ADVANCEFUEL

Monitoring RESfuels

D1.4 Monitoring framework and the KPIs for advanced renewable liquid fuels (RESfuels)

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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 CO_2 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, the project will investigate individual barriers and advanced 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 an 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 to ensure that renewable fuels are truly sustainable. A decision support tool will be created for policy makers to enable a full value chain assessment of renewable fuels, as well as useful scenarios and a 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 to 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 by 2030 and beyond.

To stay up to date with ADVANCEFUEL's stakeholder activities, sign up at:
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Executive Summary

This report is the first of a series in monitoring reports of the ADVANCEFUEL project. The objective of this report is to inform the stakeholders (i) on the status of advanced renewable fuels (RESFuels), related investments, policies in different countries, and the developments on feedstock prices, and (ii) on the preliminary outcomes of the ADVANCEFUEL project related to cost reduction potential of dedicated cropping systems and the identification of good practices and policies. The results presented here are based on a monitoring framework of selected key performance indicators (KPIs) previously presented in the ADVANCEFUEL deliverable D1.2.

Globally, the total lignocellulosic ethanol production capacity is currently ~ 300 kt/a. Brazil holds the largest installed production capacity, with a total of 30%, followed by 25% in the US. In Europe, the installed production capacity is around 11% of the overall capacity. There are, in total, 10 operational commercial-scale, first-of-a-kind (FOAK) demonstration plants. The largest ones are in the US (POET-DSM) and Brazil (GranBio). There is currently only one operational FOAK demonstration plant in Europe, termed: ChemCell Ethanol from Borregaard Industries AS in Norway. This plant utilises sulphite spent liquor from spruce wood pulping. In recent years, difficult market conditions coupled with high operational costs and financial difficulties have resulted in the closure of several lignocellulosic ethanol plants, including the Beta Renewable plant in Italy (which began operation in 2013 as the world's first commercial-scale cellulosic ethanol facility). The total installed production capacity would increase by 90% in the case where the existing idle plants become operational again. In comparison with lignocellulosic ethanol, the production of biodiesel using lignocellulosic feedstocks is negligible. The only operational renewable diesel plants in Europe (Finland and Sweden) use tall oil as the main feedstock. Renewable fuel production from non-biological (refers to synthetic fuels produced from CO_2 and H_2. H_2 can be produced via water electrolysis using renewable energy) is in a pilot and demonstration phase, and the total installed capacity in Europe is estimated to be around 6 kt/a.

The US and Italy were the first two countries to introduce dedicated mandates for advanced biofuels. In the US, a cellulosic biofuel mandate became a part of the revised Renewable Fuel Standard (RFS), which was announced in 2007, while the Italian advanced biofuel mandate was announced in 2014. In Europe, the revised Renewable Energy Directive ((EU) 2018/2001) introduced an EU-wide obligation to fuel suppliers in Europe. This directive also introduced a sub-mandate for advanced biofuels. The sub-mandate regarding advanced biofuels will be 0.2% in 2022, 1.0% in 2025, and 3.5% in 2030.

Investments to advanced biofuels have been relatively small when compared with the investments to conventional biofuel. Biofuels experienced a steady growth in new investments from 2005 to 2007, when growth in first-generation biofuels was increasing. After 2008, investments in biofuels started to decline and fluctuate at lower levels. New investments to advanced biofuels started in 2008 and has since followed a steady path.

Feedstock prices next to the capital costs are the dominant cost factor effecting the advanced biofuel production costs (feedstock costs comprise ~40% of the total production cost of biofuels). However, there are currently no established markets to define feedstock prices dedicated to advanced biofuels.

A thorough literature survey was performed to identify innovations that can help reduce production costs of dedicated crops. The production costs of those innovations were

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compared to reference scenarios (before innovation implementation) in order to identify the cost reduction potential. Biomass cost reduction can be carried out at a rate of 7-25% when innovative approaches such as: propagation by seeds and/or by stem segments, increasing the planting density, economy of scale, and learning effects are considered. Cropping on marginal lands may, however, increase the production costs (in the range of 10-17%) rather than reduce.

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Contents

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1. Introduction

This report is the first of a series of monitoring reports within Work Package 1 of the ADVANCEFUEL project. The ADVANCEFUEL monitoring framework is based on the selected KPIs which have previously been presented in deliverable D1.2[1]. These are summarised in Table 1 below (indicating in blue also which are specifically covered in this report).

Table 1: Selected KPIs of the ADVANCEFUEL project

	KPIs	Present in this report
RESfuels market progress related KPIs		
Resource specific	Wood pellet & wood chip prices	☑
	Straw prices	☑
Conversion and end use specific	Existing RESfuel plant capacity	☑
	RESfuel production and consumption	☑
	Total Investments	☑
	Public support to (advanced) biofuel technologies - Total R&D to biofuels - EU funding R&D to advanced biofuels	☑ ☑ ☑
	Status of the policy support to advanced biofuels	☑
		☑
Project related KPIs		
WP2 feedstock supply	Feedstock cost reductions due to innovative technologies	☑
	Availability of marginal land in Member states	
	Technical potential of dedicated cropping	
WP3 conversion technologies	Well-to-wheel system efficiency increase due to innovative approaches	
	Time framed CAPEX need for TRL level increase of certain technologies	
	CAPEX reduction due to opportunity for greening the fossil infrastructure	
WP4 sustainability and certification	A set of additional sustainability criteria for RESfuels	
	A set of recommendations on the harmonisation of voluntary schemes focusing on RESfuels	
WP5 end use	Best practices in Europe or outside	☑
	Fuel performance data	
WP6 integrated analysis	Gross employment effect of the selected pathways	
	GHG emission reduction of selected pathways	

The data regarding global advanced biofuel plant status the International Energy Agency (IEA) bioenergy, Task 39 database was used. This database has been elaborated and maintained by bioenergy 2020 (https://demoplants.bioenergy2020.eu/). Whenever needed the plant status were researched on internet. Straw prices were derived from Eurostat statistics. All other KPIs within the RESfuel market status chapter were based on the literature review. The project related KPIs were provided by the relevant work package leaders.

[1] http://www.advancefuel.eu/en/publications

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This report consist of two main parts:

- **RESfuel market progress monitoring,** where the aim is to systematically and continuously collect data regarding RESfuels and inform the stakeholders on the actual progress.

- **Project monitoring,** where the aim is to share the main outcomes of the project and provide new knowledge to the stakeholders stemming from the continuous work within the ADVANCEFUEL project.

How to read this report:

- **Market progress of RESfuels are presented in Chapter 2**, and include: market progress of RESfuels; lignocellulose based RESfuel status; RESfuel production and consumption in Europe; investments to RESFUEL; European Commission Funding Programs; policies promoting RESfuels; and developments regarding feedstock costs.

- **Project related KPIs are presented in Chapter 3**. These include: innovative cropping schemes and the cost reduction potential, and best practices.

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2. Market progress of RESfuels

2.1. Advanced biofuels

2.1.1. Lignocellulosic ethanol plants

The total capacity of lignocellulosic ethanol production on a global scale is around 300 kt/a. Brazil currently holds the largest installed production capacity, with 31% of total global production capacity of advanced lignocellulosic ethanol. This is followed by the US with a 25% share, whereas Canada, China, and Europe contain a rate of 16%, 17%, and 11% shares respectively. With regard to operational lignocellulosic ethanol plants in Europe, the Nordic countries, Finland, Norway Sweden, and Germany appear to be the leading countries. Annex 1 (Table 8) provides a list of operational lignocellulosic plants.

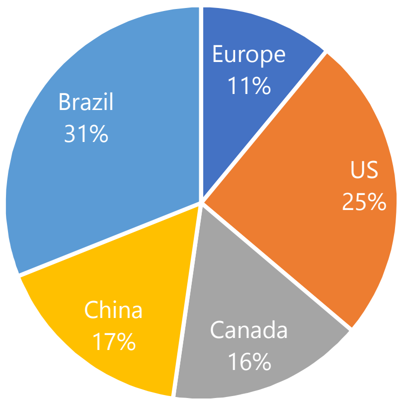

Figure 1: Lignocellulosic ethanol production capacity. (Based on data in IEA Bioenergy Task 39 database)

Globally, there are in total 10 operational commercial-scale, first-of-a-kind (FOAK) demonstration plants. The largest plants are currently;

- in the US (POET-DSM, using corn cobs, leaves, husk and some stalk with a production capacity of 75 kt/a cellulosic ethanol) and
- in Brazil (GranBio, using bagasse and straw with a production capacity of 62 kt/a).

There is at present only one operational FOAK demonstration plant in Europe, termed ChemCell Ethanol from Borregaard Industries AS in Norway. This plant has been producing lignocellulosic ethanol with an installed capacity of 15.8 kt/a, using sulphite spent liquor from spruce wood pulping since 1938.

FOAK demonstration plants play a vital role in “de-risking” technologies. They normally provide a technological performance guarantee in scaling-up and validating the conversion process performance pathways. They also verify how the CAPEX and OPEX private-sector financing can be secured.

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In recent years, difficult market conditions coupled with high costs have forced the closure of several lignocellulosic ethanol plants. Three FOAK plants are now idle (see Annex 1); two in the US and one in Italy. The Beta Renewable plant in Crescentino, Italy began operation in 2013 as the world's first commercial-scale cellulosic ethanol facility. In the first four years, the operators dealt with extensive pre-treatment issues[2] and had to reconstruct its processing procedures. The facility had downgraded to 50 million litres of annual capacity from the original 75 million litres, before closing just 4 years later in 2017 (ICCT, 2018). The plant was then shut down due its parent company having to file for bankruptcy. After two years of a slow ramp-up, DuPont sold its first large, 110-million litre (83 kt/a) facility in Nevada, Iowa and exited the business in 2018[3]. Additionally, eight demonstration plants which were previously operational are now idle. The majority of these are located in Europe and the US.

