ADVANCEFUEL

How can Europe develop a market for advanced renewable fuels?

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Note: This publication provides an overview of the work performed in the ADVANCEFUEL project and some of the key project conclusions. The project's deliverables, available via the ADVANCEFUEL Website, remain the definitive project sources. Links to the project's technical reports are provided throughout for easy reference to further, in depth reading.

The ADVANCEFUEL Community

The ADVANCEFUEL consortium has engaged stakeholders of the biofuel commercialisation process, such as industry players, researchers, policy makers and regulators in dialogue via surveys, workshops and personal interviews in order to validate results. We have also been supported throughout by our Stakeholder Platform and Advisory Board of senior biofuels experts. Our thanks go to all those who have contributed to the success of our project.

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Executive Summary

Transport remains the only sector in Europe where emissions today remain higher than their 1990 levels, and tackling emissions will require the introduction of novel technologies and fuels. As well as electrification of transport – primarily for trains, personal vehicles and public transport – biofuels have long been considered a solution for decarbonisation, especially for the maritime, aviation and heavy-duty vehicles. However, despite initial political support, concerns about the overall sustainability of biofuels emerged, including their life-cycle greenhouse gas emissions, impact on food markets, and land use change related issues, including deforestation.

Whilst these first generation biofuels – produced from food crops such as corn, rape seed oil and sugar beet – are coming under increased political scrutiny, focus is turning to second generation, or 'advanced' biofuels. These fuels are produced from lignocellulosic ('woody') biomass, from either agricultural and forestry residues and wastes, or purpose grown energy crops.

Recognising the potentials of advanced renewable fuels (RESfuels), the European Commission has used its revision of the Renewable Energy Directive (RED II) to set a mandate for use of RESfuels in the transport energy mix of 0.2% (2022), 1.0% (2025), and 3.5% (2030), and established also a list of suitable feedstocks for their production, and sustainability criteria to be enacted in 2021. A corresponding reduction in use of first generation fuels has also been mandated.

Whilst RESfuels have high potential, many barriers remain in the way to their commercialisation. The ADVANCEFUEL project ('Facilitating market roll-out of RESfuels in the transport sector to 2030 and beyond'), funded by the European Union's Horizon 2020 Programme for Research and Innovation, has explored these barriers and provides stakeholders with new knowledge, tools, standards and recommendations for overcoming them.

In particular, ADVANCEFUEL has explored:

- **Supply of lignocellulosic biomass** – At present, the high price of lignocellulosic feedstocks and a lack of clarity regarding environmental constraints are viewed as significant barriers to the roll-out of RESfuels. Bringing down costs will rely on new availability and sustainable mobilisation of lignocellulosic resources. ADVANCEFUEL explored the availability of biomass, looking into agricultural residues, the availability of marginal land and the need for agricultural innovations for growing and harvesting dedicated lignocellulosic energy crops. Whilst Europe has significant biomass potential, greater efforts are needed to support their mobilisation.

- **Conversion Processes** – Although some conversion processes are reaching technological maturity, there remain issues related primarily to access to finance, the perceived high-risk of investments and a lack of overall industry stability related in part to an absence of dedicated policy support. ADVANCEFUEL explored the current maturity of conversion technologies, their costs, and potentials for cost reductions from policy support and also integration into existing fossil fuel infrastructure. Conversion technologies at TRL 9 are already available, but the comparatively lower cost of fossil fuels mean they are not yet competitive.

- **Sustainability** – Although REDII sets out sustainability criteria for advanced biofuels, a lack of harmonised regulation and the wide divergence in national and voluntary certifications are barriers. Further, RED II does not consider all aspects of sustainability. ADVANCEFUEL has explored current standards and certification schemes finding that there are not yet sufficient sustainability criteria for forestry management, or social and economic impacts. Additionally, the project examined the regional specific impacts of growing energy crops on marginal lands.

- **End-Use and 2050 scenarios** – The high overall costs of RESfuels are the main barrier to use, with specific challenges arising for the maritime and aviation sectors – two sectors where use of advanced biofuels will be essential for reducing emissions, as few alternatives are available. ADVANCEFUEL performed a market and policy analysis to determine long-term forecasts and identify policy gaps, finding that additional interventions are required for market development.

ADVANCEFUEL has concluded that advanced biofuels will be an essential part of the 2030 and 2050 energy mix if we are to meet the decarbonisation targets and our commitments under the Paris Agreement. However, there is no silver bullet for decarbonisation. Instead, all available options will need to be used in order to phase out fossil-fuels.

Their sustainable growth of advanced renewable fuels will depend largely on the clarity, long-term stability and consistency of the policy framework which should provide confidence to investors and allow the industry to improve their technical and financial performance. Tailored policy interventions integrated along the RESfuels value chain (supply, conversion, end use) are essential for future policy formation at all governance levels in supporting market development. Additionally, there needs to be a more robust sustainability criteria covering the full value chain.

Summarised Recommendations

- Sustainable biomass is available in Europe but mobilisation remains a challenge. As well as training for farmers, financial support (for example, through the European Structural Investment Funds) should assist in development of infrastructure for new logistics. Regulations need to be adapted to recognise the benefits that can arise from dedicated biomass cropping for bioenergy;

- Financial mechanisms (such as feedstock premiums, feed in tariffs, CO_2 taxes) are necessary to develop a secure framework for reducing capital investment in conversion technologies, and reducing the uncertainty of production costs;

- Ambitious decarbonisation plans will require deployment of all renewable options, as well as increased efficiency of energy use;

- Tailored targets for heavy-duty vehicles, aviation and maritime sectors are needed. Without a dedicated and consistent policy, industrial and investment confidence is reduced;

- Biorefineries produce many different products, not only advanced biofuels, each with different sustainability requirements. Harmonised sustainability criteria could lead to less complexity, reduced costs and greater market trust in the sustainability of bio-based products.

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I. Introduction

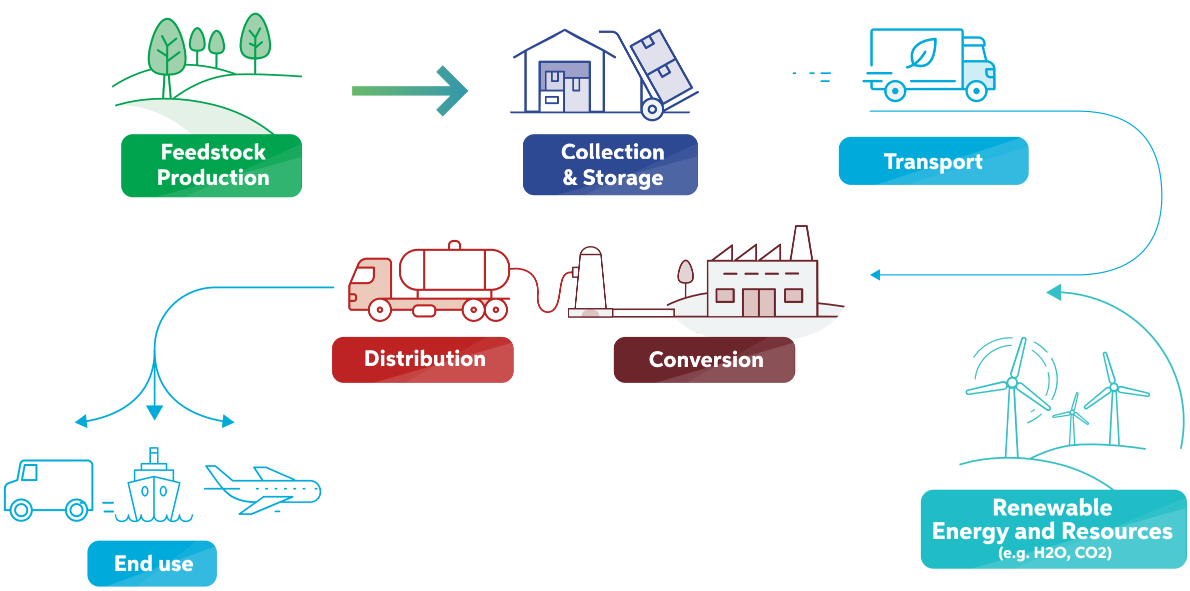
The production of biofuels has grown rapidly since the early 2000s, driven in part by political support, consumption targets and incentives. However, as concerns over the sustainability of biofuels have grown, the political winds have changed, with biofuels falling out of favour.

Sustainability concerns have included the impact on land-use patterns, competition over food resources, and carbon emissions along the full production value chain. In response, a new generation of renewable transport fuels is emerging, though a number of barriers – technical, economic, social and environmental – stand in the way to their commercialisation.

The **ADVANCEFUEL** project ('Facilitating market roll-out of RESfuels in the transport sector to 2030 and beyond') has sought to support the commercialisation of **advanced renewable transport fuels** ('RESfuels') by providing stakeholders with new knowledge, tools, standards and recommendations to help remove barriers to their uptake. The project has looked into **liquid advanced biofuels** and **other liquid renewable fuels**, examining barriers along the full value chain.

Project Scope

The project covers the full value chain from **biomass availability**, through **conversion technologies**, considerations related to **sustainability** and **market analysis and end use**, culminating in a **scenario-based assessment** to provide stakeholders with practical decision-making tools for an assessment of RESfuel production costs.

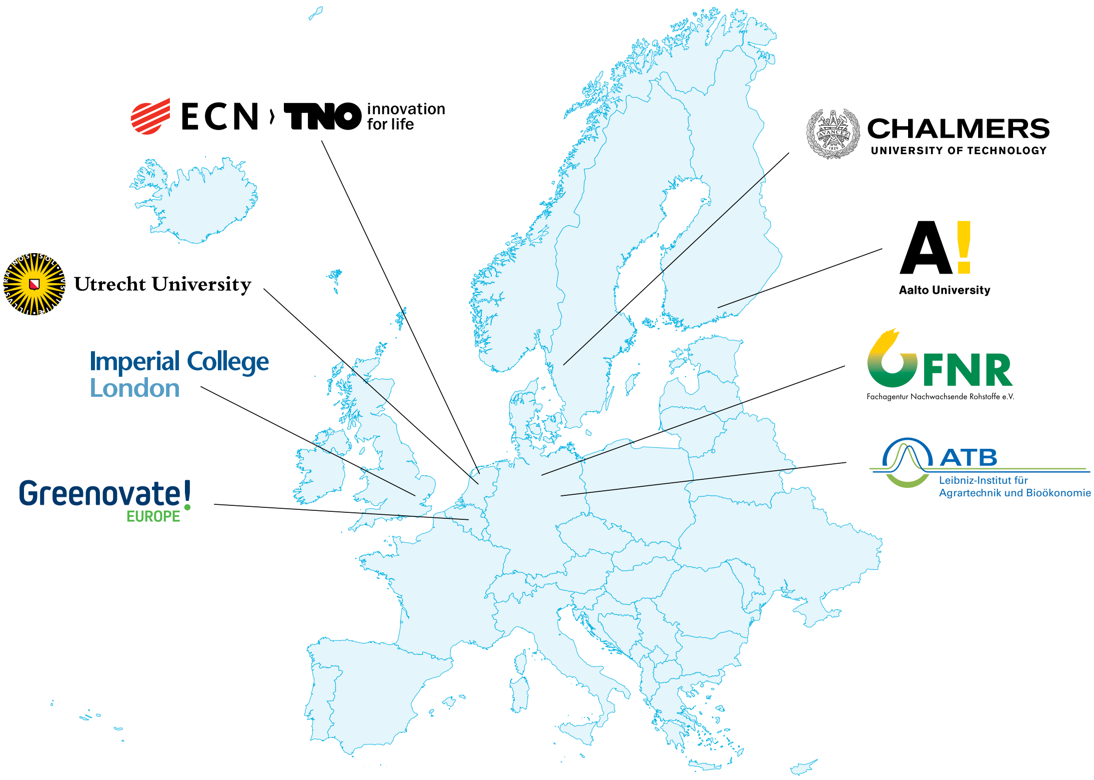


Definitions

- Liquid advanced biofuels are all liquid biofuels produced from lignocellulosic (woody) biomass, through thermochemical or biochemical pathways, with the latter including a cellulose hydrolysis step. The lignocellulosic biomass includes feedstock as provided in Annex IX of the revised Renewable Energy Directive ('RED II');
- Advanced biofuel conversion pathways are at different stages of technological maturity. The main focus for ADVANCEFUEL has been on demonstration and (near-) commercial scale technologies;
- Advanced gaseous fuels have been studied only as intermediates rather than end products;
- Other liquid renewable fuels are all renewable fuels without biomass as the feedstock; e.g., liquid fuels produced from hydrogen and CO_2, provided the hydrogen is generated from renewable resources (e.g., use of renewably generated electricity for water hydrolysis. Direct 'solar fuels' can also be included).

