# Roadmap Brief: Biofuels for Transport

This brief outlines the IEA's analysis of biofuels in ETP 2008 and the key aspects that will need to be addressed to develop an advanced biofuels roadmap. It tries to identify the key elements of IEA's projections and raises key issues for discussion during an intensive roadmapping meeting.

### *Background: Advanced Biofuels*

As described in ETP and elsewhere, the production of transport fuel from biomass, in either liquid or gas form, holds the promise of a low net fossil-energy requirement and low life-cycle greenhouse gas (GHG) emissions. However, there are many hurdles still to overcome and it remains unclear what level of biofuels production can be achieved globally on a sustainable basis by 2050. Issues such as food security and land competition with biofuels, and the potential impacts of biofuels on water resources, biodiversity and other aspects of the environment, are becoming major concerns that could severely limit the role of biofuels if not fully addressed. However, the successful development of advanced biofuels technologies, using non-food biomass feedstocks, could help overcome most barriers and achieve sustainable, very low $CO_2$, cost-effective biofuels.

There are a variety of different types of biofuels, biofuels feedstocks, and conversion technologies. Among these some are termed "first generation", typically characterized by use of sugars, starches, or vegetable oils (all of which also foodstuffs). Nearly all current biofuels production falls into this category. Second generation biofuels are typically characterised by the use of non-food/feed biomass feedstocks, such as woody and cellulosic plants and waste material. Advanced biofuels can include both first and second-generation feedstocks so long as the final fuel results in a significant reduction in lifecycle GHG emissions and improved sustainability. This roadmapping process focuses on the range of technologies associated with second generation and other advanced biofuels production.

Systems of producing second generation biofuels are not yet commercial, but hold the promise of high-yielding, low-GHG-emitting and sustainably produced liquid fuels derived from forest and agricultural residues and purpose-grown energy crops. It is likely that commercial production of second-generation biofuels to produce gasoline or diesel substitutes from a range of ligno-cellulosic feedstocks (using either thermo-chemical-based biomass-to-liquid technologies or biochemical-based pathways) will eventually complement and perhaps supersede current first-generation biofuels from grains and oil-seed crops. However, in order to speed the process of bringing the necessary technologies to the market and commercializing production, and achieving target levels of second-generation biofuels production under particular time frames, strong policies will be needed. The current process is intended to develop, in some detail, roadmaps to help guide policy makers and technology developers, and foster greater cooperation and collaboration.

### *Transition to second-generation and other advanced biofuels production*

In a situation analogous to the refining of oil to produce multiple, higher-value chemicals and plastics, it is recognised that advanced biofuels are also likely to be produced in conjunction with a series of value-added by-products – including bio-chemicals and bio-materials, and other forms of bioenergy (*e.g.* electricity and heat). This would allow a more comprehensive "biorefining" of biomass to serve multiple purposes.

Success in the development of advanced biofuel technologies will be dependent on a number of factors:

- Continuing strong public and private support for research and development around second-generation biofuels, with particular emphasis on developing links among industry, universities, and government. Policies should be part of a comprehensive strategy for bioenergy development, and should be harmonised with rural employment and agricultural assistance.

- Demonstration and pre-commercial testing of second-generation biofuel technologies. This could reduce the risks to investors and create a more likely environment for the participation of financial institutions.
- Development of concrete measures of environmental performance, including net energy balance and net GHG emissions, water and ecosystems impacts, and other attributes. Such "scorecards" should be used to develop incentives for second-generation biofuel production. As part of this strategy, life-cycle assessment tools should be further developed and used to confirm performance and to award credits to producers.
- A better understanding of the ligno-cellulosic biomass resources that could be utilised for second-generation biofuel production or bio-refinery applications. A full global mapping that helps identify optimal growing areas and promising non-crop sources (such as agricultural and forestry wastes) needs to be developed. Near-term successful deployment of second generation technologies could trigger exploitation of biomass resources (such as forests) in an unsustainable manner without proper planning and management strategies.

