A look into the maximum potential availability and demand for low-carbon feedstocks/fuels in Europe (2020–2050)

(literature review)

In light of the EU's ambitious targets for achieving a low-carbon economy by 2030, Concawe has completed a study of the long-term availability of low-carbon feedstocks and fuels, and the associated costs, based on a literature review. This article summarises the outcomes of the Concawe study.

Introduction

Over the past decades, different pathways such as biofuels or power-to-fuel technologies have emerged as viable options to reduce the life-cycle carbon emissions from the production and use of hydrocarbon fuels as well as feedstock for petrochemicals, lubricants and waxes.

Concawe, through its Low Carbon Pathways (LCP) programme, is conducting specific research on the potential integration of different well-to-wheel (WTW) opportunities to produce a holistic picture of the potential role of liquid fuels in a future EU low-carbon economy. Concawe's assessments explore the potential reduction in WTW CO_2 intensity that could be achieved in the medium (2030) and longer term (2050+), and estimate the associated abatement costs from different pathways that have the potential to contribute significantly to reducing the CO_2 intensity of the final refining products. This article looks into the medium- and long-term potential availability of alternative low-carbon feedstocks and fuels, and presents the associated costs based on a literature review. Some of the sources included in the report envisage a significant long-term role for advanced alternative fuels in Europe, identifying the main research and innovation (R&I) and policy conditions that would enable the potential of low-carbon fuels to be fully realised. Some of the ongoing Concawe LCP-related work on *The Refinery 2050*[1] draws support from the conclusions and main figures included in this article, and is scheduled for publication in April 2019.

The European Commission has recently published its long-term strategic vision for Europe, *A Clean Planet for all*.[1] Recognising that climate change represents an urgent threat to societies and the planet, the Commission has set the goal, in accordance with the 2015 Paris Agreement, of keeping global warming well below 2°C above pre-industrial levels, and pursuing efforts to limit it to 1.5°C by 2050. Efforts to improve the CO_2 efficiency of the EU transport sector, which accounts for nearly a quarter of the EU's greenhouse gas emissions, will be crucial to achieving these goals. Technologies for the production of low-carbon fuels is one area that is especially interesting in terms of helping the transport sector to accomplish these targets.

Sustainable biofuels, subject to the updated sustainability criteria currently proposed by the European Commission,[2] are one of the main low-carbon liquid alternatives to petroleum-based fuels for transport, as they are easily deployable using existing transport infrastructure. The Renewable Energy Directive (RED),[3] the Fuels Quality Directive (FQD)[4] and the 'ILUC Directive'[5] set out biofuels sustainability criteria for all biofuels produced or consumed in the EU to ensure that they are produced in a sustainable and environmentally friendly manner.

Current legislation (RED I and RED II) requires a 7% cap on the contribution of conventional biofuels, including biofuels produced from energy crops, to count towards the renewable energy directive targets regarding final consumption of energy in transport in 2020 and in 2030 . Secondly, the RED II directive (that entered into force on 24 December 2018) sets as a binding minimum a 0.5% target for advanced biofuels by 2021 and 3.5% by 2030. Thirdly, the directives harmonised the list of feedstocks (Annex IX) for the production of advanced biofuels across the EU. Those can be considered to count double (i.e. to be twice their energy content) in terms of their contribution towards the 2030 target of 14% for renewable energy in transport.

[1] One of series of publications being produced by Concawe as part of the organisation's Low Carbon Pathways programme.

These directives require that biofuels produced in new installations — starting after 1 January 2021 — emit at least 65 % fewer greenhouse gases than fossil fuels.

The Fuels Quality Directive allows gasoline fuels in Europe to contain up to 10% bio-derived oxygenates, usually in the form of ethanol, while diesel fuels can contain up to 7% fatty acid methyl ester, although other bio-derived components are also allowed.

What is a sustainable biofuel?

Burning harvested organic matter (biomass) has provided most of mankind's energy needs for millennia. Such fuels remain the primary energy source for many people in developing and emerging economies, but such 'traditional use' of biomass is often unsustainable, with inefficient combustion leading to harmful emissions with serious health implications. Modern technologies can convert this organic matter to solid, liquid and gaseous forms that can more efficiently provide for energy needs and replace fossil fuels.

A wide range of biomass feedstocks can be used as sources of bioenergy. These include: wet organic wastes, such as sewage sludge, animal wastes and organic liquid effluents, and the organic fraction of municipal solid waste (MSW); residues and co-products from agro-industries and the timber industry; crops grown for energy, including food crops such as corn, wheat, sugar and vegetable oils produced from palm, rapeseed and other sustainably produced raw materials; and non-food crops such as perennial lignocellulosic plants (e.g. grasses such as miscanthus, and trees such as short-rotation willow and eucalyptus) and oil-bearing plants (such as jatropha and camelina). Many processes are available to turn these feedstocks into products that can be used for electricity, heat or transport.

What are advanced biofuels?

Advanced biofuels are commonly accepted to be biofuels that:

- are produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams;
- produce low CO_2 emissions or high GHG reductions (at least 60% fewer GHGs than fossil fuels); and
- reach zero or low indirect land-use change (ILUC) impact.

The development of biomass resources in particular faces numerous challenges due to the complexity of land issues, related politics, cost/scale, infrastructure support, and environmental criteria. Furthermore, there is no evidence in the press or in public relations activities in Europe that any major developments are forthcoming in this area.

Scope: mid- to long-term outlook (literature review)

This study addresses the potential availability of low-carbon feedstocks, and looks at different demand scenarios to provide an outlook for biofuel potential for the 2020, 2030 and 2050 time-horizons in Europe and worldwide, covering the following scope:

- Potential biomass availability for the 2020, 2030 and 2050 time horizons
- Potential demand for the 2020, 2030 and 2050 time horizons
- Technologies conversion routes and technology readiness level (TRL)
- Potential production costs for the 2020, 2030 and 2050 time horizons
- Challenges: barriers and potential enabling conditions.

This study is based on a literature review of selected external sources. It highlights the uncertainty associated with the maximum potential availability of biofuels, which is heavily dependent on the key enabling framework conditions that would be required to unleash the full potential for low-carbon feedstocks/fuels in Europe.

The main source references used in this study are summarised in Table 1. Each source follows a specific approach in developing their estimations.

