ADVANCEFUEL

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

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ADVANCEFUEL at a glance

ADVANCEFUEL (www.ADVANCEFUEL.eu) aims to facilitate the commercialisation of renewable transport fuels by providing market stakeholders with new knowledge, tools, standards and recommendations to help remove barriers to their uptake. The project will look into liquid advanced biofuels – defined as liquid fuels produced from lignocellulosic feedstocks from agriculture, forestry and waste – and liquid renewable alternative fuels produced from renewable hydrogen and CO2 streams.

In order to support commercial development of these fuels, the project will firstly develop a framework to monitor the current status, and future perspectives, of renewable fuels in Europe in order to better understand how to overcome barriers to their market roll-out. Following this, it will investigate individual barriers and advance new solutions for overcoming them.

The project will examine the challenges of biomass availability for second-generation biofuels, looking at non-food crops and residues, and how to improve supply chains from providers to converters. New and innovative conversion technologies will also be explored in order to see how they can be integrated into energy infrastructure.

Sustainability is a major concern for renewable fuels and ADVANCEFUEL will look at socio-economic and environmental sustainability across the entire value chain, providing sustainability criteria and policy-recommendations for ensuring that renewable fuels are truly sustainable fuels. A decision support tools will be created for policy-makers to enable a full value chain assessment of renewable fuels, as well as useful scenarios and sensitivity analysis on the future of these fuels.

Stakeholders will be addressed throughout the project to involve them in a dialogue on the future of renewable fuels and receive feedback on ADVANCEFUEL developments to ensure applicability to the end audience, validate results and ensure successful transfer and uptake of the project results. In this way, ADVANCEFUEL will contribute to the development of new transport fuel value chains that can contribute to the achievement of the EU's renewable energy targets, and reduce carbon emissions in the transport sector to 2030 and beyond.

To stay up to date with ADVANCEFUEL's stakeholder activities, sign up at: www.ADVANCEFUEL.eu/en/stakeholders

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Executive Summary

The commercialisation of RESfuels requires a series of steps for further development and innovations as well as clear and long-term policy measures. The aim of this report is to identify the required actions – such as introducing policy measures - for the development of RESfuels production technologies in order to increase their TRL levels.

This report applies a three-step approach to assess the scaling up and maturity of RESfuel production technologies: identification of generic technical and economic factors, identification of possible barriers associated with the identified factors, and proposal of policy mechanisms to overcome barriers, enhance investments, prepare market conditions and scale-up production.

At the first step, the identified factors which affect the development of the biomass conversion technologies and their upscaling to commercial level are divided into two categories. These categories are technical factors which refer to process design and operation aspects of the conversion technology, (e.g., process efficiency, product cleaning, reuse of streams, achieved capacities) and economic factors which refer to investment and production costs, access to financing and market conditions (e.g., biomass supply infrastructures and prices, fossil fuel prices, compatibility of vehicle engines). The evaluation of the present state of factors that may act as barrier for the development of these technologies is then applied. Policy measures are required to influence these factors, and these are grouped into regulations, financing and information provision (i.e. "soft" dissemination actions) mechanisms. In the first category of policy mechanisms, the most important one is the regulation of fossil fuels, so they are phased out, either due to a high enough CO_2 penalty or some regulating such as a quota system. Other measures identified are product standards, exemption and reduction of taxes, feed-in-tariffs, subsidy, green procurement. The second category refers to financing mechanisms that can establish funding for the construction of "first of its kind" advanced biofuel production plants. An important possibility should be the EU innovation fund which will start in the next EU-ETS trading period in 2021. The third category includes soft actions for the dissemination of best practices and successful lessons learnt, promotion, capacity building, and awareness raising. Thus, a set of policy interventions is considered across the biomass value chain as it can better capture the different challenges and policy gaps along the value chain and allow optimising performance for all stages.

The three-step approach is applied to two case studies, namely technologies considered as highly efficient and low risk, based on the findings of previous deliverables (i.e., mainly D3.2, and D3.5): methanol production from the gasification pathway and ethanol production from the biochemical pathway. The results indicate the relatively low potential for technical development and innovation to bring down cost for methanol production, where cost reductions can mainly be expected in the assembling of plants (i.e., from more experienced project assembling

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and reduced cost for project risk hedging). On the other hand, ethanol is characterized by a higher potential of technological improvement, mainly with respect to process intensification and efficient utilisation of biomass fractionation by-products (e.g., hemicelluloses, lignin) to added value chemicals, which can significantly increase the profitability of future 2nd generation ethanol biorefinery plants. Cost reductions can, as for methanol, mainly be expected by learning and knowledge sharing in assembling existing process components within complex large scale industrial plants.

Technological development of vehicle engines to efficiently use methanol and ethanol drop-in fuels is more important than what can be expected from cost reductions of the respective conversion technologies. With respect to this factor, ethanol as a transportation fuel is in a more developed state of end-use market. For both case studies, it is concluded that market conditions and regulatory frameworks governing fuel pricing, CO_2 taxes, and creating a more stable investment environment are key factors, overarching the technology development. Or in other words, without a strong driving force for renewable fuels, it is unlikely that the production of these will reach large scale industrial production, which is required to bring down their cost.

The approach of this work can be applied to a range of RESFuels facilitating the extraction of more generic conclusions about similarities and differences among technologies with respect to technological weaknesses, economic constraints and actions for improvements. It could also be the basis for a methodological framework for a generic linking between policy mechanisms and technological barriers.

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Nomenclature

RESfuel	Liquid, renewable and advanced fuels
CHP plants	Combined Heat and Power plants
TRL	Technology Readiness Level
EU-ETS	European Union Emissions Trading System
GHG	Greenhouse gas
GoBiGas	Gothenburg Biomass Gasification Project
RED II	Renewable Energy Directive II
RTFC	Renewable Transport Fuel Certificate
FAME	Fatty acid methyl esters
IBB	Subsidy program that supports projects that improve or renew the process for supplying innovative biofuels to the transport sector
TAB	Subsidy program for filling stations for alternative fuels such as natural gas/green gas, E85 (bioethanol) and/or B30 (biodiesel)
FFV	Flexible fuel vehicles
ICVs	Internal combustion-engine vehicles
EV	Electric Vehicle

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1. Introduction

The aim of this report is to identify factors which affect the scaling-up and maturity of production technologies for liquid, renewable and advanced fuels (RESfuels), as well as to evaluate the present state of factors that may act as a barrier and hinder the development of a conversion technology. Furthermore, the report proposes policy mechanisms which can be employed to overcome these barriers and increase TRLs for technologies for RESfuels production, both on the short term (2030) and long term (2050).

