REFUEL: an EU road map for biofuels

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Abstract

A successful mid-term development of biofuels calls for a robust road map. REFUEL assesses inter alia least-cost biofuel chain options, their benefits, outlines the technological, legislative and other developments that should take place, and evaluate different policy strategies for realisation. Based on preliminary results some preliminary conclusions of the project are discussed here. There is a significant domestic land potential for energy crops in the EU, which could supply between one quarter and one third of gasoline and diesel demand by 2030 if converted into advanced biofuels. A biomass supply of 8 to 10 EJ of primary energy could be available at costs around or below 3 €/GJ. However, the introduction of advanced biofuel options may meet a considerable introductory cost barrier, which will not be overcome when EU policy is oriented to the introduction of biofuels at least cost. Therefore, conventional biodiesel and ethanol may dominate the market for decades to come, unless biofuels incentives are differentiated, e.g. on the basis of the differences in greenhouse gas performance among biofuels. The introduction of advanced biofuels may also be enhanced by creating stepping stones or searching introduction synergies. A stepping stone can be the short-term development of lignocellulosic biomass supply chains for power generation by co-firing; synergies can be found between advanced FT-diesel production and hydrogen production for the fuel cell.

1 Introduction

In view of climate change and fossil fuel supply security issues, biomass-based fuels for transport meet an ever-increasing attention. The EU has established a specific biofuels

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target for 2010 and has agreed upon a new target for 2020, and many commercial stakeholders from different parts of the biofuels chain are now actively finding new business opportunities. But on the longer term, this future is not yet clarified: will biodiesel and conventional bio-ethanol still dominate in 2020, or will advanced synfuels and ethanol from wood and straw be the most cost-effective options by then? Or will gaseous biofuels such as SNG and hydrogen take over, in anticipation of a hydrogen economy? These questions call for an analysis of the developments to be expected in the coming decades, as well as for a robust biofuels strategy stimulating the best options.

The European REFUEL project is addressing these issues today. In the project, a consortium of seven renowned partners in the biofuels field is developing a biofuels road map until 2030. The two-year project started January 1st, 2006 and is commissioned by the EU in DG-TRENs Intelligent Energy Europe programme. The road map will identify the least-cost biofuel chain options, assess the benefits they have, outline the technological, legislative and other developments that should take place, and evaluate different policy strategies for realisation.

This paper shortly describes the project's key objectives, and discusses methodology and preliminary results on three topics: feedstock assessment, biofuels assessment and the some ingredients for a biofuels development strategy.

2 REFUEL key objectives and projected results

Given the current rapid developments in the biofuels sector in the EU, a focus on the optimal development route for biofuels has become only more relevant. This is exactly what REFUEL intends to do. To stay in travelling terms, the project aims to deal with issues such as:

- *The destination:* An ambitious, yet realistic target for biofuels in EU 2030, including intermediate targets, with a baseline scenario for e.g. developments in transport, agriculture and other relevant sectors
- *The route:* A cost-effective mix of biofuels reaching this target, including corresponding biofuel chains, conversion technologies, feedstocks, and other parts of the supply chain
- *The purpose of the journey:* An impact assessment, including greenhouse gas emissions, security of supply, socio-economics, impacts on the whole energy system, and other environmental and land use issues.
- *At the wheel:* An analysis of required actions from stakeholders, in terms of technological innovations, learning, and market introductions, and corresponding implementation options and barriers
- *Paving the way:* Required policies on related fields, such as agriculture, energy, technology development and trade, to reduce barriers and create incentives for stakeholders to act.

Projected results of the project have been specified in the REFUEL Preliminary Road Map [1]. Key results of the project will be:

- A quantitative development pathway for biofuels, including applied fuels and feedstocks, costs, and impacts, as illustrated in Figure 2
- Accompanying integrated sets of policy measures, specified in their spatial and temporal time frames, based on barrier and solution analyses, and reflected upon by the relevant stakeholders.