The ADVANCEFUEL Consortium

The ADVANCEFUEL project has been funded by the European Union's Horizon 2020 research and innovation programme (Grant No. 764799), as a co-ordination and support action. The independent consortium is comprised of leading research centres and universities, co-ordinated by the German Agency for Renewable Resources (FNR).



II. The Status of Biofuels

Transport makes up around 27% of total EU-28 greenhouse gas emissions, of which 72% comes from road transport, 14% from aviation, and 13% from shipping, with the remainder made up of rail and other transport modes.[1] The sector remains the only one where emissions are higher than in 1990, the year used as a benchmark for the Kyoto Protocol. Tackling the sector's emissions will require the use of novel technologies and fuels, if carbon emissions are going to fall whilst also enabling movement and trade to continue as present.

Liquid Biofuels

Liquid biofuels are fuels of natural origin (produced from biomass), which can be blended with, or replace, liquid fuels from fossil origins. They are considered in different 'generations' based mainly on their feedstocks:

- **First generation biofuels are produced from food crops, such as corn, rape seed oil, sunflower oil and sugar beet;**
- **Second generation (or 'advanced') biofuels are produced from agricultural and forest residues, woody (non-edible) crops, and biogenic waste materials;**
- **Third generation biofuels are produced from algae – they have not been explored in the ADVANCEFUEL project.**

Liquid biofuels have long been recognised as a potential answer for tackling emissions from transport, though with some recognised limitations. Policy-makers, from the 1990s onwards, have sought to support biofuel development by setting targets and providing economic support. As well as having the potential to reduce greenhouse gas emissions, biofuels can also improve energy security by reducing dependence on imported fossil fuels, while contributing to employment, especially in rural areas.

Currently, the European biofuel market remains dominated by first generation fuels – mostly biodiesel and biogasoline – with gross inland consumption increasing from 0.7Mtoe in 2000 to 15.4Mtoe in 2017.[2] However, since then, there has been a decline in biofuel production and consumption as concerns have been raised regarding the overall sustainability of biofuels, including both their socio-economic and environmental impacts.

Challenges to first generation biofuels

The most prevalent discussion surrounding first generation biofuels remains the 'food vs. fuel' debate, with first generation fuels using food crops as a feedstock, resulting in competition for resources and an impact on world food supply. Concerns surround not only the impact on the existing markets for resources, but also

1 European Environment Agency, Greenhouse gas emissions from transport in Europe

2 EurObserv'ER – Biofuels Barometer 2019

the diversion of farmland to producing different crops. This land-use change (LUC) and indirect land-use change (ILUC) can have significant impacts on carbon emissions as well as having impacts on food markets and employment.

Debate is ongoing as to whether first generation biofuels can actually reduce greenhouse gas emissions, with studies pointing out that emissions from ILUC have often not been included in life-cycle analysis.[3] Indeed, studies have demonstrated that soy and palm biofuels had carbon emissions of 200-300% higher than regular biodiesel. Even biodiesel produced from rapeseed emits 20% more greenhouse gases than fossil fuels, taking account of ILUC, though this figure is dependent on several assumptions.[4]

- **Land-use change** (LUC) relates to changing how an area of land is used (e.g. turning forest into agricultural land), or changing the use of existing agricultural land (e.g. producing rape seed where before land had been used to produce wheat);
- **Indirect land-use change** (ILUC) relates to the result of land-use change. For example, when fuel crops are produced on existing agricultural land, the demand for food and feed remains the same, which can then lead to the production of food and feed somewhere else entirely. Other examples include the clearance of forest area for biomass production.

Environmental impacts are not limited to carbon emissions. Replacing crops with biofuel feedstocks can have other environmental impacts such as deforestation, land use change and soil erosion. There can also be impacts associated with water resources, as water is required for both crop irrigation and for the bio refineries. Further concerns relate to land access rights, with common land taken for commercial exploitation, particularly in less economically developed countries.

The resulting controversies regarding biofuels have also had an impact on public opinion and market acceptance. Whilst support remains high – a Eurobarometer in 2010 demonstrated 70% of Europeans supported conventional biofuels, and a EuroPulse survey in 2017 suggested found 69% support – the debate is nuanced.[5] A 2018 survey on acceptance of palm oil biodiesel performed in nine countries revealed the mirror image; that around 70% of respondents supported their phase out by the EU.[6] Public debate remains lively, with palm oil gaining particular notice, and countless campaigns have been implemented to draw attention to their impact.

Current production of second generation fuels

Second generation ('advanced') biofuels do not use food crops, rather making use of woody (lignocellulosic) crops such as agricultural and forestry wastes and energy crops. These fuels are not yet widely produced at commercial scale, and their production costs remain high, often being more than twice the price of conventional fossil fuels in road transport.[7]

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3 D5.4 – Updated report on policy analysis, p. 7.

4 D5.4 – Updated report on policy analysis, p. 22.

5 EuroPulse – Biofuels Opinion Survey 2017

6 Ipsos survey across Europe on consumer attitudes to palm oil biodiesel (2018)

7 D5.1 – Market analysis of RESfuels in the transport sector, p. 3.

At present, less than 25% of total biofuel use is of second generation biofuels, though these consist almost entirely of fuels made from used cooking oils and fats, whilst the current use of advanced biofuels from lignocellulosic feedstock is negligible, and face challenges in commercialisation.[8] The advanced biofuel industry is struggling to reach commercialisation in most parts of the world, but there are a few countries, and technologies, making progress. The current advanced biofuel plants in operation, as well as those planned, are either (biochemical) enzymatic fermentation plants producing ethanol, or (thermochemical) routes towards diesel substitutes.[9] Mostly this includes:

- **Lignocellulosic ethanol:** The total capacity of lignocellulosic ethanol production is around 300 kilotonnes per year (kt/a), with around 30% produced in Brazil and 25% in the USA, but only 11% in Europe. Globally, there are ten commercial-scale first-of-a-kind demonstration plants, only one of which is in Europe.

- **Lignocellulosic diesel:** Production of lignocellulosic diesel production remains slim in Europe and worldwide, with two plants in Europe producing around 120 kt/a combined.

- **Other renewable liquid fuels:** Other renewable fuels, produced from CO_2 and renewable H_2 are estimated at 6 kt/a, globally, dominated by two demonstration plants: the George Olah and Audi e-gas plants, in Iceland and Germany.

Whilst investment in biofuels reached a peak in 2006-2007 (at 28-29 billion USD per year), this figure slumped dramatically from 2008 onwards. Whilst new investment has been channelled towards advanced biofuels, this has not made up the difference, amounting to only 2-3 billion USD per year between 2008 and 2015.[10] Recent difficulties in the market, sustainability and policy uncertainties, and high operational costs have hampered further investment and also led to the closure of several lignocellulosic ethanol plants.

Potential benefits from advanced renewable fuels

Although investments remain low at present, there is significant potential for advanced biofuels if barriers can be overcome, including an estimated 60-80% CO_2 saving compared to fossil fuels.[11] As well as the potential environmental benefits from advanced renewable fuels, there is also significant opportunity for job creation within the EU. A study by a consortium of NGOs and industry actors has calculated that the EU has sufficient wastes and residues available at present to produce enough fuel for 16% of road transport energy by 2030. This could create 15 billion EUR of additional revenue, especially in rural economies, as well as creating 300,000 additional jobs: 83,000 in agricultural residue collection, 50,000 in forest residue collection, 13,000 in refinery operation, and up to 162,000 temporary jobs in refinery construction.[12]

8 D1.1 – Barriers to advanced liquid biofuels and renewable liquid fuels, p. 7.

9 D1.1 – Barriers to advanced liquid biofuels and renewable liquid fuels, pp. 10-12.

10 D1.4 – Monitoring framework and KPIs for advanced renewable liquid fuels, pp. 14-15

11 D5.4 – Updated report on policy analysis, p. 24.

12 D5.4 – Updated report on policy analysis, p. 22.

III. Policy Framework to 2030

The efforts to boost uptake of advanced biofuels are just one part of Europe's efforts to decarbonise and be climate-neutral by 2050. The EU has aimed to reduce its carbon emissions since the 1990s, setting targets for greenhouse gas emissions for 2020 and 2030, with a 2050 vision set as part of the European Green Deal. This chapter will explore just some of the key legislation specifically related to biofuels.[13]

Timeline

- 2003 – Biofuels Directive (2003/30/EC)
- 2009 – Renewable Energy Directive (2009/28/EC)
- 2009 – Fuel Quality Directive (2009/30/EC)
- 2015 – Indirect Land Use Change (ILUC) Directive (2015/1513)
- 2018 – Renewable Energy Directive (Recast) (2018/2001)
- 2019 – Delegated Regulation on High ILUC Risk Feedstocks (2019/807)

About 18% of total biomass consumption in the EU is used for bioenergy, which has grown rapidly in the past 15 years as a result of policy support, and gross inland consumption of bioenergy has increased by 225%.[14]

The European Union began implementing biofuel-related targets in 2003 with the **Biofuels Directive**, setting an indicative biofuel target of 2.00% by the end of 2005, and 5.75% by the end of 2010.[15] In 2009, the EU passed the **Renewable Energy Directive** (RED), mandating that 20% of total energy consumption in the EU be produced from renewable resources, including at least 10% of all energy in road transport.[16] Amendments made to the Fuel Quality Directive in 2009, required that the road transport fuel mix be 6% less carbon intensive than a fossil diesel and gasoline baseline by 2020.[17]

In 2015, in response to emerging sustainability concerns, the **Indirect Land Use Change (ILUC) Directive** was passed, limiting the use of food-based biofuels to 7% of final energy consumption in transport.[18]

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13 For a full overview of the policy framework, see D5.4 – Updated report on policy analysis, pp. 27-28.

14 D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels, p. 9.

15 Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport

16 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources

17 Directive 2009//30/EC – Amendment to Directive 98/70/EC on environmental quality standards for fuel (Fuel Quality Directive)

18 Directive 2015/1513 – Amendment to Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources

The revision of the Renewable Energy Directive (RED II), passed in 2018, established a new framework up to 2030, establishing a target of 32% renewable energy use by 2030, and introducing an EU incorporation obligation to fuel suppliers in Europe.[19] The RED II also foresaw the future publication of the Commission's Delegated Regulation on high ILUC risk feedstocks (EU) 2019/807, which sets out biofuels based on these feedstocks to be phased out until 2030.