The full range of impacts of biofuels – cost, environmental, and social among others, is potentially widely variant depending on fuel, feedstock and production technique. The potential co-benefits – including energy security, rural employment and diversification, local air pollution and environmental change – should not be overlooked. Thus, much more research into biofuels is needed, especially before countries become "locked in" to certain production approaches.

### *The Technology Road-mapping Process for Biofuels*

As described in the attached outline of the biofuels roadmapping process and first workshop, it is envisioned that the biofuels roadmap process will be broken into two parts: the first will focus on identifying key pathways, assessing conversion technologies, and analysing fuel distribution, refueling, and vehicle/fuel compatibility issues. A second part of the roadmap will focus on sustainable feedstock supply issues.

There are at least two, and possibly three major types of technology pathways that must be considered in the roadmapping process, and a number of other related technologies that could be considered (drawing boundaries around the roadmapping process and the technologies considered is a key consideration).

The main pathways are:

1. The conversion of biomass to ethanol, butanol, and other possible fuels via bio-chemical pathways, in particular enzymatic hydrolysis
    a. (possibly a sub-catagory or separate category): Photosynthetic conversion via micro-organisms such as algae and bacteria. New conversion pathways from yeast are also emerging. Some approaches are "heterotrophic", i.e. they do not use photosynthesis but are fueled in other ways.
2. The conversion of biomass to natural gas, diesel, and other liquid fuels via thermo-chemical pathways (e.g. so-called "biomass-to-liquids", or BtL).

Depending on how one classifies these, 1b (that includes algal and other advanced microbial approaches) may be part of bio-chemical or treated separately. In any case, for each type of patheway – and for each specific feedstock-fuel pathway identified, there are a variety of specific technologies inovolved, such as (for bio-chemical processes) those related to feedstock preparation, enzymatic hydrolysis, fermentation, distillation, etc.

To ensure an manageable discussion, a few (e.g. 4 or 5) critical technologies should be identified for specific discussion, accompanied by a discussion of more general technology development related issues in the biofuels context. For the technologies and pathways considered, we will need to characterize the current state of research and development efforts, and key technology characteristics as of 2010. Then targets should be developed for milestone years in the future (e.g. 2010, 2015, 2020) in terms of improvements in technology characteristics, reductions in cost, dates of initial deployment, rates of ramp-up of capacity and production, target R&D termination dates, etc.

In addition to addressing the technology milestones, we will also focus on other actions needed to accelerate the uptake of the overall technology into the marketplace. This will include focus on potential financial, legal and market barriers that must be addressed, and policy responses needed, in order to allow the technology to progress.

There also should be an approach developed for updating the roadmap in the future and incorporating the emergence of new technologies or other relevant developments on a regular basis.

### *IEA ETP BLUE Map Biofuels Production Scenarios*

The IEA publication *Energy Technology Perspectives 2008* contains a number of scenarios, but the one most relevant for the roadmapping process is "BLUE Map", the main scenario where energy-related CO2 emissions are reduced by 50% in 2050 relative to their 2005 level. For transport, a variety of strong measures are undertaken, including a rapid ramp-up of second-generation biofuels production after 2010.

Table 1 shows the projected production of lingo-cellulosic ethanol and biomass-to-liquids biodiesel fuel out to 2050 in the BLUE Map scenario. The production levels by 2030 is several orders of magnitude above the starting point in 2010, requiring a challenging pace of investment and construction of biofuels facilities, and increases in feedstock production. The cumulative production over this period also allows for a great deal of experience to be gained over time. Given this assumption, transport fuel demand by 2050 is projected to be over 2 500 MTOE. On this basis, biofuels would provide nearly 25% of transport fuel in that year.