3 Feedstock assessment

The availability of biofuels feedstock obviously is one of the key factors affection the further penetration of biofuels. Therefore, an extensive part of the project applies to this issue. Figure 1 depicts the followed method for the assessment of land potential. Key elements of the methodology are:

- An extensive analysis of soil, climate and other factors affecting land suitability for cropping systems, resulting in a land suitability classification for food, feed and energy crops.
- Allocation of land: Land use for other purposes, such as food production, forestry, nature conservation, infrastructure, etc. will prevail over land use for biofuels. Therefore, only ‘surplus’ land, not needed to meet other demands, will be available for biomass feedstock production. A detailed assessment was made of demand for food, feed and other land use-related products and services. The prime assumption was that Europe will maintain its current (period 2000-02) level of self-sufficiency for food and feed crops as well as for livestock products. Thus the land becoming available for biofuel production is a result of future consumption and technological progress. The latter was achieved mainly by reasonable yield increases. This can be interpreted as the land that becomes available without compromising food and feed production.
- Agricultural development: For the Western European Countries, modest crop productivity increases are predicted, based on statistical analyses of past developments. In the Central en Eastern European Countries, agricultural productivity is assumed to increase more strongly. In the baseline, it is assumed that CEEC intensity levels will converge with WEC levels by the year 2050, taking into account differences in physical productivity factors such as climate and soil quality.

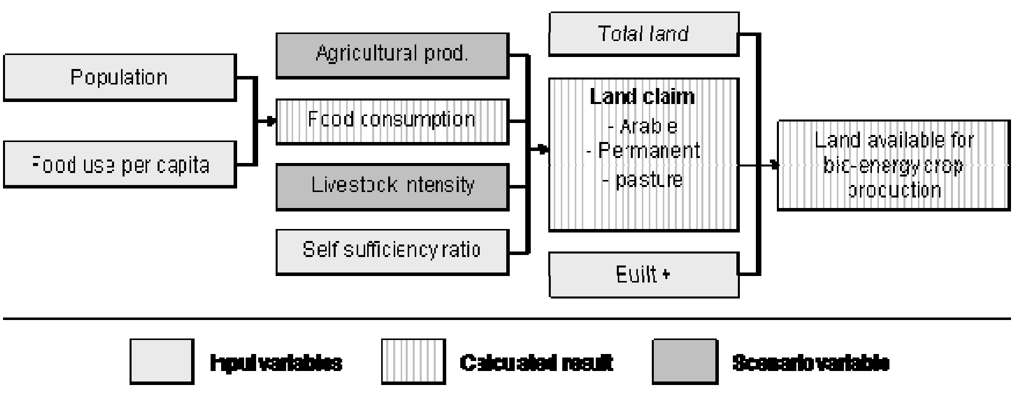

Figure 1: methodology for land potential assessment.

3.1 Land availability for energy crops

Figure 2 and Figure 3 show the amount of land that becomes available for energy cropping by the year 2030, with ‘bases case’ assumptions on the input variables. On arable land, approximately 60 Mha of land could become available; on pasture land this is another 25 Mha. In terms of the share of total arable land, the potentials in the EU12 (i.e. the Central and Eastern European member states) and the Ukraine are more than 50%. Note, however, that with such shares of bioenergy crops, the insertion of these crops, particularly annuals, into a farmer's rotation system may become a limiting factor.

Current pasture land could be opened up for herbaceous energy crops like perennial grasses. This potential is smaller than on arable land but still significant, again especially in the EU12 and Ukraine. Four types of grassland were idfentied:

1. Pasture area required for feeding ruminant animals (FEED)
2. Pasture area becoming available due to technological progress in agricultural production (i.e. the change in feed area required for ruminant livestock production between the base period and the future) (BioCrops-I)
3. Pasture area not required for livestock feed and not restricted by slope and nature conservation concerns (BioCrops-II)
4. Pasture area not required for livestock feed and reserved for reasons of nature conservation (Natural Grassland)