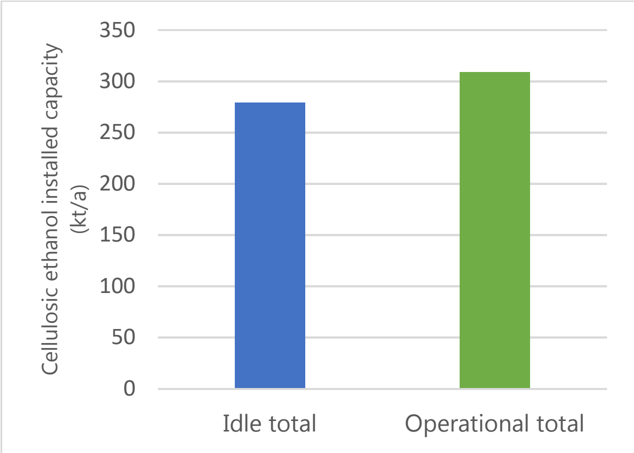

Figure 2: Operational vs idle cellulosic ethanol plants, globally (kt/a). Source: Own figure, data taken from IEA Bioenergy Task 39 database.

Figure 2 compares the current total operation plant production capacity with the total idle production capacity. As can be seen from Figure 2, the idle plant capacity is quite large, close to 90% of the total operational capacity. If idle plants were to become operational again, the total production capacity would increase to a potential 600 kt/a.

2.1.2. Lignocellulosic diesel plants

Production of biodiesel using lignocellulosic feedstocks is slim in both Europe and other countries. There are only two biodiesel plants in Northern Europe (Finland and Sweden), using tall oil[4], as the main feedstock. The total installed capacity of these two has been reported to be around 120 kt/a.

Thermochemical conversion (gasification and pyrolysis) of lignocellulosic feedstocks to fuel is a promising pathway. There are two operational demonstration plants that produce Fischer Tropsch (FT) liquids but the total capacity is very small (<2 t/a). The operational gasification plants, mainly, produce ethanol (i.e. Enerkem in the US uses municipal solid waste (MSW) as feedstock), high quality gasoline (Bioliq, Karlsruhe Institute of Technology (KIT) in Germany), bio-oil (Fortum in Finland) and SNG (Surrey Biofuel in Canada).

Many gasification-based plants in Europe are currently idle (i.e. BioMCN[5]-Netherland, BioSNG Guessing in Austria, GoBiGas in Sweden).

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2 Particularly due to rocks and dirt entering the pre-treatment system along with the feedstock
3 http://biomassmagazine.com/articles/15743/verbio-to-buy-dupont-cellulosic-ethanol-plant-convert-it-to-rng
4 Tall oil is a liquid by-product of wood pulp production using the kraft process.
5 This plant focuses on methanol production from crude glycerin, thus, it is based not lignocellulosic feedstock.

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2.2. Other renewable liquid fuels

Other renewable liquid fuels refer to synthetic fuels produced from CO_2 and H_2. H_2 is produced via electrolysis using renewable electric. These fuels are in a pilot and demonstration phase while the total installed capacity in Europe is estimated to be around 6 kt/a (Figure 3). Despite of the existence of several pilot and planned projects, this production capacity is dominated by only two demonstration plants: the George Olah plant and the Audi e-gas plant. In Iceland, the George Olah plant of Carbon Recycling International (CRI) has the capacity to produce 4000 t methanol annually. The feedstocks are provided by the geothermal power plant, which emits CO_2 and produces electricity. In the Audi e-gas plant in Werlte (Germany), CO_2 from the adjacent biogas facility is reacted with H_2 to synthesize methane. A 6 MW alkaline electrolyser delivers the H_2. The electrolyser runs especially during periods with low-demand for electricity, for instance, on the weekends and nights. In the Store&Go project power to methane, technology is demonstrated in three plants; in Germany, Italy, and Switzerland. In the largest (Germany) a 2 MW alkaline electrolyser produces hydrogen to convert CO_2 from a bio-ethanol plant in methane (~1 MW). Several smaller scale methane projects (<1 MW capacity) have been conducted and are under development, but these are not included in our overview (Bailera, et al. 2017)

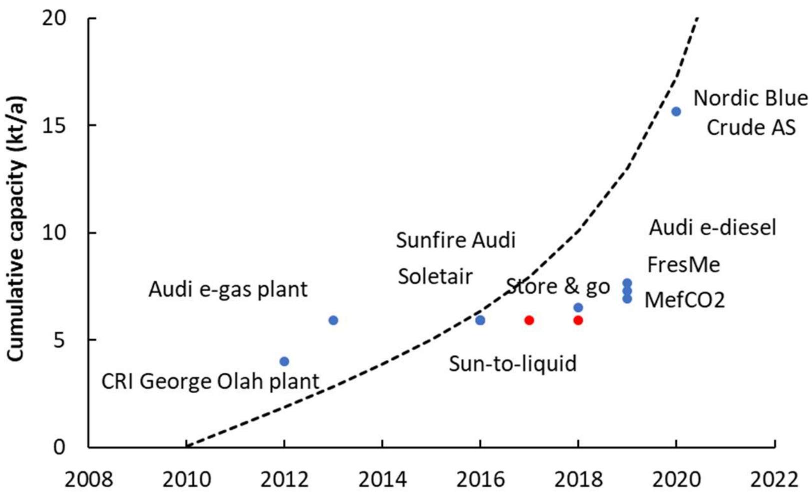

Figure 3: Cumulative production capacity of plants manufacturing synthetic fuels from CO_2 in Europe in kt per year. Beyond 2018, the capacity is based on planned projects. Striped line represents the estimated trend in growth. Plant additions are depicted in blue marks, decline in capacity (due to closure of a plant) is indicated by red marks.

In 2016, three related H2020 projects (STEPWISE, FresMe, and MefCO2) were proposed to develop the value chain of CO_2 capture and conversion to methanol. In STEPWISE, CO_2 is captured from the blast furnace gas of a steel plant in Sweden using novel SEWGS purification technology. In the FresMe project the captured CO_2 from the steel plant is converted into methanol and evaluated as fuel for shipping. In the $MefCO_2$ project, CO_2 is captured from a coal-fired power plant and converted into methanol using H_2, which is produced by electrolysis driven on intermittent renewable electricity.

In other pilot studies, the FT synthesis of hydrocarbons (e.g. gasoline, kerosene, diesel) is explored for which the syngas is produced by the reverse water-gas-shift (RWGS) reaction. CO_2 from various sources and H_2 from electrolysis are used as feedstocks. Solid oxide electrolysis was used in the Sunfire plant in Dresden (Germany), which ran for approximately 1500 hours and produced around 3 t of oil. In the Solitair project (Finland) a similar concept is followed,

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now based on CO_2 capture from air. Via FT synthesis around 6 kg of oil and wax was produced in 300 hours. Instead of RWGS, the Sun-to-Liquid project (Spain) investigates the reaction of CO_2 and H_2O in a solar thermal reactor to produce syngas, which is converted by FT synthesis into fuel for aviation. Based on these pilot studies, several larger demonstration projects are now under development. Audi is constructing an e-diesel plant in Switzerland running on hydroelectricity. In Norway, Sunfire and Nordic Blue Crude AS plan to scale-up the Dresden pilot plant to a production capacity of 8000 t/a synthetic oil.

Developments in technology components

To deploy CO_2 conversion routes to produce RESfuels at scale, development of the different technology components is needed. Hydrogen production by electrolysis is for most approaches one of the key technologies in the value chain. Although water demand is limited, water splitting is an energy intensive process and requires large amounts of electricity. This electricity should be supplied from renewable electricity sources and its deployment and costs will also determine the growth of this type of RESfuels. Besides the costs of (renewable) electricity, the investment costs of the electrolyser contribute significantly to the fuel production costs as well. Although alkaline electrolysis is a mature technology with over 20 GW of cumulative installed capacity worldwide (Detz et al 2018), more novel technologies, such as Proton Exchange Membrane (PEM) and high temperature electrolysis, are still in the development stage. Further development of electrolysers has been achieved in several pilot and demonstration projects, as well as exploring their use for various end-use applications, such as hydrogen production for the fertiliser industry, fuel synthesis, heating applications, and for the mobility sector. Novel electrolyser technologies (such as high temperature electrolysis and CO_2/H_2O co-electrolysis) are also under development, and may lead to significant results concerning efficiency in the overall synthetic fuel production scheme.

Besides the two large electrolyser facilities in the Audi e-gas plant and CRI methanol plant, a 6 MW PEM electrolyser is operating in Energiepark Mainz (Germany), and a similar size plant is under construction in Linz (Austria) for the H2Future project. Several smaller scale projects are running or under development (Schmidt 2018). Currently plans for several larger-scale electrolysis facilities (10-100 MW) are being developed. Together these projects seem to initiate a significant boost in the European electrolysis capacity in 2030 and beyond, and it is expected that the costs will reduce considerably.

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Table 2: Overview of the development status of synthetic fuel production technology

Development stage / Category	Low (TRL<7)	Medium (TRL 7-8)	High (TRL 9<)
Renewable electricity			- Solar PV - Wind Onshore - Wind Offshore - Hydropower
Electrolysis	- High temperature electrolysis - Co-electrolysis	- PEM electrolysis	- Alkaline electrolysis
CO_2 capture	- Direct air capture	- Capture from less concentrated point sources	- Capture from highly concentrated point sources
CO_2 conversion	- Co-electrolysis	- Direct CO_2 conversion pathways - RWGS - MTO	- Methanol synthesis from syngas - FT synthetic fuel production from syngas - MTG

The CO_2 source for RESfuel production is obtained from point sources based on fossil, geological, or biological carbon or from air via direct air capture. CO_2 capture and storage (CCS) technology is currently active at megaton scale, mainly for enhanced oil recovery, but also in the fertiliser industry. The capture from flue gasses with a high CO_2 concentration is preferred for energetic reasons and thus costs. In the early phase, capture from fossil-based heavy industry (as e.g. demonstrated in the STEPWISE project) may avoid some emissions by carbon re-use, but will only be a solution during a transition period. Processes running on biomass, e.g. from biogas upgrading or bio-ethanol plants, are more attractive in the long run as sustainable carbon source. As these sources may become limited, CO_2 extraction from air is needed to deploy sustainable synthetic fuel production at scale. Currently only a few companies are developing direct air capture (DAC) installations, which can deliver around 900 t of CO_2 per year.