Table 1: The approach followed by each source reference in developing their estimations

	MAIN REFERENCES	MAIN APPROACH FOLLOWED BY THE SOURCES
Biofuels[6]	SETIS	Based on EU targets for renewable energy and installed capacity
	DG R&I Ecorys	Based on extensive R&I efforts in agriculture, mobilisation of resources and development of conversion technologies, and assumptions about feedstock availability, and the degree of support from the agricultural and transport sectors
	SGAB	Based on what the industry can deliver from the conversion facilities' points of view, given the appropriate policy framework and financing structure
	IEA	Based on EU targets for renewable energy and future demand scenarios
	IRENA	Based on assumptions about policies and biofuel availability and cost
	ICCT	Based on the availability of sustainable biomass
e-fuels[7]	Agora	Based on importation from regions with cheap and full load hours electricity
	LBST and Dena	Based on demand scenarios competing with other technologies
	ICCT	Based on future electricity prices and financial parameters

Note: IEA and IRENA provide a worldwide scope, while SETIS, Ecorys, SGAB, ICCT, Agora and Dena focus on a European framework. Most of the studies only cover the potential availability and demand for advanced sustainable biofuels, and do not include an assessment of first-generation biofuel potential by 2030/2050.

Potential biomass availability for the 2020, 2030 and 2050 time horizons

In this study, potential biomass availability is analysed worldwide and across Europe. The analysis considers the availability of bioenergy throughout Europe as a whole, as well that related specifically to the transport sector (as a subgroup of the bioenergy system). The whole bioenergy system covers all sectors, such as electricity, heat, the chemical industry and transport. All these sectors compete for the same sustainable biomass resources; therefore, even at maximum levels of sustainable bioenergy production, cross-sectoral competition is high.

Worldwide biomass availability

World sustainable biomass availability is generally expected to increase continuously from a total of 2,500 Mtoe/y by 2020 (IRENA reference) to 5,700–7,000 Mtoe/y by 2050 in the max scenario (IEA/IRENA reference) mainly based on agricultural residues and energy plants (>70%).

The IEA 2050+ scenario forecasts a lower potential availability as defined by IRENA in their 2050 base scenario, with the main difference being the envisaged potential for algae. Indeed, the potential deployment of algae is uncertain (mainly due to the current efficiency levels and high cost), and while several sources recognise its role in the 2050 scenario (e.g. according to IRENA, algae could reach 478 Mtoe/y by 2050), other sources such as IEA are more conservative in this regard and do not consider that there will be any relevant penetration of algae within the 2030–2050 time frame.

Some references, such as ICCT,[8] claim that there is not enough bioenergy to decarbonise all sectors together. These have a more conservative view, and assume that the maximum global amount of low-carbon biomass that could be supplied for energy by 2050 will be around 2,150 Mtoe/y.

Figure 1 notes:

Energy contents: (1 toe = 41,868 GJ)

Conversion factors[9] used by Concawe for comparison purposes (simplified approach) are:

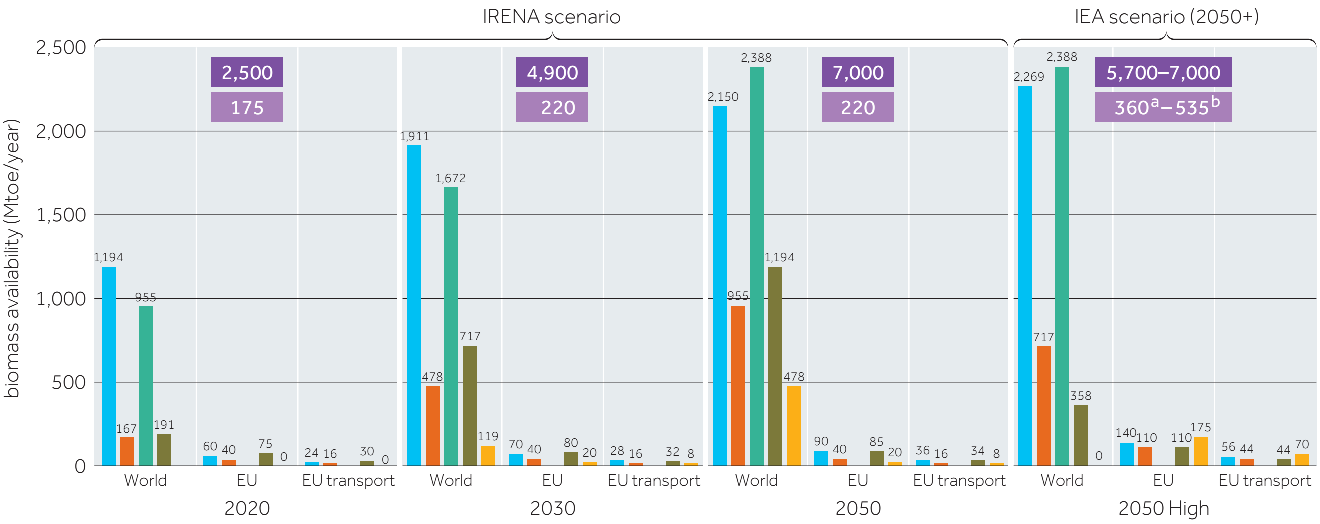
- Agriculture residues energy content: 0.56 toe/t
- Forestry energy content: 0.21 toe/t
- Waste energy content: 0.76 toe/t
- Aquatic (algae) energy content: 0.48 toe/t

Legend:

- total world bioenergy, Mtoe/year
- total EU bioenergy, Mtoe/year
- a ICCT has the most conservative view, assuming that the maximum global biomass availability in 2050 is around 2,150 Mtoe/y
- b biomass availability if the full potential for algae is realised
- agriculture (non-food related)
- forestry
- energy plants
- waste
- aquatic (algae)

Figure 1: World maximum biomass availability, 2020–2050

Source: Concawe own assessment based on data from IRENA and IEA for world availability; ICCT, DGR&I Ecorys and SGAB for EU availability