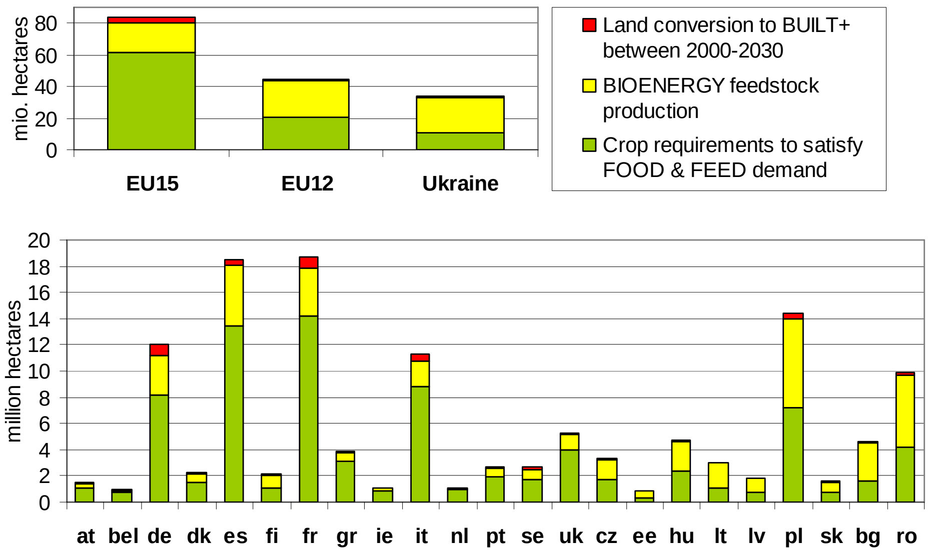

Figure 2: Energy crop potential from arable land in the EU15, EU12 and Ukraine, and per EU member state. Built+ stands for land converted into built-up area.

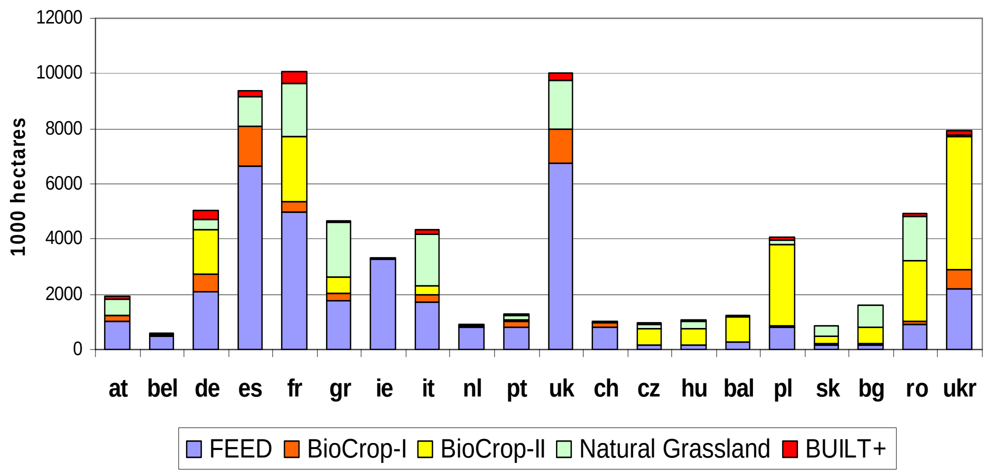

Figure 3: Energy crop potential from pasture land in the EU15, EU12 and Ukraine in the baseline scenario. For specification of categories, see text.

In order to give an impression of the bioenergy potential of the amounts of land: When planted with the most high-yielding energy crops (woody crops or perennial grasses), the total land potential in the EU27 and Ukraine could add up to a biomass supply potential of the size of circa one sixth of EU27 primary energy demand in 2030 (as predicted in the PRIMES 2006 baseline), or one tenth when only production in the EU27 is taken into account. When entirely converted into biofuels, this supply could cover one third of total fuel demand in the transport sector by 2030, or half of gasoline/diesel demand. The EU27 potential supply could cover about one quarter of EU energy demand for transport, or about one third of gasoline/diesel demand.

These potentials strongly depend on several assumptions, of which those on future trends in EU agricultural productivity are the most influential. For example, if increases in per hectare yields levels are set lower, e.g. due to an increased share in organic farming, total land potential decreases by tens of percents. On the other hand, if increases are set higher, e.g. due to the introduction of GMOs, land potential increases by tens of percents.

3.2 Biomass supply costs

The assessment of land availability and energy crop supply potentials was accompanied by cost calculations. In this, production cost for feedstock were calculated as a function of factor costs (capital, land and labour) and non-factor costs (fertiliser, seeds, etc.). Two cost variables, viz. land prices and labour wages, were taken as (sub)scenario inputs, since these costs can change significantly in the EU12 transition economies in the coming decades.