Renewable Energy Directive II Criteria

- **Overall Mandate:** Share of renewable fuels in road and rail transport to reach 14% by 2030 (consumed in all transport modes, and including renewable electricity in road and rail transport);
- **Advanced biofuels mandate** (biofuels from Annex IX, type A feedstocks): 0.2% in 2022, 1.0% in 2025, 3.5% in 2030. These figures include double counting, however, (see Note) so the real targets are 0.1%, 0.5% and 1.75%;
- **Capped biofuels:** Biofuels produced from Annex IX, type B feedstocks are capped at 1.7%, but may be double counted. Biofuels produced from crops are capped at 1% above the 2020 fraction per member state, or 7% (whichever is lowest);
- **Phase out:** Biofuels produced from high ILUC risk feedstocks to be phased out by 2030, defined in delegated act 2019/807;
- **Multiple counting:** renewable electricity used in road vehicles (x4) and rail (x1.5). Biofuels used in aviation and maritime (x1.2)

Note: Multiple counting aims to incentivise member states to support certain energy resources by enabling them to count a multiple of their contributions towards their overall national targets.

National Frameworks

As well as the European framework, several countries have also set up their own national frameworks.[20] In Europe, this includes Denmark, Finland, Germany, Italy, the Netherlands, Slovakia, Sweden and the United Kingdom.[21] The RED II leaves room for manoeuvre for countries that wish to be more ambitious than the EU-wide mandate. Denmark, the Netherlands and Italy for example, have set more ambitious interim targets of 0.9% advanced fuel use from 2020 (DK), 1% by 2020 (NL) and 2% by 2022 (IT). Countries have also implemented a number of different support policies, alongside their targets, including direct subsidies, encouragement for using voluntary certification schemes, and reduced taxes on sustainably sourced biofuels.

This flexibility in approach gives a role not only for European policy-makers, but also for national and regional actors to promote advanced fuels through national and local initiatives.

19 Directive 2018/2001 on the promotion of the use of energy from renewable sources

20 For an overview of some, see the Factsheet: Good practices along the Renewable Fuels Value Chain.

21 For more details on national schemes, see D1.4 – Monitoring framework and KPIs, pp. 18-20, and Annex I of D5.4 – Updated report on policy analysis

IV. Barriers to Advanced Renewable Fuels

Whilst the EU has made efforts to improve the framework for advanced biofuels and set targets for their use, stakeholders note a number of remaining barriers – *technical, regulatory, economic, social and environmental* – at different stages of the advanced fuel value chain.

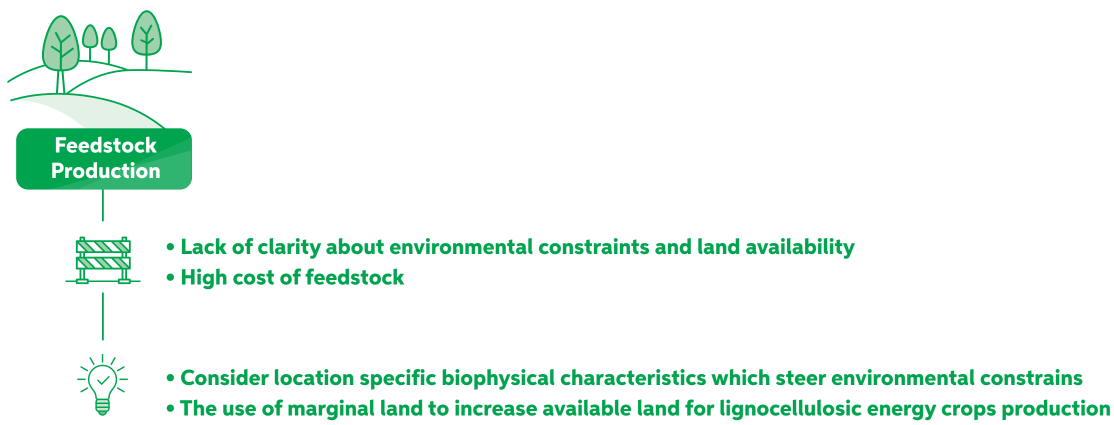
By performing a literature review, and engaging with stakeholders, the ADVANCEFUEL project identified a number of barriers for the development of advanced biofuels in Europe.

Supply of lignocellulosic feedstock

The first step in the advanced fuel value chain is the production and acquisition of suitable feedstocks for conversion. Barriers here include the difficulty of mobilising feedstocks from remote regions, ensuring the quality of feedstocks, low awareness amongst farmers of the biomass market, and reluctance to invest in implementing the required innovative cropping schemes at individual farm level for ensuring the feedstock supply for advanced biofuels. Overall though, the main concerns related to lignocellulosic feedstock supply that were identified are **high costs for feedstocks** and a **lack of clarity regarding environmental constraints.**

The high **cost of feedstock** is recognised as the single most important variable for the production of advanced fuel, being responsible for around 40% of the total production cost.[22] The further development of advanced biofuels will require a consistent, cost-efficient, supply of sustainable biomass, which will require new agricultural practices and development of new rural businesses and value chains.

In terms of the **environmental constraints** there are concerns related to the land available for the production of non-food energy crops, as well as recognition that producing more biofuel feedstocks may have an impact on soil erosion, water consumption, and overall greenhouse gas emissions from land-use change. The lack of harmonised regulation on residual biomass from farming, dedicated energy crops, and sustainable forest management are seen as major issues.



22 This can be substantially different depending on the price of wastes. 40% refers in most studies to an assumed feedstock price of 15-20 Euros/MWh. The price for waste biomass can be zero or even negative, whilst increased competition for biomass may also lead to price rises.

Conversion processes

In converting biomass feedstocks into advanced biofuels, a number of barriers were identified by stakeholders, including the **absence of dedicated policy support and difficulties in accessing project finance**, and long-term concerns related to the **overall stability and security of the industry.**

The development of renewable fuels is driven by policy and political ambitions, and the lack of long-term and stable policy support is a key concern. In particular, greater efforts are needed to level the playing field with existing fuels, including tackling the pricing and regulation of fossil fuels. The lack of long-term stability means that investors are uncertain of their return-on-investment, and the sector is seen as a risky venture also due to past failures and high capital costs.

Conversely, most of the technical challenges of conversion processes for improving overall efficiency are seen as low barriers, which could be overcome.

Sustainability

Considering the situation with first generation biofuels, being able to demonstrate the sustainability of second generation fuels is vital. The **lack of harmonised regulation** is recognised as a major barrier, as is the wide divergence of voluntary **certification schemes**, which vary in scope and ambition. In Europe, concerns are related in particular to land-use change from the growth of new biomass resources.

Distribution and End Use

At the end of the value chain, the main issues are recognised as the absence of structural mechanisms to bridge the gap between renewable and fossil-based fuels, as well as the **high overall costs** of RESfuels compared to fossil fuels. Additional barriers for end-user are found in different end-use sectors:

- In **road transport,** issues relate to vehicle performance, including the need for new vehicles to make use of fuels which are not 'drop-in fuels', challenges related to the roll-out of RESfuel infrastructure and the focus of manufacturers on electric vehicles;
- For the **maritime sector** the main challenges relate to a lack of experience in the sector in dealing with biofuels, a lack of long-term fuel test data and of separate fuel standards for RESfuels in the shipping sector.
- In **aviation**, the main issues relate to stringent fuel qualification and certification, arising from safety concerns, the high capital intensity and long investment cycles of the industry which makes investment in new technologies slow, and a lack of mandates and targets for the industry.

End use

- **Absence of structural mechanism to bridge the price gap between renewable and fossil-based fuels**
- **High production cost of RESfuels**

- **Stable investment climate enabled by policy frameworks, feed-in tariffs, reduction of financial valorisation up to penalisation of fossil fuels**
- **Reduction of capital and operational expenditures via technical learning and using current infrastructure**

ADVANCEFUEL Publications

D1.1 – Barriers to advanced liquid biofuels and renewable liquid fuels of non-biological origin

D1.2 – Monitoring framework & KPIs for advanced renewable liquid fuels

D1.3 – Common framework for the ADVANCEFUEL project

D1.4 – Updated monitoring framework and Key Performance Indicators for RESfuels

Factsheet: Removing Barriers to Advanced Renewable Fuels

Interview with Ayla Uslu, TNO – Advanced renewable fuels: From barriers to market rollout

V. Supply of Lignocellulosic Feedstocks

Together with capital costs, feedstocks are the most dominant cost factor in the production of advanced biofuels, making up around 40% of the total production cost.[23] As the bioeconomy develops further – both bioenergy and other applications – demand for biomass will grow, putting additional pressure on markets and land-use, and therefore requiring new approaches for securing biomass supply.

To this end, ADVANCEFUEL has assessed biomass feedstock potentials up to 2030 and beyond, based on the potential availability of non-food biomass from forests and agriculture, as well as the availability of marginal lands for new crop growth, and the potentials of agricultural innovations to increase yields and biomass quality.[24] Additionally, the project has examined lignocellulosic feedstock supply in relation to its compliance to sustainability criteria under the RED II (related to land-use change, greenhouse gas emissions, erosion risk, water depletion and biodiversity).

Biomass availability

Between 2000 and 2015, Europe's consumption of bioenergy increased by 225% from 60.8 to 136.7 million tonne of oil equivalent (Mtoe), mainly from forestry sources for use in heat generation. As demand grows, there is an urgent need to ensure sufficient provision of biomass, and that biomass is sustainably produced and supplied. Europe has significant biomass potential, though much of this remains untapped. ADVANCEFUEL's analysis has explored a number of different biomass feedstocks:

- **Dedicated energy crops** – Primarily perennial crops such as miscanthus and switchgrass;
- **Primary residues** – Direct residues from agriculture and forestry;
- **Secondary residues** – These refer to residues from the processing of raw resources, e.g., from wood and food processing industries;
- **Tertiary residues** – Residues from industries that use secondary residues (e.g., cooking oils and fats, wood wastes), and municipal solid waste

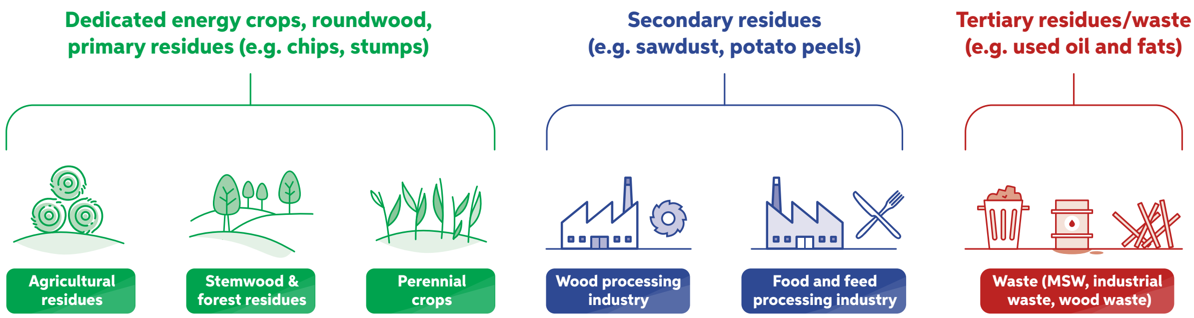
Examining existing literature and studies, the project has calculated that in a high biomass mobilisation scenario (in which additional resources and marginal land are used), estimated domestic production of biomass could amount to 525-597 Mtoe by 2050.[25] Of this, around 25-36% could come from forests (stem wood and forest residues), though much of this feedstock is already used in electricity and heating sectors. Energy crops, currently not widely grown, could account for 33-56%.[26]