CO_2 conversion technology to produce methane, methanol, or hydrocarbon liquids is developed at large scale. In most commercial routes, fossil feedstocks are converted into syngas (mixture of CO, H_2, and some CO_2). Via the water-gas shift (WGS), an equilibrium reaction the ratio in this mixture can be optimised for the following chemical conversion reaction. The reverse reaction (RWGS) allows to convert CO_2 and H_2 into a suitable syngas for processes such as methanol and Fischer-Tropsch (FT) synthesis, which are both deployed at large commercial scale. Novel reaction pathways are also investigated and CRI has successfully implemented the direct hydrogenation of CO_2 to produce methanol without first converting CO_2 to syngas. Mobil has also demonstrated that methanol can be converted into several products such as gasoline, kerosene, diesel, olefins, and aromatic compounds. Although the methanol-to-gasoline (MTG) process is now implemented in several commercial plants, production of the other fractions (here referred to as MTO) has not been commercialised at this large of a scale.

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2.3. Advanced biofuel consumption in Europe

Derived from the recent GAIN report (USDA, 2018), Figure 4 presents the amount of biofuels consumed in Europe broken down into different types. Figure 5 illustrates the share of biofuels in Europe broken down into different types. As shown, the production and consumption of advanced biofuels in Europe relates to hydrogenated vegetable oils (HVO) using used cooking oil and animal fats (referred to as Part B in the graph). Biofuel consumption from lignocellulosic feedstocks were less than 0.2% of total consumption (refers to Part A). In absolute terms, advanced biofuels produced from the feedstocks listed in Part A of the renewable energy directive is around 500 ktoe (<21 PJ) . The cellulosic ethanol production in Europe is stated as 0.2 PJ, which is only 1% of the total biofuels produced from feedstocks listed in Part A (USDA, 2018). In the US, only around 300 million gallons of cellulosic biofuels (around 22PJ) were produced against the target of 5.5 billion gallons (in 2017). The largest gains in cellulosic fuel production in the US haven't come from cellulosic ethanol at all, but rather, from the reclassification of biogas as cellulosic biofuels (ICCT, 2018a).

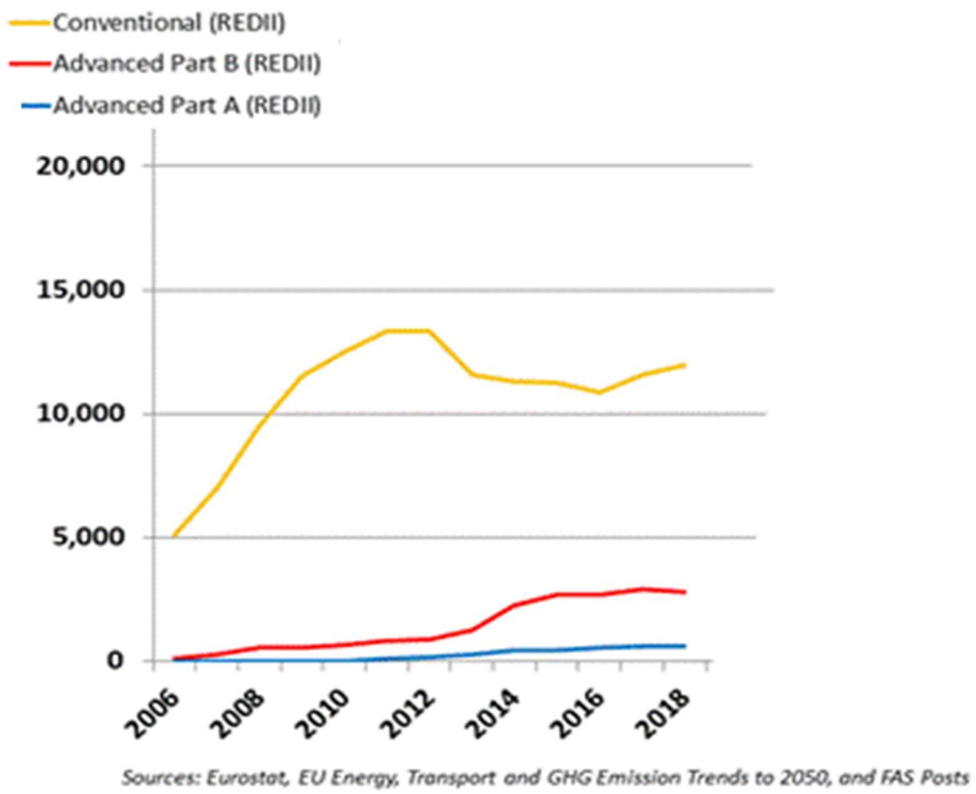

Figure 4: Trends in Conventional and Advanced Biofuels in Europe, installed capacity. Source: Eurostat (derived from USDA, 2018)

* *Part A refers to biofuels produced mainly from lignocellulosic wastes and residues. Part B refers to biofuels produced from used cooking oil and animal fats and residues. Conventional biofuels are the biofuels produced from food crop-based feedstocks.*

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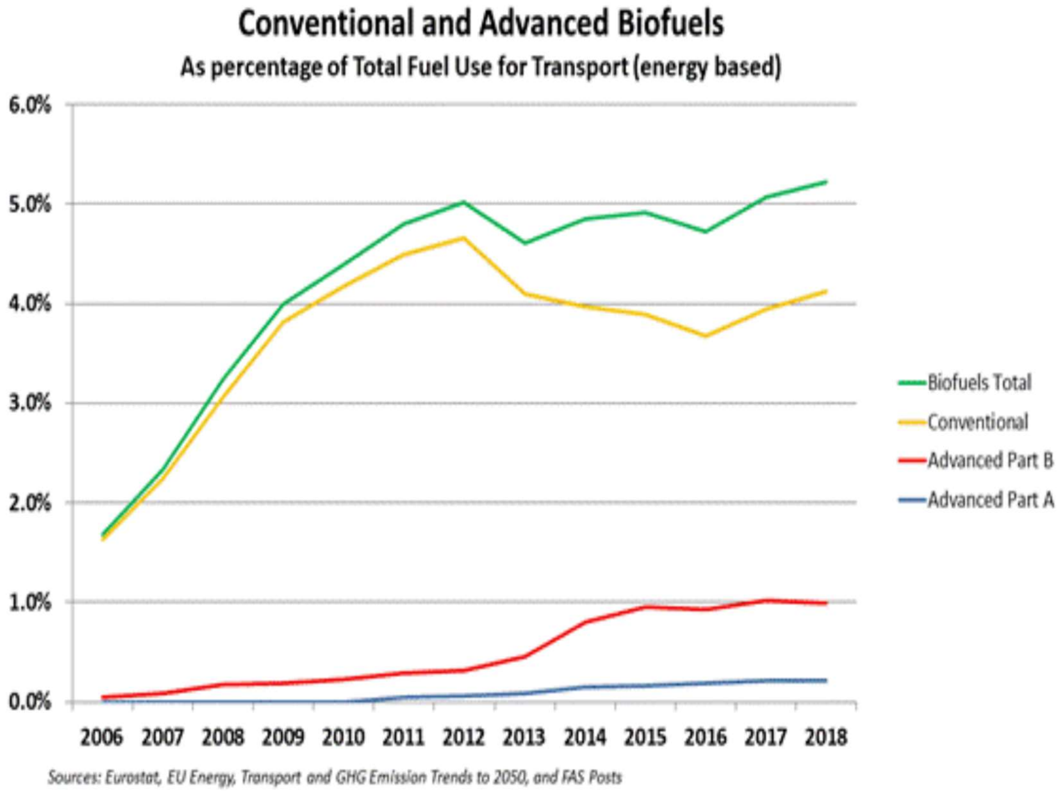

Figure 5: Conventional and Advanced Biofuels consumption as percentage of total fuel use in transport in the EU. Source: Eurostat (derived from USDA, 2018)

2.4. Investments to RESfuel

Biofuels experienced a steady growth in new investment from 2005 to 2007, when growth in first-generation biofuels was increasing. After 2008, investments in biofuels started to decline and fluctuate at lower levels. In 2016, they were lower than in 2005. Figure 6 illustrates the global new investments to biofuels and also presents the breakdown of these investments to major world regions. Plateauing of first-generation capacity may explain this decline, including uncertainties over future legislation, and the delayed development of second-generation biofuels and costs (Frankfurt School & UNEP, 2018). Investments to advanced biofuels, starting from 2008, follow a steady path and appear relatively small.