**Table 1: Second-generation biofuels production projections in the BLUE Map scenario**

| | UNITs | **2010** | **2015** | **2020** | **2030** | **2050** |
|---|---|---|---|---|---|---|
| **Biofuels production in respective years** | | | | | | |
| LC ethanol | MTOE | 0.0 | 3.0 | 10.4 | 61.6 | 120.6 |
| | PJ | 0.0 | 125.6 | 437.1 | 2579.1 | 5049.3 |
| | Billion L | 0.0 | 5.5 | 19.0 | 112.2 | 219.6 |
| | Billion Lge | 0.0 | 3.6 | 12.5 | 74.0 | 144.9 |
| BtL biodiesel | MTOE | 0.0 | 0.2 | 13.6 | 102.3 | 491.2 |
| | PJ | 0.0 | 8.4 | 567.7 | 4283.1 | 20565.6 |
| | Billion L | 0.0 | 0.4 | 24.7 | 186.3 | 894.3 |
| | Billion Lge | 0.0 | 0.2 | 16.3 | 122.9 | 590.3 |
| | | | **2010-2015** | **2015-2020** | **2020-2030** | **2030-2050** |

| | | | | |
|---|---|---|---|---|
| **Biofuels capacity required** | | | | |
| Assumed avg capacity of new plants (million litres / year) | 100.0 | 150.0 | 150.0 | 150.0 |
| New Production Facilities Required Each Year | | | | |
| Ethanol | 6.7 | 9.5 | 41.0 | 25.4 |
| Biodiesel | 0.5 | 21.2 | 63.0 | 140.5 |

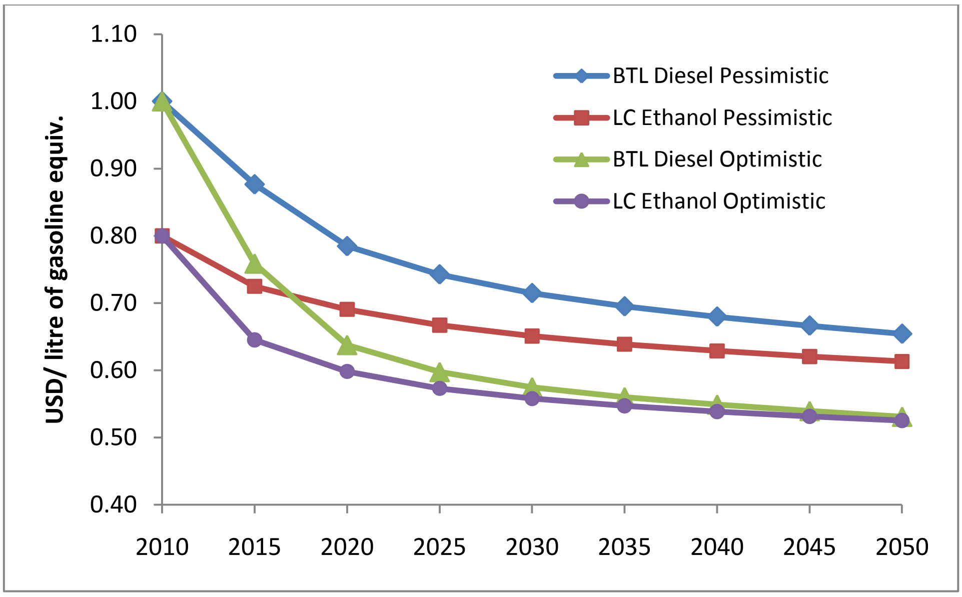
Note: LC = ligno-cellulose; BtL = biomass-to-liquids.

These ETP projections represent a *starting point* for roadmapping purposes. An important element will be to investigate their feasibility and determine if they make sense as a production ramp-up scenarios in terms of feasibility, maximum possible rates of change, investment costs, etc. It may be necessary to make adjustments within the group to reach consensus on the best targets. In any case they should be selected in the context of being as aggressive as possible within various constraints, and if possible should hit the same fuel production numbers in 2050 to stay aligned with the ETP 2008.