23 D1.4 – Monitoring framework and KPIs, p.3

24 D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels

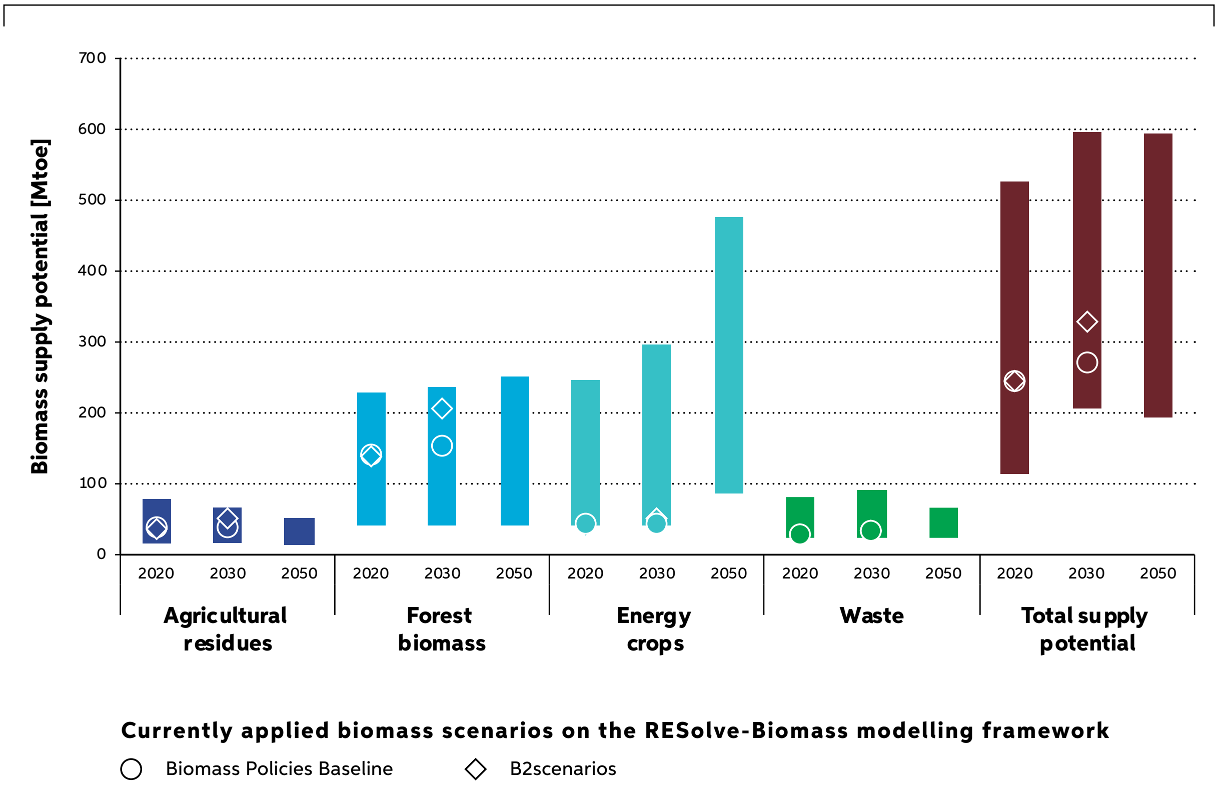
25 D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels, p. 4.

26 D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels, p. 5.



Whilst the EU produces around 1,600-2,200 megatons (Mt) of biomass are produced each year, around 450-680Mt of primary residues remains unused.[27] Making use of these potentials will require significant efforts, including infrastructure development, development of farmer experience, regulatory compliance and provision of support (financial and otherwise).

EU BIOMASS POTENTIAL AVAILABLE FOR BIOENERGY BY MAIN FEEDSTOCK CATEGORY AND APPLIED BIOMASS SUPPLY SCENARIOS IN THE RESOLVE-BIOMASS MODELLING[28]



27 D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels, p. 9.

28 D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels, p.20

Innovative crop rotation schemes for lignocellulosic energy crops

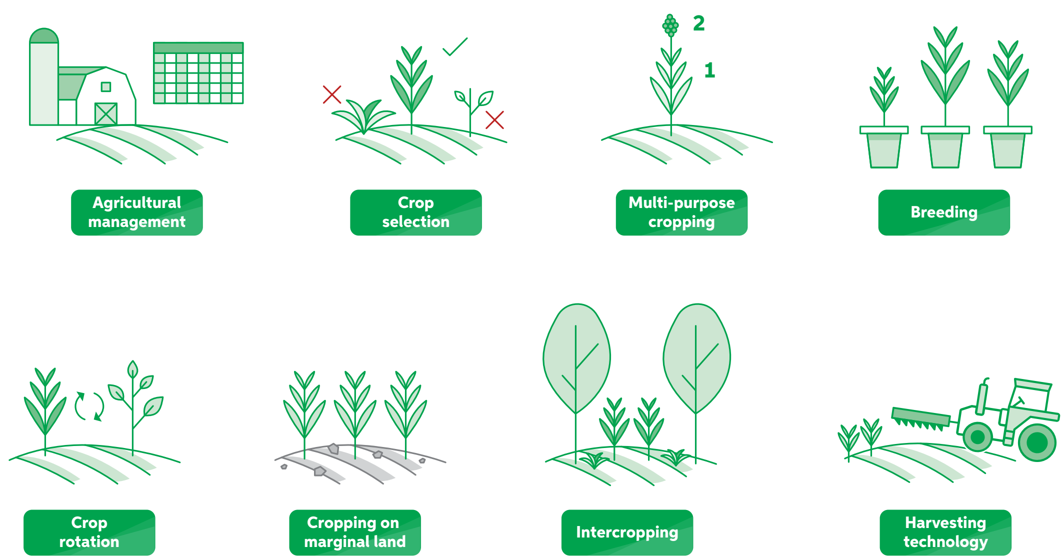
As well as increasing the amount of land available in Europe for growing biomass, innovative cropping schemes can also be used to increase yield. ADVANCEFUEL has examined eight fields of innovation in relation to their potential to reduce production costs, the environmental impact of such crops, the willingness of farmers to grow lignocellulosic biomass, and public acceptance.[29]

- **Agricultural Management** – Relating to optimisation of planting density, improvement of crop establishment and fertilisation;
- **Breeding** – Improving yield, growth rates, resistance to pests and disease, and plant propagation;
- **Crop selection** – Focusing on cultivar selection of already used species, hybrid species or selection of new species (both endemic and introduced);
- **Crop rotation** – Rotating between annual lignocellulosic energy crops, which can reduce soil erosion and improve soil quality, as well as reducing the need for fertilisers by managing the nutrient cycle;
- **Intercropping** – Growing two or more crops in close proximity, avoiding negative environmental impacts from monocultures;
- **Multi-purpose cropping** – Using different parts of one crop for different purposes;
- **Cropping on marginal land** – Growing energy crops on Europe's available marginal land (see also chapter 7);
- **Harvesting technology** – Development of new, specialised harvesting technologies to increase speed and efficiency of biomass harvesting.

Whilst all of the measures show promise, there is no single most promising practices, as application is highly context specific. All innovations are of both economic and environmental interest, and main impacts will come from combining measures in relation to region-specific constraints, denoted as a 'learning effect'. This learning effect has high potentials for both increasing biomass yields and reducing greenhouse gas emissions and negative environmental impacts. Significant efforts will be needed to accelerate the learning effect, including standardised assessment of case studies and training and educational efforts.

29 D2.2 - Innovative crop rotation schemes, pp. 24-34.

FIELDS OF INNOVATIONS



Source: D2.2 Innovative cropping schemes for lignocellulosic feedstock production

Technology roadmaps

To facilitate the market introduction of advanced biofuels, ADVANCEFUEL developed a technology roadmap for the introduction of innovative cultivation systems and technologies, which have been assessed in terms of cost reduction potential and environmental and social impact. Together with European experts, the project team developed an exemplary technology roadmap that pursues the vision of market expansion of poplar wood chips.

The roadmap includes milestones and strategies needed in the areas of rules and regulations, society, economy & business, technology implementation, as well as R&D. The main milestones to be achieved are (1) a stable long-term policy framework for the whole bio-economy sector, (2) the establishment of competence centres for lignocellulosic biomass, (3) the development of a solid network of best practice business models, and last but not least (4) investment in modern technologies to reduce production costs.

ADVANCEFUEL also evaluated strategies for upgrading business models based on case study results of successfully introduced innovations to increase the value, reliability, safety and security of supply of lignocellulosic raw material. Among the upgrading strategies identified, partnership improvement, information exchange, (economic) diversification and good practice/demonstration examples appear repeatedly. The project evaluated the innovative cases using a SWOT analysis and derived the upgrading strategies using a TOWS analysis. The project derived recommendations based on upgrading strategies of successful lignocellulosic business models:

- Turn lignocellulosic supply chains into a co-business that complements existing business activities and uses existing business elements (e.g. resources, channels, customers, etc.) to create added value;
- Establish reliable long-term co-operation with customers such as biomass/biogas/bioethanol plants for the supply of lignocellulosic biomass, and build and maintain reliable partnerships that offer opportunities to all actors;
- Produce and supply lignocellulosic biomass within a maximum radius of 50 km from the receiving biorefinery;
- The creation of a diversified portfolio of supply and demand of lignocellulosic biomass, where the lignocellulosic biomass business enables the producer to increase and diversify his income;
- Take unexpected events into account such as extreme weather conditions and price changes;
- Introduce procedures to close material cycles, such as the return of ash by-products from thermochemical processes to the field in order to maintain soil quality and save production resources;
- Design flexible supply and logistics chains that lead to social inclusion of small farmers regardless of farm size;
- Minimize storage losses by selecting suitable sizes of lignocellulosic biomass fractions depending on the type of material, storage technology and storage duration;
- Build a strong network of best practice business cases, and implement capacity building measures for producers, suppliers, manufacturing industries and business environment actors, including co-operation, financing, technology and knowledge, infrastructure, consumer agency, market, education and training.

