given the current shaping of this policy, analyses in REFUEL indicate that a mix of 1st generation biofuels is probably the most cost-effective way to meet these ambitions. In such a development, food & feed production and other land use claims in the EU would not need to be compromised. However, when we reconsider the policy drivers for biofuels, it remains questionable whether such a development is the best answer to the underlying motivation for biofuels: such a mix leads to only modest reductions of greenhouse gases, creates minor opportunities for innovation and a competitive industry, and is not very efficient in terms of land use. The required tracts of land for biofuels become relevant if we need to go to higher biofuels shares by 2020 or later, or if biomass demand from other sectors increases substantially as well.

2.1 The currently proposed EU targets assessed in REFUEL

EU ambitions

In its proposal for the new renewables directive, the European Commission sets out a number of frame conditions for the future development of biofuels. Key ingredients are:

- A binding minimum target of 10% by 2020. In contrast to the renewables target of 20%, which is differentiated among the member states, this target applies to every country.
- A minimum greenhouse gas emission reduction of 35% compared to fossil fuels. On the basis of current knowledge on greenhouse gas balances for biofuels, this minimum level is attainable for all common biofuels of today and for the longer-term options.
- Possible competition for resources between biofuels and biomass use for renewable heat and power is not explicitly mentioned in the directive.

The proposal also contains a specific incentive for 2nd generation biofuels: any biofuels produced from lignocellulosic materials should count double towards a national biofuels target. However, as it is unclear how such a policy would affect the opportunities for 2nd generation biofuels (as further specified in 4.1) our first analysis focuses on biofuels potentials regardless of this double-counting option.

There is sufficient low-cost biofuel potential in the EU and Ukraine to cover the 10% target with 1st generation biofuels, assuming that imports account for 30% of the target and other bioenergy sectors put no claim on agricultural land.

In a REFUEL full chain analysis, in which the overall EU target is 10% for 2020, the most cost-effective way to meet the target is by strong reliance on conventional biofuels. Here we assume that circa 30% of this target is met by imports from outside Europe. Particularly the Eastern European countries and Ukraine have the resource potential to produce the required amounts of feedstock at low costs. Important precondition here is that the use of biomass for power and heat remains confined to forestry materials and residues, and does not put a claim on (agricultural) land. In such a future, the introduction of 2nd generation biofuels is hampered by the high initial investment costs and corresponding biofuel production costs of the first installations. In our analysis, it appears even possible to meet a 15% target cost-effectively by 2030 using conventional fuels, mainly produced from domestic feedstock.

The 10% target is attainable because there is a substantial potential for European feedstock production against moderate costs.

An extensive part of the activities in REFUEL focussed on assessment of feedstock potentials for biofuels, and their costs. Particularly the 12 new member states to the EU and Ukraine appear to have considerable potentials for biofuel feedstock production at cost levels significantly below those in Western Europe.

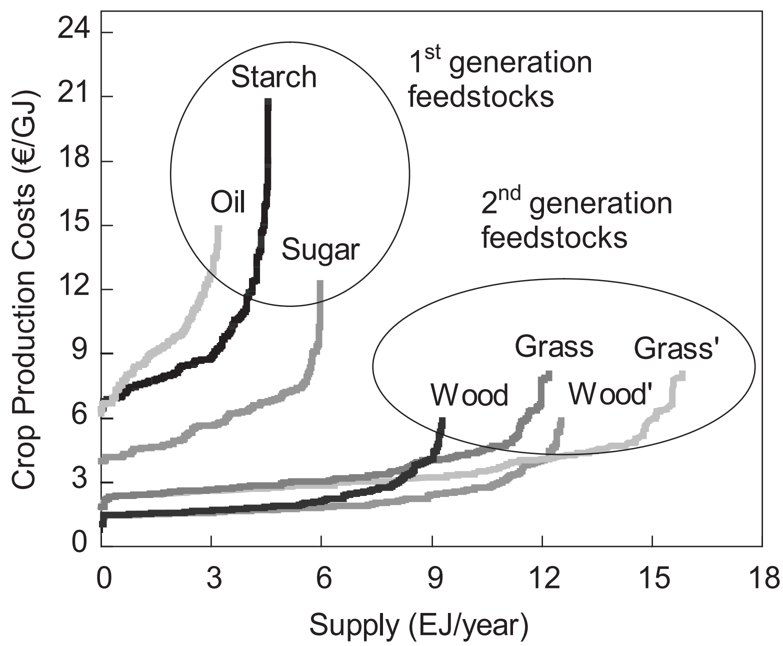


Figure 2: Cost-supply curves for the five selected crop groups. The curves for wood and grass refer to the potential on arable land, wood' and grass' refer to potential on arable and pasture land.

The land required in Europe to produce these feedstocks is available without endangering food security or nature conservation. This land is mostly located in Eastern Europe, where substantial cultivated areas can become available through sustainable gains in yield in the food and feed sector.

The future availability of agricultural land in Europe for bio-energy feedstock production is determined by several factors: future food crop and livestock demand in Europe, changes in production intensity and yields, levels achieved for European self-reliance in food and feed supply, amounts of land managed for nature conservation, and the conversion of land from agricultural to e.g. built-up land and infrastructure. Three scenarios were developed representing possible developments on these factors:

1. A low scenario (low) with special attention to nature conservation and ecological sustainable farming practices, assuming modest yield increases;
2. A business-as-usual scenario (base) respecting current trends in nature conservation and ecological sustainable farming practices, assuming average yields increases
3. A high scenario (high) with emphasis on conventional farming, respecting current trends in nature conservation and ecological sustainable farming practices, assuming high yield increases. This high scenario also allows for sustainable use (zero-tillage) of available permanent pasture land, i.e., grassland not used for feed production and not otherwise conserved or protected.

The level of EU self-reliance and conversion to built-up land was kept constant between the scenarios.

The scenario analysis indicates that for Europe between 45 million hectares (low scenario with ecological emphasis) and 70 million hectares (high scenario with emphasis on conventional farming) of land may become available for alternative use by 2030. Most of this land is located in Eastern Europe where crop yields are assumed to gradually converge with Western European yields by 2050. As a result, more than 40 million hectares of agricultural land could be freed-up and become potentially available for energy crop production, half of which in the New Member States and the other half in Ukraine. Land potential for energy crops in Western Europe is more restricted.

2.2 The objections to a development pathway with mainly 1st generation biofuels

A 10% biofuels share in 2020 with conventional biofuels. Achievable, probably the most cost-effective way to introduce biofuels; but does such a future align with the reasons why biofuels have been proposed? There are grounds for considerable doubt. Key reasons are:

Conventional biofuels only have modest greenhouse gas emission savings

One of the key motivations behind biofuels is the reduction of greenhouse gas emissions from transport. Most conventional biofuels have greenhouse emission reductions between 40% and 60% compared to fossil fuels, while advanced biofuels such as lignocellulosic ethanol and FT-diesel achieve emission reductions above 90%. This is mainly due to higher land use efficiency and lower agro-chemicals requirements. Therefore, it is questionable whether a biofuels mix dominated by conventional biofuels is a sufficient way of responding to the climate challenge. This is illustrated by several REFUEL chain analyses: if, for example, a CO_2 emission pricing mechanism is introduced in transport, the competitiveness of 2nd generation biofuels improves significantly.

Growth of conventional biofuels may cause negative effects on the environment

For reaching higher land use efficiencies (energy output per hectare) conventional biofuels grown in temperate Europe usually require high input agricultural management systems. Unless managed cautiously, there is concern that increased fertilizer and pesticide use may cause water and soil pollution, as with food crops. In contrast, production of lignocellulosic feedstocks allows less input-intensive cultivation practices. Therefore, the production of lignocellulosic feedstocks tends to be environmentally less harmful than production of 1st generation conventional crops.

Conventional biofuels require significant amounts of agricultural land and directly compete with food production

Reducing fossil oil dependency is the other key motivation for biofuels. As such, any biofuel will basically do. However, as cultivation of feedstock requires land, there is a risk that improved energy security would come at the expense of deteriorated food security. Therefore, land-efficient biofuels, with high biofuel yields per hectare, would be advantageous. In this respect, 2nd generation biofuels have several benefits. Firstly, these biofuels can use a range of agricultural and wood-related residues as their feedstock without any direct claims on land. Secondly, the land use efficiency of 2nd generation biofuels is a factor two to four higher than that of 1st generation biofuels (see Figure 3), leading to less land required per unit of energy produced. Thirdly, a wider spectrum of land could be available for these feedstocks. Notably grasslands not viable for 1st generation biofuels due to environmental and greenhouse gas implications, could become an additional resource for high-yielding lignocellulosic feedstocks under zero tillage practices. In addition, marginal areas could be considered for feedstock production under low input agricultural management systems. In short, meeting a specified biofuels target by 2nd generation biofuels entails less direct competition for land with food and feed production, and reduces the risk of price hikes.

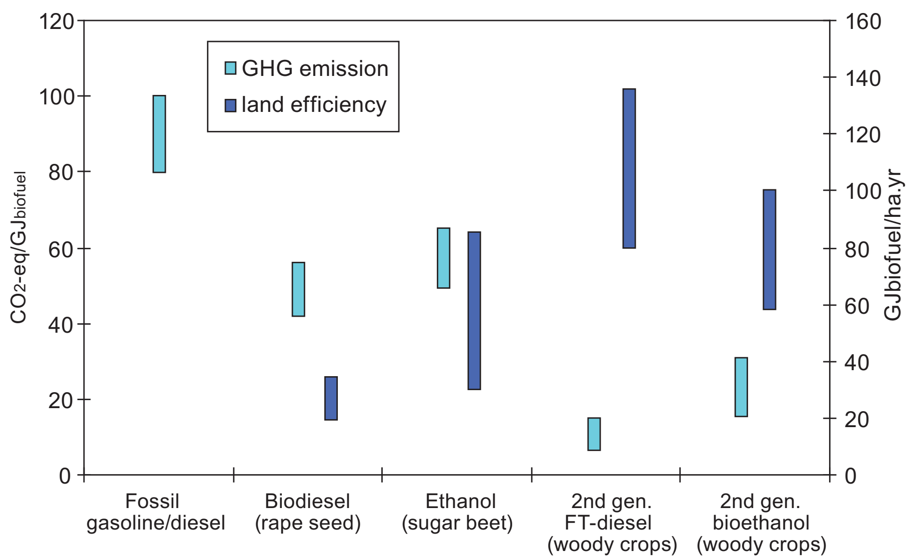


Figure 3: Greenhouse gas emissions and gross annual biofuel yields per ha[1] for the most common biofuels[2] .

[1] Average energy yields vary widely among countries and depend on climate, soils, and terrain. Energy yields here refer to an average yield across all land qualities on agricultural land and assume rain fed cultivation with sufficient nutrients and control of pests and diseases and are expressed in GJ biofuel equivalent per hectare.

[2] FT-diesel included here as representative of gasification-based biofuels. The gross biofuels yield per ha is ca 10% higher for DME, and ca 20% higher for SNG. FT-diesel, DME and SNG show comparable greenhouse gas emission reductions.

Land efficiency may become even more critical if ambitious targets for renewables also induce demand for dedicated energy crops for power, heat and biomaterials. As an illustration: A REFUEL analysis in which we reduced feedstock potential due to demand for other applications directly leads to an increase in the share of 2nd generation biofuels. In such cases, the relatively limited availability of land directly pushes the higher yielding crops into cultivation.