Figure 4 shows the cost-supply curve if all land for energy crops would be used for herbaceous perennials. This curve does not (yet) include the potential and cost of agricultural residues. It indicates that up to 10 EJ/yr could be produced by these energy crops in the EU27 by they ear 2030 at costs around or below 3 €/GJ. The grey bars illustrate the significant band with that occurs when other assumptions are made on land and labour costs. Note, however, that this methodology is based on cost assessment, not on the dynamics of price formation in markets in which energy cropping and agriculture for food compete.

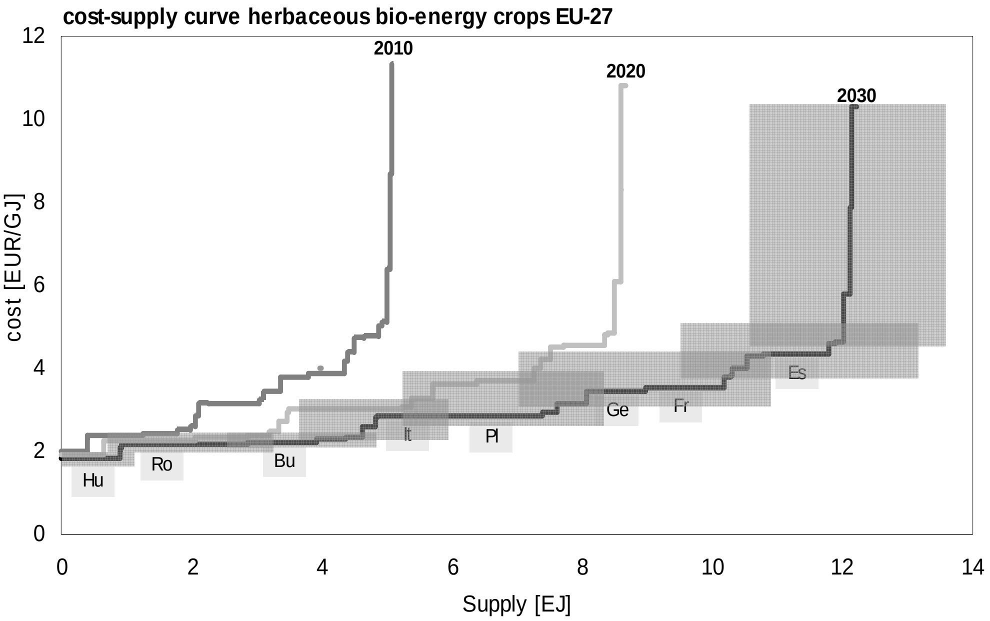

Figure 4: cost-supply curve for herbacious energy crops in the EU27.

4 Fuel mix assessment

The Biotrans model, introduced in VIEWLS and further developed in REFUEL, generates full-chain costs of all proposed biofuel chains, specified in feedstock, conversion, distribution, etc. On this basis, the model calculates an optimal, least-cost mix of biofuels, at given biofuel target shares, based on full-chain cost data of all possible fuels, related feedstock and regions of production. Compared to earlier versions of the model, it now better describes technological learning of conversion technologies and updated costs for all parts of the production chain. Below we present some preliminary results. It should be noted, however, that these may be subject to changes in their final form.