ADVANCEFUEL Publications

D2.1 – Report on lignocellulosic feedstock availability, market status and suitability for RESfuels

D2.2 – Innovative crop rotation schemes

D2.3 – Technology roadmaps and upgrading strategies for lignocellulosic feedstock supply chains (Available August 2020)

Factsheet: Energy crops and strengthening the potential of RESFuels

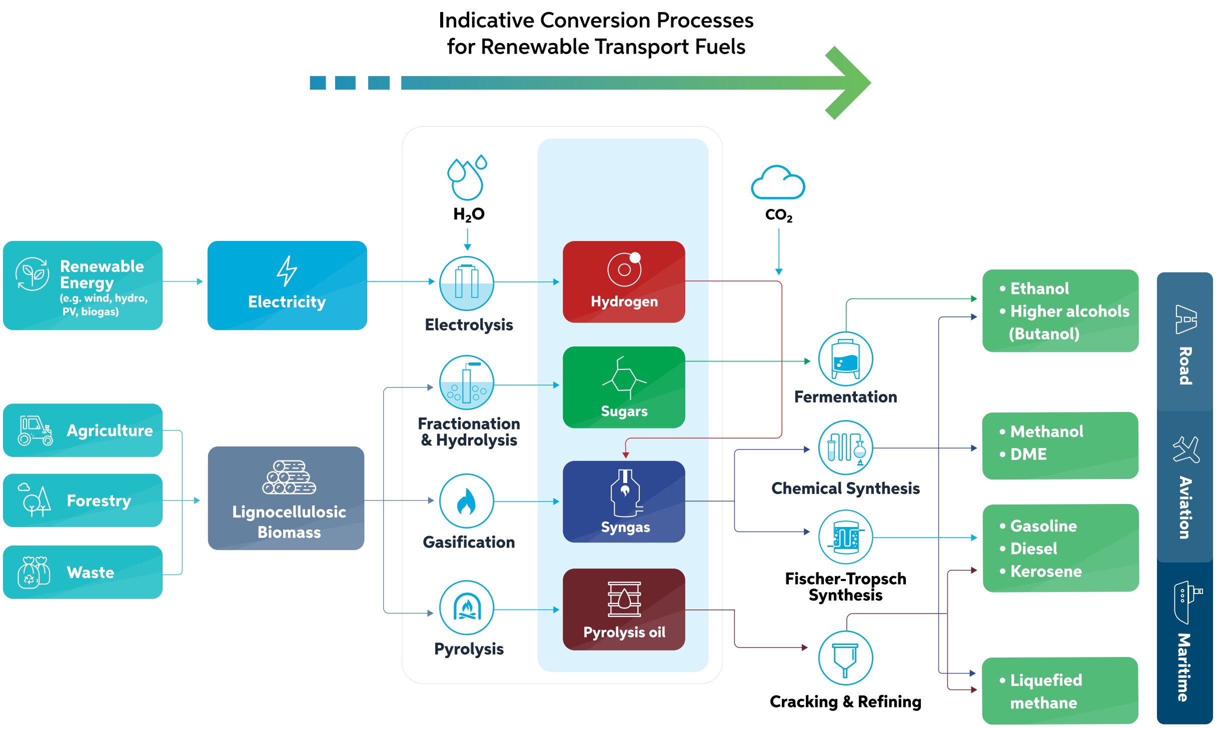
VI. Conversion Processes for RESfuels

A number of conversion processes are possible for the production of advanced biofuels from biomass feedstocks, though only a few are mature enough to produce commercial fuels. Further expansion of production will require efforts to overcome barriers, including a lack of long-term stability and policy support, as well as making use of existing fossil fuel infrastructures to bring down capital expenditure requirements.

To this end, ADVANCEFUEL has explored conversion pathways, examining them in relation to their Technology Readiness Level (TRL), Operational Expenditure (OPEX), and Capital Expenditure (CAPEX), as well as considering potentials for reducing costs through upscaling and integration into fossil fuel infrastructures.

Current mature conversion processes

RESFUEL CONVERSION PATHWAYS EXPLORED BY ADVANCEFUEL



To ensure maximum impact, ADVANCEFUEL has focused only on conversion technologies with a Technology Readiness Level (TRL) of six or more, meaning that they have been demonstrated in a relevant environment. The conversion pathways explored fit into two typologies: thermochemical and biochemical.

- **Biochemical pathways,** whereby biomass is converted via biomass fragmentation, cellulose saccharification, and **fermentation of sugars** into alcohols (ethanol and butanol), with the option of further synthesis of other advanced fuels (such as Jet Fuels);

- **Thermochemical pathways,** whereby biomass is converted via **gasification or pyrolysis,** followed by a syngas-based synthesis and pyrolysis oil upgrading (cracking and refining), respectively.

Fermentation

A number of options are available for biochemical conversion, but only the sugars to alcohol pathway is sufficiently mature.[30]

Before fermentation, lignocellulosic biomass must be treated via fractionation or hydrolysis to break it down into usable sugars. The type of process used depends on the various qualities of the biomass feedstock used.[31] These pre-treatment processes are expensive and result in low-concentrations of monosaccharides, requiring a high amount of energy for downstream separation and ethanol purification. Additionally, the resulting 'fermentation broth' can also contain pentose and hexose sugars and toxic compounds that inhibit fermentation and increase cost of production.

Sugars are fermented by bioengineered and genetically modified yeasts to produce alcohols. However, second generation ethanol plants generally produce a low ethanol concentration as a result of the low concentration of sugars available for fermentation in the feedstocks.[32] The low concentration ethanol can be made suitable for application as a biofuel through evaporation, rectification and dehydration for blending into petrol.

Maturity: Second generation ethanol production technologies have reached up to TRL9, and butanol production is at TRL 5. For ethanol, a number of projects and plants exist, ranging from TRL6 to TRL8-9 (with respect to technical performance).[33] Although lignocellulosic ethanol, produced via fermentation, has reached commercial scale of production in a number of plants, the price remains more than twice the price of fossil fuel production for road transport (100-160 EUR/MWh, depending on feedstocks and other factors), thus the technology cannot be yet rendered as economically competitive (full TRL9).[34]

Gasification

Gasification is an endothermic, thermochemical process, performed directly or indirectly. In direct (autothermal) gasification, the heat required for the process is internally generated by partial combustion of the feedstock. In indirect (allothermal) gasification, energy is also delivered via steam, the gasification agent.

Before gasification, biomass must be pre-treated by drying, torrefaction, flash pyrolysis or dissolution of wood in organic solvents, for example, depending on the technology used.

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30 D3.1 – Report on definition of parameters for defining biomass conversion technologies, p.18.

31 See D3.1 – Report on definition of parameters for defining biomass conversion technologies, chapter 1.1 for more detail

32 D3.1 – Report on definition of parameters for defining biomass conversion technologies, p.18.

33 D3.2 – Definition of biomass reference technologies, pp. 21-22.

34 D5.1 – Market analysis of RESfuels in the transport sector, p. 3.

The gas produced – known as synthetic gas (or syngas) – is composed of hydrogen and carbon monoxide, as well as methane, tar and char. Depending on the technology and feedstock used there will also be a number of impurities which need to be filtered, or else they will have an impact on downstream production.

Syngas can be converted into a number of different fuels via two processes of advanced maturity; Fischer-Tropsch Synthesis and chemical synthesis.[35]

- Fischer-Tropsch (FT) Synthesis involves clean syngas being converted into alkanes, alkenes and oxygenates using iron and cobalt catalysts. High temperature FT results in a mixture fit for petrol, whilst low temperature FT mixtures are used for diesel production. In both cases, the raw product needs upgrading via hydrotreatment and hydrocracking, as used already in oil refineries;

- A number of chemical synthesis pathways are possible, including the production of methanol from syngas with the use of copper catalysts, and dimethyl ether (DME) by dehydrating methanol in the presence of silica-alumina.

Maturity: The TRL of gasification pathways is up to TRL 8. Methane, Methanol and DME produced via gasification are produced at demonstration scale. Only a few plants exist at present, though more are planned for construction. Costs are calculated at 73-105 €/MWh-product for methane/methanol/DME, and at 95-136 €/MWh-product for FT liquids.[36]

Pyrolysis

Pyrolysis involves the thermal decomposition of biomass, in the absence of oxygen, producing energy and chemical products including pyrolysis oil (or liquid bio-oil), solid bio-char (charcoal) and pyrolytic gas. Both the biomass feedstocks used, and pre-treatment steps, will affect the yields and properties of products. Pyrolysis oil yields can be as high as 50-70% of dry biomass basis, or up to 80% at very high temperatures (1,000-10,000°C).

Pyrolysis oil needs to be upgraded prior to practical application in engines, via catalytic cracking and hydroprocessing, to produce usable liquid biofuels, such as petrol and diesel. The remaining bio-char and pyrolytic gas can be used in combined heat and power (CHP) plants.

Maturity: Pyrolysis oil production has reached around TRL 6, with a number of plants producing liquid fuels. Most pyrolysis oil, however, is used directly for heating purposes, rather than being upgraded.[37]

Reducing production costs

With production technologies still not at mature levels, and even making favourable assumptions, there remains a significant gap between the production costs of advanced biofuels and conventional fossil fuels of 20-40 EUR/MWh. This could be overcome with subsidies, but in the long-run the cost of using fossil fuels must be higher than the costs of using advanced biofuels, through CO_2 taxes, for example.

35 For more, see D3.1 – Definitions of Biomass conversion technologies, pp. 23-25.

36 D5.4 – Updated report on policy analysis, p. 16.

37 D3.2 – Definition of biomass reference technologies, pp. 15-16.

Conversion costs remain high, and the high investment costs for advanced biofuel plants also carry with them high investment risks. Technologies for each step in the conversion process will need to be at sufficient scale to reduce costs. ADVANCEFUEL has assumed a future plant capacity of 100-200 MW, though this will also need to be accompanied by full load hours, which in itself will need experience to achieve.

Cost reductions can be expected as a result of the cumulative annual growth rate of the corresponding technologies and learning rates of the corresponding technology components and their assembly in production lines. ADVANCEFUEL examined two **Scenarios**: (A) marginally higher cumulative annual growth rates of advanced biofuels compared to current trends, and (B) higher cumulative installed capacities, meeting the target of 20-25% of transport fuels to be met by advanced biofuels.

Scenario A suggested 10-25% reductions in capital expenditure (CAPEX) for a new plant by 2050 compared to today, whilst **Scenario B** suggested a 40-50% CAPEX reduction.

Integration into existing fossil fuel infrastructure

Several studies have suggested possible CAPEX reductions via integration of advanced biofuel plants into existing infrastructure, such as power plants, gasifiers, refineries and chemical plants.[38] This is regarded as a low-risk option for increasing renewable transport fuel use in Europe, finding synergies with other parts of energy and industrial sectors.

ADVANCEFUEL has calculated that this could result in savings of:

- 15-40% by co-processing biogenic feedstock (e.g., bio-oil, FT-waxes) in crude oil refineries;
- Up to 50% by co-location of second generation bioethanol plant with infrastructure of first generation plants;
- Up to 50% by converting and integrating boilers (e.g., for district heating, pulp mills) into gasification systems.

Oil and gas platforms can provide a number of opportunities for processing biomass or biomass-derived intermediaries by using existing facilities, such as oil cracking, hydrotreating, gasification and chemical synthesis. In a future system, the intermediates can be produced at standalone plants, within refinery sites or at other locations, for example in connection to revamping of existing power or combined heat and power plants. The resulting products could include gasoline, diesel, olefins, alcohols, acids, waxes, and many other commodity chemicals derivable from syngas.

There are also indirect technological options, such as co-firing or combined heat and power in district heating networks, which combine bio- and fossil-based infrastructures and contribute indirectly to the ramp-up of biomass use, though these are not in the scope of the ADVANCEFUEL project.

38 D3.4 – Key European fossil-fuel infrastructures

ADVANCEFUEL Publications

D3.1 – Report on definition of parameters for defining biomass conversion technologies

D3.2 – Definition of biomass reference technologies with respect to TRL levels and performance indicators

D3.3 – Key needs for development and potentials for innovations for highly efficient and low risk biomass conversion technologies, including required financial instruments

D3.4 – Key European fossil-fuel infrastructures, which can facilitate the ramp-up of biomass use

D3.5 – First data on efficient, low-risk ramp-up of liquid biomass conversion technologies: from short to long term

D3.6 – Efficient low-risk ramp-up of liquid biomass conversion technologies – from short-term to long-term (Available August 2020)

Factsheet: Conversion technologies of lignocellulosic biomass to advanced fuels

VII. Sustainability Criteria

As already discussed, advanced biofuels can contribute to decarbonising the transport sector, generally having higher greenhouse gas savings compared to first generation fuels, whilst also avoiding pressures on agricultural markets ('food vs. fuel'). However, the sustainability of advanced biofuels is not guaranteed, and ensuring sustainability along the supply chain will be key for fostering market uptake of advanced biofuels. To this end, sustainability criteria and certification schemes are essential for safeguarding sustainability. Without them, there is no reassurance, and a risk that advanced biofuels could have negative environmental and socio-economic impacts.