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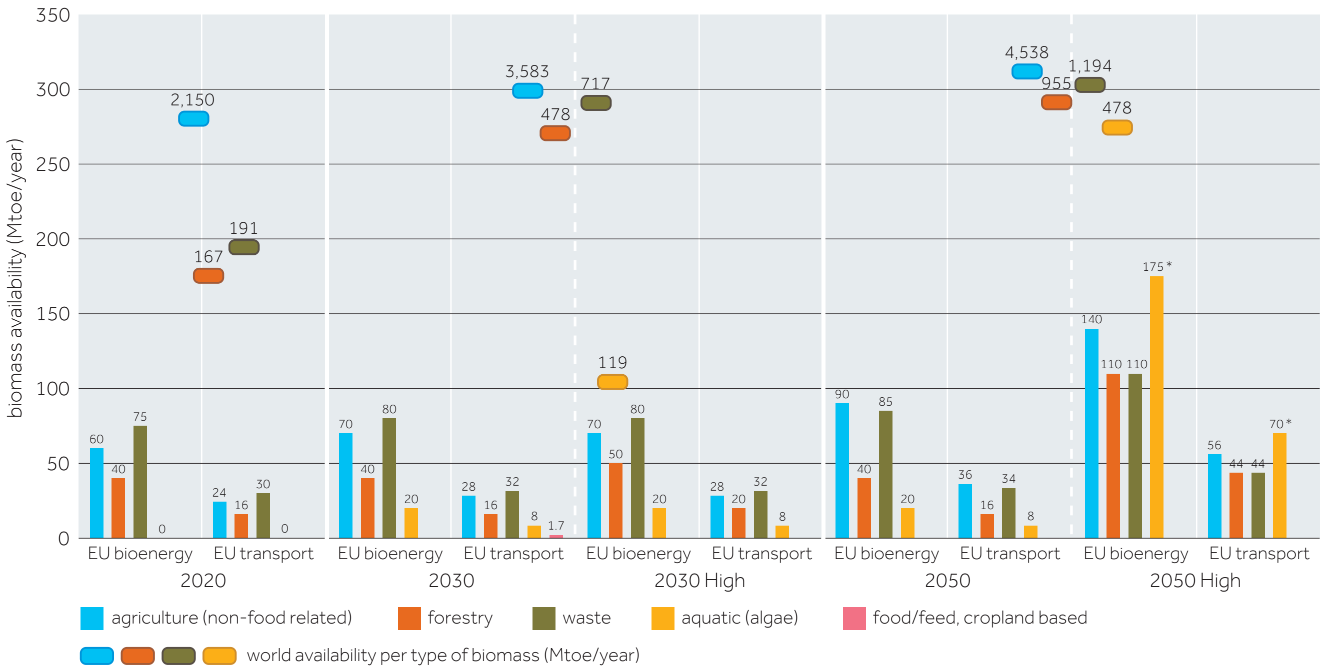
European biomass availability

When considering the availability of sustainable biomass in Europe, it should be noted that the whole of the bioenergy system is estimated to grow from 175 Mtoe/y (2020) to approximately 350–535 Mtoe/y by 2050. According to DG R&I Ecorys, the amount of biomass that will need to be available to meet the demand for bioenergy is expected to be 360 Mtoe/y. It is estimated that 15 Mtoe/y of this will be imported, hence the maximum level of biomass that will need to be available in Europe could be approximately 350 Mtoe/y. If the full potential for algae is realised, this could increase the level of available biomass from around 350 up to 535 Mtoe/y; however, according to DG R&I Ecorys, the full potential for algae is not expected to be reached because of its high cost. According to the European Commission,[0] the production of feedstock in Europe will be lower by 2050, and could range from 210 to 320 Mtoe/y (the majority coming from the waste sector). It is assumed that most of the biomass used in the EU economy will be produced within Europe (imports of sustainable solid biomass will be limited to 4–6% of the solid biomass used for bioenergy by 2050).

For the transport sector, different sources estimate that the biomass contribution could range from a total of 70 Mtoe/y (2020) to 140–210 Mtoe/y by 2050. In terms of energy content, agricultural residues and wastes are expected to contribute the most, followed by forestry residues and algae.

Figure 2: European biomass availability, 2020-2050

Source: Concawe own assessment based on data from IRENA and IEA for world availability; DG R&I Ecorys for EU availability



Notes:

* Algae uncertainty in 2050 high Ecorys scenario. High scenario considers high learning rates for all technologies.

- For the purpose of this assessment, it is assumed that a percentage of 40% of total bioenergy could be allocated to transport (based on Ecorys demand scenarios).
- Energy contents: 1 toe = 41,868 GJ
- As a general reference, the energy content of one hectare of miscanthus is 12 toe/ha.
- ICCT provides a more conservative EU availability by 2030 (only a total of 84 Mtoe/y for bioenergy) while SGAB provides a more optimistic view (350–400 Mtoe/y).
- IRENA worldwide values are based on average data. There is high variability in extreme data (e.g. energy plants by 2050 could vary from 10 to 1000 EJ).

Potential demand for the 2020, 2030 and 2050 time horizons

The previous section assesses the maximum potential for R&I to enable secure, low-cost and sustainable biomass feedstock for energy (including the transport sector). In contrast, this section focuses on the potential contribution of biofuels towards achieving the EU's ambitious climate change objectives from the perspective of what might be demanded by the different bioenergy sectors (demand scenarios).

The maximum potential demand for advanced biofuels in the EU, assuming there is sufficient availability, is estimated to grow from ≈ 0 Mtoe/y in 2015 to 70–140 Mtoe/y by 2050. According to the European Commission,[0] advanced biofuels could represent a smaller contribution to the transport sector fuel mix by 2050 (up to 50 Mtoe/y). Power and industrial sectors would absorb most of the biomass (< 20% allocated to transport).

Based on resource availability and allocation across all European bioenergy sectors, there could be significant variability in potential demand according to different references. The DG R&I Ecorys 2050 high scenario is significantly higher than the rest, followed by IEA.

There is also high variability regarding e-fuels. According to the Dena reference, e-fuels play a role by 2030 (36 Mtoe/y) and 2050 (80 Mtoe/y). However, DG R&I Ecorys have a more conservative view: they estimate a potential e-fuel production of 10 Mtoe/y (~10 Mt/y) in their 2050 high scenario. According to ICCT, e-fuels are not expected to play a role without significant policy support. According to the European Commission,[0] e-fuels could represent from 0 to 71 Mtoe/y of transport energy demand in 2050.

Figure 3 notes:

As a general reference, the energy content in a typical road tanker full of gasoline is assumed as the conversion factor = 23 toe.

In 2050, wider and shorter red columns refer to the DG R&I Ecorys base scenario.