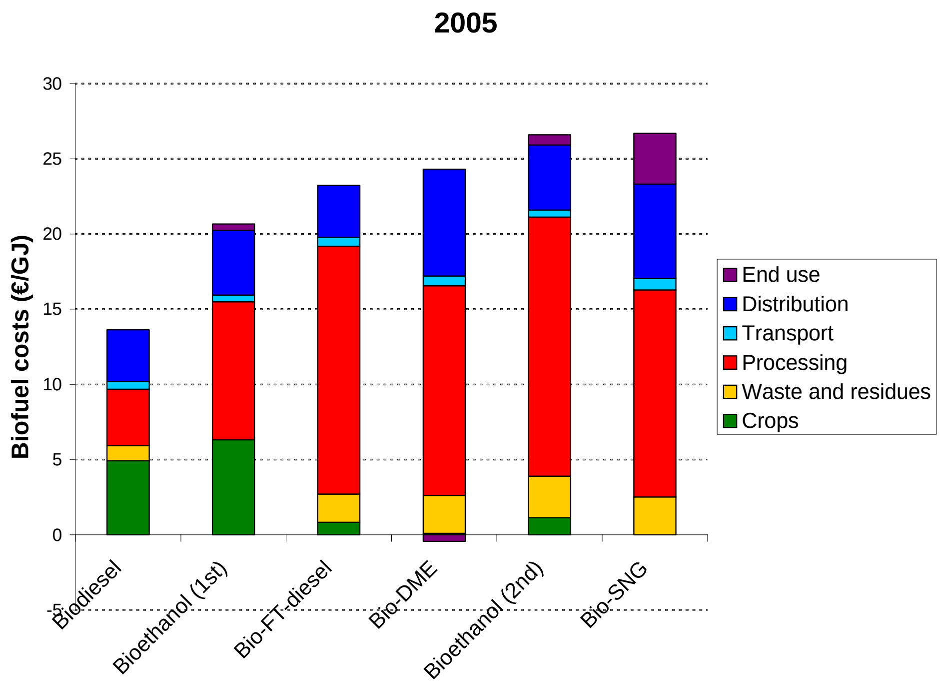

Figure 5: 2005 costs build-up for the six key biofuels in Biotrans.

Figure 5 shows preliminary model results on the costs of the six key biofuels. Final model results will be available in autumn 2007.

The two first-generation fuels (biodiesel and bioethanol from sugar or starch crops) are the least-cost options, with biodiesel being the cheapest option. This is also because in the 2005 situation in the mode, a significant part of this feedstock can is provided by residues (e.g. animal fats). Note, however, that this cost build-up is based on production *costs* of biofuel feedstock, not on current or future market prices. Based on current *market prices*, with rape seed prices above € 500/tonne (or ca 15 €/GJ), biodiesel costs would be significantly higher.

Preliminary runs with the full-chain model until 2030 provide the following indications. Diesel substitutes may dominate the market when a purely least-cost approach is adopted. Cost differences with bio-ethanol, however, are relatively minor in the longer term, and therefore both options may still enter the market.

Forcing gasoline substitutes into the market, the market penetration of bio-ethanol may lead to lower full chain costs on the long term. However, preliminary results indicate a friction between total full chain costs of biofuel production and the biofuels' potential to reduce GHG emissions.

The introduction of 2nd generation FT-diesel may meet a significant barrier due to high initial cost, resulting in a relatively long dominance of 1st generation options in the diesel substitute segment. 2nd generation options have a stronger cost reduction potential, since they are innovative and learning effects will have stronger impacts than for conventional, 1st generation options. However, it may take considerable time before 2nd generation fuel chains become more attractive than 1st generation options when only taking least cost into account. Basically, there are two situations in which advanced technologies will take over more easily:

- When the higher greenhouse gas reduction impact of 2nd generation fuels is taken into account. When expressed in terms € per tonne avoided CO_2 equivalent, the ratio between advanced and conventional fuels may be quite different then on a €/GJ biofuel basis. This will be illustrated by additional Biotrans calculations.
- At high biofuel target levels, the availability (and cost) of feedstock for conventional biodiesel en ethanol becomes a limiting factor, forcing advanced biofuels on the basis of lignocellulosic feedstock into the market. However, in the Biotrans base runs this effect only occurs at biofuel target levels above 20%. However, since REFUEL works with feedstock production cost, not with market prices, this effect may be stronger on real prices and thereby lead to better chances for 2nd generation technologies.

On the basis of these results, it seems that advanced biofuel technologies will meet sever difficulties in entering the market without any specific policy incentives. This could be shaped either by creating a specific subtarget for 2nd generation options, or by including the external advantages of advanced biofuels part of the target.