If 10% is not the end term for biofuels, 2nd generation biofuels will become more competitive

Finally, it would be a bit too simplified only to look at 10% biofuels by 2020. First, a sustainable long-term development will most probably call for further growth of the share of renewable fuels after 2020. Second, it remains to be seen whether the EU will meet its overall 20% renewables target with a 10% share of biofuels in transport. For example, the German subtargets for meeting the 20% renewables target include a 17% target for biofuels. However, with increasing ambitions, the urge for biofuels to be land-efficient will only be stronger. Illustrative in this context is a REFUEL analysis with targets up to 14% by 2020 and 25% by 2030 (see Figure 4): in these analyses, the most cost-effective biofuels mix contains a significant share of 2nd generation biofuels.

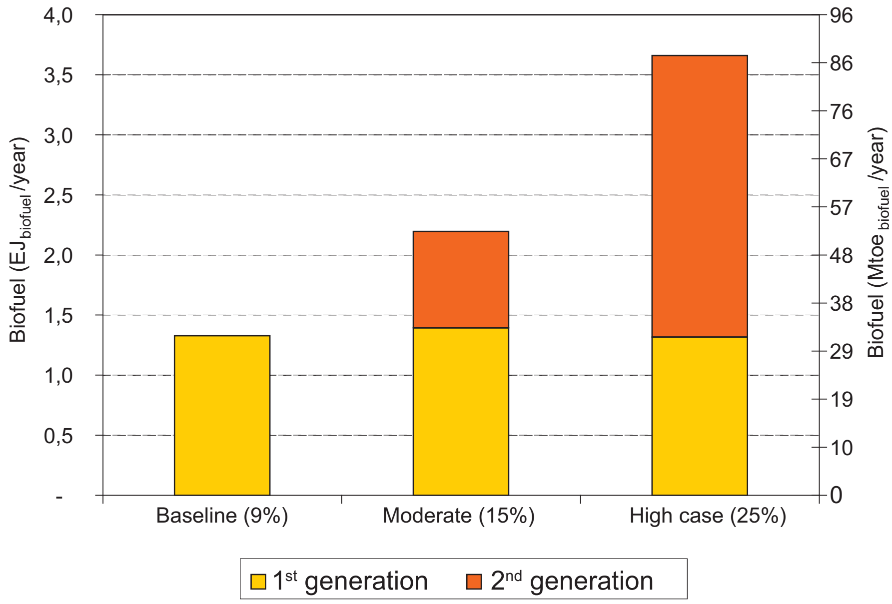


Figure 4: Split between 1st and 2nd generation biofuels by 2030 at different levels of total production if the target is met by European biofuels only.

The development of 2nd generation biofuels would require innovation, improving the EU's position in an emerging market

A future more sustainable energy economy will strongly depend on technologies allowing low-grade feedstock to be converted into high-value energy carriers. By taking early steps in the domain of these types of technologies, the EU could reach a strongly competitive position on an emerging international market with substantial export opportunities. Furthermore, once the initial cost barrier for 2nd generation biofuels is overcome, technological learning leads to substantial cost reductions improving the competitiveness of these fuels compared to 1st generation biofuels.

Second generation biofuels create less (low-educated) employment in agriculture, but more (high-educated) employment in an innovative industry

A final argument on biofuels and renewable energy in general is that they enhance the development of a sustainable and competitive new industry, including new employment. However, analyses in REFUEL clearly indicate that 1st generation biofuels use relatively conventional conversion technology. The major part of the employment creation takes place in rural areas – mainly in the agricultural sector - involving relatively low-qualified employment. On the other hand, 2nd generation biofuels create more highly qualified employment in the industrial sector. From a neoclassical economy perspective however, the use of employment creation in nations as a rationale for energy policies for bioenergy can be questioned.

3. Additional perspectives on biofuels policy

> *A biofuels target share alone does not seem to induce the development of biofuels that best respond to the drivers for biofuels policy. Therefore, we defined and analysed several 'policy packages' that are built up on a specific policy perspective, or concern for biofuels. It appears that any policy package taking into account the wider meaning of biofuels leads to an introduction of 2nd generation biofuels before 2020. An early start with advanced biofuels leads to biofuels that better meet the drivers behind biofuels than the conventional mix, and an early start also leads to earlier cost reductions in conversion technology due to learning effects. There are several ways to enhance advanced biofuels, given these perspectives. Specific policy for 2nd generation may be the easiest, but other packages may have comparable effects.*

Working only with a biofuels target of 10% by 2020 may lead us to a biofuels mix that is cost-effective in strict terms, but less attractive when we take the underlying interests in biofuels into account. Next question would be how to translate these interests into additional policies. A first-order option would be to include a specific subtarget for 2nd generation biofuels. But in order to broaden the minds, we conducted some supportive analysis on biofuels development if we start our reasoning by the key underlying motivations for biofuels, and define (sets of) policy measures consistent with these motivations.

Policy perspectives for biofuels

Therefore, we defined three policy perspectives for biofuels related to their key drivers, as a basis for discussion.

- A climate protection perspective (or 'Kyoto'). In this perspective, biofuels are chiefly introduced as a measure to reduce greenhouse gas emissions. They are part of several measures to reduce these emissions: increasing energy efficiency, renewable power and heat, etc. As biofuels are generally considered a relatively expensive option in terms of costs per tonne of avoided CO_2, priority is set to the use of biomass in the stationary sector and biofuels have a moderate target.
- An energy security perspective (or 'Moscow'). In this perspective, security of energy supply is considered the dominant issue to be addressed. As the transportation is the sector with the highest (forecast) fuel import dependency, there is a high ambition level for biofuels, with a more moderate attention for biomass in other sectors.
- A competitiveness and innovation perspective, (or 'Lisbon'). In this perspective, enhancement of an innovative and competitive EU industrial sector is the key driver for biofuels. As biofuels, and specifically the 2nd generation, are generally products with a relatively high added value, the ambition level for biofuels is high, specifically for 2nd generation biofuels.

Furthermore, we defined a couple of perspectives that do right to other arguments in the biofuels debate. These are:

- A biodiversity perspective. Possible detrimental effects of biofuels on (EU and global) biodiversity are often used as an argument against biofuels. This perspective is a combination of measures aiming at the prevention of such effects.
- An agricultural support perspective. Support of agriculture in the EU has always been one of the (sometimes somewhat hidden) motives for biofuels. This perspective is based on a preference for this argument

As a final contribution, we defined a 'REFUEL' perspective; a set of measures that we as a team of experts consider an ambitious but balanced approach to biofuels given their underlying drivers and the possible critical factors.

These perspectives were translated into policy packages as given in Table 2. For an explanation of the measures and their motivations, see Annex 1. Such a translation is by nature subjective, but it provides a fair range of possible policy mixes to show the impacts.

Table 1: Translation of different perspectives on biofuels into policy packages.
For motivation see Annex 1.

Policy measures	Policy making priority			Critical issue		Team
	GHG	SES	Innovation	Biodiversity	Agriculture	'REFUEL'
Biofuels target pathway	Moderate	High	High	Moderate	High	High
Ambition levels RES-E/H	High	Moderate	Low	Moderate	Low	High
Assumed levels of import	High	None	None	Limited	None	High
CO_2 pricing	Yes	No	Yes	Yes	No	Yes
Energy crop premium	No	Yes	No	No	Yes	No
Investment subsidies	No	Yes	Yes	No	No	Yes
Specific targets 2nd generation	No	No	Yes	Yes	No	No

Analysis of the perspectives in REFUEL

An evaluation of biofuels development subject to these policy packages shows substantially different results compared to the developments when only the 10% target is applied.

- First, there is an earlier introduction of 2nd generation biofuels in all perspectives. The introduction year varies between 2010 and 2015, which is ambitious but possible given the developments in the related technologies.
- By 2030, 2nd generation biofuels dominate in all perspectives (see Figure 5). The dominance is clearest in perspectives with high ambitions for biofuels, but also packages based on a strong environmental perspective (such as the Kyoto and biodiversity perspectives) induce a major development of 2nd generation biofuels. Even in the agricultural perspective, the high ambition level finally necessitates the introduction of these biofuels.
- In terms of feedstock use, 2nd generation biofuels first start applying residues, and only after this low-cost feedstock has run out of potential, dedicated crops are being introduced. By 2030, residues still make up roughl one-third of feedstock supply for 2nd generation biofuels (see Figure 6)
- Obviously, these perspectives show substantially better greenhouse gas emission reductions than the 'base' policy with a 10% target alone. For example, while a biofuels mix dominated by 1st generation biofuels reduces greenhouse gas emissions by rougly 40% compared to fossils, the innovation perspective increases this reduction to more than 90%.
- In terms of land efficiency, the strong role of 2nd generation biofuels leads to significantly higher average biofuel yields per ha than in the 'base' policy.
- In terms of costs, policy packages inducing higher shares of 2nd generation biofuels also lead to higher average costs per GJ biofuel. However, this cost increase lies in the order of 1 €/GJ (or several cents per litre), given the approach and limitations of this study.

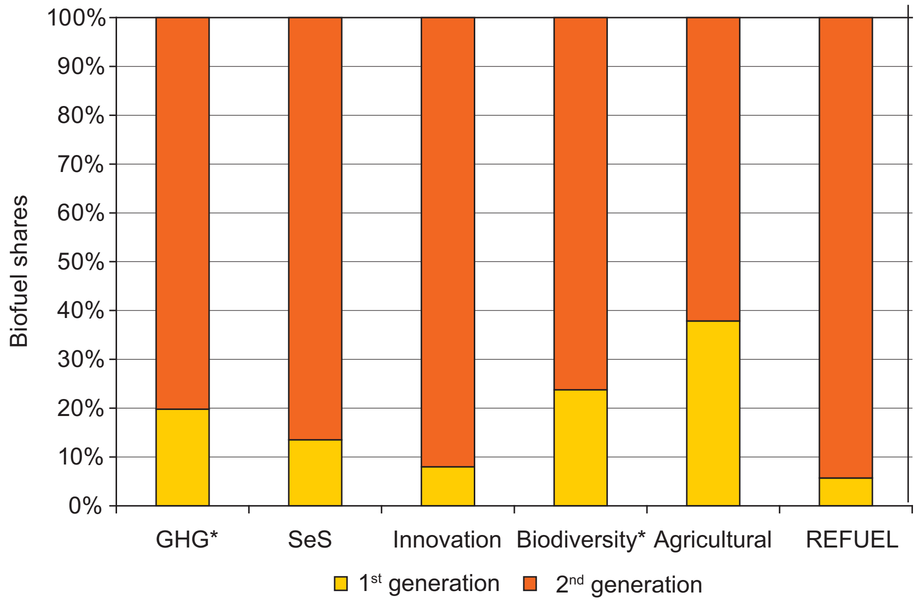


Figure 5: The 2030 balance between 1st and 2nd generation biofuels in the different perspectives, indicating the effect of the different policy packages.

- An early start with advanced biofuels leads to biofuels that better meet the drivers behind biofuels promotion than the conventional mix, and an early start also leads to an earlier cost reduction.
- In terms of employment effects, there is a clear difference between the 'base' policy and the perspectives discussed here. The high share of 2nd generation biofuels leads to less (lowly educated) employment being created in agriculture, but there is more (highly educated) employment created in industry. Especially in agriculture, these impacts are relatively minor compared to total employment in the sector, and in both sectors the impacts will (partly) be counterbalanced by indirect effects.
- There are several ways to increase the share of advanced biofuels, given these perspectives. Specific policy for 2nd generation may be the easiest, but other options are also possible.