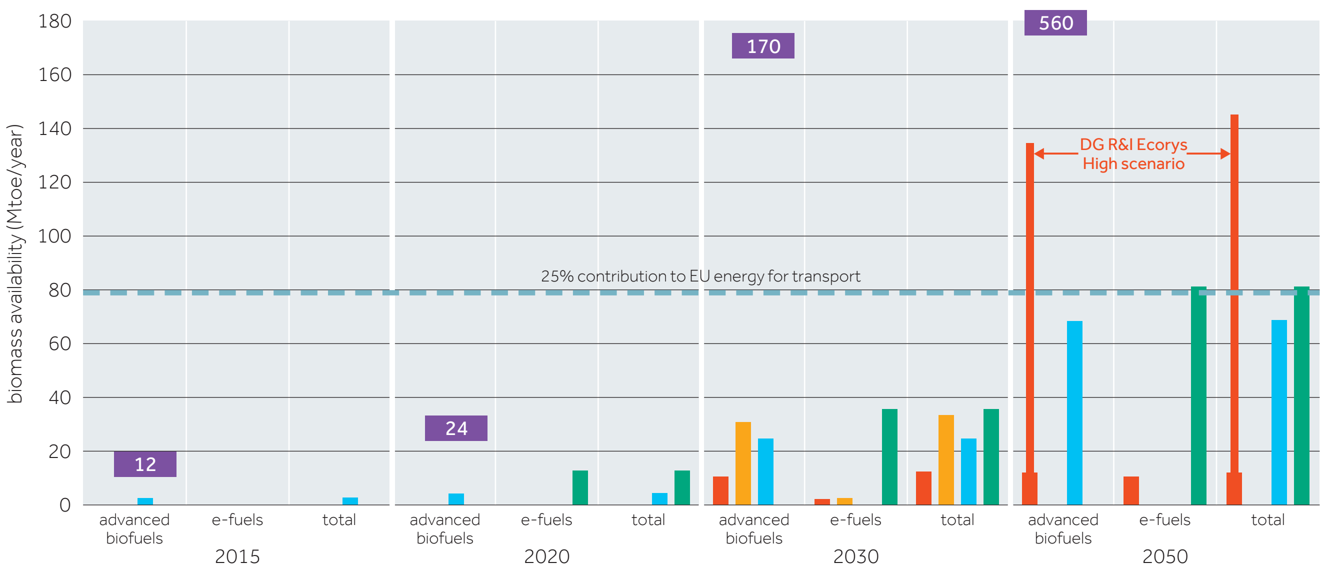
In 2030, the IRENA worldwide value is 100 Mtoe/y (below the IEA's estimation of 170 Mtoe/y), considering a lower heating value (LHV) of 44 MJ/kg (100% HVO/FT diesel). For oxygen-containing biofuels, the LHV would be closer to 37 MJ/kg.

Legend:

- xx advanced biofuels, worldwide values (IEA)
- DG R&I Ecorys
- SGAB
- IEA
- DENA

Figure 3: Maximum potential low-carbon fuels demand (advanced biofuels and e-fuels), 2020-2050

Source: IEA and IRENA for world demand; DG R&I Ecorys, SGAB, IEA, ICCT and Dena for EU demand



These assessments are summarised in Figure 3, and compared to the potential worldwide demand. In the most optimistic scenarios, European demand for advanced biofuels would be equivalent to 16% of what could become available in the rest of the world. Future demand scenarios outside Europe have not been included in this comparison.

The DG R&I Ecorys high scenario is significantly higher. This is due to the approach taken by the study. It examines the R&I potential for advanced biofuels under future scenarios where EU targets are met. DG R&I Ecorys have developed base, medium and high scenarios, each assessed using different assumed levels of R&I efforts.

The key factors necessary for realising the full potential of biofuels in Europe are:

1. Improvements in feedstock supply

   Examples include:
   - An increase in conventional (food/feed) crop yields due to breeding efforts which aim to build up the resistance to biotic and abiotic stresses (drought, pests and diseases) as well as to increase residue to crop ratios (straw/grain ratio). This can lead to an absolute increase in main crop biomass and crop residues, and potentially provide more space for growing energy crops (if demand for food/feed can be satisfied with less land).
   - An increase in yields from energy crops due to the development of hybrid crops specifically dedicated to energy. This can include the development of more robust, stress-resistant energy crops as a result of prebreeding and breeding activities, as well as the domestication of new energy crop species.
   - Increased production by growing dedicated energy crops on unused agricultural lands. Further expansion of energy crops on non-agricultural land (marginal lands) is anticipated in the future. Expansion on marginal lands will be possible because of breeding efforts targeted at developing more robust plants which are able to grow in less suitable conditions.
   - The effects of developments in genetic research over the longer term.
   - Fertilisation of forests growing on poor soils.

2. Improvements in the efficiency of the whole biomass to biofuel process chain

   Examples include:
   - Improved agricultural management practices (e.g. selection of crop varieties, crop rotation and intercropping, fertilisation, water management, adoption of precision agriculture practices) to bridge the current gaps in yields among EU member states.
   - Improved harvesting practices and machinery (development of new equipment for both conventional and dedicated energy crop harvesting, improving harvesting practices, development of precision farming).
   - Increased mobilisation of agricultural biomass by optimising supply chain logistics (mobilisation of unexploited biomass by using cleaner, more efficient and more cost-effective technologies, technology transfer, streamlining biomass supply chains with existing practices, and development of new supply chains for dedicated energy crops).
   - Harvesting trees more efficiently, thereby reducing harvest losses

3. Decrease in conversion costs
   - Improvements in the efficiency of the process chain can reduce conversion costs (as mentioned above).

4. The high potential of algae
   - Increased R&I efforts for the development of photobioreactor (PBR) systems.
   - Targeted R&I efforts on algae strains with high productivity rate and lipid content such as chorella.
   - Adaption of harvesting methods that are commercially available for the food and feed sector such as flocculation, sedimentation and filtration, as well as centrifugation for microalgae-to-biofuel value chains.
   - R&I efforts on the direct conversion of microalgae to biofuels via hydrothermal liquefaction (HTL) at pilot scale.
   - Increased R&I efforts in the field of aquaculture production of macroalgae, while the harvesting of wild seaweeds is decreased.

5. High learning rates for all technologies
   - The learning rates represent the effect of R&I in the learning-by-doing mechanism, which will have an influence on the capital costs of conversion technologies as capacity increases.

6. Significant investments in advanced biofuels capacity
   - To achieve the 2020 targets, the currently installed capacity for advanced biofuels will need to increase from 0.2 GW to close to 1.1 GW, at an estimated cost of €4.5–5 billion. Advanced biofuels also have the potential to reach the 2030 and 2050 targets if capacity is increased to 30 GW in 2030 and to 250 GW in 2050.

7. Substantial efforts and coordination between stakeholders
   - Increased awareness and capacity of the various actors involved in the biomass supply chain.

8. R&I policies
   - Targeted policies, e.g. R&I for feedstock and conversion technology, are crucial to unlocking this potential. Such policies should also address the substantial investments needed for the market transition to large-scale production of advanced biofuels; a lack of sufficient investment could be the greatest obstacle for the development of advanced biofuels. These policies may include efforts to attract foreign capital. Most EU countries (apart than Finland, France, Germany, Italy, Poland, the Netherlands, Spain, Sweden and the UK) do not currently produce advanced biofuels, but they do have potential for the production of sustainable feedstock and advanced biofuels in the future.

Technologies conversion routes and technology readiness level (TRL)

Currently, several conversion and upgrading technologies are available, with different technology readiness levels (TRLs), from research status (TRL 1) to commercialisation (TRL 9). A high-level overview is presented below. Biofuel production costs will vary depending on the conversion technologies, feedstocks and TRL.