### *IEA Biofuels Cost Projections*

BLUE Map includes the IEA's projection of production costs for the two major second-generation biofuels pathways under development. The rate at which the cost of production declines will depend on feedstock prices, economies of scale realised from commercial plant development, and the benefits of experience and learning as cumulative production rises. Current costs and projected long-term "best-case" costs are shown in Figure 9.11. At an optimistic learning rate (a 0.78 progress ratio), both ligno-cellulosic ethanol and BtL biodiesel production costs drop rapidly after 2010 and reach a near-long-run cost level by 2030. At a more pessimistic learning rate (a 0.88 progress ratio), costs come down more slowly and permanently remain about USD 0.15/lge (litre gasoline equivalent) higher than the optimistic cost curve.

**Figure 9.11: Second-generation biofuel production cost assumptions to 2050**



Note: BtL = Biomass-to-liquids LC= ligno-cellulose.

The cost reductions over time reflect the cumulative production associated with the ETP BLUE scenario, so they would be affected by changes in production ramp-up assumptions.

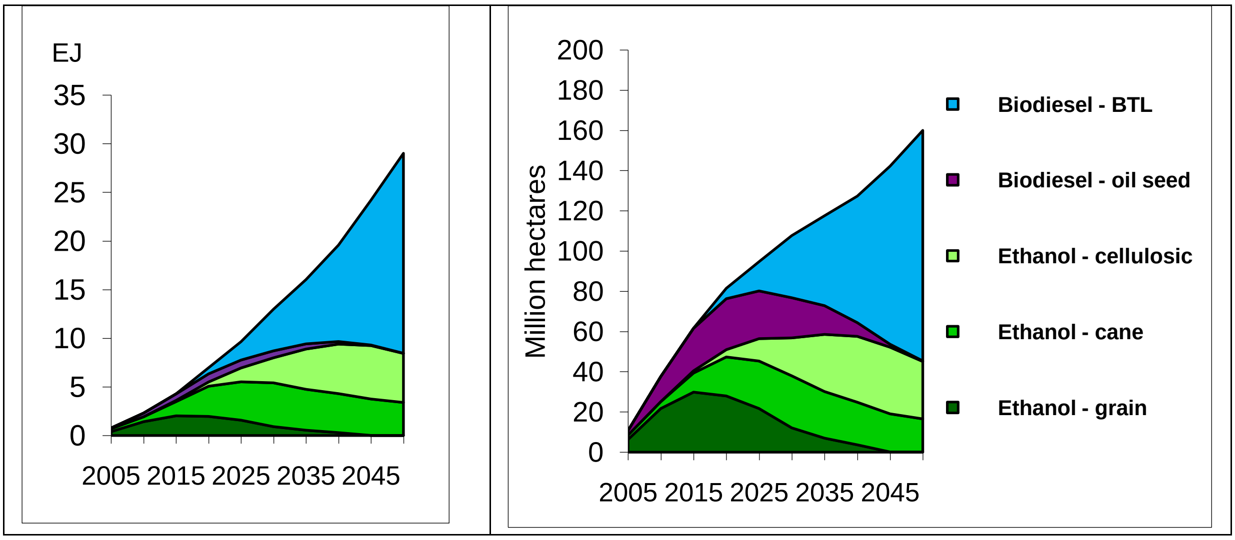
***Land requirements for biofuels in ETP BLUE Map***

For BLUE Map, the IEA has estimated current and future biofuel yields by feedstock type and region, based on various estimates of yields and land requirements in recent literature (shown in ETP 2008). Simple assumptions were used regarding future yield improvements, on the basis of historic crop yield improvements and potential future improvements (including those from possible developments in genetic modification). These point estimates should be taken as rough averages; in reality there is a wide range in yield for any given feedstock/fuel/region combination.

There is significant variation in our yield estimates across the various feedstocks, fuels and locations considered. Brazilian sugarcane-to-ethanol has the highest yield, whereas United States and European biodiesel from soybean and oilseed rape are lowest. The more intensively biofuels are produced in regions with soils and climates that support high-yield feedstocks and approaches, the less total land will be required to produce a given amount of fuel. On the other hand, some of the highest yielding land is also excellent land for food crops, so land competition for different uses becomes a concern.

Putting these yield estimates together with the projected future demand for biofuels in the BLUE Map scenario, the land area that will be required to produce the biofuels can be estimated (Figure 9.12).