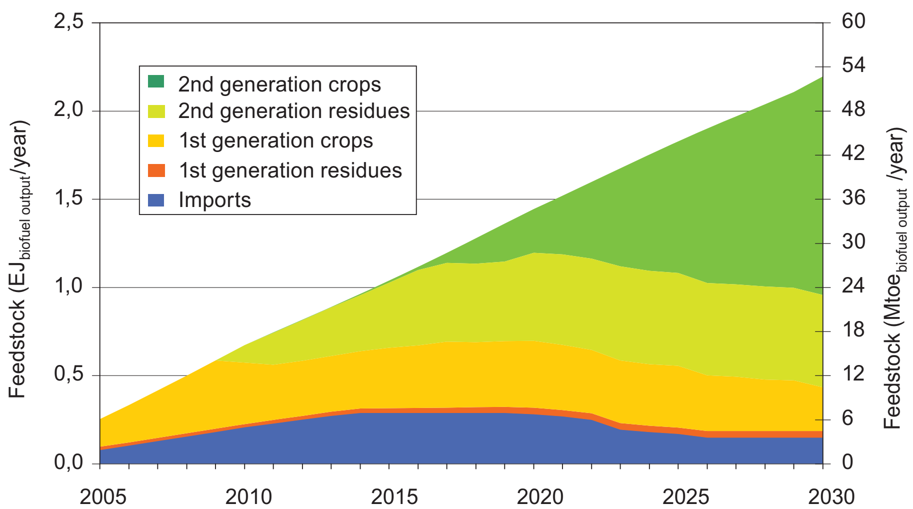


Figure 6: Development in net feedstock use in the policy packages based on the Kyoto perspective.

4. Policies and strategies for 2nd generation biofuels

When developing a policy strategy for biofuels, it is clear that the risk profile of 2nd generation biofuels differs fundamentally from that of 1st generation biofuels. The introduction of the related perennial cropping systems faces an introduction barrier, possibly increased by a strong initial demand for conventional (1st generation) feedstock. Furthermore, the high investment costs for 2nd generation production plants lead to a higher vulnerability for volatilities in the biofuels price, while its lower feedstock costs entails lower vulnerability to feedstock price hikes. A policy aiming at the introduction of 2nd generation biofuels should take these differences into account. As for feedstock supply, points of attention are research on cultivation practices of perennial crops, adaptation of the EU Common agricultural policy and spatial policies in order to accommodate them, cross-sector policy harmonisation and the creation of lignocellulosic markets able to absorb large-scale supply chains. In order to reduce the initial risks for 2nd generation production plants, stepping stones may be created by finding synergies with biomass co-firing for power (preparing stable feedstock supply) and by integration of plants in district heating systems (output diversification).

All broader policy perspectives on biofuels point in the direction of a substantial share of 2nd generation biofuels. What specific policies would then be essential for the introduction of these biofuels? Obviously, this development requires actions from different stakeholders, varying over time as well (see Figure 7 for an illustration), and a manifold of measures can be conceived to support this process (e.g. Figure 8). In this section, we go into a number of policy making issues. First, we argue that the current stimulation of conventional biofuels will have positive as well as negative impacts on the prospects for advanced biofuels. Second, we go into some specific issues related to the development of lignocellulosic feedstock supply. And finally, we discuss two strategies that can reduce the initial risks related to the setting up of 2nd generation biofuel chains by matching their introduction with other developments in the energy sector.

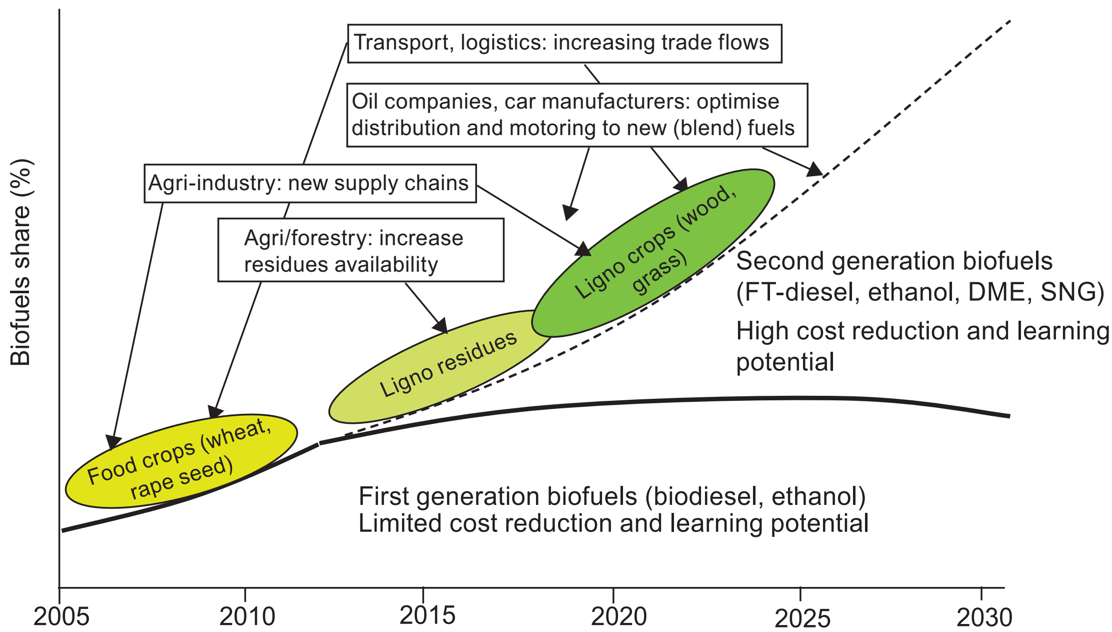


Figure 7: Possible development pathway for biofuels, including implications for different market actors.

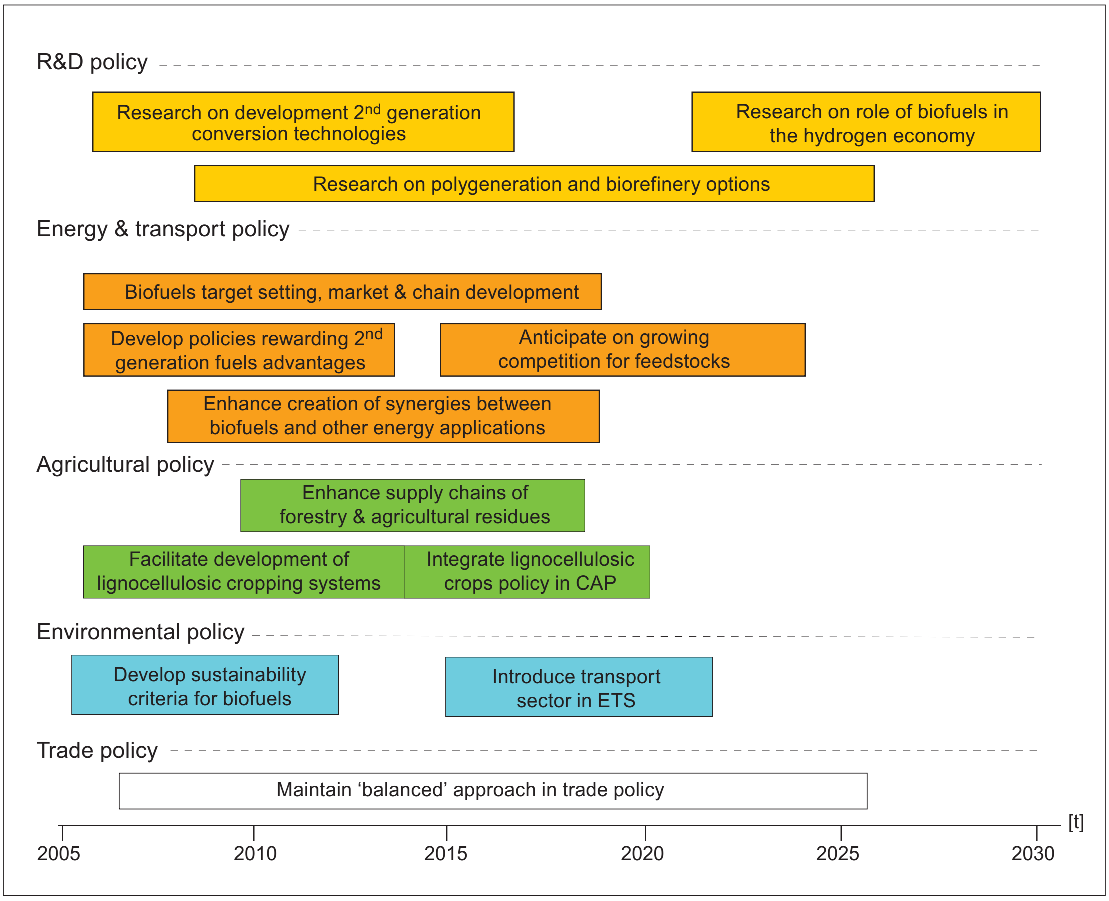


Figure 8: Policies in different policy domains that might be applied to enhance biofuels development, 2nd generation biofuels in particular.

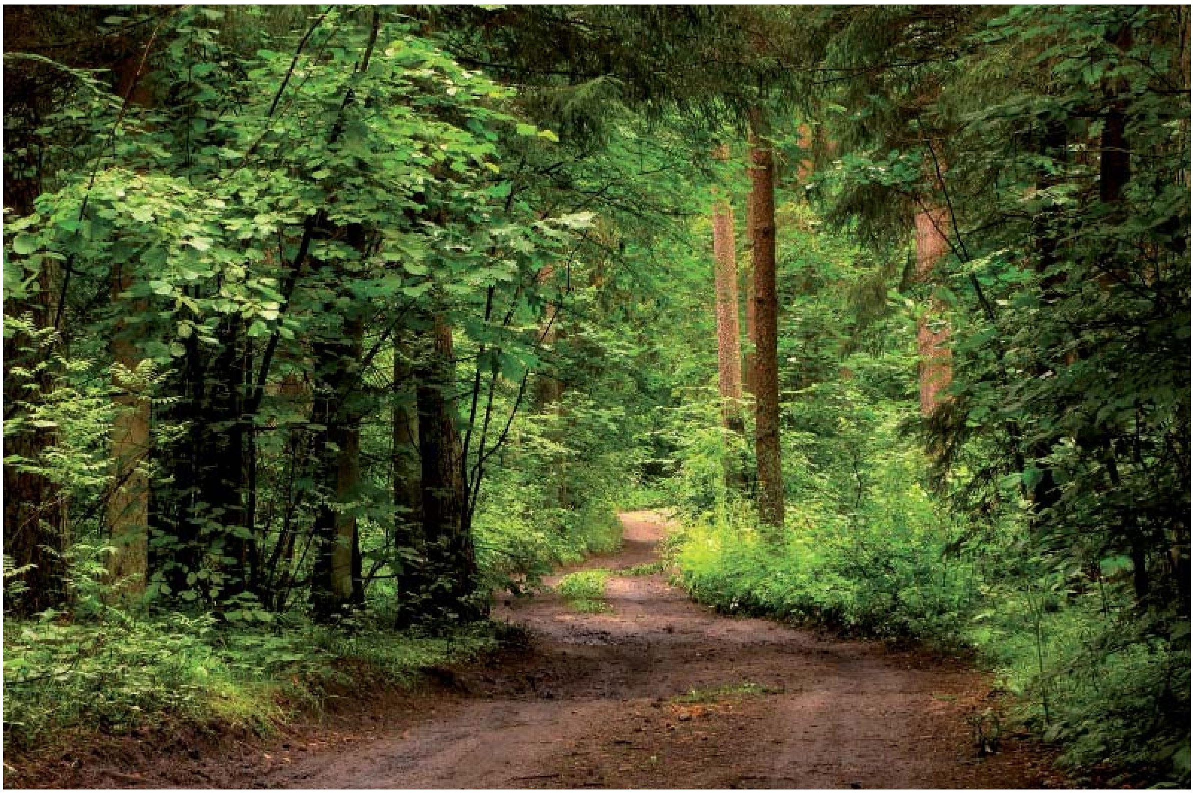
4.1 Are policies stimulating 1st generation biofuels effectively paving the way for 2nd generation biofuels?