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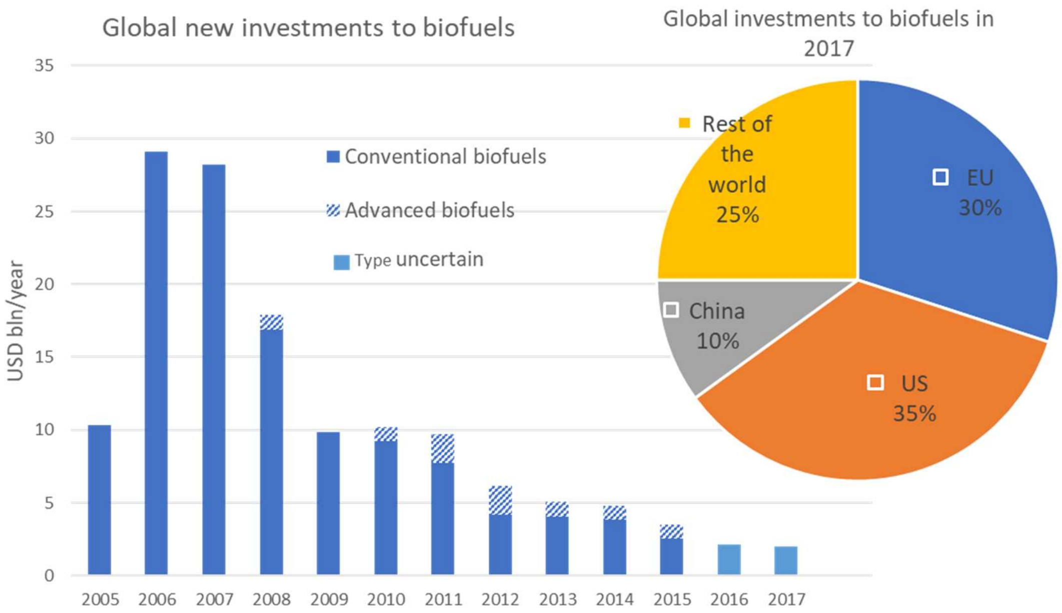

Figure 6: Global new investments to biofuels (Data from Frankfurt School & UNEP, 2018 combined with IRENA, 2016)

Total investments of a number of plants are introduced in Annex 2.

2.5. EC Funding programs

Next to governmental support to biofuels European Commission initiates public co-funding to enable industrial-scale demonstration of advanced biofuels through programs, such as NER300, Horizon2020 (H2020), European Industrial Bioenergy Initiative (EIBI), ERA-NET+, Bio-Based Industries Joint Undertaking BBI JU.

NER300

NER300 is a financing instrument[6] to fund innovative low-carbon energy demonstration projects, including bioenergy and advanced biofuels. This instrument is managed jointly by the European Commission (DG CLIMA), European Investment Bank and Member States. The available funding comes from emission trading allowances (of 300 million) under the New Entrants' Reserve of the ETS. NER300 competition was established under Article 10a(8) of the Emission Trading Directive 2009/29/EC. The first calls were launched in 2011 and 2012. Among these projects were five advanced biofuel, and three bioenergy projects announced to receive funding. However, the majority of these proposals were withdrawn. Currently, the Verbio project in Germany is the only operational plant. This plant converts straw into biomethane and there are plans to extend the plant to reach 16.5 MW capacity by 2019.

The second NER300 call was in 2014, whereas six of the selected projects were bioenergy projects. Two of them aimed to produce ethanol for the transport sector, in which one of them

[6] The NER300 program provides financial support only after production has begun, offering no concrete assistance for companies in covering high capital costs.

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was withdrawn. The status of these projects, also including the bioenergy related ones, is presented in Table 3 below.

Table 3: Status of bioenergy projects announced to receive NER300 funding (SETIS, ETIP Bioenergy, 2019).

Category	Project/ Organisation	Country	Fund. €Million	Status
First call				
Advanced biofuels	Ajos BTL	Finland	88.5	Ongoing-environmental permission is expected in early 2018. The project aims at starting the production by the end of 2019.
Advanced biofuels	BEST	Italy	28.4	Ongoing-initially operational but shutdown in 2017. Eni's Versalis won the bidding and is in the process of transferring the business[7]
Advanced biofuels	CEG Plant Goswinowice	Poland	30.9	Withdrawal
Advanced biofuels	UPM Stracel BTL	France	170.0	Withdrawal
Advanced biofuels	Woodspirit	Netherlands	199.0	Withdrawal
Bioenergy	Gobigas phase 2 SNG production	Sweden	58.8	Withdrawal
Bioenergy	Pyrogrot pyrolysis oil)	Sweden	31.4	Withdrawal
Bioenergy	VERBIO Straw biomethane production	Germany	22.3	Operational
Second call – 8 July 2014				
Advanced biofuel	W2B MSW-to-ethanol	Spain	29.2	Ongoing-as of January 2017, the project sponsor is awaiting for the competitive public tender process to be called by the local authorities.
Bioenergy	BIO-Bio2G Bio SNG to be injected into the gas grid	Sweden	203.7	Ongoing[8]-basic design or pre-FEED (front-end engineering design) work has been concluded but the work has not started yet. Planned entry into operation is June 2021.
Advanced biofuel	MET Cellulosic ethanol	Denmark	39.3	Withdrawn
Bioenergy	Fast Pyrolysis	Estonia	6.9	Withdrawn
Bioenergy	TORR torrefaction	Estonia	25	Ongoing-the environmental and construction permitting process is started.
Bioenergy	CHP Biomass Pyrolysis	Latvia	3.9	Withdrawn

7 See https://www.biofuelsdigest.com/bdigest/2018/10/01/enis-versalis-wins-biochemtex-and-beta-renewables-at-auction/

8 Officially not yet withdrawn but 'unlikely' or 'put on hold', according to interviews and info from NER300.com (Åhmana, et al., 2018)

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H2020

The Horizon 2020 framework (2014-2020) programme for research provides funding for advanced biofuels. Figure 7 presents an overview of the H2020 projects related to advanced biofuels and bio-refineries with a TRL level greater than 4.The data refers to the projects that started within the time-frame between 2015-2017 and that are applicable for funding greater than 250 k€.

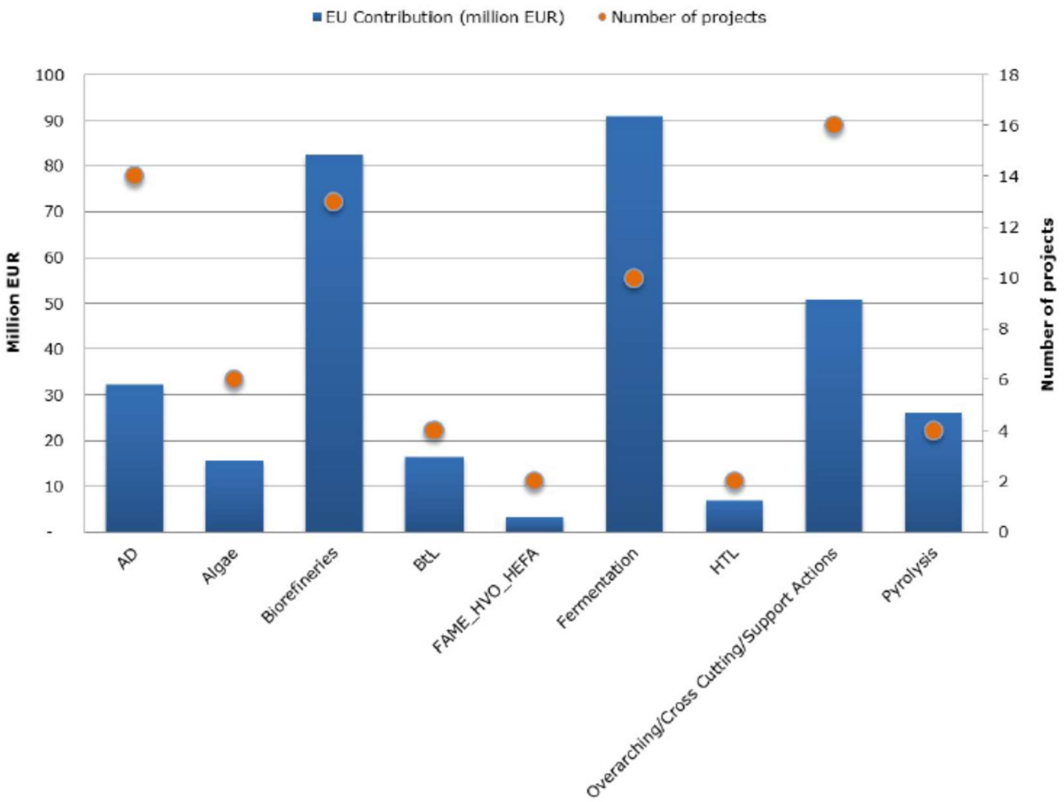

Figure 7: Distribution of EU funded advanced biofuel technologies projects above 250 k€ ((Lonza & O'Connel, 2018).

EIBI

The EIBI (one of the industrial initiatives under the SET-Plan[9]) aims to have the first commercial plants in operation by 2020 with a focus on advanced biofuels (ETIP, 2019). InnovFin Energy Demo Projects (EDP) Facility enables the EIB to finance innovative first-of-a-kind demonstration projects in the field of renewable energy and hydrogen/fuel cells. InnovFin Energy Demonstration Projects provides loans, loan guarantees or equity-type financing (typically between EUR 7.5 million and EUR 75 million) to innovative demonstration projects in the fields of energy system transformation. This includes but is not limited to renewable energy technologies, smart energy systems, energy storage, carbon capture, and storage or carbon capture and use, helping them to bridge the gap from demonstration to commercialisation.

[9] https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

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2.6. Policies promoting RESfuels

An important driver behind policy support towards (advanced) biofuels is the overall goal to comply with the 2015 UNFCCC Paris Agreement, whereas countries are required to present voluntary goals for 2030 under the Nationally Determined Contributions (NDCs). For the EU28, the decarbonisation of the transport sector as well as other sectors is anchored in various EU acquis, such as the 2009 Directive on the promotion of Renewable Energy (Directive 2009/28/EC), which had to be transposed into national legislation in the EU Member States.

The European Commission's 2009 Renewable Energy Directive was revised in 2015 following concerns about the impact of indirect land use change (iLUC) on GHG emissions savings. Revisions included, among others, a voluntary sub-target for advanced biofuels, whereas Italy became the first EU member state to mandate an advanced biofuels target.

Mandates and quotas are the most common measure used to promote biofuels, in some cases with sub-mandates/targets for advanced biofuels. Some countries are implementing sub-targets for advanced biofuels in 2020. Governments also mitigate the relatively high costs of advanced biofuels production with additional instruments such as tax exemptions and grant schemes.