This report applies a three-step approach to assess the scaling up and maturity of RESfuel production technologies: identification of generic technical and economic factors, identification of possible barriers associated with the identified factors, and proposal of generic policy mechanisms to overcome barriers.

Technical factors refer to process design and operation aspects of the conversion technology, (e.g., process efficiency, product cleaning, reuse of streams, achieved capacities) and economic factors refer to investment and production costs, access to financing and market conditions (e.g., biomass supply infrastructures and prices, fossil fuel prices, compatibility of vehicle engines). The present state of these factors is evaluated to identify those factors that may act as barrier for the development of the investigated conversion technologies.

When it comes to proposal of policy mechanisms, these are further grouped into regulations, financing and information provision mechanisms associating them to barriers and by extension to technical and economic factors of conversion technologies. The grouping proposed here is not unique (i.e., different approaches of grouping policy mechanisms would be possible). Yet, we consider it essential to identify a set of policy interventions across the biomass value chain to capture the different challenges and policy gaps and allow optimising performance for all stages. However, it is important that any policy measure has a clear aim and that in case of a set of interventions these are not contradictory.

- Regulations[1] are here referred to as rules that control the operation of companies. In the field of biomass value chains these can include quota obligations, product standards, exemption and reduction of taxes, targets for RESfuel shares in production and/or consumption and qualifying criteria for incentives, feed-in-tariffs, subsidy, green procurement, etc.[2]

[1] https://www.collinsdictionary.com/dictionary/english/regulation

[2] Mozaffarian M, Stralen Jv, Uslu A. Deliverable 3.2 Biomass Policies: Benchmarking bioenergy policies in Europe. ECN; 2016.

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- Financing mechanisms include provisions for financial support and taxation, such as biomass feedstock premiums, capital grants, technology and feedstock related feed in tariffs or premiums, tax incentives, user charges and research funds.
- Information provision mechanisms include soft actions for the dissemination of best practices and successful lessons learnt, promotion, capacity building, awareness raising, etc.

The approach of grouping policy mechanisms is applied to two case studies, namely technologies considered as highly efficient and low risk[3] : ethanol production from the biochemical pathway and methanol production from the gasification pathway.

Ethanol: With respect to TRL, the case well beyond the TRL threshold of the ADVANCEFUEL project (i.e., the scope of the project refers to technologies with TRL>5) is second-generation ethanol production technologies. However, the ranges reported for the cost of ethanol production are relatively wide (i.e., 103-158 €/MWh-product according to Landälv et al. (2017) and 102-228 €/MWh-product considering the assumptions of D3.2) and are subject to many factors beyond the conversion technology, such as type and cost of feedstock, on-site or off-site enzyme production, and the utilisation of lignin and other by-products.

Methanol: The gasification-based pathways for the defined ADVANCEFUEL products such as methanol are well established (i.e., demonstrated at commercial scale) for the synthesis technologies starting from syngas. The limiting part of this pathway to reach a higher TRL is the gasification technology to produce syngas for the subsequent synthesis steps. So far only a few demonstration plants have reached an adequate operational performance consisting of process steps of an industrial type so that efficient scale-up can be expected. It should also be considered that the production cost for methane and methanol lies generally within a narrower range and at a lower cost (i.e., total production cost of 73-89 €/MWh-product[4]) than biochemically produced ethanol (with costs as given above) and Fischer-Tropsch liquid fuels produced via biomass gasification (for which total production cost is in the range 95-136 €/MWh-product).

Additionally, the technologies analysed here also present opportunities for integration into existing infrastructures as reported in D3.4. The case of integration of 1st generation (produced primarily from food crops such as grains, sugar beet and oil seeds) and 2nd generation (produced primarily from lignocellulosic materials such as cereal straw, bagasse, forest residues, and purpose-grown energy crops such as vegetative grasses and short rotation forests) biofuels can

[3] Based on conclusions from D3.2 with respect to TRL and production costs.

[4] For methane production via biomass gasification, production costs of 60 €/MWh-product have been reported (e.g., https://www.chalmers.se/SiteCollectionDocuments/SEE/News/Popularreport_GoBiGas_results_highres.pdf).

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be implemented by co-location of plants that could potentially share energy services, logistics infrastructure and human resources. Energy integration of electricity and process heat demand (e.g., through existing CHP plants) is a key option used in several cases of 2nd generation bio-ethanol production in Brazil, where the respective plants are already co-located with first generation biofuel production facilities (e.g., the GranBio Bioflex plant in Brazil that is collocated with a 1st generation ethanol plant, sharing a CHP unit using both sugarcane bagasse and lignin and the Raizen IOGEN plant in Brazil, collocated with a 1st generation sugarcane ethanol plant) (EC, 2017c). For the case of methanol production, mixing of syngas from steam reforming of natural gas and biomass gasification is technologically feasible, taking advantage of common plant downstream infrastructure.

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2. A 3-step approach from technology factors to barriers and policy mechanisms

The commercialisation of RESfuels requires a series of steps for further development and innovations. As mentioned above, a systematic approach is desirable in order to get a clear mapping of the current state of the technology, identify problems and needs for development and propose appropriate mechanisms and related actions required to get investments in place, prepare market conditions and scale-up production. The approach applied here for this type of analysis consists of the following steps:

- **Identification of factors** which affect maturity of bio-fuel processes. This step results in a list of technical and economic factors for which barriers need to be overcome to advance the TRL towards competitive biofuel production at industrial scale.
- **Identification of barriers related to each factor** which constrain the development of a conversion technology and which must be overcome to increase the TRL status. The barriers refer to the current state of a particular conversion technology or one of its sub-processes. Depending on their significance, barriers are characterized as severe (S) or moderate (M).
- **Proposal of policy mechanisms** which should be adopted to overcome barriers and facilitate the development of RESfuels technologies. The choice of mechanism is done based on benchmarking with existing mechanisms for other similar technologies and are also informed through stakeholder interviews in the framework of the ADVANCE-Fuel work on Good Practices (reported in D5.3).

Identification of factors affecting process maturity

The factors which affect the development of the biomass conversion technologies and their upscaling to commercial level are divided into two categories: technical factors which refer to process design and operation aspects of the conversion technology, (e.g., process efficiency, product cleaning, reuse of streams, achieved capacities) and economic which refer to investment and production costs, access to financing and market conditions (e.g., biomass supply infrastructures and prices, fossil fuel prices, compatibility of vehicle engines).