The promotion of first generation biofuels to meet near term biofuels for transport targets is often motivated by the argument that it 'paves the way' for advanced, 2nd generation biofuels. It enhances e.g. deployment of dedicated pumps at fuelling stations and increased availability of biofuel-prepared vehicles. Furthermore, it is argued that such promotion allows the public to get acquainted with biofuels in general. However, these positive impacts may be more than outweighed by undesirable effects, for which additional compensation measures might be needed.

As for the claimed positive effects: the currently dominating strategy of blending biofuels into gasoline and diesel does not lead to the introduction of dedicated pumps at fuelling stations, nor to a strong incentive for adapted vehicles. A strategy focusing on higher blends would have stronger effects of this kind. Furthermore, the public debate on biofuels is now focusing on the negative impacts of (1st generation) biofuels: their assumed impacts on food prices, their possible role in deforestation and biodiversity losses, and possibly resulting net increases in greenhouse gas emissions. Although several of these claims may be disputed, the view that current biofuels do not contribute much to reducing climate impact or improving energy security has already contributed to dwindling public support for biofuels. In such a polarised debate, there may be little place for the nuanced view that 2nd generation biofuels perform far better on these issues.

In agricultural production of biofuel feedstock, promotion of 1st generation biofuels will probably be more of a hindrance than an enhancement to 2nd generation feedstock. A shift to 2nd generation biofuels would shift feedstock demand to forest biomass and other lignocellulosic feedstocks, resulting in lower demand for conventional crops. At sufficient demand levels, dedicated lignocellulosic crops may become a new option for agriculture, but these crops face agronomic, institutional and not least cultural barriers (see section 4.2). This because their cultivation is less well-known than that of conventional crops, their market outlets are less diverse, and their perennial cultivation is less flexible. First attempts in Sweden indicate that farmers generally require a substantial risk premium for shifting to these new crops. In agriculture, a strong development of 1st generation will therefore hardly spur the development of 2nd generation feedstock, and may even create a vested interest hindering their introduction. As farmer-owned companies are also often involved in 1st generation production plants, this can apply to the entire production chain.

As for industry investing in biofuel production, the cost structure differs significantly between 1st and 2nd generation biofuels. For biodiesel producers, investment costs consist of about ten percent of biodiesel production costs per litre; the bulk of the costs lie in variable costs (mainly feedstock costs). This allows a producer to run at submaximal production capacities in times of poor market circumstances. For a 2nd generation biofuels plant, investment costs take about half of production costs per litre, with a relatively low share of variable costs for e.g. feedstock. Therefore, a 2nd generation plant has a different risk profile: it is more vulnerable to price volatilities in the biofuels market, and less vulnerable to price volatilities in feedstock markets. As a consequence, policies will have different impacts on the two, depending on how they affect the biofuels and feedstock markets. A biofuels market in which an invester in 1st generation production can handle its risks may still be too unstable for the investments related to 2nd generation biofuels, even when strict production costs are the same.



In short, we see little synergies and quite some potential conflicts between enhancement of 1st generation and the future breakthrough of the 2nd generation. Other policy domains may create better synergies. From a farmer's perspective, the further development of alternative markets for lignocellulosic feedstocks – notably heat and power production – would reduce the perceived risk of switching to these crops. For industry, biofuel production processes that are based on biomass gasification and apply excess heat to power generation or district heating may reduce vulnerability to price volatilities in the biofuels market. These two options are further discussed in Section 4.3.

4.2 Development of lignocellulosic feedstock supply

The role of energy crops is anticipated to grow substantially to meet ambitious renewable energy targets. While feedstocks for use in the first generation biofuel conversion technologies utilize existing food and feed crops (cereals, oil crops, and sugar crops) for producing biofuels, advanced 2nd generation technologies rely on feedstocks rich in lignocellulosic plant material.

Besides crop and forestry residues, energy crops grown on agricultural land could play a key role in providing sufficient lignocellulosic feedstocks required for the 2nd generation biofuel production chain. These feedstocks can also very well be used for biomass based heat and electricity production.

However, the production of lignocellulosic energy crops differs from conventional crops in several respects. First generation biofuel feedstocks are well known to farmers and only imply and alternative use of conventional crops and hence no change in agricultural management. On the contrary, a successful introduction of lignocellulosic supply entails changes of agricultural management and farm technology as well as of the supply logistics. Important factors for a successful introduction of lignocellulosic feedstock supply from agricultural land include:

(i) Agricultural research on management and cultivation practices

In Europe, experience and relevant field-scale data on management techniques of the production of lignocellulosic feedstocks is limited. Additional research is required for optimizing management of lignocellulosic energy crops for the diverse biophysical conditions across Europe. As the experience of European farmers with energy crop plantations is very limited, the transition to lignocellulosic feedstock systems may require tailor-made support services assisting farmers on the various aspects of production such as planting, crop treatment and harvesting.

(ii) Perennials in Common Agricultural Policy and spatial policies

Lignocellulosic feedstocks are perennials with plantation cycles of 10 to 20 years depending on feedstock and variety. Large scale production of lignocellulosic feedstocks implies a major land use conversion. Arable land used for growing annual crops (for food, feed or first generation biofuel feedstock) offers the farmer a great flexibility to respond to market demands. Plant materials and establishment account for a major fraction of production costs of lignocellulosic feedstocks and once the plants have been established on arable fields the farmer is bound to produce for some 10 to 20 years. Back conversion to either traditional food and feed crops or first generation energy feedstocks is difficult, environmentally deleterious and costly. The conversion of land producing annual crops for food and feed into energy crop plantations needs careful considerations beyond agronomic and economic factors. In particular, potential uses of some arable land for perennial energy crops would have to be reflected in regulations and spatial policies both at the national level and in the Common Agricultural Policy (CAP).

(iii) Harmonization of policies between sectors

Lack of experience with lignocellulosic feedstocks and less flexibility due to perennial use may constitute key barriers for farmers to invest in the production of new energy crops providing lignocellulosic biomass. Therefore, the obstacle for farmers and their hesitation to produce lignocellulosic feedstocks is likely to be much larger than for the production of the conventional annual crops used for the first generation biofuel production pathway. Yet, large scale local supply will be essential for cost-effective biofuel industries. In this respect a harmonization of policies between sectors including energy, agriculture, industry, as well as spatial planning is of importance. Long-term contracts for lignocellulosic supply can be beneficial for both the farmer supplying lignocellulosic feedstocks and the industries that depend on reliable and cost-effective provision of biomass. Comprehensive planning and interaction between the different stakeholders (especially farmers, industry, and policy makers) constitutes a crucial element for successful and sustainable development of lignocellulosic supply.

(iv) Enhancement of large-scale supply chains

Economies of scale will have a major influence on the production costs for bioethanol and gasification-based biofuels from lignocellulosics. Biomass logistics will then also become a relevant cost factor. Once technologies for conversion of lignocellulosic feedstock into biofuel are available for commercial application, decisions on locations of commercial plants will be guided by existing potentials for a long-term adequate and reliable biomass supply at economic prices, and a reliable biofuels market. This suggests that large scale supply chains should be stimulated, and requires the indentification of optimal locations for industries, balancing feedstock and biofuel logistics.

(v) Multipurpose energy use of lignocellulosic biomass

Lignocellulosic feedstocks can equally well be used for conversion to heat and electricity. Developing these options parallel to 2nd generation biofuels creates a more diverse demand for lignocellulosics, providing farmers a risk reduction by diversification of possible market outlets. Parallel to this, potential synergies between the different conversion routes can be identified to further enhance the energy output per unit of biomass input.

4.3 Stepping stones for the introduction of 2nd generation technologies

As mentioned, 2nd generation biofuel chains come with significantly higher risks than those of conventional chains. Therefore, the REFUEL project has sought for the development and analysis of biofuel stepping stones; strategies aiming at promoting cost effective implementation paths for 2nd generation biofuels by removing or reducing specific barriers or opening up additional benefits for these technologies. Such stepping stones strategies have in common that they exploit existing energy infrastructures in order to reach lower costs. REFUEL specifically aimed at stepping stones strategies that also support developments in the fields of heat and power.

Two strategies have been studied in more detail: linking 2nd generation biofuels with existing options for biomass co-firing, and integration of gasification-based biofuel plants with existing heat distribution infrastructure. The analyses indicate that both biomass co-firing and district heating integrated biofuel production could be an attractive option for stimulating the development of 2nd generation biofuels. In many member states, the prospects for such stepping stones are sufficient to motivate investigations into how policy can establish them.

Biomass co-firing as a stepping stone to advanced biofuels production

Co-firing of biomass with coal in existing boilers for power production allows for the generation of RES-E with high efficiency and low cost. It is also an option for specifically stimulating lignocellulosic crops production, inducing development and cost reduction in the supply infrastructure. By providing an early market for these crops, co-firing can pave the way for not yet commercially available technologies providing 2nd generation biofuels. In a situation where biomass demand for co-firing is gradually decreasing over time due to gradual decommissioning of outdated power plants, 2nd generation biofuel technologies may represent the major subsequent use of the lignocellulosic crops and thus benefit from an already established biomass supply infrastructure.

Results from REFUEL analyses using the Chalmers EU Power plant database indicates that biomass co-firing could contribute substantially to RES-E targets for 2010 in many member states. If linked to the production of lignocellulosic crops, biomass co-firing could become a prime mover for such crops by requiring production that is clearly significant in comparison to the biomass demand related to the 10% biofuel for transport target in 2020 (see Figure 9).

Gasification based biofuel production and district heating

The second biofuel stepping stone strategy focuses on biofuel production processes that are based on biomass gasification with subsequent synthesis to biofuels such as FT-diesel, DME and SNG. These plants generate excess heat that could be used in district heating systems, improving energy efficiency as well as economic viability. For some plant configurations also electricity can be produced, further improving the cost competitiveness. Since most of the present district heat deliveries in the EU are based on fossil fuels, this strategy would also reduce the CO_2 emissions in the heat sector. This option can be considered one of the ways to combine biofuel production with the production of other energy forms or material, also called polygeneration or biorefinery. Common feature is that combined production may reduce production costs of biofuels and increase overall efficiency.