Table 4 provides a brief summary of the instruments in different regions/countries.

Table 4: Overview of policy support measures to promote (advanced) biofuels in different regions/countries. (Source: ICCT, 2018; UPEI, 2018; ePURE, 2018)

Region / Country	Sub-mandate for advanced biofuels	Double Counting	(Tradeable) Certificates	Penalty for non-compliance of sub-mandate[10]	Tax incentives to advanced biofuels	Additional support
Denmark	✓ (will be introduced from 2020)	✓			✓	
Germany	✓ (will be introduced from 2021)	✓			✓ (reduced taxation for biofuels)	✓
Finland	✓ (will be introduced from 2021)	✓			✓ (reduced taxation for biofuels)	✓
France	✓ (0.2% in 2019)	✓			✓ (E10 and E85 taxed less)	

[10] Fuel suppliers, nearly in all member states, that fail to meet their overall renewable fuel obligation are liable to a penalty or can pay a buy-out price. There is no penalty system for suppliers that do not fulfil the biofuel obligation in Latvia and Denmark (ePURE, 2018).

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Region / Country	Sub-mandate for advanced biofuels	Double Counting	(Tradeable) Certificates	Penalty for non-compliance of sub-mandate[10]	Tax incentives to advanced biofuels	Additional support
Italy	✓ (0.6% in 2018 to 1.85% in 2022)[11]	✓	✓	✓ (€150 per GJ advanced biofuels)	(tax reductions phased out in 2011)	✓ (indicative budget of €4.7 billion for 2018 – 2020)
Netherlands	✓ (0.6% in 2018 to 1.0% in 2020)	✓		✓		
Sweden			✓		✓ (exemptions from carbon and energy taxes)	
UK	✓ (in 2019 at 0.1% increasing up to 2.8% in 2032)[12]	✓	✓	✓		
US	✓[13]			No penalty	✓	✓ (covers capital costs as well as feedstock logistics)

[11] Biofuels produced from UCO and animal fats are not considered as advanced biofuels (Upei, 2018)

[12] UCOME and tallow are not eligible for the development fuel sub target (Upei, 2018).

[13] Within the US RFS, a 2019 final rule sets the total U.S. renewable fuel volume requirements at 19.92 billion gallons, a 630 million gallon increase in the advanced biofuel target relative to 2018 levels. For advanced biofuels, the quantity is set at 4.92 billion gallons, including 418 million gallons for cellulosic biofuels. Advanced biofuels include fuels such as imported sugarcane ethanol as well as fuels that qualify for the biomass-based diesel (biodiesel and renewable diesel) and cellulosic biofuel targets. In recent years, the majority of advanced biofuel RFS credits have been generated from biomass-based diesel consumption.

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All countries in Europe included in the above table (except for Sweden) have defined mandates for advanced biofuels, although the ambition varies widely from 0.05% in Germany to 1% in the Netherlands (in 2020). In Sweden, the main support mechanism for biofuels (in general) has been exemptions from carbon and energy taxes. The UK has the longest-term mandate, with an increasing sub-target for advanced biofuels reaching 2.8% in 2032. The prices for non-compliance, particularly initially, is €150 per GJ for advanced biofuels.

Certain biofuels (including cellulosic ethanol) are counted twice against the mandates. As it can be seen above in Table 4, double counting is permitted in France, Italy, Denmark, the Netherlands, and the UK. Definition and eligible feedstock vary by MS. For example, the quantity of advanced biofuels that can be double counted in France is strictly limited in order to favour biofuels produced in France (if it was not limited, this measure could lead to an increase in imports of advanced biofuels at the expense of domestic "conventional" biofuels).

More recently, the revised Renewable Energy Directive (EU) 2018/2001 introduced an EU incorporation obligation to fuel suppliers in Europe for advanced biofuels. Sub-mandated advanced biofuels will be 0.2% of total energy consumption road and rail transport in 2022, 1.0% in 2025, and 3.5% in 2030. Fuels may be double-counted to achieve this target, which implies that the physical targets are only 0.1%, 0.5% and 1.75%

The US, introduced with the 2005 Energy Policy Act and the 2007 Energy Independence Act, also requires a minimum volume of biofuels in transport, enshrined in the Renewable Fuel Standard (RFS). The RFS includes sub-targets for cellulosic ethanol and other advanced biofuels. These sub-targets are presented in gallons, and not as a percentage. In the US, tax credits have been applied, e.g. second generation biofuel producers have been eligible for a tax incentive in the amount up to $1.01 per gallon. This tax incentive expired after 2017. A bill has been proposed which aims, among others, to extend the second generation biofuel producer tax credit through 2018[14]. Furthermore, additional financial support to biomass feedstock crops for advanced biofuels facilities and production of advanced biofuels available. Loan guarantees are provided where the government commits to paying a company's investment loans if that company is unable to pay them. These loan guarantees are meant for early commercial-stage projects. Loan guarantees supported Project LIBERTY, the country's first commercial scale cellulosic ethanol plant sponsored by POET.

Whilst this section presents an overview of policies supporting the promotion of advanced biofuels in a selection of countries, section 3.2 makes a first analysis of Good Practice policies.

2.7. Developments regarding feedstock costs

Feedstock prices next to the capital costs are the dominant cost factor in effecting the advanced biofuel production costs (feedstock costs comprise ~ 40% of the total production cost of biofuels). There are currently no established markets to define feedstock prices dedicated to advanced biofuels. The main feedstock used in the existing (lingo)cellulosic ethanol plants are mainly the agricultural residues such as cereal strove and, to a limited degree, straw. In the

14 https://ethanolrfa.org/tax/

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medium to long term, biofuels from other woody biomass are expected to increase their market uptake as well. Two KPIs are determined as proxy to present the feedstock price developments for advanced biofuels; straw and wood pellet prices, and their historical price developments are presented below.

Straw price developments

The figure below presents the difference and variability of straw prices in several member states according to Eurostat. Currently the straw price developments mainly relate to demand for straw to be used in food and bedding for cattle (see Figure 8). There are relatively large regional differences. These differences relate to the weather, forage harvest and animal stock density in each country.

The market price for biofuel production will be influenced by the factors such as the ratio of supply and demand and how much is in stock from the demanding sectors and the energy sector's willingness to pay. The cellulosic ethanol operators are expected to supply straw from local farmers with the long-term contracts. In Denmark, for instance, straw has been used to produce heat and electricity since 1980s' and the straw price has been rising since 2007/08 due to the large increase in power plant capacity (Kuhler, 2013).

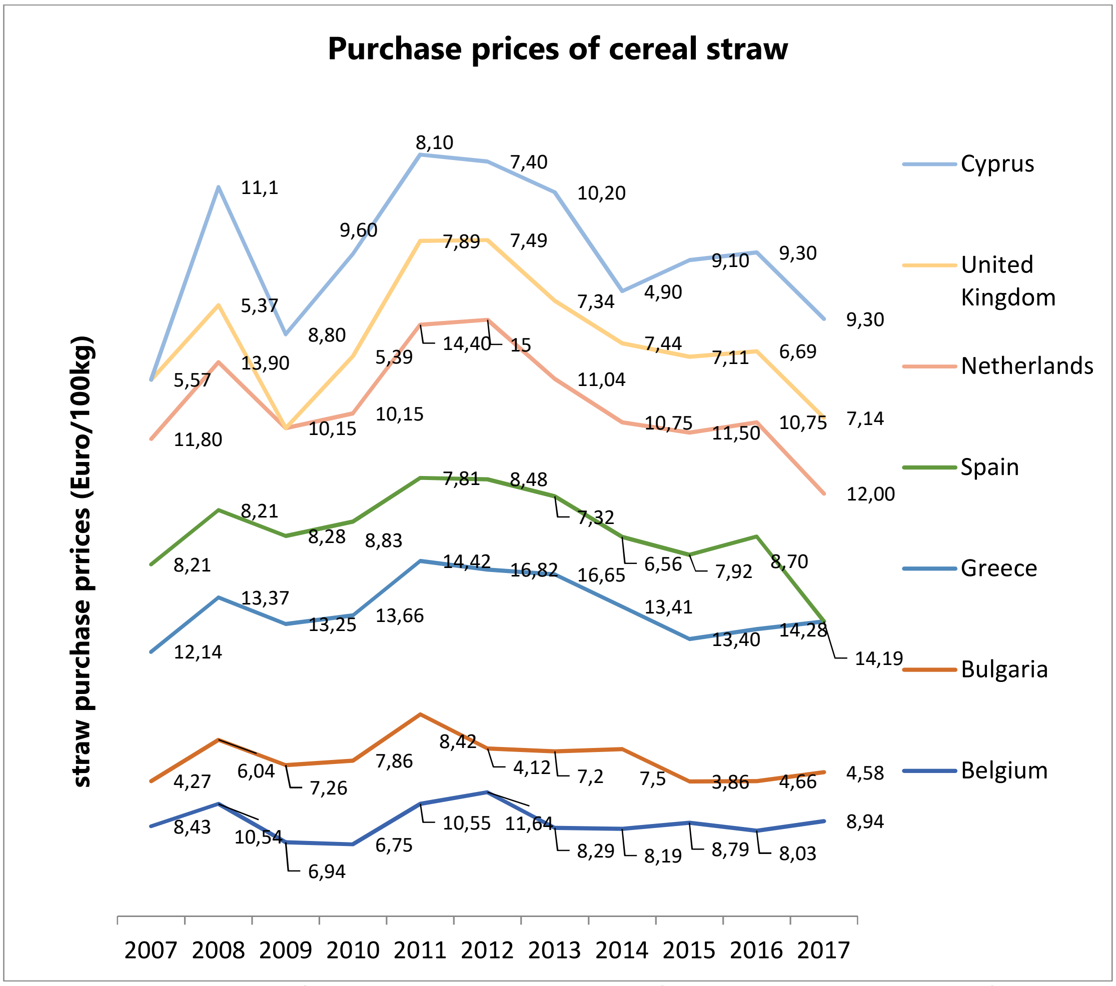

Figure 8: Purchase prices of cereal straw (Eurostat, 2019)(refers to real purchase prices on farm)

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Wood pellet prices

Wood pellet price developments relate to residential and industrial use for energy production. There is currently no market regarding wood pellet use in advanced biofuel plants. Thus, these data should be interpreted carefully. There are two main categories; industrial-grade pellets, aimed for medium- and large-scale application (such as co-firing in coal plants), and residential grade pellets, mainly used in small-scale heating appliances.