**Figure 9.12: Demand for biofuels and land requirements in the BLUE Map scenario**




By 2050, about 160 Mha of mainly crop and pasture land would be needed to produce the volumes of biofuel required to meet the demand expected in the BLUE Map scenario. This is included in the 375 Mha to 750 Mha required for total biomass production outlined above. It is around 3 to 4% of the 6 billion hectares of agricultural area in use today. However, if concentrated in certain countries and regions, particularly if in food-producing areas, it could have substantial impacts in terms of crop displacements and other land-use changes. For example, rapid increases in the production of biofuels in the United States and the European Union in recent years appear to have contributed to rises in prices of certain agricultural commodities (such as corn in the United States and rapeseed oil in the European Union) as competition for crops and land has increased.

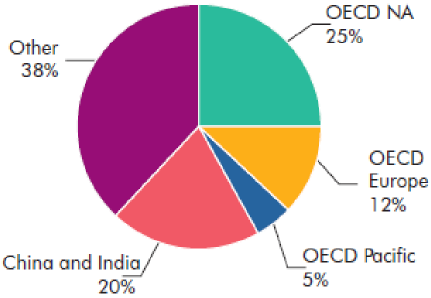
These estimates neglect the possibility of producing biofuels (particularly second generation biomass-based fuels) from non-crop sources such as agricultural, forestry, and other waste biomass. Clearly use of such feedstocks would have the major advantage of causing few impacts on land use. The more that such sources can be utilised, the lower the net land requirement for producing biofuels. Net $CO_2$ emissions reductions could also be higher.

To the extent possible with the group involved in the workshop, it would be helpful to further develop the scenarios of feedstock supply, in terms of types and locations, in order to have a clearer picture of whether the biofuels ramp-up scenarios we develop appear feasible and sustainable from a land-use point of view. It is understood that it will be difficult to make definitive statements about the sustainability of different land use scenarios, but crafting a rough picture of one or two possible scenarios would be helpful. This can also be dropped if it is deemed outside the expertise of the group, or too complex a task for the meeting.

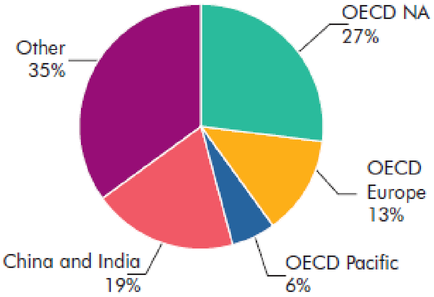
The following two pages reproduce the biofuels roadmap from Chapter 4 of ETP 2008, (the roadmaps chapter). These take an initial view on key indicators for roadmapping biofuels, including deployment dates and cost estimates. These represent a starting point for the analysis that will be conducted in the current roadmap project.