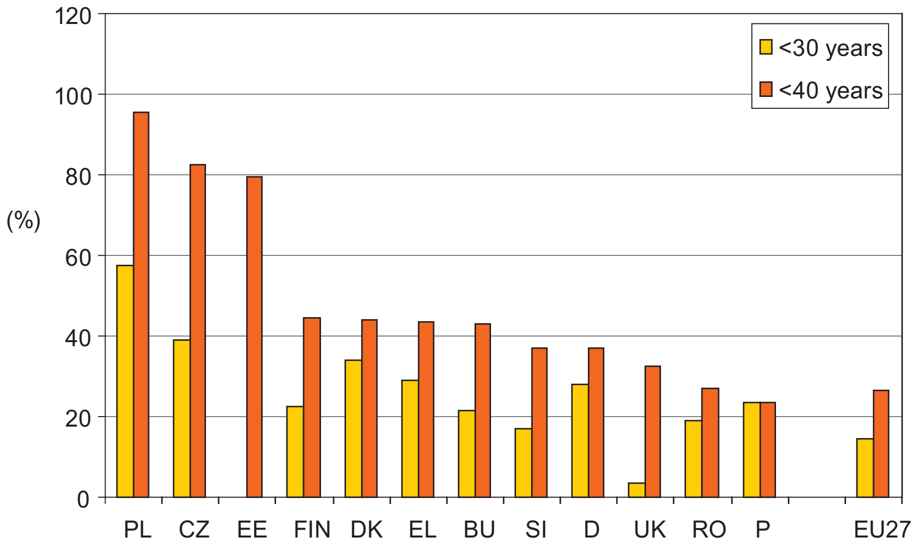


Figure 9: Current biomass co-firing potential in power plants as a share of the amount of biomass needed to meet the 10% biofuels target in 2020. Top-12 EU member states and EU27 average, for power plants <30 years and <40 years.

REFUEL analyses with the Euroheatspot model show that heat demand in district heating systems is substantial. If, for example, all heat demand in district heating were to be met by combined heat and biofuels production, this would generate more than 200 Mtoe (roughly 10 EJ) of biofuels, or ca 70% of 2005 gasoline and diesel consumption in the EU. But the extent to which biofuel production plants can actually profit from integration with district heating depends on several factors, such as its competitiveness against combined heat and power. If this options maintains its dominant position in district heating, the potential for combined heat and biofuel production decreases to less than 10% of its original potential. Furthermore, combined heat and biofuels will only fit in district heating systems with sufficient demand to absorb the heat generation of a full-scale biofuels plant. Finally, local biomass supply might be a limiting factor.

System impacts of stepping stones

For both stepping stones, some critical aspects need to be considered. Biomass use for co-firing may be considered a lock-in risk hampering their use for biofuels. However, biomass co-firing and biofuels production will depend on governmental support. Therefore, appropriate modifications can be incorporated into this support to allow a fair competition between new co-firing and biofuels production by the time a power plant is decommissioned and an investment decision for either of the options needs to be made.

The impacts of the stepping stones on overall greenhouse gas emissions strongly depends on substitution effects. If integrated heat and biofuel production successfully competes against combined heat and power in the European district heating systems, its electricity generation will need to be replaced. The climate benefit of expanding integrated heat and biofuel production will obviously look very different when this lost generation is compensated for by either increased coal based power or by renewables,. Comparably, shifting a biomass-for-cofiring supply chain to biofuels needs to replacements as well. It is a world of difference whether this power generation substitute is e.g. wind-based or coal-based. Therefore, accompanying policies and incentives will probably make or break the attractiveness of these stepping stones, on economic as well as environmental terms.

5. Broader strategic issues

When stimulating biofuels, the wider perspective biomass use in the entire energy economy is essential. The optimal allocation of biomass over applications like power, heat and biofuels is subject to many factors. Application in heat and power is often mentioned as most cost-effective in terms of greenhouse gas emission reduction, but this conclusion strongly depends on the expected competitiveness of alternatives in the different sectors. Common feature is that lignocellulosic feedstocks provide the best opportunities. The food-fuel competition effect is also lower for these feedstocks, although competition for the best soils may still occur. With their substantial feedstock potentials, the Central and Eastern European countries currently develop a conventional biofuels industry rapidly. Biofuels policies aiming at introduction of the 2nd generation might need to pay specific attention to this region. Finally, we specify some common environmental criteria for any type of feedstock production.

Apart from policy and strategy issues related to the introduction of 2nd generation biofuels, REFUEL has also generated some insights and suggestions with a broader strategic scope. Here, we shortly go into the more general competition and synergic effects between biofuels and the power and heat sector, the subtleties of perennial crops and the food-fuel debate, some specific implications for Central and Eastern Europe, and the common need for sustainability of biofuel feedstock production.

5.1 Biomass competition and integration possibilities with the stationary sector

As for the land demand for biofuels, 2nd generation biofuels have the advantage of a wider potential of applicable residues, and a higher productivity of the related woody and grassy crops. This is in line with findings from more narrow analyses comparing the climate impact of different bioenergy options: the advantage of lignocellulosic crops compared to traditional agricultural crops, as emphasized from a well-to-wheel perspective, is also validated from an energy system modelling perspective.

Using this feedstock, however, creates more direct interactions between biofuels and power and heat generation. Analyses with the energy and transport system model PEEP indicate that a policy regime with both ambitious climate targets and specific targets for biofuels may lead to competition for domestic lignocellulosic biomass resources – especially if import opportunities are constrained. Biomass is, given the CO_2 emission target, most cost-effectively used in stationary applications (primarily heat). An additional target for biofuels for transport induces a redirection of biomass flows from stationary uses to the production of transport fuels. Further analyses, however, indicate that the sector in which biomass is used depends to a large degree on the availability of carbon neutral transport options that do not rely on biomass, such as hydrogen and electric vehicles in the transport sector. If models attach low potentials and/or high costs to these options, biofuels become the only carbon neutral alternative for the major transport activities. Analyses with such models often show a significant application of biomass in transportation, especially at high ambition levels for greenhouse gas emission reduction.

Using biofuels for transport reduces the dependency on imported oil. On the other hand, the use of biomass in stationary applications may reduce the dependency on imported natural gas and improve the security of electricity supply. Therefore, the relative appeal of the different bioenergy options depends, from an energy security perspective, on how oil and gas import dependencies are weighed relative to each other.

Despite that different policy objectives promoting bioenergy appear to assign different priorities to individual bioenergy options, the promotion of options based on lignocellulosic feedstocks is a common feature. The earlier presented stepping stones strategies represent expansion options that contribute to heat/power targets while at the same time bridging towards more cost competitive production of 2^{nd} generation biofuels.

5.2 Perennial crops, market disturbances and the food-fuel debate

As already noted, rising agriculture commodity prices have caused concern over the possible impacts of rapidly increasing bioenergy on food prices and food security in vulnerable regions. The REFUEL potential assessment is based on the food first paradigm, defining land availability for energy crops as the amount of suitable land available after food requirements are met. Thus, the project did not explicitly analyze the food-fuel competition for land and other resources. However, we'd like to make some specific statements on 2^{nd} generation biofuels.

As mentioned earlier, 2^{nd} generation biofuels are suggested over conventional biofuels as a way to mitigate land use competition with food: their biofuel yields per ha are higher, and several types of residues can be used. Thus less land will be required to meet a given biofuels target. Furthermore, some lignocellulosic crops can be grown on poor soils less suited for food production such as grasslands, and environmentally sensitive lands such as sloping erodible soils. This implies that one can avoid food-fuel competition by cultivating suitable bioenergy crops on marginal/degraded lands. However, as bioenergy use increases and farmers adopt lignocellulosic crops, they will consider the development in both the food and bioenergy markets when planning their operations. The economic realities at the farm level may then still lead lignocellulosic crops to compete with food crops, since all crops have their highest yields on the good soils. Thus, it may be possible to produce lignocellulosic crops on more marginal soils, but this does not mean that they will find their way there automatically. They will rather be pushed away from the better to the poorer soils if crop prices for food and feed are sufficiently competitive.

This competition can be reduced by adoption of rules and regulations that e.g. specifically allocate bioenergy crops to marginal soils. Regulations may also prevent farmers from using more than a certain share of their land to lignocellulosic crops. And generally, research on specific crops with higher yields and lower production costs on marginal lands could mitigate the food-fuel competition by reducing the general scarcity of land.

5.3 Specific implications for Central and Eastern Europe

As with many other characteristics, the positions of Western and Central and Eastern European countries are quite different. The Western EU-15 member states already have high consumptions of energy for transport, with relatively limited potentials for domestic supply of biofuel feedstock. On the contrary, the EU-12 new member states show relatively modest (though rising) levels of transport fuel consumption, with substantial potentials for domestically produced biofuels. Here, we shortly discuss some conceivable developments in the new member states.

Short term: Strong attention for 1st generation biofuels

Energy policy in the Central and Eastern European countries is substantially driven by energy security concerns, including gas and oils supply. Therefore, most of the EU-12 new member states developed their national biofuels strategies and seem to be more open to fostering biofuels than to green electricity. Since biofuels production from biomass currently has a high political priority, it might be assumed for the near future that the majority of currently unused biomass potential will be used for the production of transport fuels. This production will be dominated by new investments in 1st generation biodiesel and upgrading and better use of already established bioethanol production capacity.

This can already be observed in practice. In 2007, 19 biodiesel plants in the new member states were starting operations, or were under construction/planning. Relatively large plants can be found in Lithuania, Poland and Romania, with capacities of 100,000 tonnes/year. The tendency in building new, larger biodiesel plants in the new member states is still growing, and the targets of the new framework RES directive for 2020 will probably further spur this development, both for the domestic biofuels market and for exports to the Western EU-15.

Furthermore, the biofuels industry in the EU-12 will likely be supported by the National Development Plans within the framework of the EU cohesion and structural policy 2007-2013. According do the EU commissioner for regional policy, Ms Danuta Huebner, EU Member States devoted € 4,8 bln for renewable energy, with a major share for the EU new member states. In the EU-12, a substantial part of this funding (roughly 20% of the total) is dedicated to biofuels; for example € 235 mln in Poland. Such money should be spent on new investment by 2013. Due to the immaturity of 2nd generation biofuels, current technology development and market state of the art in the new member states, this funding will mostly be used for 1st generation biofuels production.

Longer term: Differences in accents between member states

The period between 2010 and 2020 will be critical for the development and introduction of advanced conversion technologies for 2nd generation biofuels. New member states will probably adopt these technologies in varying ways. For example, these countries differ from each other in the ratio between forest and agricultural land (see Figure 10). Due to these differences in land use, countries like Estonia, Latvia and Slovakia may be more interested in the use of forestry-related residues, either for advanced biofuels or for applications in heating or CHP, while countries with a dominance of agriculture like Poland and Hungary would see a dominance of agricultural potentials for energy and biofuels. This might put up more barriers for 2nd generation biofuel introduction in these countries, as a shift to perennial crops requires more drastic changes in the agricultural sector. Note, however, that the size of the different member states also varies widely: for example, the Polish forestry sector may still be larger than this sector in Latvia.