Most technical factors were obtained from reports and studies presenting attributes which affect industrial maturity (Vimmerstedt et al. 2015, Samadi, 2018, EC 2017a, EC, 2017b). Other

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sources of information are detailed technoeconomic studies related to the development and cost-effectiveness of first of its kind plant in demonstration scale and problems for upscaling (Thunman et al. (2019), Landalv, 2017), It should be stressed that the results given in Thunman et al. (2019) are unique in the sense that they provide detailed cost data from an industrially scaled project consisting of a gasifier with all additional gas upgrading steps for producing a high-quality syngas; this data would not differ much to any other gasification based industrial process for RESfuel production to be used in aviation or internal combustion engines for vehicles). A comprehensive discussion on this cost data is presented in D3.5.

The factors collected from these reference studies can be summarized as follows:

- *Process efficiency:* The degree to which process yields, energy and material intensity, are likely to achieve efficiencies high enough to be competitive in an industrial production and/or close to the theoretically possible efficiency in which case no or only marginal improvement is possible (e.g., from thermodynamical and carbon/atom economy perspective).
- *Operating capacity:* The degree to which facilities can perform at nominal capacity for long operational times (i.e., the number of full-load hours).
- *Co-location with (and/or retrofitting of) existing infrastructures:* Possibilities for co-location with existing industrial facilities (e.g., refineries, industrial clusters, district heating network, market for the product, etc) to utilise common processing chains, potential heat sinks and sources, and fuel/feedstock supply chains and benefit from reduced installation costs, by-products as well as existing knowledge and experience (de Jong et al. 2017). Opportunities for retrofitting facility to accommodate different feedstocks and diversify their product portfolio can also be part of this factor (de Jong et al., 2015).
- *Process design aspects:* The required process complexity for achieving desired product quality, downstream recovery of utilisable/marketable by-products, reducing waste streams and minimising emissions and energy requirements.
- *Scale-up aspects*: The degree to which a process consists of commercially available components, the technical challenges and innovations required to assemble them in a full-scale production, and the minimisation of operational risk through multiple units and back-up production systems[5].

The most important economic factors which affect maturity of bio-fuel processes can be summarized as follows:

[5] For example, for first of its kind, large scale plants, multiple and oversized units should be installed and back-up systems of proven technologies should be present (e.g., steam reformer for fossil methane next to a biomass gasifier) to reduce the risk of interruption in sellable products.

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- *Market conditions*: The general state of economy with its market conditions, including price levels of materials, services and labour cost. These are often overlooked factors in academic works but are at the same time typically the main reason for differences in costs when implementing industrial projects. Another aspect in this category is the establishment of attractive biofuel market conditions, for instance as a result of increased taxation of fossil fuels (e.g., this was not the case for the GoBiGas project and thus it was terminated after some years of successful operation).
- *Capital investment and production costs:* A key is the difference in total fuel production cost between biomass conversion technologies to the equivalent fossil-based products. Thus, it is crucial to identify the most contributing cost elements, the process parts with high potential for technological development, and the cost aspects that can be expected to be mostly influenced by policies and financial instruments. Among these, as pointed out in D3.5, the biomass price is a large share of the total RESfuel production cost (typically 50% or more) and, thus, perhaps the most significant cost factor. Hence, it is important to stress that any technical learning which reduces investment costs will have a limited effect on the overall production cost for RESfuels. This will be further enhanced by the fact that in case of larger penetration of RESfuel production, the biomass prices will go up (see also D3.5 for discussion).
- *Variability of production cost:* Impact of temporal and geographical dependencies of specific cost components such as feedstock, chemicals and energy utilities, and labour and services for plant construction and operation.
- *Investor risk premium:* Risk premium will differ between first-of-its-kind and nth-of-its-kind plant, i.e., the first-of-its-kind plant investments would typically require a higher premium. Yet, this can partly be mitigated if financing these first plants is shared between public and private investments (e.g., by EU's new innovation fund, starting in the new EU-ETS trading period from year 2021). An example of risk sharing is the GoBiGas gasification plant with financing shared between the main stakeholder Göteborg Energi and the Swedish Energy Agency. Private, national and European funds were utilised in the case of Cresentino Biorefinery in Italy, but the lack of investors' confidence was the main obstacle to large deployment in this case (IEA, 2018).
- *Access to debt financing:* This refers to the extent to which the local or wider economy conditions allow low interest rates and companies with low debt to equity financing ratios can be involved (i.e., companies with lower debt-to-equity financing ratios would be more easily involved). Considering that biofuel plants are capital intensive, large private companies (and possibly public companies) with diversified business portfolio (i.e., not just biofuels) should form joint partnerships to have easier access to debt financing.

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- *Commercially available process components*: Evaluation of the degree to which the process consists of components that have already reached the nth installation and learning. Such components will obviously make the overall plant more reliable but will also exhibit less likelihood of technology learning and, thus, less cost reduction can be expected. In this case, cost reductions are mainly expected from learning to assemble these parts into a new system.
- *End-use market development (or vehicle engine development):* The existing technical capacity for end-use of renewable fuels. For instance, the extent to which vehicle engines can directly use renewable fuels (as drop-in fuel), mixtures with other fossil-based or biofuels (e.g., mixtures with gasoline/diesel), engine adjustments required and forecast of the engine development.
- *Enviro-economic aspects:* Environmental impacts including CO_2 emissions, carbon footprint, and life cycle assessment aspects (cradle-to-grave perspective). Thus, this will correspond to what externalities are lowered using RESfuels and possibly which ones are added (e.g., from negative impact on other sustainability development goals such as biodiversity). For example, Renewable Energy Directive II (RED II) introduces sustainability for forestry feedstocks as well as GHG criteria for solid and gaseous biomass fuels. (EC website, https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii)

Identification of barriers related to each factor

The current state of each factor may act as a driver or barrier to the maturity level (TRL) of the biofuel production technology under investigation and its future development. As the technology becomes more mature, the state of each factor is assumed to resemble that of the nth-of-its-kind plant. The state of each of the above factors is defined by taking into account representative case studies.