Figure 4: Commercialisation status of advanced fuels conversion technologies

Source: IRENA

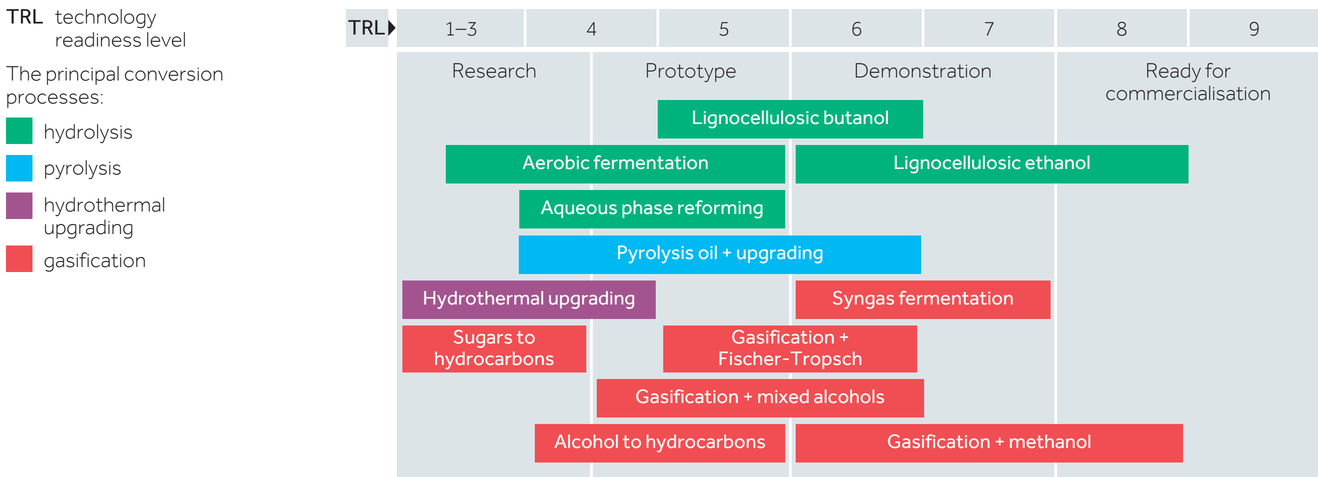
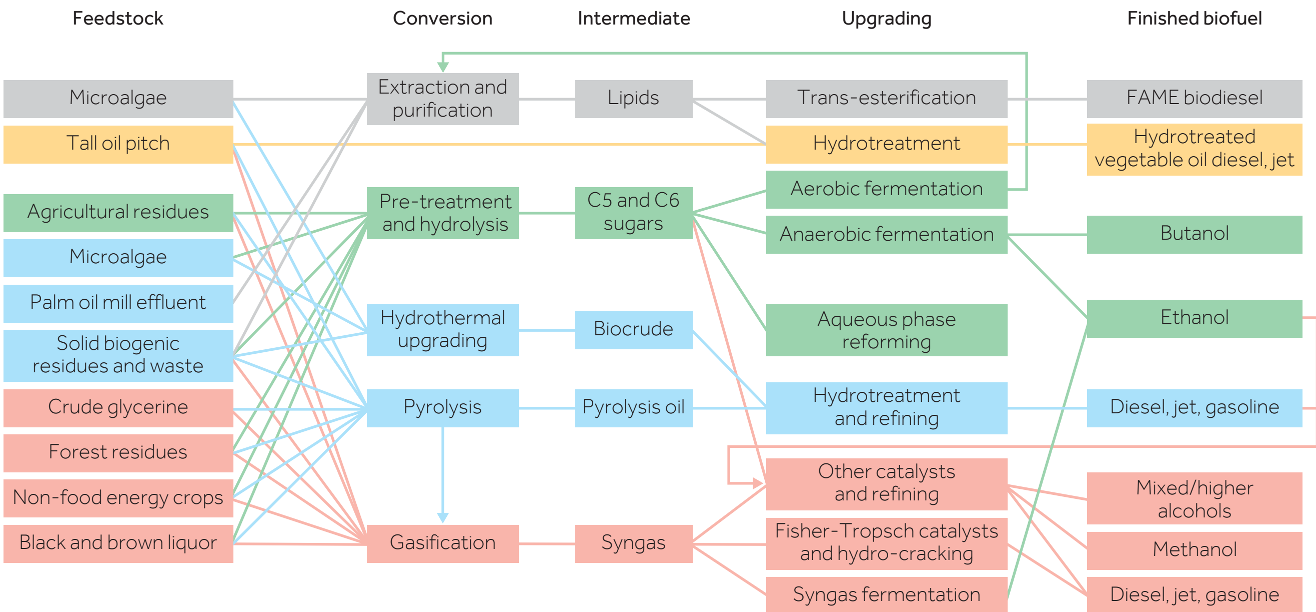


Figure 5: Advanced biofuels pathways

Source: IRENA



Potential production costs for the 2020, 2030 and 2050 time horizons

Production costs for advanced biofuels and e-fuels are higher compared to the costs for equivalent oil-based gasoline or diesel. Different source references note the potential for the production costs of both feed cropland-based biofuels and conventional gasoline/diesel production costs to be significantly reduced by 2050 (<2 €/litre diesel equivalent); this will be highly variable depending on the conversion technologies used.

IRENA claims that, based on potential improvements in conversion efficiency, capital cost reduction, scaling up, learning rates and efforts to reduce the costs of feedstock supply, the production costs for advanced biofuels could become competitive with fossil fuel at an oil price above 100 $/bbl. At an oil price below 80 $/bbl, advanced biofuels pathways are unlikely to be able to compete directly with gasoline and diesel over the next three decades unless very low or negative cost feedstocks are available.

An overview of future costs associated with both feedstock prices and conversion technologies follows, and shows the high uncertainty around the projections developed by the different sources consulted.

Figure 6 notes:

Key data: 1 toe = 41,868 GJ

Diesel LHV: 44 MJ/kg

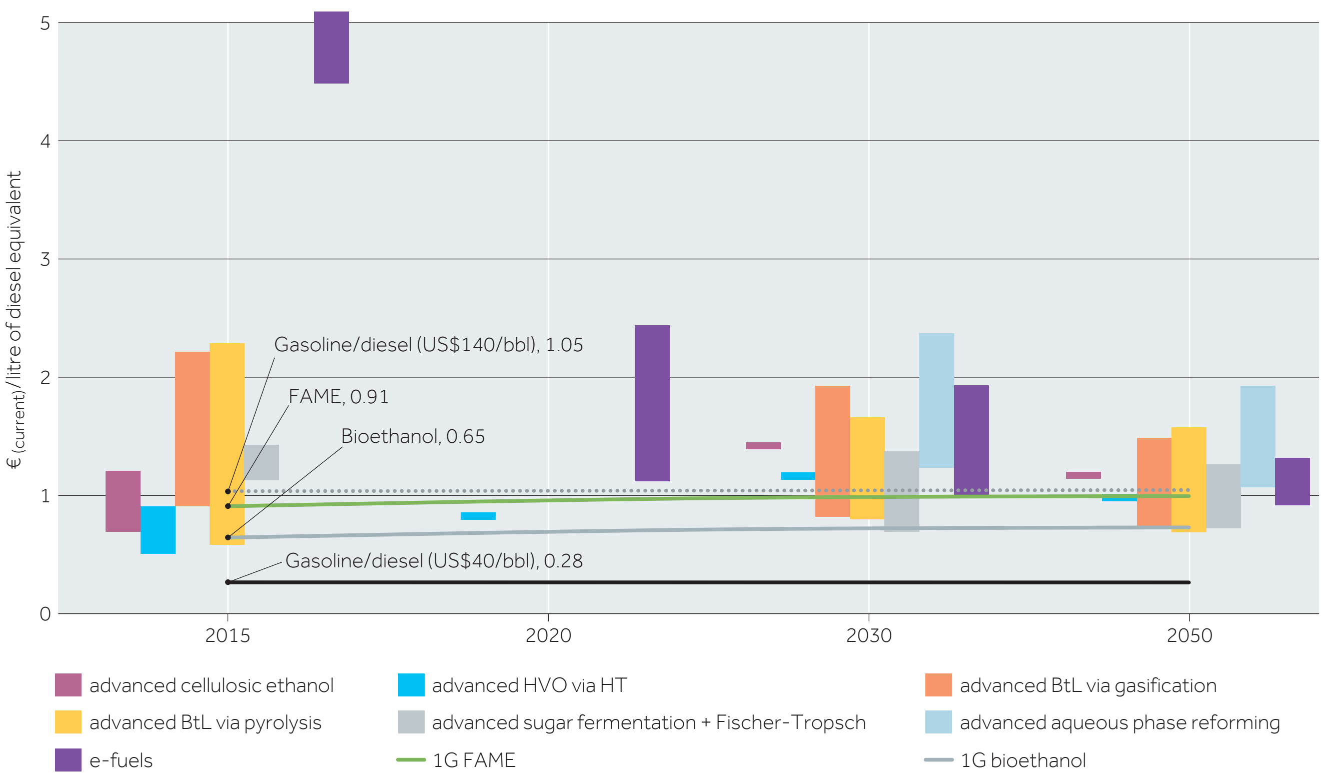
Diesel density: 0.832 kg/l

Gasoline/diesel production costs are reported without taxes.

Production costs for feed cropland-based biofuels (FAME and bioethanol) are expected to be in the same range as the costs of conventional gasoline or diesel at a crude oil price of US$100/bbl, according to the IEA.

Figure 6: Potential production costs, 2015–2050

Sources: DG R&I Ecorys; SGAB; IRENA; IEA; ICCT; IPIECA; CEFIC; Dena; and Frontier Economics/Agora.



An overview of the different conversion technologies

Figure 7: Potential production costs according to different references and technologies, 2015–2050

Sources: DG R&I Ecorys, SGAB, SETIS, IRENA, IEA, ICCT, IPIECA

Figure 7 notes:

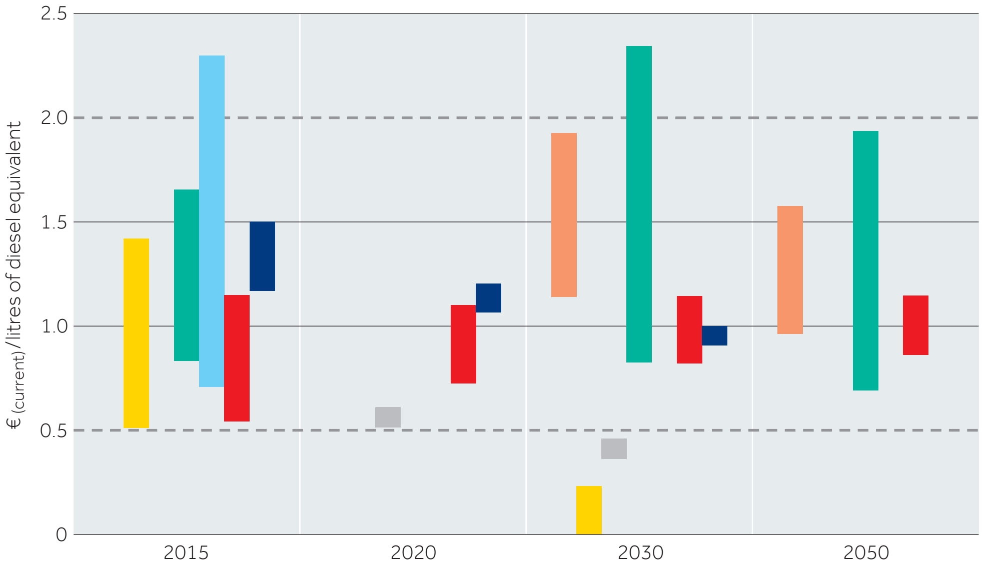
Key data: 1 toe = 41,868 GJ

Diesel LHV: 44 MJ/kg

Diesel density: 0.832 kg/l

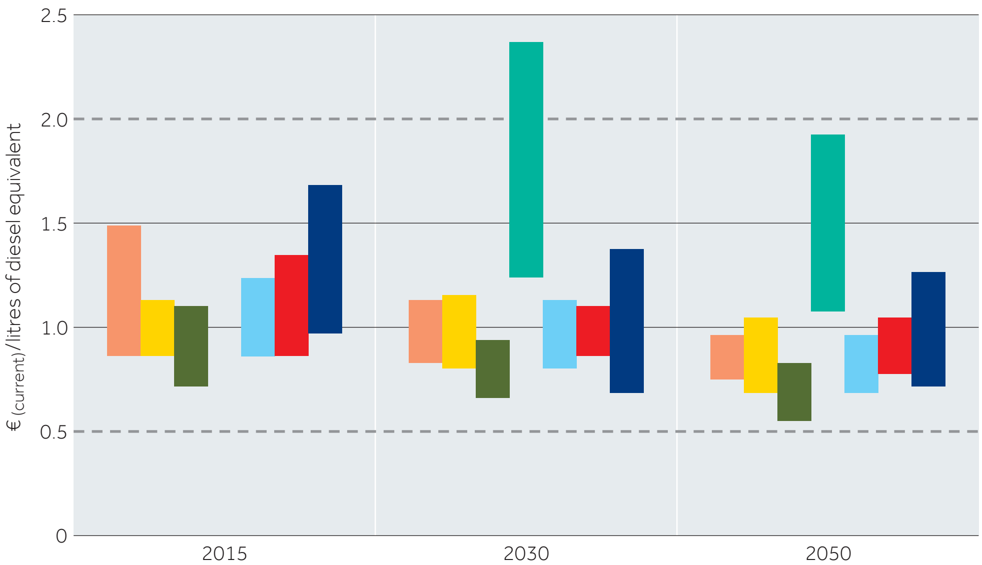
Change: $/€ $_{2014}$: 1.329

a) Biofuel costs according to all references



Ecorys
SGAB
SETIS
IRENA
ICCT
IEA
IPIECA
average cost band

b) Deep dive per type of technology (example from IRENA)