## Second-generation biofuels

**ACT 1.8 Gt savings 2050**




**BLUE 2.2 Gt savings 2050**



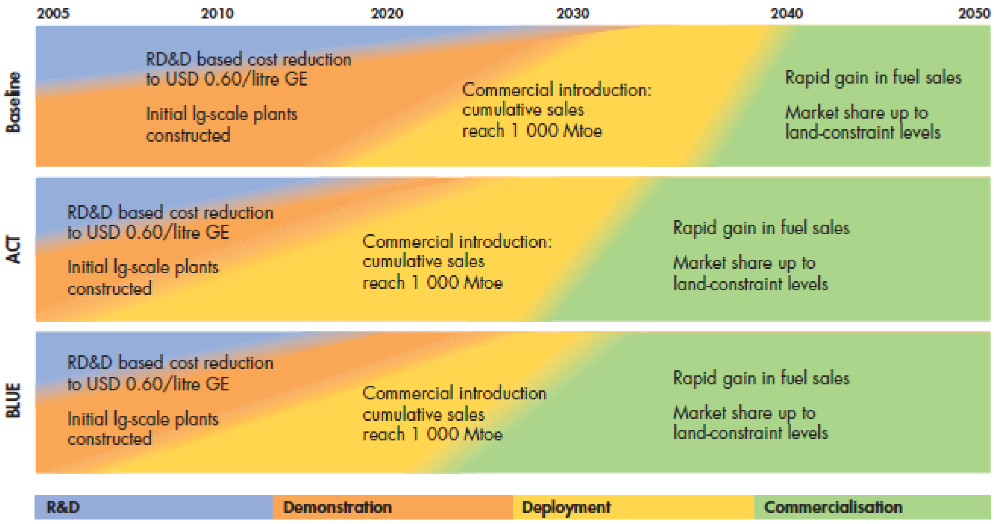

| | Global Deployment Share 2035 | RDD&D Inv. Cost USD bn 2005-2035 | Commercial Inv. Cost USD bn 2035-2050 |
|---|---|---|---|
| OECD NA | 25% | 25-30 | 1 300-1 500 |
| OECD Europe | 12% | 15-20 | 850-950 |
| OECD Pacific | 5% | 5-10 | 250-300 |
| China & India | 20% | 15-20 | 800-850 |
| Other | 38% | 30-35 | 450-500 |

| | Global Deployment Share 2030 | RDD&D Inv. Cost* USD bn 2005-2030 | Commercial Inv. Cost USD bn 2030-2050 |
|---|---|---|---|
| OECD NA | 27% | 30-35 | 1 100-1 300 |
| OECD Europe | 13% | 15-20 | 900-1 000 |
| OECD Pacific | 6% | 8-10 | 300-350 |
| China & India | 19% | 15-20 | 1 400-1 600 |
| Other | 35% | 30-35 | 1 400-1 600 |

## Technology targets

| | ACT: Emissions Stabilisation | BLUE: 50% Emissions Reduction |
|---|---|---|
| **RD&D** | | |
| Cellulosic ethanol | Cut cost of ethanol production to USD 0.60 per litre gasoline equivalent (GE), mainly via better enzymes, by 2015-2020 | |
| BTL (F-T) gasoline/diesel | Cut cost of BTL production to USD 0.70 per litre GE by 2015-2020 via optimisation of biomass handling, gasification, and synthesis gas production steps | |
| **Deployment** | | |
| Cellulosic ethanol | Deployment begins by 2015, full commercialisation by 2035 | Deployment begins by 2012, full commercialisation by 2030 |
| BTL (F-T) gasoline/diesel | Deployment begins in 2015, full commercialisation by 2035 | Deployment begins by 2012, full commercialisation by 2030 |

## Technology timeline




## Key actions needed

- Both ligno-cellulosic ethanol and Fischer-Tropsch "biomass-to-liquids" are reaching the demonstration and, perhaps within a few years, the deployment phase, though basic R&D in some areas is still needed.
- Ligno-cellulosic demo. projects amounting to over USD 1 bn are expected in North America from 2008-2012; various technologies will be tested at scales less than half of expected future commercial size.
  - Similar trials are needed in other parts of the world; better data on feedstock availability and cost by region are needed; land use change analysis.
  - Pathways and strategies to get from demo. to deployment to commercialisation must be developed and clarified.
  - More work on co-products and bio-refinery opportunities.
- For BTL fuels, a small demo project in Germany has been announced, others expected (particularly in Europe) by 2010-2015.
  - Continued engineering research on feedstock handling, gasification/treatment, co-firing of biomass and fossil fuels.
  - Better understanding of cost trade-offs between plant scale and feedstock transport logistics.

## Key areas for international collaboration

- Ongoing basic research collaboration (e.g. feedstock and enzyme research, feedstock handling/transport, process and plant scale optimisation).
- Global assessment of biomass availability / cost for production of 2nd generation biofuels.
  - Impacts on GHGs, sensitive eco-systems soils, food security, alternative uses of land ("land use change").
  - Assessment of economic viability of 2nd generation biofuels in the developing world.
- Better co-ordination of demo. projects, trials, deployment policies, biofuels trade.