The RED II sets out sustainability criteria regarding bioenergy to be implemented after 2020. Amongst others, these sustainability ensure a minimum of 65% greenhouse gas emission reductions compared to fossil fuels. Additionally, as other bio-based sectors become more interlinked with renewable fuels, there is need to consider a harmonised sustainability framework for bioenergy and the bio-based material outputs of lignocellulosic biorefineries, including greenhouse gas emissions, biodiversity protection, land use change and risk-based approaches.[39]

Review of standards and certification schemes

The sustainability criteria of RED II, including land criteria and greenhouse gas emissions requirements, have been established to ensure the sustainability of RESfuels, however, they do not take full account of the entire value chain. For RESfuels to be counted towards national targets, they must meet the requirements of certification schemes, approved and recognised by the European Commission. Numerous such certification schemes exist – both voluntary and national schemes, though voluntary schemes are more prominently used.

Working from literature review and stakeholder consultations, ADVANCEFUEL has identified sustainability issues across the value chain for RESfuels and compared them against both RED II sustainability criteria and existing certification schemes (some of which are more stringent than the RED II criteria). The conclusion of the analysis was that the RED II criteria are not yet sufficient to ensure the overall sustainability of RESfuels and additional criteria are required.

To ensure truly sustainable renewable fuels, criteria must include new requirements for sustainable forestry management (SFM), social impacts, and economic impacts. Additional efforts are also required for the mutual recognition of national initiatives and voluntary schemes, the risk-based approach and international agreement on definition and measurement of sustainability criteria such as indirect land-use change, biomass cascading, and social and economic aspects.[40]

There is additionally a need for the development of an EU-wide comprehensive set of sustainability requirements that apply not only to biofuels, but also to heat and power produced from biomass which use similar lignocellulosic feedstocks to advanced biofuels.

39 D5.4 – Updated report on policy analysis, p. 19.

40 D4.1 – Review of existing standards and certification schemes, p. 56.

ADVANCEFUEL'S RECOMMENDED SUSTAINABILITY CRITERIA FOR BIOENERGY

Sustainability categories	Waste and residues	Agricultural biomass	Forest biomass	Compared to RED II
Environmental criteria:				
GHG emissions saving	•	•	•	Similar
Sustainable forest management			•	More stringent
Carbon stock preservation	•	•	•	More stringent
Biodiversity conservation		•	•	More stringent
Protection of air, soil and water	•	•	•	More comprehensive
Prevention of ILUC risks		•	•	Similar to definitions in the delegated ILUC regulation
Environmental category:				
Land use, land use change and forestry			•	Similar
Verification of sustainability compliance:				
Chain of custody	•	•	•	Similar
Risk-based approach			•	Additional
Socio-economic criteria: binding to imported feedstocks				
Labour rights	•	•	•	Additional
Land rights		•	•	Additional
Food security		•	•	Additional
Resource efficiency	Monitoring of efficient biomass use	Additional		

Sustainability criteria and certification schemes for lignocellulosic biorefinery systems

Drawing from this conclusion, ADVANCEFUEL has explored the sustainability of lignocellulosic biorefineries, which convert biomass feedstocks into products including advanced renewable fuels, heat, power and bio-based products. These biorefineries are expected to play a significant role on reducing greenhouse gas emissions, not only from fuels, but also by reducing greenhouse gas emissions from producing other products, many of which are currently produced from fossil fuels.

Lignocellulosic biorefineries must comply with RED II sustainability criteria if producing heat or power beyond a certain threshold, or if producing biofuels, but not for producing only bio-based products and materials. Many, though, produce more than one end-product, and these multi-output biorefineries face both harmonisation possibilities, as well as trade-offs, to demonstrate their sustainability.

Environmental, social and economic sustainability criteria for biorefineries are voluntary and as such a number of different initiatives and schemes are used, creating complexities and diverging standards, which may ultimately lead to higher costs and time requirements for sustainability compliance. ADVANCEFUEL has made a number of recommendations related to harmonisation and potential trade-offs.

The RED II has broadened its scope to all bioenergy sectors including biofuels, electricity and heat. It also includes new criteria for forest and agriculture biomass that need to be implemented in updated national legislation and sustainability certification schemes for the period after 2020. This is an important moment to recognise and implement the sustainability aspects of advanced biofuels as well as sectors that are still exempted from binding criteria such as bio-based chemicals and other novel materials towards a harmonized sustainability framework for the bio-based economy.[41]

Regional specific impacts of biomass feedstock sustainability

Marginal land is land on which cost-effective food and feed production is not possible under given site conditions and cultivation techniques.

The use of marginal lands for lignocellulosic biomass production has been considered as a possible alternative for securing feedstock supplies while reducing LUC-related environmental impacts. In addition. Lignocellulosic biomass production does not displace other crops, and avoids the food vs. feed dilemma.

Previous projects exploring marginal land have calculated that around 45% of Europe is marginal land – about 200 million hectares (Mha). However, it must be noted that not all marginal land is available for biomass cultivation, as they also fulfil other functions, including provision of ecosystem services, fauna and flora conservation, groundwater recharge, carbon sequestration, recreation or hunting. Taking account of such restrictions, around 63Mha are available for biomass production.[42]

41 D4.2 – Sustainability criteria & certification for lignocellulosic biorefineries, pp. 36-37.

42 D2.1 – Lignocellulosic feedstock availability, market status and suitability, p. 33.

Examining marginal land under the RED II land-related sustainability criteria, phenological requirements of eight energy crops crop, and spatially explicit biophysical conditions such as climate, soil and elevation reveal additional limitations. ADVANCEFUEL has calculated that around 21 million hectares (Mha) could be allocated to biomass production in 2050, with perhaps a third of this (7.5Mha) being suitable for *lignocellulosic energy crop* cultivation.[43]

Greenhouse gas footprint of advanced biofuels

The greenhouse gas saving performance of advanced biofuels is generally well exceeding the minimum threshold of 65% required by the RED II, if the right feedstock and conversion pathways are used. Nevertheless, there is a large range in performance between different production pathways. Key determining factors are conversion efficiencies and the use of fossil fuels in the supply chain, for example for feedstock transportation and the production of hydrogen. The cultivation of lignocellulosic energy crops on marginal land could potentially improve the greenhouse gas performance by net carbon sequestration when cultivated in the right locations. However, it could also result in carbon emissions from land use change. Region specific impacts should therefore be considered in site selection and sustainability assessment of advanced biofuels.

Related ADVANCEFUEL Publications

D4.1 – Review of existing standards and certification schemes

D4.2 – Sustainability criteria and certification for lignocellulosic biorefinery systems: Harmonisation possibilities and trade-offs

D4.3 – Regional specific impacts of biomass feedstock sustainability

D4.4 – Options to tailor existing national and voluntary schemes towards harmonised sustainability certification that fit RESfuel requirements (Available August 2020)

D4.5 – Assessment of environmental and socio-economic performance of RESfuel supply chains (Available August 2020)

Factsheet: Towards sustainable advanced biofuels

Interview with Dr. Ric Hoefnagels, Utrecht University: Towards Sustainable Advanced Biofuels

43 D4.3 – Regional specific impacts of biomass feedstock sustainability, p.48.

VIII. End-use and Performance

The transport sector is the only sector where greenhouse gas emissions remain higher now than the 1990 level established under the Kyoto Protocol, being 20% higher now. Whilst road transport remains the main emitter, the highest rise has been in aviation, a sector which is expected to continue growing (although the current COVID-19 pandemic may have an impact on this trend). Additionally, as global trade continues to rise, shipping is expected to also have a larger impact. A study by the European Parliament suggests that to meet obligations for limiting global warming to 1.5°C, aviation emissions should be reduced by 41% and shipping by 63%. According to ADVANCEFUEL, emissions from road and rail transport, aviation and inland shipping should be reduced by 85% in 2050 compared to 1990, whilst emissions from international shipping should be reduced by 50% compared to 2008 levels. Advanced biofuels are one of the few options available in the short-to-medium term, especially for aviation and shipping.

Market Analysis

ADVANCEFUEL has performed a market analysis to understand the order of magnitude by which the market uptake of RESfuels could grow by 2030 and 2050. The project has looked not only at historical trends and cost competitiveness, but also at polices and regulations that drive market development.

Whilst road and rail transport within the EU are addressed with mandatory targets for renewable energy, aviation and shipping are addressed only at international level. In aviation, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is expected to be operational from 2021, being voluntary until 2027, with the aim to reduce carbon emissions by 50% by 2050 (compared to a 2005 base level). For shipping, the International Maritime Organisation has adopted a strategy to reduce greenhouse gas emissions from shipping by 50% by 2050.

Scenarios for the European Commission have indicated that large quantities of RESfuel will be required by 2050 to meet the Paris Agreement goals and sector specific targets. Projections suggest that liquid biofuel demand for all transport modes except international shipping will be in the range of 1,200-1,800PJ, including 580-960PJ for aviation. Shipping could add between 930-1300PJ. This will, however, depend on long-term policy support.

Whilst electrification will be important in road and rail transport, advanced biofuels will remain the most viable options for shipping and aviation. Current high production costs for RESfuels, and low fossil fuel prices, hamper this roll-out, and long-term competitiveness will largely depend on cost reductions from technological learning, economies of scale, efficiency improvements, and innovations in sustainable feedstock supply.

Policy analysis and recommendations

A consistent policy framework will be essential for the continued growth of advanced biofuels, and the EU should provide a stable policy framework tailored to the specifications of the advanced biofuels sector. This would give clear market direction, and increase investor confidence. Significant effort will also be needed to ensure harmonisation of policy across member states, but also across sectors, with agriculture, forestry and waste, for example. To enable the creation of an integrated policy framework, ADVANCEFUEL has explored good practices in both policy and industry, and performed a policy analysis, identifying opportunities, challenges and policy gaps to define future options, as presented in the Conclusions and Recommendations chapter.

Fuel Performance Analysis

In order to understand the most dominant properties of current RESfuels, ADVANCEFUEL studied the properties of different fuels and different engine technologies, including compression ignition engines (heavy-duty road vehicles and shipping), jet turbines, (aviation) spark ignition engines, compression ignition engines, flexi-fuel vehicles and fuel cells (light-duty road transport). The RESfuels were investigated in terms of fuel consumption and CO_2 emissions, and in relation to compatibility with existing engine types.

The work resulted in the **End-Use Analyser** (EUA), a numerical tool which enables users to select engine and fuel types, to calculate fuel consumption and CO_2 emissions while local emissions, like NOx, particulate matter (PM), and unburned hydrocarbon emissions (if applicable). The numerical tool is expected to serve project's stakeholders, especially fuel producers, to provide insight in the possibilities of new fuels to be implemented in the market in short or longer term.