Pellet price fluctuations for residential consumers (see Figure 9) in Europe relate to production costs, over or under supply in the market (as occurred in 2016), weather conditions (soft versus cold winters), and external shocks including (dollar) exchange and shipping rate developments (as it is a tradable commodity) (Thraen et al., 2018).

Industrial wood pellet markets are characterised by a few central factors that are crucial for price developments (Thran et al., 2018). These factors are:

- The industrial pellet market is demand driven, which depends on policy schemes including underlying remuneration levels and related regulations
- The wood pellet market is small in comparison. It lacks the liquidity of true commodity markets and it is dominated by a few market actors (Olsson et al., 2016), effecting the spot market prices easily (i.e. the fires in Drax power plant resulted in general price decreases in Europe).
- Exchange rate fluctuations can influence economics of industrial pellet consumers who often purchase pellets in United States Dollars (USD) but receive their revenue (from electricity sales) in their respective local currencies.

Figure 10 illustrates the industrial wood pellet price fluctuations.

The operational advanced biofuel plants are currently very limited to have any impact on the feedstock market. The operational plants resource their feedstock from the nearby locations and the prices are much likely to be low (or in some cases might be negative, i.e. when wastes are used). However, when the market evolves and the demand increases above factors, at least the ones mentioned for the industrial wood pellet markets, are likely to effect the feedstock prices. In case the advanced biofuel plants run on clean wood the existing wood pellet market may expand and also supply to biorefineries next to power and heat markets.

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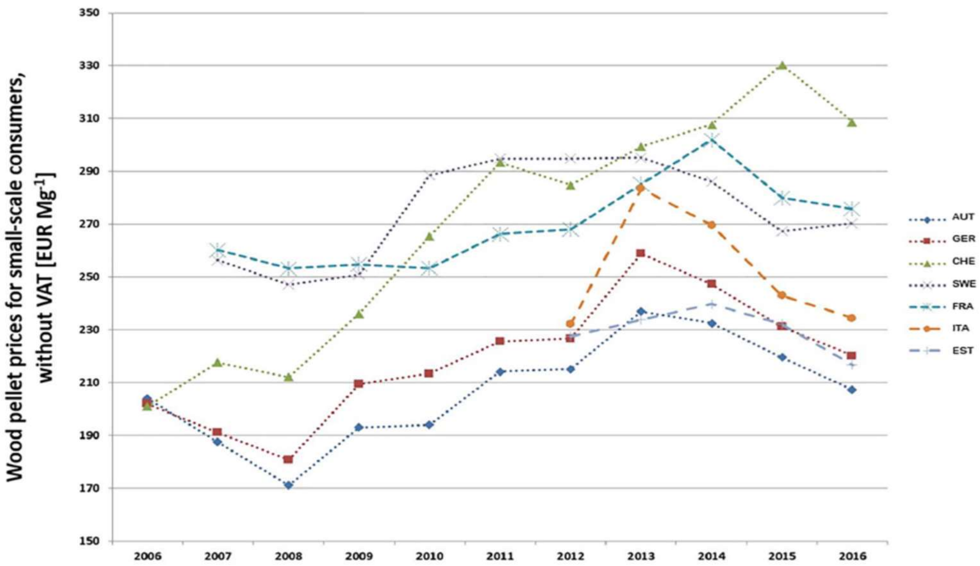

Figure 9 Comparison of wood pellet prices for small scale consumers, delivered either in bulk or in bags (Thraen et al. 2018).

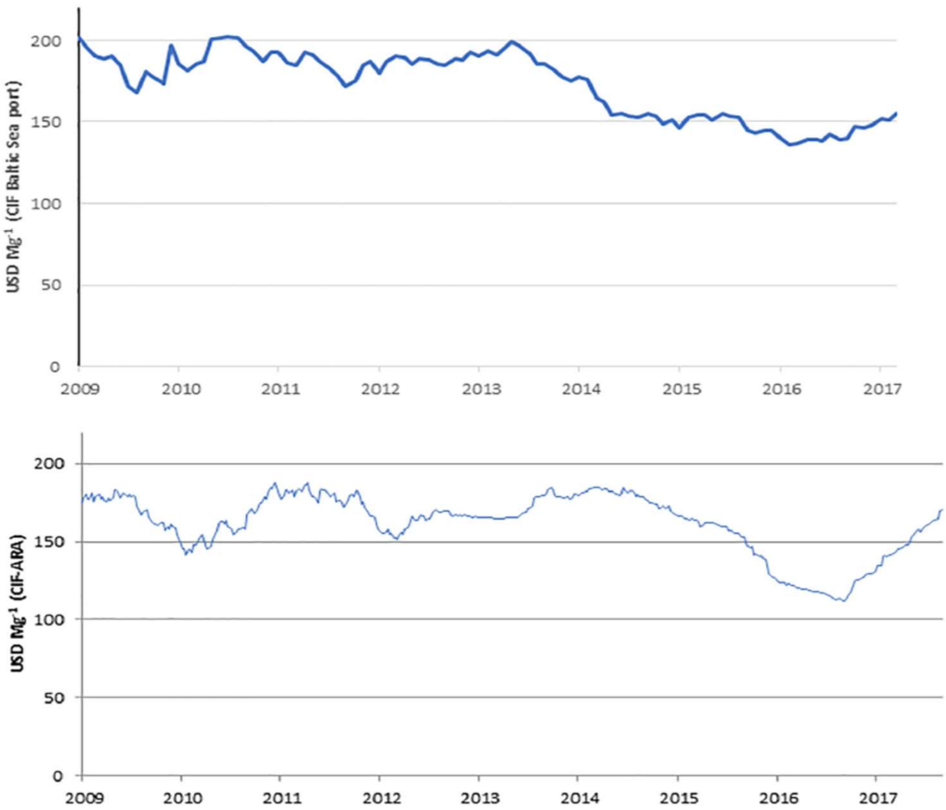

Figure 10: Industrial wood pellet prices 2009–2017 in the Baltic Sea region (upper pane) and the Amsterdam-Rotterdam-Antwerp (ARA) region (lower pane) (Thran et al., 2018).

Note: the effects on ARA prices of the February 2012 Tilbury fire, as well the dampened prices in 2015–mid 2016 as policy uncertainty coincided with significant capacity increase. (The Baltic Sea prices have been converted from EUR MWh−1 to USD Mg−1 using an energy density of 4.7222 MWh Mg−1 and monthly EUR/USD exchange rates from the Swedish Riksbank.) (Argus, 2018; Foex Index, 2018).

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3. Project related KPIs

Two project related KPIs are presented below. The first one relates to the research within WP2 that looks at the innovative approaches to reduce production costs of cropping schemes. The work has been conducted by Germer et al. 2019. The detailed analysis can be found in deliverable **D2.1, "Report on lignocellulosic feedstock availability, market status and suitability for RESfuels".**

The second KPI relates to defining Good Practices. This work is conducted within WP5 of ADVANCEFUEL project by Christensen et al., (2019) and the details regarding the approach in defining Good Practices and first results can be found in **D5.2, "Good practices along the RESfuels value chain".**

3.1. Dedicated cropping schemes and the preliminary cost reduction potential due to innovations

The estimated area cultivated for miscanthus and short rotation coppices in 2016 was 90,000 hectares in the EU28. At least an equivalent area was cultivated with other potential energy crops, namely switch grass, reed canary grass and hemp. This equals 0.1% of EU28 total agricultural area.

Cost reduction potential

Production costs of dedicated crops (lignocellulosic biomass) are mainly influenced by the factors establishment costs[15] and achieved yields. Establishment costs depend mainly on the applied technology and, hence, related cost reduction potentials might be similar for different regions within Europe. Yields, however, might depend on technological improvements, but also on the natural environment, crop and variety selection, cropping management and farmer knowledge. A thorough literature survey was performed to identify innovations that can help reduce production costs of dedicated crops (Table 5). The production costs of those innovations were compared to reference scenarios (before innovation implementation) in order to identify the cost reduction potential. Further details regarding the survey performed and the analysis, are provided in deliverable D2.2, **"Innovative cropping schemes for lignocellulosic feedstock production".**

[15] Crop establishment costs are costs that occur only before the first harvest of perennial corps including field preparation, herbicides, planting material. These costs need to be divided by the lifespan of plantations in order to derive annual costs.

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Table 5: Biomass production cost reduction potentials [%] for different innovations (negative reduction = increase of costs).