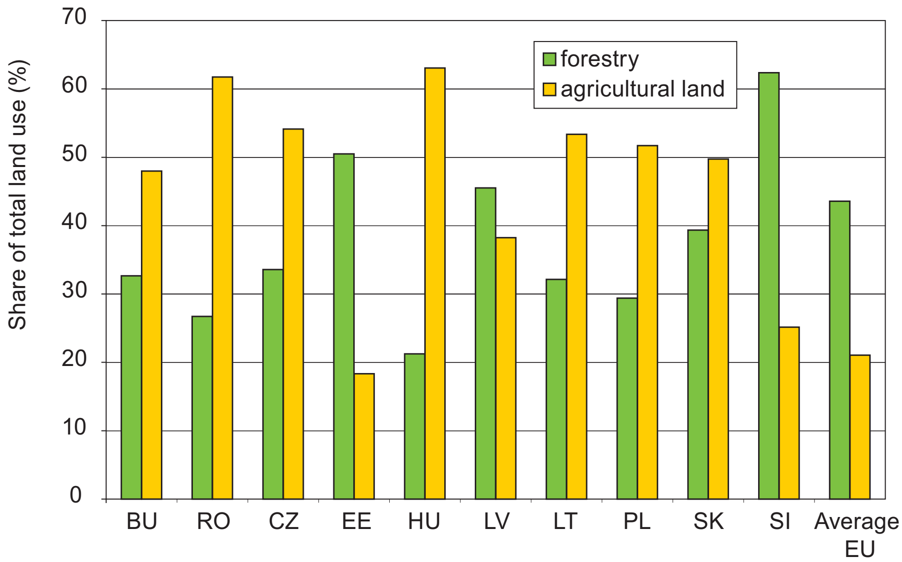


Figure 10: Shares of forest and agricultural lands in total land area for selected new member states.

5.4 Sustainability of feedstock production

Regardless of the specific types of biofuels and feedstocks, their development will need to be accompanied by several other considerations in order to safeguard a basic level of sustainability. Such a sustainable agricultural practice, whether for food, feed or energy purposes, should at least consider the following elements:

- Considerable greenhouse gas (GHG) savings compared to the use of fossil fuels.
- The use of environmentally sound forestry and agricultural management systems for biofuel feedstock production.
- Non-obstructiveness to the preservation of landscapes with significant value for biodiversity, nature conservation, and cultural heritage.
- Safeguard of concerns for impacts of social exclusion.
- Integration with food, feed and materials production in a way that reflects societal aspirations and priorities in relation to national/regional supply and demand for energy services, food and material products – considering also the economic, security and environmental implications of this supply/demand pattern.

Greenhouse gas saving – One of the key drivers for biofuels is GHG emission saving compared to the use of fossil based transport fuels. The degree to which biomass-to-biofuel routes save GHG emissions varies considerably. Depending on site-specific characteristics (e.g. agro-ecological circumstances), management intensity and other aspects, variation also occur within each biomass-to-biofuel route. Two aspects are essential in this respect. The development of a standardised methodology that provides default values per route, or components thereof and a minimum requirement GHG emission saving to be eligible for policy stimulation, e.g. by subsidies.

Environmentally sound management – Scenario forecasts indicate that vast amounts of land can potentially become available for biomass production. The exploitation of biomass and the choice for a specific bioenergy crop for the purpose of biofuel production can have positive, negative or neutral effects on biospheric carbon stocks. For example the utilization of former pasture land might be an option only considered for reforestation or cultivation of herbaceous biofuel crops (e.g. miscanthus, switch grass, etc.), explicitly excluding annual crops, under zero-tillage (i.e. no ploughing) systems, with no or negligible soil carbon release. As for agricultural commodities, cross compliance is an essential part of the reformed Common Agricultural Policy (CAP). Through cross compliance, it is ensured that in order to receive support, farmers must fulfil certain rules and standards. These relate to the environment, public, animal and plant health, animal welfare and the maintenance of the land in good agricultural and environmental condition.

Preservation of landscape – In Europe an extensive system of designated areas exists. In particular those in the NATURA 2000 framework should be safeguarded. Member countries must ensure that biofuel production has no negative effects on designated areas, neither due to plantations being introduced within the NATURA 2000 areas, nor due to regional impacts such as fertiliser leakage or groundwater depletion.

Social exclusion – As with other agricultural commodities a profitable biofuel market may trigger intensified agricultural production systems favouring a large scale farming practice, outcompeting smaller land owners. Also land prices may rise as a consequence of increased demand driven pressure on land. In certain areas this could lead to social imbalances or degradation of social infrastructure.

Integration with food and feed – Ideally, any biofuels policy would be integrated with food, feed and materials production in a way that reflects societal aspirations and priorities in relation to national/regional supply and demand for energy services, food and material products. Such apolicy would also consider the economic, security and environmental implications of this supply/demand pattern. The degree to which biomass demand for energy purposes affects supply levels and market prices for food and other raw material commodities is largely unclear. It should hence be a point of attention in further elaboration of any biofuels policy.

All five elements apply equally to domestically produced as well as imported biofuels and biofuel feedstocks. Therefore the above considerations are important not only for guiding domestic EU feedstock production but should be applied as well when evaluating and regulating biofuels and biofuel feedstock imports.

6. Sensitivities and limitations

As in any long-term vision, we based our statements on a wide variety of assumptions, and made quite some simplifications. In this section, we shortly go into the most critical sensitivities of our analyses to external developments. Furthermore, we go into the inherent limitations of the models and tools we applied, and discuss some of the critical introduction barriers for biofuels that we did not explicitly take into account.

6.1 Barriers

This road map has not focussed on several implementation barriers in the domain of end use. We do not consider these barriers, however urgent on the short term, as the most critical ones on the longer term. However, it should be clear that:

- Technical specifications of biofuels and of fossil/biofuel blends should be clear, standardised and applicable over the entire market;
- A common market for biofuels across the EU will be more cost-effective than a set of (blocks of) national submarkets with trade barriers. This does not automatically imply that biofuels promotion measures should be harmonised.
- A generally accepted certification system is needed to ensure the environmental sustainability of biofuel products and sustain long term public acceptance
- High blends (or pure versions) of biofuels, particularly of ethanol and biodiesel, may require vehicle adaptations. Fleet replacement becoming a potentially limiting factor for the penetration rate of these blends.
- Harbour and shipping capacities may become a limiting factor for the rapid set-up of new supply chains for biofuels and their feedstock. However, as agricultural and energy commodities are already traded around the globe, we expect that the key limiting factor will be the production and local logistics of feedstock, not their long-distance transport.
- We have not paid explicit attention to the integration of biofuels supplies into the European refinery infrastructure. Current and future mismatches between the gasoline-diesel split in EU fossil supply and demand may also influence the opportunities for biobased gasoline and diesel substitutes.

6.2 Sensitivities

As any long-term vision, this REFUEL road map is sensitive to several external developments that may affect its analysis and the future of biofuels in general. Here we mention the most critical ones.

The future role of biofuels in the transport sector strongly depends on the developments of potentially competing options for more sustainable transport. Particularly the electric vehicle and the hydrogen-powered fuel cell vehicle are promising options for transport to become less CO_2-intensive and less dependent on fossil oil. On the short term, their role will remain relatively limited, mainly because of the technical breakthroughs still needed, e.g. in battery capacities and in fuel cell technology. But especially after 2020 these options may lead to significant reductions in demand for liquid transportation fuels. However, we expect that several subsectors will continue to rely on liquid fuels, such as long-distance heavy-duty transport, in which the electric and the fuel cell engine have very limited advantages compared to efficient diesel propulsion. In short, the transportation market is sufficiently large to absorb innovative fuel-engine combinations and accommodate ambitious production levels of biofuels for conventional engines. Finally, biofuel production technologies based on gasification also provide a suitable platform for the production of hydrogen.

Technological developments in other parts of the energy sector may also affect biofuels development significantly. For example, the introduction of CO_2 capture and storage technologies offers new fossil but carbon-neutral options for the power generation sector. This might reduce the role of biomass in the power sector, possibly opening up more feedstock supply for transport. Furthermore, ethanol production and gasification-based biofuel production technologies co-produce pure flows of CO_2 well suitable for storage. Basically, all energy options influence each other and major breakthroughs in one sector will have impact on others.

Obviously, price developments in fossil energy markets will have strong impacts on the prospects for biofuels. Depending on the different projections of future oil prices, one can come to net costs or net benefits for biofuels. With the introduction of CO_2 pricing mechanisms such as the EU ETS, these markets have become even more complex. CO_2 prices also have their impacts on biofuels, both directly and indirectly, e.g. via their impact on the position of coal in the power generation sector and the position of biomass-to-power as a competitor.

Developments in global food commodity markets will influence the degree to which any region will want to be self sufficient. Increase in commodity prices, driven by lower supply to demand ratio, can induce a higher degree of protectionist policy. This may influence the amount of commodities that are used for energy purposes directly, affecting 1st generation biofuels. However this may also entail more land being used for food (and feed) production, of which the temporary abolishment of the set-aside policy is a clear illustration.

Climate policy and the treatment of land use change and forestry may also affect the prospects of feedstock production for biofuels. Currently, impact of land use change in terms of entailing changes in soil carbon stocks are not explicitly taken into account in any CO_2 pricing system. A rewarding system for changes in soil carbon stocks will lead to an incentive for 2nd generation feedstocks, which generally cause these stocks to rise, and to a neutral or negative stimulus for conventional crops for 1st generation biofuels.

6.3 Limitations of the methods and tools applied

Although we have tried to only draw conclusions only where we find these relatively robust for the limitations of the methods and tools we applied, it may be relevant for the reader to have insight in these limitations. First, our analyses have merely been based on production costs, for conversion technologies as well as for feedstock. In practice, both will operate in dynamic markets. First, prices resulting from a match between biofuel demand and supply may differ significantly from the average production costs. Furthermore, biofuel feedstocks, which relate to (agricultural) commodity markets, may face significant price volatility due to developments in supply and in global feedstock demand for other applications than biofuels. Therefore, there may be significant differences between actual prices and the calculated costs on which our conclusions have been based. These limitations apply to EU-domestic feedstock production and to imported biofuels and feedstocks.

The supply figures in the REFUEL analysis stem from modelled yields for energy crops. Differences in site-specific yields stem from agro-ecological circumstances, leaving out differences in management intensity. For the long term one may assume this does right to what can be expected, namely optimized management systems for biomass for energy production. Also in regions where currently food production is extensive and poorly managed. On the shorter term for traditional crops, however, this approach of assuming an optimized management may overestimate productivity in some regions (large parts of the CEEC) and underestimate it in others (high productive area, e.g. the Netherlands, Belgium, Ireland et cetera).

Our modelling of biofuels is based on optimisation to a least-cost fuel mix meeting a given demand for biofuels. This leads to quite radical choices between biofuel chains, also when the cost differences between the chains are relatively minor. In reality there will always be niche situations in which costs differ from the average, and investors will have imperfect information, so biofuels with slightly higher production costs may be introduced anyway. That is why we merely refer to '1st generation biofuels' and '2nd generation biofuels'; not specifically to biodiesel, bioethanol or e.g. FT diesel. Especially for the 2nd generation biofuels, whose production costs lie in the same order of magnitude and contain considerable uncertainties, we do not pretend to be able to identify the winner in this 'battle of the options'. We do conclude that the biofuels market will be sufficiently large to allow the entrance of more than one of these advanced technologies.