Some examples of barriers are related with the slow growth of transport biofuels due to too low prices for fossil fuels and insufficient policies in the sector (see Conclusions in D3.5). Other barriers are related to the fact that conversion technologies have typically high production costs and require large capital investment. Although technologies for the production of advanced biofuels are typically in the demonstration phase, they can be built up, to a large extent, by commercially available process steps, provided that they are built on an industrial scale (as discussed in D3.5). The development to commercial scale requires investment and implementation to bring down costs, mainly of those components that have not yet reached commercial scale applications. Technical challenges need to be overcome, such as finding energy-cost efficient ways of converting waste residues from the processes to fuels and achieve efficiencies close to theoretical limits. Yet, as concluded in D3.5, cost reductions can mainly be expected in the assembling of the plants and lowering the risk costs (i.e., reducing the risks which firms typically

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hedge by increasing profit margins; this is related to the investor risk premium stated above as part of the economic factors).

Table 1 presents a matrix associating barriers with the previously mentioned technical and economic factors. It should be noted that generally the state of some factors may cancel a specific barrier (and thus promote a specific technology). For example, cheap catalysts and/or enzymes may result in efficient processes for specific technologies. Thus, the matrix can be used to identify the potentially relevant barriers for an unfavourable state of a given factor of an investigated technology; vice versa, it can be used to identify which technical and economic factors a certain barrier may be affecting. In this context, Table 1 presents a representative sample of barriers and it is not exhaustive for all the possible barriers associated with the advanced biofuels production paths. Thus, it can be revised and updated according to the requirements of a wide range of conversion technologies.

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Table 1. Association of barriers to specific technical and economic factors. The “+” symbol indicates the correlation of a barrier with a factor. It should be noted that one barrier can be correlated with more than one factors and vice versa.

Barriers	Technical					*Economic*							
	Process efficiency	Operating capacity	Co-location	Process design aspects	Scale-up aspects	Market conditions	Capital invest-ment and pro-duction costs	Variability of production cost	Investor risk premium	Access to debt financing	Commercially available process components	End-use market de-velopment (or vehicle engine de-velopment)	Enviro-economic aspects
Costly auxiliaries or not available in commercial scale (e.g., enzymes, spe-cial catalysts) and trade-off among ef-ficiency and cost	+				+		+						
High pre-treatment costs, high biomass price, and high lo-gistics costs			+		+		+	+					
Lack of process in-tegration (heat and materials, reuse)			+	+					+				
Lack of regulatory framework to pro-mote greening of fossil-fuel infrastruc-tures			+				+		+				+
Restricted knowledge/experi-ence in assembling technology compo-nents			+	+	+		+		+		+		
Biomass price fluctuations							+	+	+				
Unknown conditions for efficiency related		+			+				+				+

Barriers	Technical					*Economic*							
	Process efficiency	Operating capacity	Co-location	Process design aspects	Scale-up aspects	Market conditions	Capital invest-ment and pro-duction costs	Variability of production cost	Investor risk premium	Access to debt financing	Commercially available process components	End-use market de-velopment (or vehicle engine de-velopment)	Enviro-economic aspects
parameters (e.g. en-zymes selection, ad-justment of reaction conditions)													
Impurities in the feedstock influenc-ing the performance, excessive wear of certain equipment, cellulose washing		+		+	+		+						
Low enzymatic hy-drolysis perfor-mance due to lignin product quality, yeast process inhibi-tor, many organic waste streams, recir-culation of solvents and solvent recovery	+	+		+	+								
Liquids properties not known, difficul-ties in mixing				+	+							+	
Reactors and sepa-rations should be adjusted to scale up conditions				+	+					+	+		
Lack of systematic framework to assess 2nd generation fuels sustainability												+	+

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As can be seen in Table 1, the barrier associated with most of the technical factors refers to the knowledge and experience of assembling technology components, even if for some of them there is substantial industrial practice. There is clearly a learning step for the scale-up, operation and design of the new technology system, both for greenfield plants and when co-location to existing plants is considered. This can obviously affect estimates of production costs too. With respect to economic factors, the lack of regulatory framework is the dominant barrier to be considered; the biomass price fluctuations are also important and, in some extent, interlinked with the existence of regulatory frameworks. The biomass logistics, also related in some extent to the biomass price, can pose capacity constraints, limiting in this way the scale-up potential of a biofuel plants.

Proposal of policy mechanisms to overcome identified barriers

The recommended policy mechanisms are associated with barriers of the conversion technologies but also include market-oriented dimensions due to the interactions of the various parts of a value chain. Categories of policy mechanisms are obtained from D5.2 and D5.3 and summarized below:

- **Regulatory framework** (quota obligations, product standards, tax exemption and reduction, targets and qualifying criteria for incentives, feed-in-tariffs, subsidy, green procurement)
  - EU RESfuels policy targets exclude aviation, marine and freight sectors from the obligatory quotas and GHG emission reduction targets, and national targets have no specific provisions in place to promote the use of advanced biofuels[6]. In some Member states these sectors are not even eligible for the renewable certificates while in United Kingdom they are qualified for Renewable Transport Fuel Certificate (RTFC).[7]
  - Quotas/mandates have been a successful measure for the increase of the overall biofuels share in transport where Netherlands, Italy, Germany, Denmark, Slovakia and Sweden all have national mandates to reach certain advanced fuel shares by Year 2020 and 2030.
  - Investor and market confidence must be established (i.e., reduction of investment risk, robust action for regulation, and potentially significantly reduce costs by unleashing investment) through consistency and clarity in the direction of policy support.

[6] The Netherlands allows for aviation biofuels to contribute to the transport blending target, but these fuels do not have to be advanced biofuels (e.g. HEFA)

[7] There are voluntary initiative such as Fly Green Funds (although very limited so far). KLM is for example promoting this (http://www.flygreenfund.se/wp-content/uploads/2016/07/Juli_FGFSommar-brev_2016_eng_A.pdf)

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- Product standards set the requirements, test methods and blending ratios with conventional fuels such as EN228, European Norm biodiesel-FAME (Fatty acid methyl esters), EN14214 European Norm Diesel fuel, EN590.
- Green procurement such as Energy Taxation Directive (Dir. 2003/96/EC) promotes environmentally-friendly consumption by introducing taxes on CO_2 emissions and energy use of products and companies. Hence, this produces incentives for companies to invest in alternative energy sources such as biofuels, since there are less CO_2 emissions produced. The 2030 Framework for climate and energy establishes targets and measures for the EU to tackle climate change issues by securing the energy sector to be more competitive and sustainable. [8]