ADVANCEFUEL Publications

D5.1 – Report on market analysis

D5.2 – Good practices along the RESfuels value chain

D5.3 – Report on policy analysis

D5.4 – Updated report on policy analysis (Available August 2020)

D5.5 – End-use performance of alternative fuels in various modes of transportation

Tool: End-Use Analyser

Factsheet: Good practices along the renewable fuels value chain

Factsheet: Market uptake of advanced biofuels

IX. Scenario Analysis to 2050

In order to support long-term roll-out of advanced renewable fuels, ADVANCEFUEL has sought to provide evidence for policy-makers and industry on future market trends, and has analysed the role that RESfuels can play up to 2050.

As a starting point, ADVANCEFUEL has updated TNO's RESolve-Biomass model to be used for the integrated assessment of innovative approaches related to biomass feedstock. The model covers all relevant fuel supply options (including biofuels, Power-to-X options such as H_2 and e-fuels and direct electrification), and all major transport modules, and has been used to analyse the future of RESfuels using different scenarios, drawing from work in the previous work packages.[44]

Role of renewable fuels in transport up to 2050

Strategies for further development of RESfuels should be based on solid insights in the supply chain, taking account of feedstock costs and potentials, logistics, technology performances and market demand. To do this, two scenarios and numerous 'what-if' and sensitivity cases have been constructed. The scenarios are influenced by two main variables – technology development and the availability of renewable electricity. Biomass supply is considered to respect the RED II sustainability criteria.

The scenarios are:

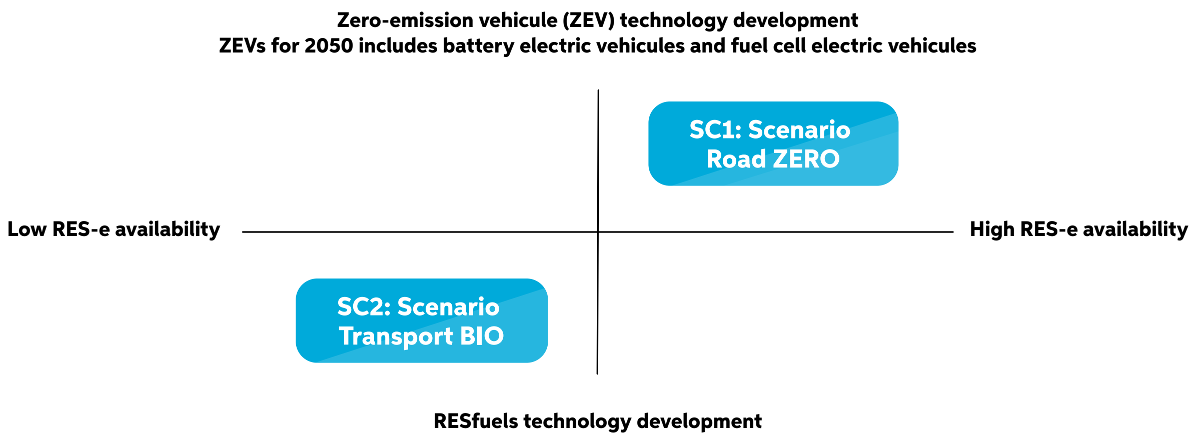
- **'Transport BIO'** – a scenario in which there is rapid technological development in advanced biofuels, where renewable electricity prices are higher, and (sustainable) biomass import is high;

- **'Road ZERO'** – a scenario in which there are technological breakthroughs in zero tailpipe emission vehicles, such as electric vehicles, renewable electricity prices are lower, and domestic biomass supply is lower.[45]

44 D6.1 – Updated and verified RESolve-biomass model

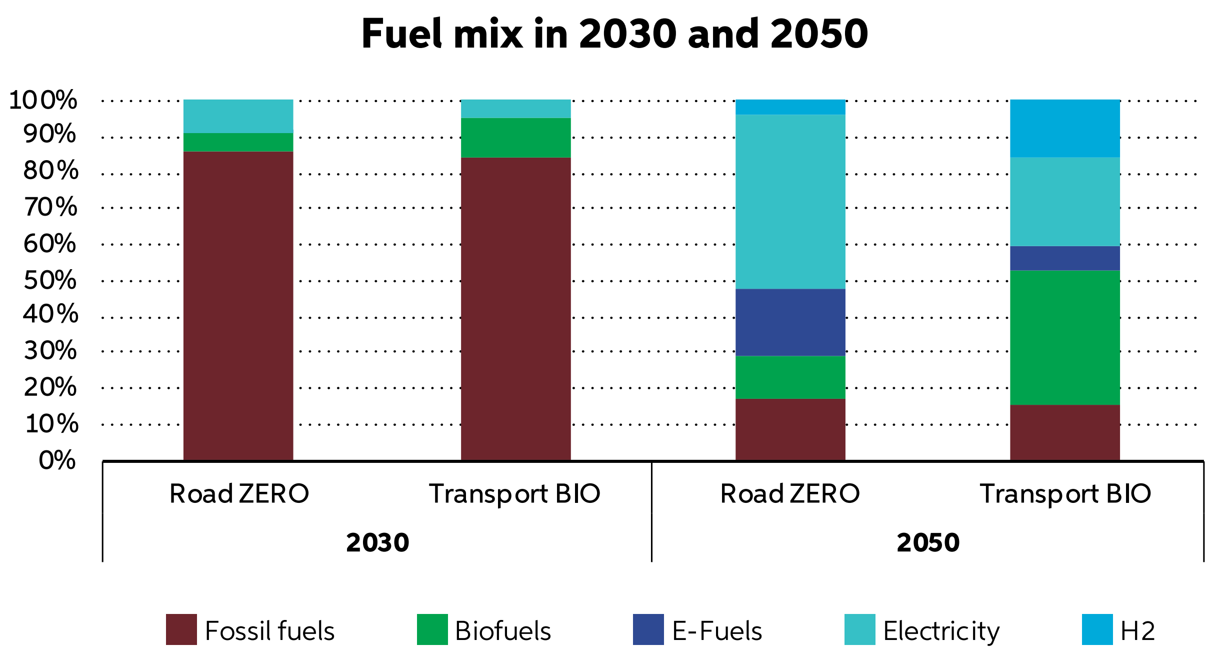
45 D6.2 – Role of renewable fuels in transport up to 2050, pp. 12-13.

ILLUSTRATION OF THE SCENARIO CONSTRUCTION BASED ON UNCERTAINTIES



Both scenarios assume a CO_2 reduction target of 85% by 2050 (from 1990 level) for road, rail, inland navigation and aviation, a 50% target for CO_2 reduction in the maritime sector (from 2008 level), and both use a the same assumptions regarding transport final energy demand, and biomass demand from other sectors (heat, power, biobased industries).

FUEL MIX IN 2030 AND 2050



Overall, whilst the optimal mix is different, both scenarios show that all renewable transport fuel supply options will be needed to meet the CO_2 targets – biofuels, electricity, e-fuels, hydrogen and some remaining fossil fuels. The ultimate role of biofuels will depend on the timely deployment of zero-emission vehicles, but both scenario still show a significant need for biofuels: in Transport BIO, an increase of 700% by 2050, and in Road ZERO of 165%.

The scenarios further reveal that meeting the Transport BIO scenario will rely on significant mobilisation of Europe's sustainable biomass potential, with maximum biofuel demand limited mainly by the supply of feedstock and competition with other sectors, with 80% of total feedstock categories expected to be utilised, even higher cost energy crops.

Even with high biofuel deployment, the scenarios reveal that power-to-fuel (PtX) supply options will be needed, though hydrogen and e-fuels are not expected to emerge until 2030 and contribute to the fuel mix from 2035. Eventually, PtX fuels will reach around 23-24% of the fuel mix by 2050 in both scenarios, requiring around 52-56% of net EU electricity generation (based on 2017 levels).

Turning to specific sectors, greenhouse gas emissions from maritime and aviation will continue to grow, unless demand in these sectors is significantly reduced by incentivising RESfuel use. Meeting the 50% emissions reduction targets set for aviation and maritime by 2050 does not appear to be feasible under either scenario.

Total system costs and the employment effects of biofuel deployment

The total system costs (including costs related to renewable energy carriers, energy conversion, transportation of biofuels and biomass feedstocks, additional engine and distribution costs compared to fossil references) of renewable fuels in 2050 correspond to 2-4% of EU gross domestic product (GDP) according to the ADVANCEFUEL scenarios.[46] Biofuels comprise only 10-30% of the total system costs of renewable fuels according to Road ZERO and Transport BIO, respectively. The investments needed for biofuel conversion technologies play the dominant role in total system costs (more than 45% of the total), followed by the feedstock costs and the costs related to transporting biomass and biofuels (around 24% each). Engine adaptation and distribution costs (i.e. filling stations) play a much smaller role (less than 5%).

The biofuel deployment rates projected in Road ZERO and Transport BIO scenarios indicate significant employment opportunities. The employment assessment methodology is based on the 'fallow the money' approach. Results show that the total employment related to CAPEX could be around 1-3 million job years in the time frame 2018-2050. These jobs will include those related to equipment manufacturing, construction, consultations, engineering, and other services. Operation and maintenance related jobs are calculated to be 75,000 full-time equivalents (FTE) for Road ZERO and more than 300,000 FTEs for the Transport Bio scenario. Feedstock related FTEs for 2050 are calculated to be around 270,700 FTEs for Road ZERO and Transport BIO respectively.

Principles for a long-term policy perspective

Advanced biofuels represent the most significant solution for the short to mid-term decarbonisation of the transport sector, especially for aviation, maritime and heavy-duty road transport sectors where there are

46 In 2019, EU28 GDP is stated as 16,452 billion EUR

presently no other options. A major barrier remains the lack of a clear long-term policy for supporting market development, as well as the complicated links with other primary production sectors, such as forestry, waste, and agriculture, requiring trade-offs to be made.

- There is no silver bullet for decarbonising Europe's transport sector. A balanced set of options (and development of new conversion routes) will be needed to meet greenhouse gas emission reduction targets, accompanied by efficiency improvements and demand side management, to avoid pressure on feedstock markets, as well as the electricity and heat sectors.

- One of the options to reduce the pressure on the lignocellulosic feedstock markets is the development of energy crops grown on marginal land, which requires major policy efforts, including the development of infrastructure, farmers' experience, regulatory compliance and support, as they are more expensive compared to other supply options;

- Policies could prioritise biomass supply to the sectors with few alternatives for decarbonisation – including the transport sector – at the expense of other sectors that have alternatives (e.g. electricity generation), thus reducing the stress on additional power demand and electricity infrastructure in Europe;

- The policy measures to be implemented need to be strong and stable enough over a longer period to gain confidence of the relevant stakeholders and to ensure that significant amounts of RESfuels and ZEVs are deployed. These need to go hand in hand with the energy efficiency improvements;

- Enabling renewable fuels for aviation requires dedicated support to increase the jet fuel production share in multi-output biorefineries that produce a mixture of fuels. Otherwise, multi-product technologies may not be sufficient to meet the demand from this sector;

- A combination of policies, such as the quota obligation combined with a feed-in premium, or investment subsidy, is recommended to provide secure and reliable market conditions until the RESfuel technologies become more mature, particularly for aviation and also maritime sector.

- Both maritime and aviation sectors have adopted RESfuels as key solutions for their future decarbonisation and have been actively engaged in research, innovation and commercial activities. This should be further encouraged and supported.