Innovation	Breeding (propagation by seeds)	Propagation by stem segments (not rhizomes)	Planting density increase by 3 times	Economy of scales	Learning effects	Cropping on marginal land
Miscanthus	7-16[1)]	9[1)]	7[1)]			-11[3)], -44[4)]
Switchgrass						-10[3)]
Willow SRC				10[2)]	25[2)]	
Giant Reed						-17[3)]

Data source: [1)] (Germer, et al., 2019), [2)] Sweden (Rosenqvist, et al.,, 2013), [3)] (Soldatos, 2015), [4)] former mining site compared to average of 6 agricultural sites (LfULG, 2014)

- Breeding (propagation by seeds): Currently miscanthus is planted using subterranean stem material (rhizomes), which is expensive as big volumes of planting material and huge areas to produce this material are needed. Breeding seeks at producing miscanthus hybrids with high seed yields in order to perform planting by direct seeding.
- Propagation by stem segments: For Miscanthus the subterranean stem material (rhizomes) might be substituted by above ground stem segments as planting material. Using above ground material decreases the cost of planting material as harvest of aboveground material is cheaper than subterranean material.
- Planting density increase by three times: Increasing the number of plants per area can increase the biomass yield up to a point when competition between individual plants increases too much. The challenge is to find the optimal planting density per site. If costs per hectare stay constant then the increase in yield directly reduces the biomass production cost.
- Economies of scale: At present only small areas are used for lignocellulosic energy crops. Substantial expansion of the cropping area increases the biomass production per farmer or farmer cooperation. Increased production leads to decreased biomass production cost as fixed costs (production inputs and upfront investments) stay constant independent of scale
- Learning effect: Progress in plant breeding and cultivation practices are mainly expected to increase yields per hectare, while machinery improvements are expected to decrease planting and harvesting costs. Both changes reduce production costs with time.
- Cropping on marginal land: In order to produce biomass for biofuel without interfering with the food or feed production marginal land should be used, which has been abandoned due to low productivity, contamination or other reasons. Common lower yields from marginal land compared to fertile agricultural land lead to biomass production cost increases.

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Deliverable D2.2 **"Innovative cropping schemes for lignocellulosic feedstock production"** also examined factors influencing yields include breeding, field selection and management (Table 6).

Table 6: Yield change potentials [%] or expected changes (+: increase, -: decrease) for different innovations.

Innovation	Breeding for yield increase	Breeding for quality increase	Cropping on marginal compared to agricultural land	Cropping on small compared to big scale[2)]	Learning effects	Breeding for yield increase
Miscanthus	+	-	-70[2)], -37[3)], -31[4)]	-80	+	Miscanthus
Switchgrass	+	-	-31[2)], -42[3)]	-74	50[5)]	Switchgrass
Willow SRC	+	-	0[2)]	-38	+	Willow SRC
Poplar SRC	+	-16-24, >30[1)]	-39[2)]	-91	+	Poplar SRC
Giant Reed	+	-	-37[3)]	-	+	Giant Reed

Data source: [1)] (Acker et al., 2014; Keplé et al., 2007), [2)] changes of maximum yield (Searle & Malins, 2014), [3)] changes of average yield (Soldatos, 2015), [4)] former mining site compared to average of 6 agricultural sites (LfULG, 2014), [5)] for study case in the USA (Karp & Shield, 2008)

- Breeding for yield increase: Breeding is performed in order to find hybrids with increased yields per hectare. Despite the direct increase of biomass per plant, breeding focuses on the decrease in plant mortality or the increase of plant resistance to diseases in order to increase yield per hectare.
- Breeding for quality increase: Breeding can also focus on improving e.g. ethanol yields from biomass, which might, however, reduce biomass yields per hectare.

Cropping on small compared to large scale: Energy crop yields are usually overestimated if cropping takes place on small test sites compared to large commercial sites. This overestimation is due to higher yield at field edges that have a higher proportion per field for small plots compared to big plots and due to manual harvest preventing significant biomass loss at small fields compared to mechanically harvested on commercial fields, where losses are unavoidable.

3.2. Good practices

For the purposes of this analysis, a good practice (FAO, 2014) is defined as "*a practice that has been proven to work well, produce good results and is designed to achieve some deliberative target*"(Bretschneider, 2004).

The policy related good practices analysed in ADVANCEFUEL refer to renewable fuel programs and strategies that have high performance in assets such as: i) *include a mix of policy mechanisms* (regulatory, financing, and information provision), which are *integrated across the value chain* (feedstock production, conversion, end use), ii) *set ambitious targets* that evolve with market development and address sustainability and iii) sustain and continuously improve a strong *network of key stakeholders* from policy and industry.

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Table 7: Overview of some selected examples of Good Practices in policy for Renewable fuels

Country	Good practice	Type of RES fuels	Policy mix	Targets for market shares	Stakeholders engagement
Finland	Excellent integration of policy instruments across value chain Consistency in biomass/ biofuels policy Very efficient taxation system that promotes the best of biofuels; regular monitoring, adjustments and evolution of targets	Advanced biofuels	Regulatory Financing Information provision	30% biofuels by 2030; 10% of which will be advanced without double counting	Continuous collaboration and knowledge exchange between relevant Ministries and industry
Italy	Dedicated support to advanced biofuels through State Aid	Advanced Biofuels	Regulatory Financing	10% biofuels by 2020 (1.6% advanced biofuels incl. double counting) 2% advanced biofuels by 2022	Very good alignment of economic, environmental and energy stakeholders
Netherlands	Long term and consistent policy Evolution of policy instruments to meet societal challenges in the country. Policy includes a priority to use sustainable biomass for fuels in heavy road transportation, aviation and shipping, while favoring electrification and hydrogen for other transportation modes.	Advanced biofuels	Regulatory Financing	0.6% in 2018 and 1% by 2020	Continuous collaboration and knowledge exchange between relevant Ministries and industry

Finland

Finnish policy promotes biofuels as a cost-effective way to reduce CO_2 and acts synergistically with the strong commitment of Finnish industries considering low carbon economy and innovation as well as the domestic availability of raw materials. In early 2019, the Finnish Parliament approved a law that sets a gradually increasing 30% biofuels target for 2030. Furthermore, the law sets a world-leading advanced biofuel target of 10% in 2030, without double counting.

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The Finnish policy framework has a variety of mechanisms that can ensure the successful delivery of the set targets as well as efficient monitoring and updates when required. As a result, the country exhibits one of the longest and consistent renewable fuel programs in Europe as well as worldwide. There is strong, consistent, and continuous collaboration across all governmental bodies that are involved in biomass supply, environmental protection, economy, and energy.

Key lessons to be transferred: Long-term consistency and strong collaboration in policy formation for the fuels and other (forestry, economy, etc.) sectors involved.

Italy

Italy has been the first Member State to mandate the use of advanced biofuels. The Italian legislation has been consistently supporting biofuels since 2005 with a quota mechanism obliging fossil fuel producers to supply a minimum quota of biofuels annually based on the total amount of fuel supplied. The 2014 amendments[16][1] established the trajectory from a 5% (2015) biofuel blending quota obligation to 10% in 2020, updating the provision of previous legislation.

The concept of "Advanced biofuels" has been introduced by a ministerial decree and a mandatory quota for "advanced biofuels" has also been introduced (2018 1.2%, 2019 1.2%, 2020 1.6%, 2022 2%). Furthermore, a support scheme has been introduced in March 2018, under EU State aid rule, dedicated to the production and distribution of advanced biofuels, including advanced methane, for use in the transportation sector. The scheme has an indicative budget of €4.7 billion and runs from 2018 through 2022.

The Italian government made an off-take agreement for advanced biofuels (in 2013/14) with a private business group "Gruppo Mossi Ghioslfi," fostering the deployment of 2nd generation biorefineries in Italy.

Key lessons to be transferred: Consistency in policy for biofuels and separate targets for advanced biofuels which are also coupled with support from State Aid are critical to the project.

Netherlands

In 2018, the Dutch government raised the biofuel mandate to 16.4% by 2020, including double-counting[17]. The country increased the advanced biofuels mandate from 0.6% in 2018 to 1% by 2020. The remaining quota of the mandate is expected to be filled by double-counted biofuels.

Aviation biofuels are not subject to the mandate, but bio-kerosene and bio-naphtha producers can opt in and be eligible to obtain renewable certificates (Dutch Emission Authority, 2018).

The Dutch government signed the country's Climate Agreement in 2017 with the goal of reducing transportation CO2 emissions by 7.3 million tons by 2030 compared to 1990[18]. It includes a priority to use sustainable biomass for fuels in heavy road transportation, aviation

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[17] (Decision of 3 May 2018, containing rules relating to the annual obligation for renewable energy transport and the reporting and reduction obligation for transport emissions, for the implementation of Directive (EU) 2015/1513 [...]), Staatsblad, Nr. 134, 17 mei 2018, http://wetten.overheid.nl/BWBR0041050/2018-07-01

[18] Official website of the Dutch climate agreement, accessed November 8, 2018, https://www.klimaatakkoord.nl/.

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and shipping, while favouring electrification and hydrogen for other transportation modes. Legislation to implement the Climate Agreement is still being discussed (Giuntoli, 2018).

Key lessons to be transferred: Long term consistency in policy formation and prioritization of market segments by fuel types.

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4. Conclusions

Based on the KPIs presented in the previous chapters, a number of conclusion can be drawn including:

- The advanced biofuels industry is struggling to reach commercialisation in most parts of the world, whereas in other few regions progress is being made.
- US currently holds the largest installed capacity of ethanol production from lignocellulosic feedstocks. Production of biodiesel using lignocellulosic feedstocks is limited in comparison to lignocellulosic ethanol.
- In recent years, difficult market conditions coupled with high operational costs and financial difficulties companies were facing, have forced the closure of several lignocellulosic ethanol plants.
- Synthetic fuel production from CO_2 and renewable H_2 are in a pilot and demonstration phase and the total installed capacity in Europe is estimated to be around 6 kt/a.
- Biofuels experienced a steady growth in new investments from 2005 to 2007, when growth in first-generation biofuels was increasing. After 2008, investments in biofuels started to decline and fluctuate at lower levels. New investments to advanced biofuels, starting from 2008, follow a steady path and appear relatively small.
- The US and Italy were the first two countries to introduce dedicated mandates for advanced biofuels. With the revised Renewable Energy Directive (EU) 2018/2001, there will be an EU-wide obligation for fuel suppliers in Europe to utilise advanced biofuel, starting in 2022.
- Feedstock prices next to the capital costs are the dominant cost factor in effecting the advanced biofuel production costs. While there are currently no established markets to define feedstock prices once the sector matures, the feedstock prices may follow an increasing trend depending on the buying capacity of the biofuel plants and the market supply of certain feedstock (i.e. straw).
- According to a thorough literature survey, production costs of dedicated energy crop can be in around 7-25% lower when compared to reference scenarios (before innovation implementation). Costs are reduced by applying innovative approaches such as propogation by seeds and/or by stem segments, planting density increase, economy of scale and learning effects.
- The cultivation of dedicated energy crops on marginal lands may, however, increase the production costs (in the range of 10-17%) rather than to reduce those.