- **Financial instruments** (grants, feedstock premium, feed in tariffs, feed in premium, tax incentives, research and innovation funds)
  - Tailored financing mechanisms can finance part of capital costs for the first-of-a-kind advanced biofuel plants. The EU-ETS Innovation fund, an initiative within the EU-ETS phase 4, 2012-2030, is an example of this type of mechanisms, aiming at acceleration of deployment of new renewable energy technologies and industrial innovation in low-carbon technologies and processes, for both breakthrough and pre-commercial demonstration projects. Another example is the Netherlands' Clean and Efficient Strategy which promotes certification and training facilities for new innovative technologies.
  - Access to new technologies means removing restricted knowledge/experience.
  - Investment subsidies and support schemes play an important role, especially for the first-of-its kind plant. For instance, Denmark and the Netherlands have subsidy schemes (e.g., the latter has subsidy programmes targeted for market players and producers like IBB for innovative Biofuels and TAB for installing filling stations). In general, subsidies can solve a wide range of barriers since they are direct financial contributions to a value chain development. However, even if subsidies may serve as an additional boost to develop technologies and initiate markets, if there is no high enough barrier to use fossil fuels, subsidies are very unlikely to result in an economically sustainable biofuel market.

[8] Key targets for 2030:, At least 40% cuts in greenhouse gas emissions (from 1990 levels), 32% share for renewable energy, 32.5 % improvement in energy efficiency**,** The framework was adopted by the European Council in October 2014 (https://ec.europa.eu/clima/policies/strategies/2030_en)

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- **Other soft measures (e.g. best practices, lessons learned, capacity building, raising awareness)**
  - Lessons learned from good practices, according to D5.2 findings, include:
    - Proximity and close collaboration with feedstock suppliers (such as UPM or Eni Versalis) which leads to exploiting recycling nutrients, decreasing transport emissions, higher knowledge/awareness of land use change and stewardship. This can provide solution to barriers as a safeguard of stability of supply, biomass price and fluctuation and thus investment risk. It also strengthens enviro-economic aspects of the value chain.
    - Industrial integration and partnerships can create immediate availability of valuable by-products, energy/nutrient inputs, start-up financing, transport links, technical know-how, and corporate trust. Plant integration within one plant or adopting a site-wide approach can contribute to efficient integration of biofuel production with existing or new industrial symbiosis (e.g. Kalundborg in Denmark, Jacobsen (2006)). Such integration can provide solution to barriers related to the use of auxiliaries, process integration, and offer solutions to restricted knowledge/experience. Thus, it may unleash co-location and process design factors, and opens more doors for debt financing and risk premiums.
  - Feedstock sourcing diversification and appropriate versatile conversion pathways can decrease barriers associated with variability of production cost (i.e. resulting in volatility in biomass price), access to debt financing (i.e., diversified portfolio), and operating capacity (i.e., more changes of having a stable sourcing)
  - Learning through R&D and knowledge spill-overs from other technologies:
    - Although there are large uncertainties in cost predictions, particularly for complex, multi-component processes, learning curve metrics can be useful to gather and structure cost data for estimating future reductions in capital investment and production costs on the basis of foreseen capacity growth. The potential for technical learning will differ between technologies depending, not only on their overall maturity but also on their complexity in terms of number of process components and their individual maturity (see D3.5 for a discussion). In any case, learning curves can be used to highlight critical development steps in muti-component processes, although currently there is a lack of detailed data from real world units.
    - Knowledge is considered the base of any innovation and it can be related with opportunities of initial innovations from universities, scientific breakthroughs, and experience centers. Additionally, knowledge development can also be motivated by user demands. Concerning diffusion of knowledge, it is not easily extendable, and it is typically accessible for firms, depending on their role or network they belong to. Thus, it should be important to establish

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networks with industry, academia and governmental institutions to facilitate wide-spread knowledge on advance fuel production.

- EU and Member States can initiate non-financial incentives and provide information provisions to keep the consumers and market players informed. This should be followed up with financial incentives and investment grants to promote the new innovation technologies which can make the respective sectors carbon efficient and finally regulate market with regulatory instruments like feed-in premiums, certification and standardisation.

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3. Case studies

The three-step approach associate the technical and economic factors (maturity factors) with different barrier types and policy mechanisms. This chapter applies the three steps approach to methanol production via biomass gasification and ethanol production via biochemical pathways, as described in D3.2.

Development needs, potential for innovation and policy mechanisms for methanol production from biomass gasification

The methanol from gasification was extensively analysed in D3.5 with respect to the technology components (i.e., considering the many processing steps), process inventory and production cost data, as well as expected cost reductions from 2020 to 2050 based on learning curve theory. The analysis of D3.5 identified the state of each technical and economic factor described in the methodological framework. Then, from Table 1, possible barriers associated with the state of each factor are considered and the specific barriers for methanol production are described in Table 2. The corresponding policy mechanisms to overcome these barriers are also listed there.

The results of Table 2 show, as expected, that the most severe barriers are those associated with the economic factors. The process efficiency for methanol production is high, close to thermodynamical limits, and the process is certainly technologically ready for large-scale industrial production. Moreover, the technology mostly comprises industrially established process steps, where cost reductions can mainly be expected from learning in assembling the process and reduced costs from reducing high risk premiums of first-of-a kind-type of projects. The cost factors introducing uncertainty are mainly those associated with market conditions and regulatory mechanisms (e.g., fossil fuel pricing and CO_2 taxes, biomass price and logistics), as well as the uncertainty in to what extent there will be development of vehicle engines which can use methanol as a drop in fuel (e.g., for marine transportation and heavy trucks). Capacity building, innovation funds and public-private partnerships will help tackle barriers such as those related to investor risk premium and access to debt financing whereas cost reductions gained from experience when moving from fist-of-its-kind to nth-of-its-kind plants, either for greenfield projects or co-location to existing infrastructures, will play a secondary role.

Development needs, potential for innovation and policy mechanisms for 2nd generation ethanol production from biomass via biochemical technologies

The maturity of the second-generation ethanol production was obtained from the discussion in D3.2, based on available reports discussing the process performance and the main challenges for a few demonstration and commercial plants (i.e. this fuel was not analysed for each process step in D3.5).

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Table 3 summarizes the results from the three-step assessment of the maturity of the ethanol process. A main difference compared to the methanol case study is that the profitability of future ethanol plants will depend, among other factors, on technological solutions related to increasing the overall biomass conversion efficiencies (i.e., not necessarily to ethanol but considering currently not optimally utilised biomass fractions of lignin and hemicelluloses), and further intensifying the biomass fractionation and fermentation processes (e.g., through advanced continuous operations, higher product concentrations). Thus, the role of research and innovation grants will be more important for this type of plants.