Feedstock availability for biofuels, and their costs, will also be influenced by developments in the in the stationary energy sector, which uses biomass for power and heat generation. Competition for biomass between the stationary and transport sectors, as well as prospects for synergies, will be analysed based on Biotrans runs in conjunction with modelling using another model available in REFUEL: PEEP, which includes both the stationary and transport sectors. Some examples of relevant analyses are given further below

5 Strategies for 2nd generation biofuels

One of the key issues in the future development of biofuels is the proposed shift from 1st generation biofuels to 2nd generation biofuels. Apart from technology development, this shift meets several barriers. For example, while 1st generation fuels use conventional feedstocks, currently available, lignocellulosic biomass feedstocks (e.g. fuel wood) require new supply chains to be set up. Furthermore, especially for synfuels such as FT-diesel, conversion technologies depend on biomass gasification, which needs to be introduced on a large scale, creating an investment barrier. Finally, biofuels are often considered an intermediate step for the transport sector, with the hydrogen-fed fuel cell penetrating the market later on. In REFUEL, these strategic issues are reviewed, and strategies are developed to overcome these barriers by the introduction of stepping-stones or bridging options.

In this paper, we shortly dwell on two strategic issues. First, the possible synergies between lignocellulosic biomass application in power/heat and for biofuels. Second, we go into some possible synergies and conflicts between biofuels and the introduction of hydrogen and fuel cells.

5.1 Setting up lignocellulosic supply chains

As for the first issue, an example was elaborated in Johnson et al [2] in a case study for Poland. This study proposes short-term co-firing of woody biomass in existing (coal-based) power plants as a supply chain step-up for wood-based advanced biofuels. It matches the regional availability of woody biomass with the currently available capacity of coal-based power plants. Essential conclusions are:

- Co-firing of biomass in existing power plants is a low-cost early option to increase the share of renewable resources in the electricity mix., with a potential of ca 3% of total electricity demand in Poland by 2010.
- As a significant part of the existing power generation capacity will be decommissioned after 2010, biomass co-firing will not lead to a technology lock-in: in the period after 2010, the biomass supply chain can be used either in power plants to be newly developed, or in new installations for the production of advanced biofuels. This makes short-term development of co-firing an interesting bridging option towards new biomass-based energy applications, either for fuels or for electricity. As a consequence, a development pathway for co-firing in existing plants in the coming decades could look like in Figure 6.
- The medium to long term prospects for biomass co-firing with coal will depend on the development of C prices, since despite the use of biomass these plants still emits large volumes of fossil CO2, which may be too costly at high C prices. It also depends on whether technology development allows for an increasing share of biomass in the fuel mix in retrofitted or new plants (as a response to increasing C prices). Future plants may also co-produce biofuels: one possible pathway could be a gradual development towards polygeneration plants using biomass/coal as feedstock for the production of transport fuels, heat and electricity. Especially in a combination with carbon capture and storage, such plants may play an important role in a world with ambitious climate targets.

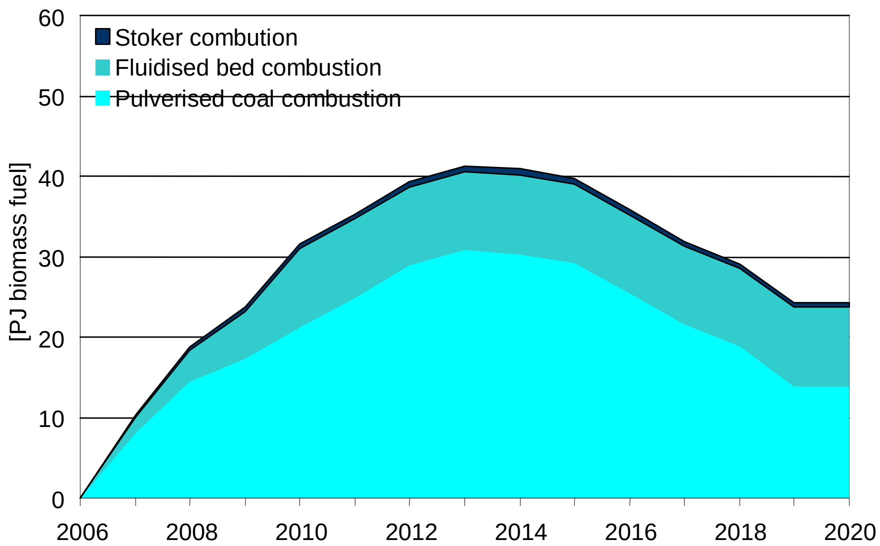

Figure 6: Potential development pathway for biomass cofiring in existing plants in Poland. After 2012-2014, the available existing capacity of coal-fed power plants for cofiring decreases, leaving the possibility to use the existing biomass supply chain either for new power generation plants or for 2nd generation biofuel production.