Fischer-Tropsch synthesis
pyrolysis oil upgrading
methanol to gasoline
aqueous phase reforming
mixed alcohol synthesis
syngas fermentation
lignocellulosic fermentation
average cost band

The average costs are expected to remain the same, from 0.5 to 2.0 €/litre diesel equivalent, although the variability among different references suggests an uncertain future for the development of conversion technologies as they are scaled up. The costs of aqueous phase reforming for biofuels are claimed to be higher than the average (from a maximum of 2.4 €/litre by 2030 to 1.9 €/litre by 2050, according to IRENA); cost reductions and an increase in yields are the main challenges to be overcome before this technology is likely to be adopted for widespread use in the transport sector.

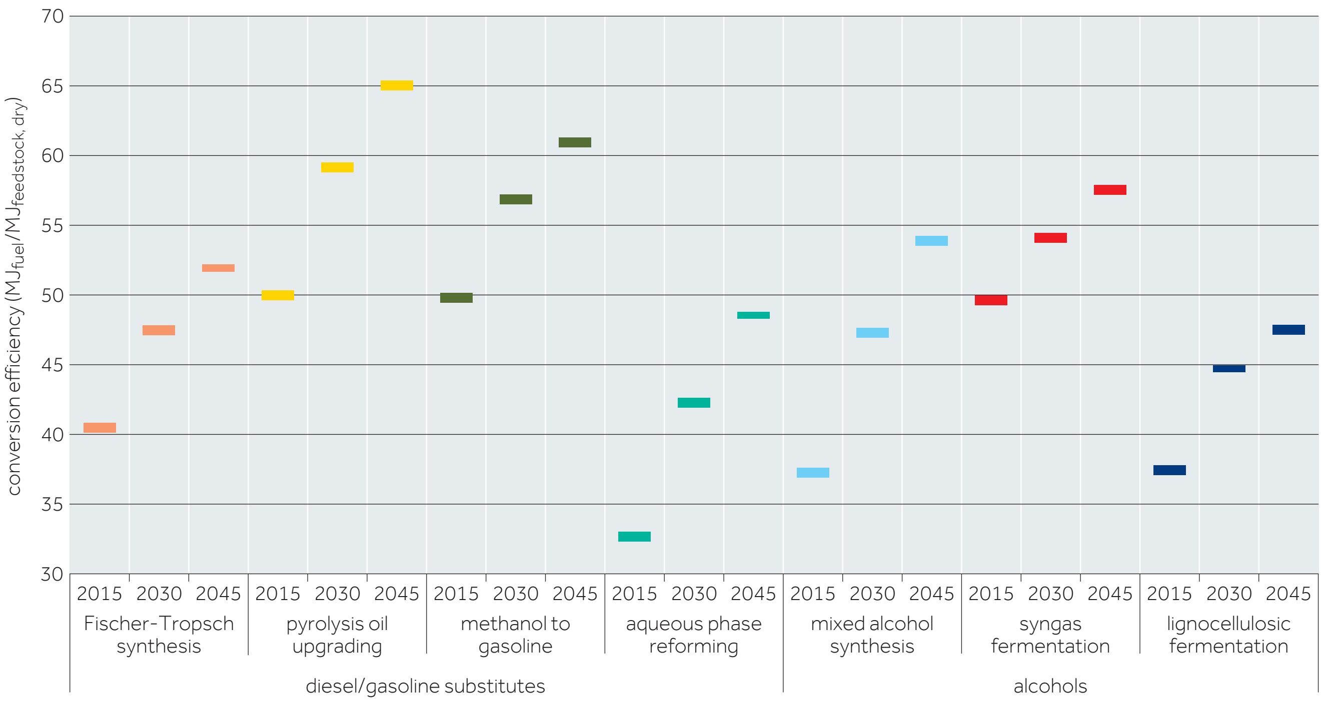
According to IRENA, gasification (Fischer-Tropsch (FT) synthesis), pyrolysis pathways and methanol-to-gasoline technology show higher maximum theoretical conversion efficiencies compared to other pathways. The majority of these pathways may still achieve significant improvements in overall conversion efficiency, with the exception of fermentation. This will potentially enable these technologies to achieve lower production costs over the next decades.

Lignocellulosic fermentation and syngas fermentation pathways for ethanol production are currently operating close to their maximum theoretical yields. There is thus less scope to increase yields in these cases.

Figure 8 shows the forecasted improvements in process efficiencies in the next decades.

Figure 8: Comparison of process efficiencies

Source: IRENA



Biomass supply costs

The forecasted cost of biomass is one of the main uncertainties due to future competition for resources among different bioenergy sectors (including transport).

According to IRENA, for example, biomass costs could potentially range from -2 to 8 €/GJ depending on the origin of the biomass: the costs of producing energy crops as feedstocks are claimed to be higher than for waste, followed by agriculture residues and, finally, forest residues.

According to DG R&I Ecorys, the cost of biomass supply is expected to increase from 2020 to 2050, but is expected to decrease according to IRENA.

IRENA claims that the feedstocks used in most pathways account for 40–70% of production costs, using typical wood or agricultural residue cost assumptions. As learning rates increase and efficiencies improve, the contribution of the feedstock cost to overall costs may increase over time. Reducing the feedstock supply cost is key to reducing production costs.

Figure 9: Biomass supply costs according to three different references, 2015–2050