In this project, we did not account for any indirect effects related to land use conversion. Several recent studies indicate that conversion of grassland or forest into agricultural land may induce substantial greenhouse gas emissions due to losses in soil organic carbon. Each hectare of grassland, savannah or forest converted to arable land can cause significantly higher up-front emissions than potential savings from biofuel replacing fossil fuels. However, in this study, we assess potential availability of agricultural land for biofuels; lands for e.g. nature conservation remain unaffected in this approach. Changes from agricultural cropland for food to cropland for energy crops have limited positive or negative impacts on soil organic carbon. However, if the ambition level for biofuels over time creates land demand that exceeds the land potential that gradually becomes available due to yield increases, supply stress may trigger higher crop prices, and farmers in and outside Europe may respond by converting grassland or forest into cultivated land. This particularly happens when such land scarcity is not tempered by a shift towards 2nd generation biofuels, with their substantially higher land efficiency.

Finally, REFUEL has focused on energy crop and biofuel production in Europe. As for imports from outside Europe, we only made some very crude assumptions on global potential available for imports, and further assumed that imports would not cover more than ca 30% of total biofuel consumption in the EU. Obviously, a lot can be said about imports, particularly in relation to sustainable potentials and policy conditions such as possible new WTO agreements. Imports and international trade are an important dimension to biofuels, that needs to be discussed and evaluated in all its facets.

Annex 1. Elaboration of perspectives into policy packages

On the basis of the often mentioned drivers behind biofuels, we developed four policy packages:

GHG perspective ('Kyoto')

In this perspective, biofuels are solely introduced as a measure to reduce greenhouse gas emissions. They are part of several measures to reduce these emissions: increasing energy efficiency, renewable power and heat, etc. We translated this into the following measures:

- As biofuels is generally considered a relatively expensive option in terms of costs per tonne of avoided CO_2, priority is set to the use of biomass in the stationary sector as a more cost-effective option. Therefore, biofuels have a moderate target pathway and the feedstock potential is limited to 40% as a result of an ambitious policy for RES-E and H/C.
- Obviously, a GHG perspective includes pricing of greenhouse gas emissions, starting with € 20/tonne CO_2 in 2012 and increasing to € 70/tonne in 2030.
- In this perspective, imports are allowed but are also subject to CO_2 pricing.
- As this perspective is solely aimed at GHG emission reduction, other measures such as cropping premiums, investment subsidies and specific targets for second generation biofuels are left out.

SES perspective ('Moscow')

In the perspective with a focus on improving EU energy security, the balance of measures is as follows:

- As transportation is the sector with the highest (forecast) fuel import dependency, there is a strong emphasis on biofuels, with a more moderate attention for biomass in other sectors. Therefore, the 80% of the feedstock potential is available for biofuels, which has a high target pathway.
- In this perspective, there is no greenhouse gas pricing mechanism operational, nor are there specific subtargets for 2nd generation biofuels.

As domestic production is the key point of attention, imports are minimised, and domestic production is enhanced by cropping premiums and investment subsidies.

'Lisbon' perspective

In the Lisbon perspective, enhancement of an innovative and competitive EU industrial sector is the key driver for biofuels. This leads to the following measures:

- As biofuels are generally products with a relatively high value added compared to RES-E/H, the ambition level for biofuels is high, while it is relatively low for RES-E/H from biomass.
- As innovation comes with the development of new biofuel technologies, there is a GHG pricing mechanism in place and there are specific subtargets for advanced, 2nd generation biofuels. Furthermore, these technologies are spurred by investment subsidies. These apply to all conversion technologies, but as conversion is the dominant cost item in advanced biofuels, this measure has the strongest impact on 2nd generation biofuels.
- As domestic production is valued most, import levels are minimised. As agriculture is a sector with relatively little value added, no cropping premiums are in place.

In addition, we developed three packages that each has their own accent because of a specific reason:

Biodiversity perspective (narrow)

Biodiversity concerns often enter the discussion on biofuels and bioenergy in general. While bioenergy can be beneficial to biodiversity on the long term by abating climate change, impacts on the short term may be negative. Therefore, we developed a package with specific attention for biodiversity:

- Ambition levels for biofuels and biomass in RES-E/H are set moderate, in order to prevent an excessive demand for biomass.
- There is CO_2 pricing since climate change is one of the key threats to biodiversity.
- Imports are possible, but to circa half of the original potential since production of palm oil and bioethanol can also lead to increased deforestation and entailing biodiversity losses in the tropics.
- In order to enhance the use of low-grade feedstock in land-efficient production systems, 2nd generation biofuels are actively enhanced.
- There are no cropping premiums or investment subsidies in this package.

Agricultural employment in biofuels perspective

Support of agriculture in the EU has always been one of the (sometimes somewhat hidden) motives for biofuels. We translated this driver as follows:

- As biofuels offer the best opportunities for agricultural feedstock, targets are ambitious for biofuels and low for other biomass applications.
- As this package focuses on agricultural production, only the energy cropping premium is in place, while any other additional policies are left out.

'REFUEL-team' perspective

As a final ingredient to the debate, we developed a set of policy measures that the REFUEL team considers an ambitious but balanced policy pathway. This consists of:

- High ambition levels for both biofuels and biomass in other sectors.
- A GHG pricing mechanism in place
- Imports allowed
- Investment subsidies for conversion, but no support schemes for energy crops
- No subtargets for 2nd generation biofuels

Table 1: Elaboration of policy packages on the basis of several basic perspectives on biofuels.

	GHG perspective	SES perspective	Innovation perspective	'Biodiversity' perspective (narrow)	Agricultural employment perspective	'REFUEL-team' perspective
Policy making priority	GHG emission reduction	Improving EU energy security	Innovative, competitive industry	Sustainability of biofuels production	Agricultural employment as the key interest	All these priorities
Policy measures:						
Biofuels target pathway[4]	Moderate	High	High	Moderate	High	High
Ambition levels RES-E, H[5]	High	Moderate	Low	Moderate	Low	High
Ex-EU import levels[6]	High	None	None	Limited	None	High
GHG pricing[7]	Yes	No	Yes	Yes	No	Yes
Energy cropping premium[8]	No	Yes	No	No	Yes	No
Investment subsidies[9]	No	Yes	Yes	No	No	Yes
Specific targets 2nd gen.[10]	No	No	Yes	Yes	No	No
Crucial issues:	GHG profiling	Land efficiency	Innovative fuels	Land use impacts	Agri support	All these
Specific pitfalls:	GHG profiles of imports?	SES in other sectors?	Costs? Technology definitions	Defensive strategy delays intro 2nd generation?	High costs for maintaining rural employment?	Potentially all these?

4 High pathway: 5,75% (2010), 14% (2020), 25% (2030). Moderate pathway: 5% (2010), 10% (2020), 15% (2030).

5 Low ambition level for RES-E/H: 80% of feedstock potential for biofuels. Moderate: 60% of feedstock potential is for biofuels, High: 40% of feedstock potential is for biofuels.

6 High: imports potential is 13 Million tonnes of bioethanol against € 280/m^3, and 10 Million tonnes of palm oil against € 220/tonne. Maximum import share is 30% ('high'). 'Limited' excludes palm oil, none excludes all imports.

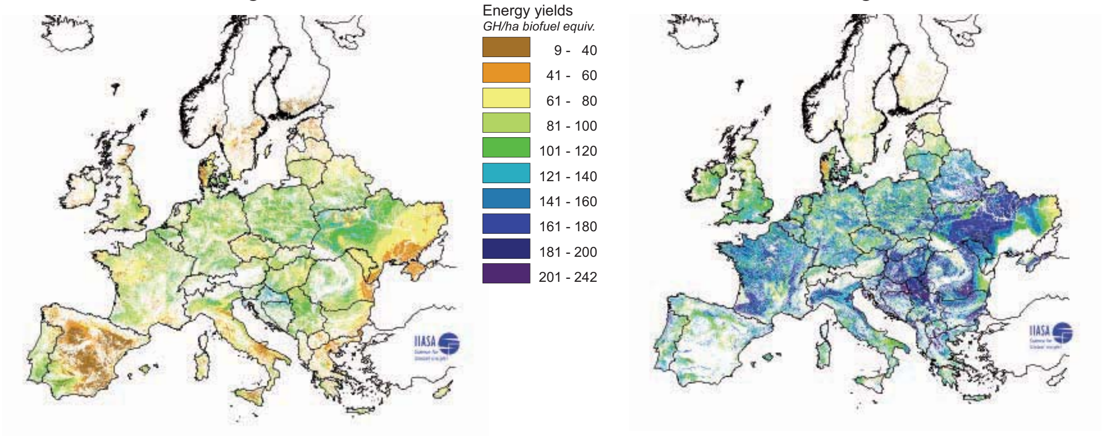
7 Yes: CO_2-eq pricing starts with € 20/tonne CO_2 in 2012 and increases linearly to € 70/tonne CO_2 in 2030.

8 Yes: Subsidies calculated as the number of eligible farm hectares [ha] x regional reference yield [t/ha/yr] x direct payment [€/t] x rate of aid [%] (current method for cereals and oil crops). For an average regional yield of 5 t/ha of cereals this results in: 1 [ha] x 5 [t/ha] x 63 [€/t] x 80 [%] = 252 €/ha/yr.

9 Yes: investment subsidy for conversion technology of 50% for all technologies.

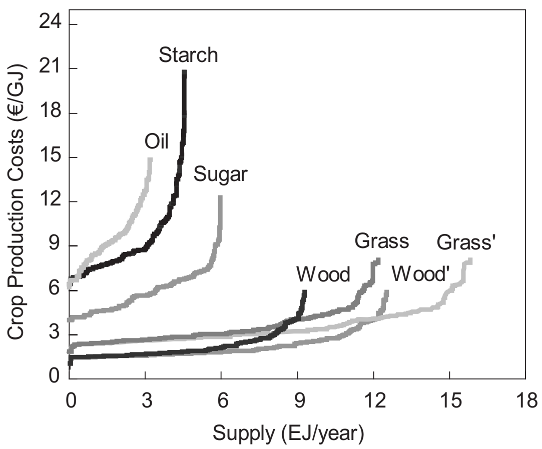
10 Yes: Subtarget of 2,5% of all biofuels for 2nd generation in 2011, increasing linearly with 2,5% a year to a 50% share in 2030.