On the other hand, similar barriers and related policy mechanisms to the case of methanol are also applicable here, as far as the economic factors are concerned. The main difference lies in the more developed state of end-use market for ethanol as a transportation fuel.

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Table 2: Technical and economic factors, barriers and policy mechanisms for methanol production from lignocellulosic biomass gasification.

Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
Technical			
Process efficiency	N	Gasification plants can reach, after modifications, theoretical efficiency yields in commercial scale. Conversion efficiency form feedstock to biomethanol is comparably high.[9]	Capital investment grants for higher efficiency technologies should focus on maximum utilisation of resulting by-products (e.g., tars), and reduce loss of carbon atoms to CO_2 emissions (e.g., by innovative CCU pathways).
Operating capacity	N	Regarding the operating capacity, gasification plants have achieved continuous operation (e.g., the case of GoBiGas).[10]	Capital investment grants with priority to specific technological pathways and conversion efficiencies. This can support increasing the number of demonstration plants to verify the stability of continuous opera-

[9] As for the syngas production part of the methanol path, it generally reaches the highest feedstock conversion efficiencies, typically in the range of 71.7-83.5% (Anderson et al. 2013). The combination of potential improvements in a gasification plant (measures improving the efficiency including the use of additives (potassium and sulfur), high-temperature pre-heating of the inlet streams, improved insulation of the reactors, drying of the biomass and electrification as decarbonisation means (power-to-gas)) can increase the cold gas efficiency to 83.5 % LHV-daf, which is technically feasible in a commercial plant. (Alamia et al. 2017).
Energy efficiencies for biomass to MeOH/DME synthesis were found to be 56-58% and 51-53%, respectively, taking LHV as reference. This efficiency is enhanced to 87 to 88% (LHV) if district heating is also counted as one of the products. (Sikarvar et al. 2017)

[10] The plant has been in continuous operation in a single run since the beginning of December 2017, namely for more than 1,800 hours, with consistent performance. In total, the gasifier has been operated for more than 15,000 hours, since its commissioning in 2014. The plant was operational after an initial period of 6 months. Potassium was added to saturate and stabilise the chemistry that controls the catalytic effect, to assure the quality of the produced gas thereby avoiding any clogging of the product gas cooler. The bed height of the gasifier was lowered so that the fuel could be fed closer to the surface of the bubbling bed in the gasifier, thereby reducing the heat transfer and clogging of the fuel-feeding screw and enabling 1800 h of continuous operation (Thunman et al. 2019).

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
			tion and test diversified biomass feedstock.
Co-location with existing infrastructures	M	Co-location of biomass gasification with existing methanol synthesis plants from natural gas is feasible from a technical point of view with respect to integration of material and energy flows. However, other parameters such as economic and regulatory reasons may constrain it.	Premiums and reduced taxation Capacity building
Process design: aspects	M	Issues with product quality, tar fouling in heat exchangers during syngas cleaning, and tar utilisation are solvable but may require innovations, especially if these issues appear in technologies demonstrated only in lower scales.[11]	Regulations and R&D grants
Scale-up aspects	M	Serious technical scale up issues from demonstration to full scale do not exist, other than biomass availability and logistic constraints (i.e., the theoretical economic optimum in terms of capacity may not be reached because of biomass logistics issues) No large biomass gasification plants have ever been built, however their economic performance can be assessed with some certainty on the basis of the operation of demonstration plants.	R&D grants and Innovation Fund
Economic			
Market conditions	S	Competition with other uses of biomass and development of alternative fuels for the transportation and power sector will play an important role for the enviro-economic assessment of methanol production via biomass gasification.	All policies mentioned below affect market conditions Labor costs policies for this kind of plants

[11] It should be noted that the gas cleaning complexity is very similar to what you have out from steam crackers of naptha or old coal gasifiers aiming for providing the petrochemical industry with building blocks; so large-scale plants can use the solutions previously applied to this kind of processes.

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
Capital investment and production costs	S	Biomass price, logistics and production costs are high; capital costs are also high, especially when no collocation is assumed or retrofitting of existing plants. In particular, the investment cost for handling and preparation of the feedstock (including drying) is considerable because of the low energy density and high moisture content of the fresh biomass. Biomethanol in the stage of first of its kind plant has similar production costs compared to biomethane and DME via biomass gasification. As mentioned in the scale-up aspects, there is an inherent trade-off between the economy of scale and the logistics of biomass for the plant.	Sufficient tax (or other CO_2 penalty) for using fossil fuels Feedstock premiums for low cost residual and waste biomass types
Uncertainties of production cost	S	For first-of-its-kind plant the biggest uncertainty is in getting high enough availability, thus assuring redundancy that avoid unplanned stops in the production is a must.[12] Temporal and geographical uncertainties pertaining to the estimated production costs are timing of the investment, the location of the installation and price of feedstock.	Feedstock premiums towards a common framework in EU countries (a challenging task)
Investor risk premium	M	High investment risk premium is expected due to unstable regulatory framework for investment and market prices of RESfules. Because the technology is still at the level of first of its kind plants (at least for the biomass to syngas part) uncertainty for investments increases. The GoBiGas plant was built by Göteborg Energi, which is an energy company owned by the municipality of Gothenburg	Capital grants and Innovation funds Capacity building and training for investors and industry on the needs of this sector

[12] For newly built processes it is a big challenge to reach high availability as fast as possible after commissioning.