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6. Annexes

Annex 1

Table 8 List of operational lignocellulosic ethanol plants. Source: IEA Bioenergy Task 39 database.

Type	Name/place	Feedstock	Technology	Capacity (t/a)
US				
Demo	Renmatix	Lignocellulosics	Fermentation	500
Demo	American Process/Thomaston GP3+ Biorefinery	Forest residues	HTF	180
Demo	LanzaTech/US Mobile Demo	Woody biomas syn-gas	Gasification	70
FOAK	Quad-County Corn Processors, Galva	Lignocellulosics	Fermentation	6 000
FOAK	POET-DSM Advanced Biofuels, Em-metsburg	Agricultural residues	Fermentation	75 000
FOAK	American Process/Alphena Biorefin-ery	Forest residues	HTF	2 100
CANADA				
Demo	Tembec Chemicals	Lignocellulosics	Gasification	13 000
Demo	Enerkem Alberta Biofuels LP/Westbury, Edmonton	Forest residues	Gasification	4 000
Demo	Iogen Corporation	Lignocellulosics	Fermentation	1 600
Demo	Woodland Biofuels	Organic residues and waste streams	Fermentation	6 000
FOAK	Enerkem Alberta Biofuels LP, Ed-monton	Organic residues and waste streams	Gasification	30 000
BRAZIL				
Demo	Cane Technology Center (CTC)	Lignocellulosics	Fermentation	2 400
FOAK	GranBio, San Miguel	Lignocellulosics	Fermentation	62 000
FOAK	Raizen Energia, Costa Pinto	Lignocellulosics	Fermentation	31 600
EUROPE				
Demo	North European Oil Trade Oy/Cellu-lonix, Finland	Lignocellulosics	Not specified	7 900
Demo	Chempolis Ltd./Chempolis Biorefin-ery plan, Finland	Lignocellulosics	Fermentation	5 000
Demo	North European Oil Trade Oy/Etha-nolix GOT, Sweden	Organic residues and waste	Fermentation	4 000
Demo	Clariant/Sunliquid, Germany	Lignocellulosics	Fermentation	1 000
Demo	SP/EPAP/Biorefinery demo, Sweden	Lignocellulosics	Fermentation	160

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Type	Name/place	Feedstock	Technology	Capacity (t/a)
Demo	Borregaard AS/BALI Biorefinery, Norway	Lignocellulosics	Fermentation	110
FOAK	Borregaard Industries/ChemCell Ethanol, Norway	Lignocellulosics	Fermentation	15 800
CHINA				
Demo	Anhui BBCA Biochemical	Lignocellulosics	Fermentation	5 000
Demo	Shandong Zesheng Biotech Co.	Lignocellulosics	Fermentation	3 000
Demo	Jilin Fuel Alcohol/Jilin 2	Lignocellulosics	Fermentation	3 000
Demo	COFCO Zhaodong Co.	Agricultural residues	Fermentation	500
Demo	LanzaTech/Asia Mobile Demo Plant	Waste gases (MSW syngas)	Fermentation	70
Demo	Longlive Bio-technology Co. Ltd.	Lignocellulosics	Fermentation	60 000
FOAK	Henan Tianguan Group/Henan 2	Lignocellulosics	Fermentation	30 000
FOAK	Henan Tianguan Group/Henan 1	Lignocellulosics	Fermentation	10 000

Table 9: List of idle lignocellulosic ethanol plants. Source: IEA Bioenergy Task 39 database.

Type	Name/place	Feedstock	Technology	Capacity (t/a)
US				
Demo	Pacific Ethanol/West Coast Biorefin-ery	Lignocellulosics	Fermentation	8 000
Demo	BP Biofuels/Jennings demo	Agricultural residues	Fermentation	4 200
Demo	GeoSynFuels	Agricultural residues	Fermentation	4 500
Demo	ZeaChem,	Lignocellulosics	Fermentation	750
FOAK	DuPont/commercial facility, Nevada, Iowa	Agricultural residues	fermentation	82 700
FOAK	Abengoa Biorefinery, Kansas	Agricultural residues	fermentation	75 000
CANADA				
Demo	CORE Biofuels	Organic residuals and waste streams	Gasification	53 500
EUROPE				
Demo	Inbicon/Dong Energy, Denmark	Lignocellulosics	Fermentation	4 300
Demo	Abengoa Bioenergy (Babilafuente), Spain	Lignocellulosics	Fermentation	4 000
Demo	Abengoa Bioenergy (Salamanca), Spain	Organic residues and waste	Fermentation	1 200
FOAK	Beta Renewables	Lignocellulosics	Fermentation	40 000

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Table 10: List of operational, planned, and idle synthetic fuel plants in Europe. Sources: Bailera 2017, Schmidt 2018, http://database.scotproject.org/projects, and project websites

Type	Name/place	Feedstocks	Technology	Output	Capacity (t/a)
Demo	CRI George Olah plant, Iceland	H_2O, and electricity and CO_2 from geothermal powerplant	Alkaline electrolyser and methanol synthesis reactor	Methanol	4 000
Demo	Audi e-gas plant, Germany	CO_2 from biogas plant, H_2O, and electricity	Alkaline electrolyser (6 MWe), methanation reactor	Methane	1 900
Pilot	Store & go, Germany	CO_2 from bio-ethanol plant, H_2O, and electricity	Alkaline electrolyser (2 MWe), methanation reactor	Methane	600
Pilot	STEPWISE, Sweden (related to FresMe and MefCO_2)	CO_2 captured from the blast furnace gas (BFG) of a steel plant	CO_2 capture with SEWGS	CO_2 (and H_2)	5 100
Pilot (idle)	Sunfire, Germany	CO_2 from biogas plant, H_2O, and electricity	RWGS with H_2 from solid oxide electrolyser, FT synthesis of synthetic hydrocarbons	Gasoline	16
Pilot (idle)	Soletair, Finland	CO_2 from air, H_2O, and electricity	CO_2 air capture, electrolysis to produce H_2 and either methanation to produce methane by the Sabatier reaction or RWGS and FT to produce liquid fuels	Gasoline	2
Pilot	Sun-to-liquid, Spain	CO_2, H_2O, and sunlight	Solar thermochemical plant (50 kW) producing syngas, which is converted by FT into hydrocarbon fuels.	Kerosene	9
Pilot (planned)	FresMe (related to STEPWISE and MefCO_2)	CO_2 (and H_2) from steel plant, additional H_2 from electrolysis	electrolysis, and methanol synthesis	Methanol	400
Pilot (planned)	MefCO_2, Germany (related to FresMe and STEPWISE)	CO_2 from powerplant, intermittent renewable electricity, and H_2O	electrolysis, and methanol synthesis	Methanol	400
Demo (planned)	Audi e-diesel plant, Switzerland	CO_2 from biogas plant, hydroelectricity, and H_2O	RWGS with H2 from electrolyzer, FT synthesis	Gasoline/Diesel	330

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Type	Name/place	Feedstocks	Technology	Output	Capacity (t/a)
Demo (planned)	Nordic Blue Crude AS with Sunfire, Norway	CO_2 from fertilizer plant, electricity, and H_2O	H_2 production by SOE, RWGS and FT synthesis	Crude synthetic oil	8 000
Demo	Energiepark Mainz, Siemens, Germany	Wind electricity and H_2O	H_2 production by PEM electrolysis (6 MW)	Hydrogen	-
Demo (planned 2019)	H_2Future, Austria	Renewable electricity and H_2O	H_2 production by PEM electrolysis (6 MW)	Hydrogen	-
(planned 2019)	Nouryon, Gasunie, Netherlands	Renewable electricity and H_2O	H_2 production by alka-line electrolysis (20 MW)	Hydrogen	3 000
(planned 2021)	Nouryon, Tata, Netherlands	Renewable electricity and H_2O	H_2 production by alka-line electrolysis (100 MW)	Hydrogen	15 000

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Annex 2

Table 11: Investment costs of Advanced Biofuel production plants. Sources: IEA Bioenergy Task 39 database and various project websites

Plant name/location	Type of main input and output	Output capacity (t_{fuel}/a)	Total investment (M€2018)	Total investment/ capacity output€2018/t_{fuel}	Operational since
Fermentation					
Chempolis Biorefinery (Finland)	Lignocellulosic crops to ethanol	5 000	23	4 500	2008
Sunliquid / Clariant (Germany)	Lignocellulosic crops to ethanol	1 000	17	16 900	2012
Project Liberty / POET-DSM Advanced Biofuels (US)	Agricultural residues to ethanol	75 000	259	3 500	2014
Costa Pinto project, Raizen (Brazil)	Lignocellulosic crops to ethanol	32 000	105	3 300	2014
Bioflex 1, GranBio (Brazil)	Lignocellulosic crops to ethanol	65 000	216	3 300	2014
Gasification					
GoBiGas Phase 1 (Sweden)	Lignocellulosic crops to methane	11 200	155	13 900	2014
Enerkem, Edmonton	Municipal waste to ethanol	30 000	111	3 700	2014
Hydrothermal					
Licella (Australia)	Biowaste to bio-oil	350	5	15 500	2011
CO_2 conversion					
CRI George Olah plant, Iceland	CO_2 and electricity	4 000	8	1 900	2012
Audi e-gas plant (Germany)	CO_2 and electricity	1 900	21	10 800	2013

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