5.2 Biofuels and hydrogen: synergies, conflicts

Biofuels (on the short term) and hydrogen (on the longer term) are generally considered to be two major options for a more sustainable transportation sector. However, since both options require the development of new technologies, the question is to what extent the development of both leads to conflicts and lock-in situations, or to potential synergies in technology development. Therefore, we compared the preliminary outcomes of two road mapping projects (ref): REFUEL for biofuels (with a focus on advanced biofuel options) and Hyways for hydrogen (see www.hyways.de for further information).

Some conclusions from this comparison:

- The only apparent conflict lies in the competition for biomass resources, which can be used for both the production of hydrogen and of biofuels. However, in case biomass resources are limited with the evolvement of a manifold of biobased energy options, a hydrogen/fuel call combination on the basis of biomass offers major advantages over biofuels with conventional engines due to its higher efficiency in terms of kilometres driven per ha of biomass plantation. Another argument for aiming at hydrogen use is that from the coal-based competitors of both fuels – Coal to Liquid and coal-based hydrogen respectively – the latter is preferable as it allows for CO2 capture and storage at the production site, retaining the option of zero-emission vehicles.
- As a consequence, biofuels and their use in an internal combustion engine might be regarded as transition options rather than the final solution for sustainable passenger transport. However, for heavy duty trucks, this situation is different. Here, hydrogen and fuel cells do not provide similar benefits, because the efficiency advantage of the fuel cell is much less with high continuous loads, and the fuel storage potentials are a drawback for application in long-distance transport. Therefore, freight transport could provide a lasting and sizable market for the second generation of biofuels. Together with the application in passenger cars for the period until hydrogen in fuel cell cars has become affordable, this justifies the current efforts in developing (second generation) biofuels. A consistent development pathway of biofuels and hydrogen might therefore look like Figure 7.

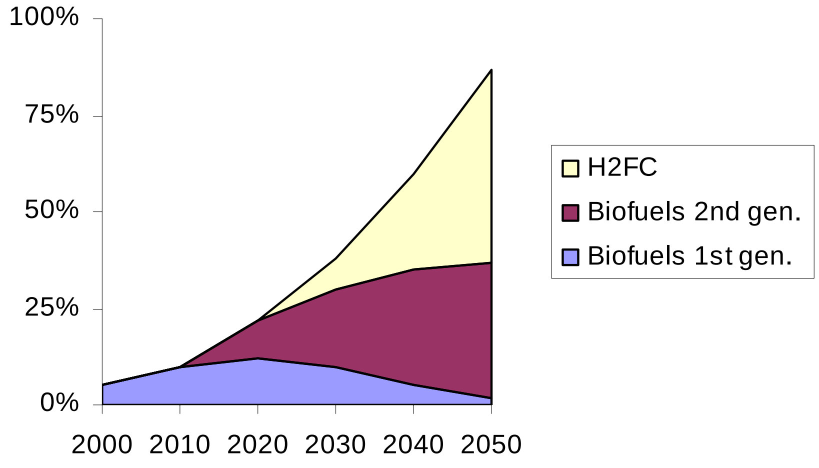

Figure 7: Proposed development pathway for biofuels and hydrogen

- Consequently, the long-term objective could be to deploy hydrogen in passenger cars and advanced biofuels in trucks. If this is pursued, major synergies can be achieved in the 2nd generation FT-diesel (BtL) production chain, because it is based on a gasification process route that can also be used for hydrogen production. Note, however that dramatic progress of plug-in hybrids and range-extended electric vehicles may strongly reduce the need for transportable fuel.

6 Conclusions

Current REFUEL results indicate that:

- There is a significant domestic land potential for energy crops in the EU, which could supply between one quarter and one third of gasoline and diesel demand by 2030 if converted into advanced biofuels. A biomass supply of 8 to 10 EJ of primary energy could be available at costs around or below 3 €/GJ.
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