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
		and was supported by the Swedish Energy Agency.	
Access to debt financing	M	This will mainly be a barrier for companies with high debt-to-equity financing ratios. On the other hand, for larger companies with a diversified business portfolio and low debt-to-equity financing ratios, as well as for public-private partnerships this will not be a significant barrier. The presently low interest rates also help overcome this barrier.	Development of green bonds or loans for green projects. The new EU innovation fund. Public Private partnerships and Joint Ventures
Commercially available process components	M	Only one component is considered less mature, namely the gasifier. The rest of the process components of the technology have already reached the nth-of-its kind installation and learning will only be related to the assembly of these parts into a new system.	Training, capacity building, and certification.
End-use market development (or engine development)	S	Methanol as an alternative fuel for marine and heavy duty applications is gaining interest. However, methanol is not a drop in fuel, therefore it requires dedicated engines to be used.[13] Presently, methanol is more popular in Asian countries, especially China used it in road transportation in light duty vehicles. In China, there are standards (GB/T23510-2009, implemented in 2009) allowing the use of up to 100% methanol fuel (pure	Standardisation (e.g., implementation of European standards allowing the use of methanol in high concentrations) R&D grants for engine development (e.g., dedicated to

[13] Methanol is a good fuel for spark-ignition (SI) reciprocating engines. However, the use of methanol requires various modifications in the current SI engines, in order make them compatible. Therefore, methanol cannot be used directly as a drop-in fuel. Besides SI engines, methanol could be utilized in special diesel engines (dedicated to methanol), having high compression ratios, or piloted with a small amount of diesel fuel. Therefore, methanol cannot be used in the diesel engines as a drop-in fuel as well. Methanol is a good option for marine application, nevertheless, it still requires dedicated engines with for example special injectors etc. The benefit of methanol over the methane in a form of LNG for marine application is a significantly lower onboard fuel storage size required for methanol, as it remains in a liquid state. Additionally, investment costs are much lower for methanol compared to LNG when retrofitting the vessels. According to FCBI Energy (FC Business Intelligence Ltd.) "installation costs of a small methanol bunkering unit have been estimated at around $430,000, and a bunker vessel can be converted for approximately $1.5 million. In contrast, an LNG terminal costs approximately $50 million and an LNG bunker barge $30 million". Therefore, methanol has a big potential in marine application.

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
		methanol). Besides road transportation, methanol has a potential for marine application, where presently Stena-line has a methanol-powered vessel.[14] Methanol has attractive physicochemical properties, e.g., very high octane number, low carbon to hydrogen ratio, but is also highly toxic.[15]	methanol powertrains) Social perception related to the toxicity of methanol Introduction of tax incentives for using biomethanol in fuels. Comprehensive LCA studies are essential for comparing alternatives.[16] Increasing the methanol refueling infrastructure

[14] Properly formulated blends with alcohols in petrol have been and are today in safe use. Current gasoline standard EN228 allows 3% of methanol in the blend. Alcohols are not miscible with diesel fuel and would require emulsions, which is not preferable. It can be concluded that the "best" use of methanol on a short-term horizon is as a low blending component or for use in fuel-flexible vehicles. As no new methanol-compatible flexible fuel vehicles (FFV) are available at the moment, the use of methanol for low blending is the most likely option for the near future (Lundgren, et al., 2012). However, commercial methanol dedicated powertrains and vehicles exist in Asian markets (presently 10 091 vehicles in operation in China), therefore the biggest challenges to accelerate the end-use EU market deployment are regulations, infrastructure, and possibly but not necessarily costs of the fuel.

[15] Methanol has a very high octane number, which brings great potential to reduce fuel consumption in the future generation of IC engines running with high compression ratios or advanced combustion regimes. Additionally, methanol has the lowest carbon to hydrogen ratio which yields the lowest CO_2 emissions per unit of traveled distance, compared to other fuel alternatives. The disadvantage of methanol is toxicity, which is higher than ethanol and similar to gasoline. However, methanol vapors must be four times more concentrated in the air than gasoline to ignite, which is why methanol is safer fuel. Besides, methanol is also a very good option for fuel cell applications.

[16] Comprehensive LCA based approach would be required for an in-depth comparison of the environmental impact of biofuels used in internal combustion engines (ICVs) and electric vehicles (EVs). Yet, both these depend on the system boundaries and how the surrounding system develops over time. Thus, the environmental impact of production of batteries and operating of the EVs will depend on how the electricity mix develops (i.e., its associated GHG emissions). The IC and batteries operating life time and the potential for recycling their materials after their end of use, particularly when it comes to rare meals in batteries, should also be considered. Finally, biomass use will be linked to other environmental goals such as biodiversity which may also be subject to discussion and therefore need to be analysed. Considering the urgency of mitigating carbon emissions, it is likely that both EVs and biofuel fired IC vehicles are needed, but with different penetration over time.

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
Enviro-economic aspects	M	Sustainability goals in RED II do not clearly include CO_2 emission targets per sector, and CO_2 taxation in the future is uncertain.	Regulations Targeted investments and R&D in value chains for the enviro-economic optimal transportation sectors.

Table 3: Technical and economic factors, barriers and policy mechanisms for 2nd generation ethanol production from lignocellulosic biomass via biochemical technologies.

Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
Technical			
Process efficiency	S	Relatively low conversion efficiencies 15%-25% on mass basis (or, 25%-40% on energy basis) are reported in a few running demonstration and commercial scale plants.	Technology and/or innovation premiums[17]
Operating capacity	M	Lignocellulosic ethanol is on the verge of being commercial with several industrial scale first-of-its-kind plants using a variety of integrated technologies in early operation. The technology developers are competing in licensing their technology to locations with strong support policies. All of them are based on agricultural residues while technologies based on forestry residues still have to reach the level of demonstration scale. In the first period of operation there were issues with impurities in the feedstock influencing the performance as well as excessive wear of certain equipment. These hurdles were overcome during the first year of	R&D grants and Innovation funds for 2nd generation ethanol from forest waste. Capital investment grants with banding for increasing the number of demonstration and commercial plants to verify the stability of

[17] Technology or innovation premiums aim at stimulating the capacity for innovation of companies engaged in research and development.

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
		operations reaching continuous operation of 40,000-60,000 hours (EC, 2017c). A potential technology barrier is obtaining a long-term stable process with biocatalysts like enzymes and yeast.	continuous operation and test diversified biomass feedstock
Co-location with existing infrastructures	M	Co-locating an existing 1st generation plant and a new greenfield 2nd generation plant can have mutual commercial and technical benefits. However, effective policy instruments are crucial. A market start-up will only happen if stable support to technology development and technology commercialisation is given (by way of economic incentives) for a reasonable timeframe reflecting investment lifetimes.	Premiums and reduced taxation Capacity building
Process design aspects	S	A wide variety of technical challenges exist in the different steps of bioethanol processing from pretreatment to the final separation of the ethanol–water mixture. These include: - Improvement of micro-organisms and enzymes. - Use of C5 sugars, either for fermentation or upgrading to valuable co-products. - Use of lignin as value-adding energy carrier or material feedstock. - Feedstock handling and processing in cellulosic plants.	R&D grants
Scale-up aspects	S	The cost of cellulase has been one of the deterrents in the profitable business case of a commercial scale cellulosic ethanol plant. The integrated enzyme production substantially lowers this cost and makes the business case profitable for commercial scale production reaching cost savings of more than - 50% compared to on-site enzyme production and of more than - 70% compared to off-site enzyme production.	Support was made available by a FP7 demonstration project for a scale-up
Economic			