ADVANCEFUEL Publications

D6.1 – Fully updated and verified RESolve-Biomass Model

D6.2 – Role of renewable fuels in transport up to 2050 – a scenario based analysis to contribute to Paris Agreement goals

D6.3 – Report on socio-economic assessment (Available July 2020)

D6.4 – Toolset for stakeholders (Available August 2020)

X. Conclusions and Recommendations

Advanced biofuels can have significant positive benefits for Europe's economy and environment, but further support is needed for their development and roll-out. The European Union has set interim goals for the use of advanced biofuels, but there remains a significant need for policy interventions that can support market development. At present advanced biofuels make up a negligible share of the transport energy mix, but their potential is very high. Advanced biofuels have significant scope to play a role in Europe's future transport energy mix, but care must be taken across the entire value chain.

- Europe has significant biomass potential, but greater efforts are needed to support their mobilisation, including the development of agricultural innovations;
- For conversion, the main challenge is not the technological processes, but their costs and competition with fossil fuels;
- The RED II sustainability criteria are a welcome strengthening over RED I, but they are still not sufficient to ensure the overall sustainability of advanced fuels;
- There remain significant policy gaps, particularly for aviation and maritime sectors. New interventions are required along the entire value chain;
- Advanced biofuels will need to be a significant part of 2050 transport energy mix to meet the Paris Agreement target, but cannot be relied upon alone.

Recommendations

Current policy mechanisms have not been enough to support the market uptake of renewable energy fuels (RESfuels). Their sustainable growth however depends largely on the clarity, long-term stability and consistency of the policy framework which should provide confidence to investors and allow the industry to improve their technical and financial performance. Tailored policy interventions integrated along the RESfuels value chain (supply, conversion, end use) are essential for future policy formation at all governance levels. The work in ADVANCEFUEL has delivered the following policy related recommendations:

Biomass feedstocks

- Sustainable biomass feedstocks are present in Europe but their efficient and timely mobilisation remains a challenge;
- Rural land-use planning must be combined with incentives to produce biomass;
- Financial support measures like the European Structural and investment funds (ESIF), including the European Regional Development Fund (ERDF), etc. must account for capital costs related to the development of infrastructure for the logistics related to waste and residue collection, as well as large scale energy crop production, supply and logistics;

- The roll-out of new innovations can be supported via the European Innovation Platform for Agricultural (EIP-Agri), knowledge sharing through the European Network for Rural Development (ENRD), and provision of funding from ESIFs, namely the ERDF, Cohesion Fund, and funding for farm diversification under the European Agricultural Fund for Rural Development (EAFRD);

- Existing regulations could be refined to account for multi-purpose benefits that arise from dedicated biomass cropping for bioeconomy, e.g. harvest of short rotation coppices next to water bodies offers advantages both for water purification and raw material production.

Conversion

- Tailored financing mechanisms (such as feedstock premiums, feed in tariffs and premiums, CO_2 taxes, etc.) are necessary to develop a secure framework to reduce capital investment and uncertainties of production costs;

- Innovations in technology development involve high capital costs and thus high financial risk; measures to bolster this must be introduced;

- Funding schemes (e.g. European Innovation Fund), banks and financial institutions must increase budget shares for RESfuels in their investment portfolios;

- Capacity building and public-private partnerships will help tackle barriers such as those related to investor risk premium and access to debt financing;

- Research and innovation grants should ensure continuity in funding for RESfuels to overcome technical barriers such as process design (i.e. increase process efficiency) and scale-up considerations.

End use

- Ambitious decarbonization plans require deployment of all renewable options, increased efficiency of the transport system and significant shifts towards more energy efficient transport modes;

- RESfuels are likely to exhibit increased shares first in road transport, however it is critical to enable similar and timely shift to heavy duty vehicles, maritime and aviation which have less alternatives and are more challenging in terms of CO_2 emissions reduction. Without tailored targets for these sectors this shift may be difficult to manage;

- E-fuels, produced from renewable electricity and direct air capture, are essential to complement the contribution of advanced biofuels in transport decarbonisation. They can be particularly useful in aviation due to the limited number of certified biofuel value chains for this sector;

- Biomass to Liquid (BtL) value chains such as bioLNG, bioDME, FT liquids, pyrolysis oil co-processing must be deployed before 2030 to ensure fossil diesel substitutes are in place to meet the targets.

Integrated sustainability criteria

The sustainability of advanced biofuels needs to be monitored and verified all the way along the value chain, from feedstock to end-use. Existing criteria need to be strengthened with to include sustainable forestry management, social impacts and economic impacts. Additionally, there needs to be greater mutual recognition of national and voluntary certification schemes across Europe. At present, only biofuels and some cases of heat and energy production from biomass, are required to meet RED II sustainability criteria. However, lignocellulosic biorefineries use the lignocellulosic feedstocks to produce many outputs – not only advanced renewable fuels, but also heat, electricity and bio-based products – and there are a number of different schemes used for sustainability, with various standards and criteria. A harmonised sustainability criteria could lead to less complexity for biorefineries, reduced costs, and greater market trust in the sustainability of their outputs.

Tailored targets for aviation, marine and heavy duty

RESfuels deployment in aviation, marine and heavy duty is immature, and most value chains still require improvements. This implies high investment risks. Without a dedicated and consistent policy in place industrial and investment confidence is reduced and market uptake remains low. Together with increased efficiency and shifts towards more energy efficient transport modes future policy should be clear and include tailored targets for RESfuels and high CO_2 emission reductions. These must be aligned with REDII, the EU climate and energy targets, the Effort Sharing Regulation and account for provisions to meet the Paris Agreement aspirations.

Inform, involve and inspire stakeholders

Stakeholders are central to the successful market uptake of RESfuels. Their active and continuous involvement, consultation and approvals during policy formation, implementation and monitoring is vital for the future of the sector. Future policy making must involve stakeholders, inform them and inspire them to become 'transport efficient' individuals.

Annex – Barriers and ADVANCEFUEL Solutions

TYPE OF BARRIER	BARRIER	ADVANCEFUEL SOLUTIONS AND EVIDENCE
LIGNOCELLULOSIC FEEDSTOCK SUPPLY		
ENVIRONMENTAL	Lack of clarity about environmental constraints and land availability	**Lignocellulosic crops on marginal land** Sustainable land use for dedicated biomass production is an essential element for resource efficient advanced fuel value chains. A spatial explicit approach that assesses the current and future availability of marginal land under RED II sustainability criteria, and land-use change related environmental impacts from lignocellulosic energy crops production on these lands provides valuable evidence for Europe to prioritise planting lignocellulosic crops on marginal land. ADVANCEFUEL's assessment covers current/future land availability, biomass potentials and environmental impacts of lignocellulosic energy crops cultivated on marginal lands in Europe for 2030, 2040 and 2050. See ADVANCEFUEL report D 4.3
ECONOMIC	High cost of feedstock	**Cost efficient lignocellulosic feedstock availability, market status and suitability for RESfuels** Learning effects of innovations, i.e. breeding and selection of new genotypes as well as improved agricultural management and logistics, knowledge exchange and training, have greater potential to increase biomass yields and reduce biomass production costs. ADVANCEFUEL analysed the potential availability of non-food biomass from forests and agriculture to determine key factors including the availability of land (marginal lands) and constraints (sustainable removal rate, competing uses etc.). Furthermore, up-to-date lignocellulosic biomass extra-EU import scenarios have been assessed. See ADVANCEFUEL report D2.1 **Innovative crop rotation schemes** ADVANCEFUEL analysed innovation in cropping schemes assessing fields of innovation in cropping lignocellulosic energy crops and evaluating these innovations. The evaluation focuses on: (a) the potential of these innovations to reduce biomass production costs, (b) the environmental impact of growing such crops, and (c) the willingness of farmers to grow lignocellulosic energy crops and public acceptance regarding post implementation of new cropping schemes. Crop rotation increases yield and, hence, decreases biomass production costs, and at the same time have potentially positive effects on environmental (e.g. erosion, soil fertility, soil organic carbon) and social impacts (e.g. jobs, environmental values). See ADVANCEFUEL report D2.2

CONVERSION		
REGULATORY/ ECONOMIC	Absence of dedicated policy support and access to project finance	**Recommendations for policy support tailored to the conversion technology type** Significantly high targets must be introduced within the time frame 2030-2050 and combined by policy instruments that can help bridge the financial gap between RESfuels and fossil fuels. The commercialisation of RESfuels requires a series of steps for further development and innovations as well as clear and long-term policy measures. ADVANCEFUEL identified the required actions – such as introducing policy measures - for the development of RESfuels production technologies in order to increase their TRL levels. See ADVANCEFUEL report D3.3
REGULATORY	Concerns on stability/security of the industry	**Symbiosis with current infrastructure** Significantly high targets must be introduced within the time frame 2030-2050 and combined by policy instruments that can help bridge the financial gap between RESfuels and fossil fuels. Using existing fossil fuel infrastructures to incorporate biomass has been found to constitute a low-risk option for ramping up renewable fuels in the EU. ADVANCEFUEL analysed key European fossil-fuel infrastructures which can facilitate the ramp-up of biomass use. See ADVANCEFUEL report D3.4

TYPE OF BARRIER	BARRIER	ADVANCEFUEL SOLUTIONS AND EVIDENCE
SUSTAINABILITY OF BIOMASS SUPPLY		
REGULATORY/ ENVIRONMENTAL	Lack of harmonised regulations	**Clarity for sustainability requirements** Sustainability criteria for biofuels will need to be harmonised and implemented for all uses. Further social sustainability criteria is recommended to be included. ADVANCEFUEL and stakeholders assessed the sustainability requirements in voluntary schemes that are recognised by the European Commission and national initiatives used to certify sustainable biofuels used in transport. See ADVANCEFUEL report 4.1 **Sustainability criteria & certification for lignocellulosic biorefineries** Harmonising sustainability criteria of voluntary schemes focusing on RESfuels is essential. ADVANCEFUEL assessed current/future sustainable production of RESfuels against sustainability criteria, including harmonisation of national standards, certification schemes and sustainability initiatives for stimulating sustainable production of RESfuels, and national guidance on sustainability reporting required for economic operators and sustainability criteria related to feedstock production and land use, methods and data collection to calculate GHG emissions, chain of custody and social & economic criteria. See ADVANCEFUEL report D4.2

TYPE OF BARRIER	BARRIER	ADVANCEFUEL SOLUTIONS AND EVIDENCE
END-USE		
REGULATORY	Absence of structural mechanism to bridge the price gap between renewable and fossil-based fuels	**Stable investment climate enabled by policy frameworks and feed-in tariffs** A combination of policy instruments, such as quota obligation combined with feed-in premiums, can provide a stable investment climate and help bridging the gap. ADVANCEFUEL reviewed existing policies and illustrated that respective countries and regions are actively implementing sustainability provisions and have national mandates and targets in place to support the growth of advanced biofuels. However, their market shares are at different scales and countries need to introduce new financial and provisional measures to build and sustain their national capacities. See ADVANCEFUEL report D5.2
ECONOMIC	High production cost of RESfuels	**Reduction of CAPEX and OPEX** Reduction in conversion technologies' capital expenditures (CAPEX) via learning will help reducing the production costs only with a significant increase in installed capacities (e.g., 20%-40% reduction. Next to that, using existing infrastructure can further reduce both CAPEX and OPEX. ADVANCEFUEL analysed biomass conversion technologies with respect to their basic characteristics for feed, process conditions and output products based on qualitative and quantitative information and assessing their present status of TRL and cost related KPIs (OPEX and CAPEX) as potential biofuels for road, aviation and maritime transport. See ADVANCEFUEL report D3.5 See ADVANCEFUEL report D3.4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