Source: DG R&I Ecorys, SGAB, IRENA

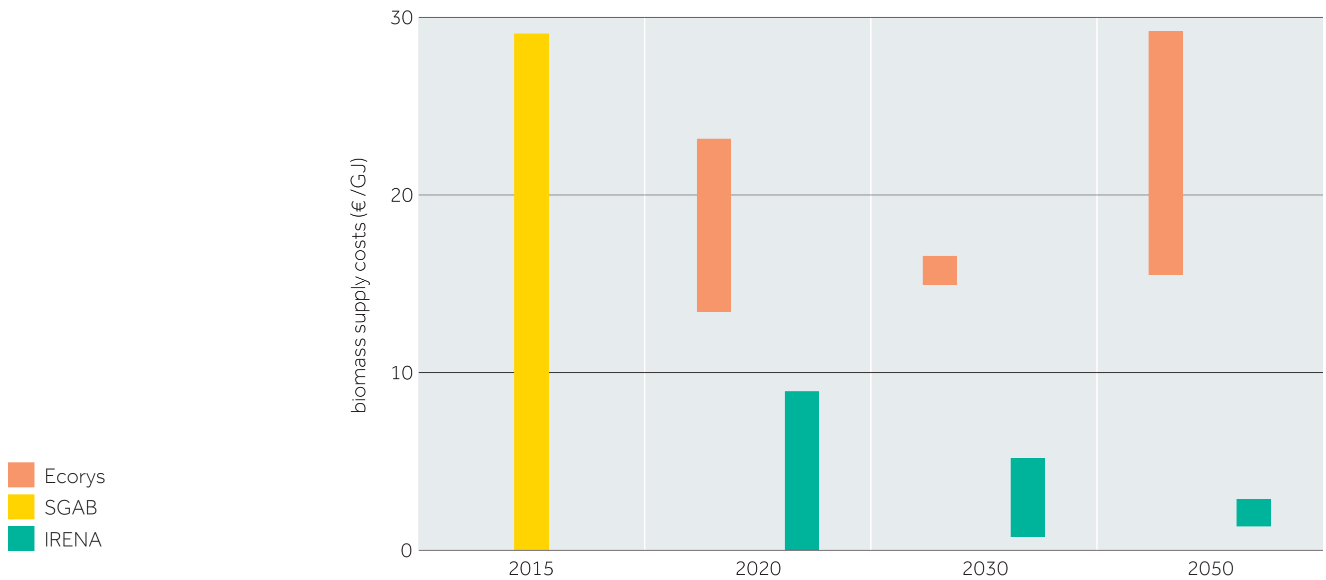
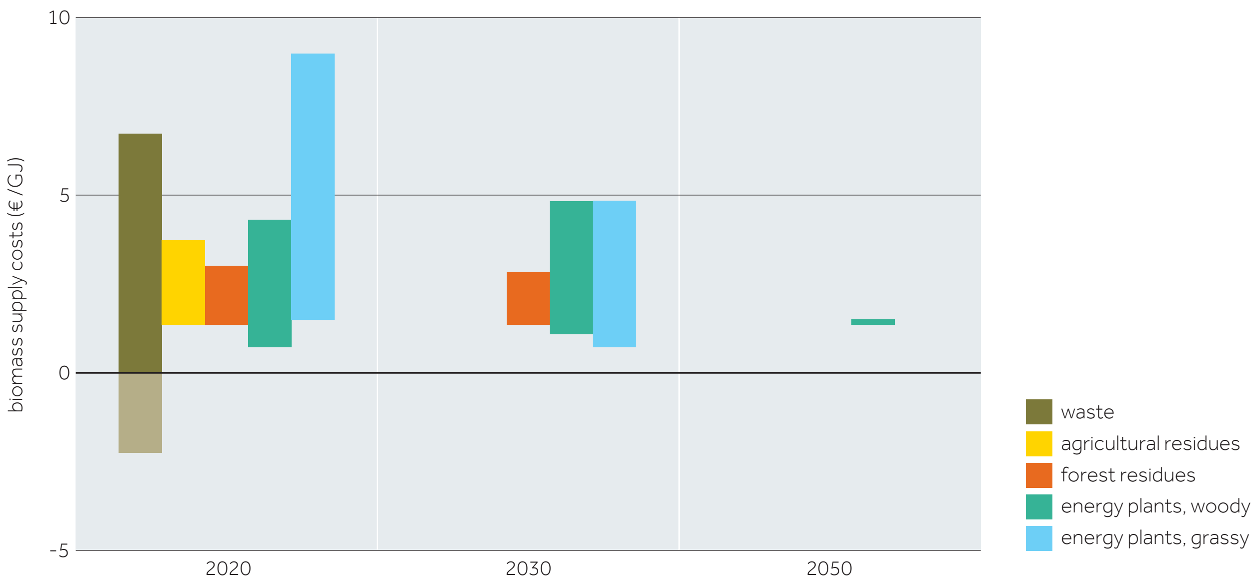


Figure 10: Biomass supply costs for different feedstocks, 2020-2050 (example from IRENA)

Source: IRENA



Challenges: barriers and potential enabling conditions

A stable demand outlook for advanced biofuels is needed to establish a market and boost development. Maximising the cost-competitiveness of biofuels will require production levels sufficient to achieve economies of scale. In addition to policy-related challenges, a range of enabling conditions will play a key role in promoting the further development and mass deployment of low-carbon fuels.

Currently, the main reasons behind the slow uptake of technology are claimed to be:

- high barriers to entry, including long investment cycles, the capital-intensive nature, and high fuel certification standards; and
- high production costs for advance biofuels compared to fossil fuels and conventional biofuels.

To overcome some of these barriers, the main enabling factors cited by several sources are summarised below:

- Support for emerging technologies at low TRLs to increase efficiency, as well as for continued R&I efforts in high-TRL technologies to comply with reduced cost projections, GHG emissions goals and deployment.
- Supporting sustainable feedstock mobilisation is perceived as a key enabler to boost availability and minimise supply chain risks. The development and use of currently unexploited sustainable waste, biomass and land resources to supply the advanced technologies, with particular emphasis on the application of the principles of a circular economy, are perceived as one of the key enablers to release the full potential of advanced biofuels.

- Development of infrastructure and logistics across the whole value chain from the production stage to the transport and conversion stages to produce the final fuel for end-use or intermediate customers.
- Recognition of the role of renewable fuel/bioenergy in transport, through a holistic approach across the whole well-to-wheels or even life-cycle value chain, is perceived to be one of the key drivers to establish a market across all means of transport in Europe and boost technology development.

Concawe, as part of the Low Carbon Pathways programme, is exploring the concept of an EU refining system being integrated in a hub of industries to take advantage of the opportunities that both economies of scale and the use of existing infrastructure may offer to deploy low-carbon feedstocks across the whole economy.

Annex

Advanced biofuels currently under discussion and included in Annex IX of RED II (Directive (EU) 2018/1001)[10] are summarised below:

Vegetable oils

- Algae, if cultivated on land, in ponds or in photobioreactors.
- Used cooking oil.

Waste (municipal/industrial)

- The biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.
- Bio-waste, as defined in point (4) of Article 3 of Directive 2008/98/EC, from private households subject to separate collection as defined in point (11) of Article 3 of that Directive.
- The biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food, fish and aquaculture industries.

Straw

- Straw.
- Palm oil mill effluent and empty palm fruit bunches.
- Bagasse.
- Grape marcs and wine lees.

Forestry and agricultural residue

- Tall oil pitch.
- Nut shells.
- Husks.
- Cobs cleaned of the kernels of corn.
- Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre-commercial thinnings, leaves, needles, tree tops, sawdust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil.
- Other non-food cellulosic material.
- Other lignocellulosic material, except saw logs and veneer logs.

Animal residues

- Animal manure and sewage sludge.
- Crude glycerine.
- Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009.

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