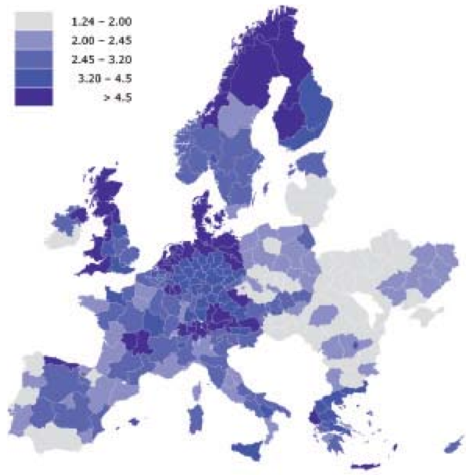
Annex 2 Tools applied

Part of the work:	WP2: Resource assessment
Key partner(s):	IIASA, Copernicus
Model applied:	Agro-Ecological Zones Model; Scenario development of land availability for biofuel feedstocks
Key outputs:	Europe's biofuel feedstock production potentials for a 1 by 1 km grid cell; Agricultural land availability for biofuel feedstocks
Output examples:	Potential energy yields of 1st and 2nd generation feedstocks. The maps show the best feedstock for the 1st and 2nd generation production chains.
First generation	**Second generation**
	
Method key features:	Assessment of biofuel feedstock productivity on a 1x1 km grid cell basis: • <u>First generation</u>: **Oil crops** (Rapeseed, Sunflower), **Starchy crops** (Wheat, Rye, Maize, Triticale), **Sugar crops** (Sugar beet, Sweet sorghum) • <u>Second generation</u>: **Woody lignocellulosic** (Poplar, Willow, Eucalyptus), **Herbaceous lignocellulosic** (Miscanthus, Switchgrass, Reed canary grass) Scenario projections of agricultural land availability for alternative uses based on detailed calculations of future area requirements for food, feed, nature conservation, built-up conversion.
Key inputs, assumptions:	Harmonized pan-European land resource inventories including: (i) **Climatic resources**, (ii) **Terrain resources**, (iii) **Soil resources**, (iv) **Land use**; (based on most recent GIS sources from CRU, JRC, EEA) Country level statistics: (i) **agricultural** production, trade & yields, (ii) **land use**; (EUROSTAT, FAOSTAT)
Detailed info:	WP2 Final report: See http://www.refuel.eu/publications/

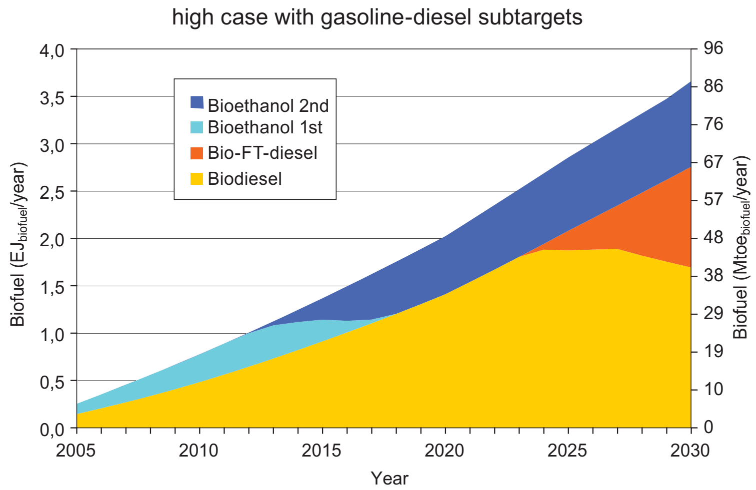
Part of the work:	WP3: Feedstock cost-supply curves
Key partner(s):	Copernicus, IIASA
Model applied:	Excel based analysis
Key outputs:	• Cost-supply curves for five crop groups with scenario ranges • Cost-supply curves for forestry and agricultural residues • Detailed spatially explicit maps of resource and production cost distribution in Europe
Output examples:	• Energy crop cost-supply curves (left) • Spatially distributed biofuel production costs (€/GJ, in this illustration woody crops)

Summary baseline 2030



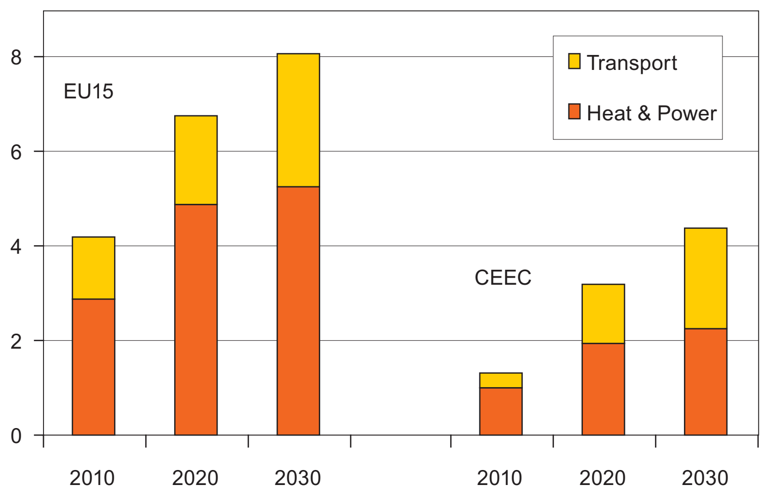


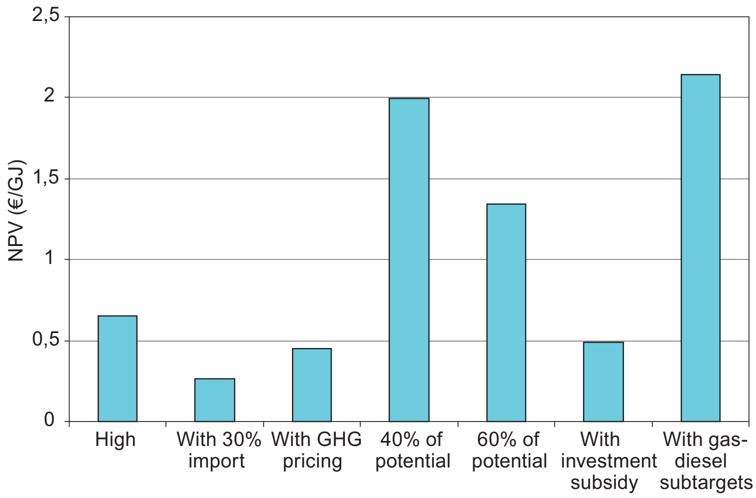
Method key features:	• Scenario development: description of a coherent rationale of key steering variables (e.g. agricultural productivity, land use change, macro-economic developments). • Bottom up agricultural production cost analysis • Analysis of agricultural and forestry residue supplies and production costs. • Coupling of spatially explicit productivity figures (WP2) with production costs
Key inputs, assumptions:	• Supply potentials for five crop groups (14 crops) (WP2) • Scenario variable values (e.g. agricultural productivity projections et cetera) • Physical and cost inputs into the agricultural production system
Detailed info:	WP3 Final report: See http://www.refuel.eu/publications/

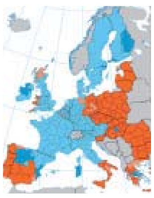
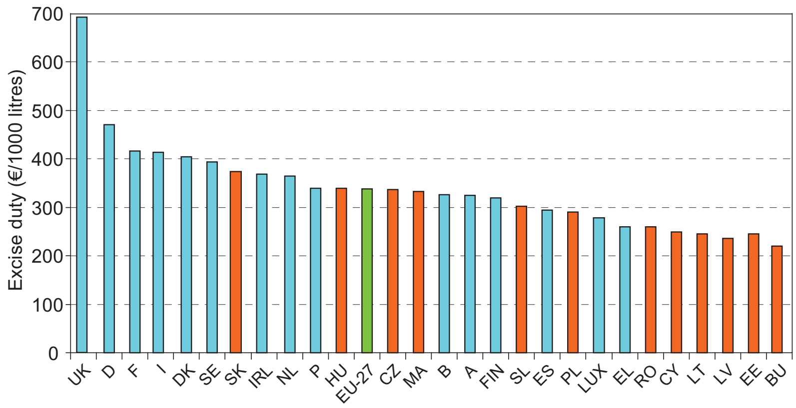
Part of the work:	WP4: Biofuels full chain cost analysis
Key partner(s):	ECN, Copernicus, Joanneum Research
Model applied:	Biotrans, version 2.0
Key outputs:	• Development of the least-cost biofuels mix (see example) • Related feedstock use • Cost build-up of the average biofuel • Cost build-up per biofuel type • Greenhouse gas impacts of the biofuels mix
Output examples:	

Method key features:	• Least-cost optimisation
	• Detailed modelling of technological learning:
	  • Based on progress ratio approach (1st generation)
	  • Based on gradual scale increases (2nd generation)
	• Sensitivity to several policy options:
	  • Target height
	  • Greenhouse gas pricing
	  • Projected level of imports
	  • Target allocation (all fuels or gasoline/diesel separately)
	  • Energy crop premiums
	  • Investment subsidies

Key inputs, assumptions:	• Detailed crop cost-supply inputs (WP3) • Cost data on residues as feedstock • Costs for transport, conversion, distribution and end use • Given biofuels target pathway
Detailed info:	WP4 Final report, Biotrans model description and data overview: See http://www.refuel.eu/publications/

Part of the work:	WP5: Strategies and interactions with RES-E/H
Key partner(s):	Chalmers
Model applied:	PEEP, Euroheatspot, Chalmers power plant database
Key outputs:	• Development of the least-cost bioenergy use in the EU transport and energy systems given targets for CO_2 and/or biofuels for transport (see example) • The potential for cogeneration of biofuels for transport and heat for district heat systems in EU25 • The potential for biomass co-firing with coal in EU27
Output examples:	Sector use of biomass (EJ/yr) 
Method key features:	• Least-cost optimisation with sensitivity analyses • Comprehensive energy system inventories • Scenario based model assessments using detailed databases for present power plant infrastructure and present district heating systems in the EU
Key inputs, assumptions:	• Detailed crop cost-supply inputs (WP3) • Cost and supply data on residues as feedstock • Costs for energy technologies and infrastructure • Characteristics of the power plant and district heating systems in EU • Energy demand scenarios (Primes)
Detailed info:	WP5 Final report: See http://www.refuel.eu/publications/

Part of the work:	WP6: Socio-economics and implementation barriers
Key partner(s):	COWI
Model applied:	Specific spreadsheet model based on biofuel production cost
Key outputs:	• Net Present Value, EUR/GJ • Employment in agriculture and processing industry, persons/year • for alternative scenarios/policy packages
Output examples:	• Socio-economic costs (NPV) in €/GJ for alternative cases 
Method key features:	• Add-on to output from WP 3 and WP 4 modelling • Allow for sensitivity analysis on oil prices • Consider oil cost pass on to biofuels costs
Key inputs, assumptions:	• Fossil fuel price forecast, EC European Energy and Transport. Trends to 2030 - update 2005 • Calculation rate 4% • Standard refinery costs for diesel and gasoline • Employment effect/million EUR wage in agricultural sector ILO Laborstat, assumption on hourly wage level increase • Employment per million GVA in NACE classification DF, Eurostat
Detailed info:	WP6 Final report and workshop report on barriers: See http://www.refuel.eu/publications/

Part of the work:	WP7: Policy strategy and Eastern Europe context
Key partner(s):	EC-BREC/IEO, ECN
Model applied:	Desk study on national and European policy documents and output from major biofuels related conferences Final report on policy measures and fiscal regimes with specific emphasises on CEEC
Key outputs:	• Inventory of policy measures and fiscal regimes on fossil fuels in EU member states • Detailed info on the role of biofuels in the national development programmes (structural funds)
Output examples:  EU Cohesion Policy 2007-2013: Regions eligible for financial support for renewables and biofuels	Excise duties for oil in EU countries 
Method key features:	• Analysis of the fiscal regimes in the EU member states • Analysis of policy measures in selected member states • Analysis of the potential financial support from the EU cohesion and structural policy and state aid, including RTD policy and priorities • Analysis of biofuels statistical trends • Analysis of CAP policy and biofuels potentials/limitations in the new member states • Comparison of the desk study results with the results of stakeholder consultation (WP6) • Povision of background for stakeholders consultation (WP6) • Cross checking of the assessment of biomass potentials, agricultural restructuring and sustainability (WP 2, WP3, WP5)
Detailed info:	WP7 Final report: See http://www.refuel.eu/publications/

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