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
Market conditions	S	Competition with other uses of biomass and development of alternative fuels for the transportation and power sector will play an important role for the enviro-economic assessment of methanol production via biomass gasification.	All policies mentioned below affect market conditions
Capital and production costs	S	Bioethanol production from lignocellulosic biomass at large scale has not yet been fully demonstrated as an economically feasible option (i.e., early commercialisation stage). To reduce the cost of bioethanol production, it is necessary to clarify and further improve the important technological steps (i.e. enzyme development: activity, stability and production costs). (Achinas et al. 2016) The production cost of cellulosic ethanol typically exceeds 100 EUR/MWh subject to the feedstock cost. For cellulosic ethanol plants cash cost contributes with a large portion to the overall production cost, with cost of feedstock often being the biggest single element (strongly dependent on cost of feedstock and ethanol yield)	Feedstock premiums for low cost biomass, tax in fossil fuels
Uncertainties of production cost	S	Feedstock supply at economically attractive prices are still challenging.	Feedstock premiums
Investor risk premium	M	Moderate to high investment risk premium (e.g., lower than the gasification- based fuels because of experience from the operation and logistics of the 1st generation plants). It shares, however, with all RESfuels the unstable regulatory framework for investment and market prices. Moreover, there is already market for ethanol as transportation fuel, so access will be easier.	Capital grants and Innovation funds Capacity building and training for investors and industry on the needs of this sector
Access to debt financing	M	Companies with experience in 1st generation plants (either for co-allocation with 1st generation or for greenfield 2nd generation ethanol projects) are expected to have substantial know-how in access to debt-financing. Still, larger companies with a diversified business	Public Private partnerships and Joint Ventures

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
		portfolio and low debt to equity financing as well as public-private partnerships will overcome this barrier more easily. The presently low interest rates also help overcome this barrier.	
Commercially available process components	N	Typical process components of this technology are commercially available, including bioreactors, although for the latter on-going R&D focuses on intensifying the processes from batch to continuous operations operating with in more concentrated solutions.	R&D grants
End-use market development (or engine development)	M	Today ethanol has a considerable utilisation in road transport but there is a significant potential for the use of ethanol in aviation application as well. If it comes to marine application, ethanol might be too expensive, compared to methanol.[18] In the European market, there are available blends of ethanol with gasoline in both low and high concentrations such as E5, E10, and E85. Ethanol can be utilized directly in special jet engines (under R&D). However, in 2018, ASTM D7566 certified the jet fuel produced from ethanol, so-called alcohol to jet (ATJ) using ethanol as a feed. Important is that all fuels compatible with ASTM D7566 are compatible with ASTM D1655, which is an international standard for regular Jet A/A1. ATJ conversion pathway creates pure paraffins and isoparaffins from ethanol by dehydration, oligomerisation, hydrogenation, and fractionation (a good example is a LanzaTech technology).	Regulations and Green procurement Standardization R&D grants (e.g., related to the dedicated to ethanol powertrains) Introduction of tax incentives for using ethanol fuels Increasing the ethanol refueling infrastructure Comprehensive LCA studies are essential for comparing alternatives (see note in Table 2)

[18] Ethanol is a very good fuel for spark-ignition reciprocating engines. Using blends of ethanol with gasoline in the low concentrations of ethanol (i.e., <10%) does not require any modifications in engines in the current fleet of vehicles. Ethanol blends with diesel fuels (ED95) were utilized in dedicated heavy-duty diesel engines with a very high compression ratio (e.g., commercial Scania trucks). Most of the gasoline sold in Europe contains around 5% ethanol (EN 228). Blends between 10 to 25% ethanol require modified fuel injection systems, fuel pump, fuel pressure device, fuel filter, ignition system, evaporative system, fuel tank, and catalytic converter. Blends between 25% to 85%, require also basic engine, motor oil, intake manifold, and exhaust system upgrade. Blends with over 85% ethanol, on top of all mentioned changes, require special cold start system needs to be implemented. Flexi-fuel vehicles have all the necessary adjustments, so they can run the high ethanol blends, more effectively than unmodified regular SI engines

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Factor	Barrier (Severe (S), Moderate (M), None (N))	Explication	Policy mechanisms to overcome barriers
Enviro-economic aspects	M	Sustainability goals in RED II do not clearly include CO_2 emission targets per sector, and CO_2 taxation in the future is uncertain.	Regulations Targeted investments and R&D in value chains for the enviro-economic optimal transportation sectors.

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4. Conclusions

This report presents and applies a three-step approach for associating the most important technical and economic factors with relevant barriers for biomass conversion technologies to advanced fuels and identifying policy mechanisms to overcome such barriers. Although only the most important conversion technology factors and barriers are presented in this report, the three-step approach can be extended to additional barriers and factors, and links between them. This approach can be considered as a first step towards a methodological framework for a generic linking of policy mechanisms to barriers and technology factors.

The approach is applied to two case studies (i.e., methanol production from the gasification pathway and ethanol production from the biochemical pathway) representing biomass conversion technologies considered as efficient and low risk, based on the findings of previous deliverables (i.e., mainly D3.2, and D3.5). The results indicate that the potential for technical improvements and innovation potential are rather limited in the case of methanol production. Technological development of vehicle engines to efficiently use methanol as a drop-in fuel are more important than the innovation of the biomass conversion technologies for this pathway. Cost reductions for the methanol conversion processes can mainly be expected from learning and knowledge sharing in assembling existing process components in the process, which is rather complex. More important are economic factors influenced by market conditions and regulatory frameworks on fuel pricing, CO_2 taxes (i.e., especially in an initial phase to make-up for price differences between fossil fuels and advanced biofuels), blending targets, and creating a more stable investment environment.

The case of 2nd generation ethanol production differs from the methanol process with respect to the potential of technology improvement. Although this case has reached the commercialisation stage, more technological innovations are expected with respect to the possibilities to utilise the by-products from the process (e.g. hemicelluloses and lignin) to create added value chemicals, which can significantly increase the profitability of the plants. On the other hand, similar barriers and related policy mechanisms to the case of methanol are also applicable here, as far as the economic factors are concerned. The main difference lies in the more developed state of end-use market for ethanol as a transportation fuel.

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