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ADVANCEFUEL

Good Practices Along the RESfuels Value Chain through mixed methods analysis

D5.2 Good Practices Along the RESfuels Value Chain

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ADVANCEFUEL at a glance

ADVANCEFUEL (www.ADVANCEFUEL.eu) is a market research project formed by 8 partners from Chalmers University, Imperial College London (ICL), Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Aalto University, The Agency for Renewable Resources (FNR), Energy Research Centre of the Netherlands (ECN), Utrecht University and Greenovate Europe aiming 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 focuses on advanced renewable fuels – defined as liquid biofuels produced from lignocellulosic feedstocks from agriculture, forestry and waste – and liquid renewable alternative fuels produced from renewable hydrogen and CO2 streams.

As a way to support commercial development of these fuels, the project firstly develops 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 investigates individual barriers through stakeholder consultations and discusses validation and potential solutions during stakeholder workshops. The project then examines 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 are also explored in an effort to see how they can be integrated into energy infrastructure.

Sustainability is a major concern for renewable fuels and as part of this report 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 tool 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. For instance, the Stakeholder Platform (accessible online) contributes to this objective. ADVANCEFUEL is thus a coordinated effort to support 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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Contents

Summary

This report presents Good practices cases in both the plant/biorefinery and policymaking arenas for the production and development of advanced renewable fuels. Its complementary report (D5.3) delivers a policy analysis with the aim of providing evidence on policy interventions which can be used to promote innovations across the RESfuels value chains. In the following months, the second version of this report (D5.6) shall further analyse the value of these Good practices through system dynamics modelling.

The aim of this report is to inform stakeholders of what has been or is currently being carried out in industry and in policy making and how it facilitates the growing market uptake of advanced renewable fuels from renewable sources (RESfuels) for the European road, aviation and marine transport sectors.

Objectives

1. **Presenting plant/biorefinery Good practices:**

- 10 plants from pilot, demonstration and commercial development stages are analysed through an environmental, economic and social lens to make the case for Good practices enacted for the production and implementation of RESfuels along the full value chain
- Practices are measured against greenhouse gas emissions savings and sustainability measures, total production capacity and gross added value, and total employment generated by the plants
- 6 transferable practices as lessons learnt are presented to inform stakeholders
- The Annex of this report includes the methodology behind systems dynamics analysis whereby practices will be further analysed (D5.6) with mixed methods

2. **Presenting policy Good practices**:

- 12 renewable fuel policies are analysed from 10 different countries (Denmark, Finland, Germany, the Netherlands, Italy, Slovakia, Sweden, United Kingdom, Brazil, Canada), the European Union and the state of California in the US
- Policy mechanisms employed and respective special provisions for aviation, marine and heavy-duty road transport for markets in initial, early and mature development stages are presented and assessed for their transferability
- The preliminary assessment of good practice performance done jointly with interviewed stakeholders is measured against the quality of policy integration, strategy for market segments with limited alternatives for decarbonization and stakeholder engagement

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1. Introduction

1.1.Background

The European Union (EU) is committed to reduce greenhouse gas emissions (GHG) by 80-95% by 2050 compared to 1990 levels in line with the Paris Agreement to maintain temperature levels below 2°C, as compared to preindustrial levels. Renewable energy sources (RES) will have a major contribution to these targets. So far, the RES share in final EU consumption has increased from 8% in 2004 to 17% in 2016, while the first Renewable Energy Directive (2009) set a target of 20% by 2020 (RED, 2009/28/EC). Recently, the RED II recast has also set a binding Union target of at least 32% share of renewable by 2030[1] .Amongst the renewable energy sources, RESfuels are expected to contribute highly towards the decarbonisation of transport and their sustainable production is of outmost importance for the successful market development.

According to the 2018 Bioeconomy Strategy published by the European Commission[2], there are more than 800 biorefineries throughout Europe, with more than 360 producing liquid biofuels. Multi-product biorefineries can improve the efficiency of biomass utilisation by exploiting side-flows, reusing waste and resides and adding further value to materials beyond their energy source, such as using lignin in lightweight material and chemical products. While there are high expectations from the RESfuels sector, most of the plants are first of a kind, demonstration and pilot, they include highly innovative components, involve high investment risks and as such there is much scope for learning from Good practices achieved so far both in the development and operation of the plants but also from the formation of consistent, long term and appropriately tailored policy.

The aim of Task 5.2 is to identify, jointly with stakeholders, Good Practices of successful market uptake of RESfuels in Europe and global level. The work is performed in two stages. The first one (M6-M18), which is presented in this report, aims to map the landscape for selected operational advanced biofuel plants in Europe and renewable fuels policies and assess them based on their key assets and relevant performance for Good practices (D5.2 submitted March 2019).

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[1] DIRECTIVE (EU) 2018/2001

[2] European Commission (2018) A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment, Updated Bioeconomy Strategy

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Following, during the second stage (M19-M36), a combination of qualitative and quantitative data from the reported good practices shall be integrated to a full value chain analysis with Vensim[3], which will allow the validation of i) practices that contribute most to policy targets and market uptake and ii) performance indicators that best illustrate good practices in every step of the value chain (feedstock production, conversion, end use). This second version of the deliverable (D5.6 to be submitted August 2020) shall be further used in the future for effective policy formation.

For the purposes of this analysis, a good practice[4] is defined as '*a practice that has been proven to work well, produce good results and is designed to achieve some deliberative target*[5]*.*

An overall of twenty-one (21) good practices are presented in this report; ten (10) concern advanced biofuel plants and twelve (12) concern renewable fuel policies.

1.2. Approach and data collection

The good practices presented here have been identified through literature and stakeholder consultations and the analysis was supported by semi-structured interviews.

The aim of conducting semi-structured interviews was to gather similar data with the questionnaire as well as seek additional contextual information surrounding either supply chain configurations and capabilities or past, present, and future trends in policy support mechanisms.

Two versions (one for plants and one for policy) of an online survey were launched in M16 for a period of two months on the project website. The rationale behind the survey was to ensure that the good practices identified were selected among a variety of cases that extend beyond the knowledge and capacities of the project consortium and also take into account the multi-actor approach and ensure a participatory process across the selection, mapping, analysis and formation of good practices and recommendation. The questionnaires and the list of stakeholders interviewed are included as Annexes in this report.

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[3] Vensim is an industrial-strength simulation software built to improve the performance of real systems. Vensim's rich feature set emphasizes model quality, connections to data, flexible distribution, and advanced algorithms. https://vensim.com/vensim-software/

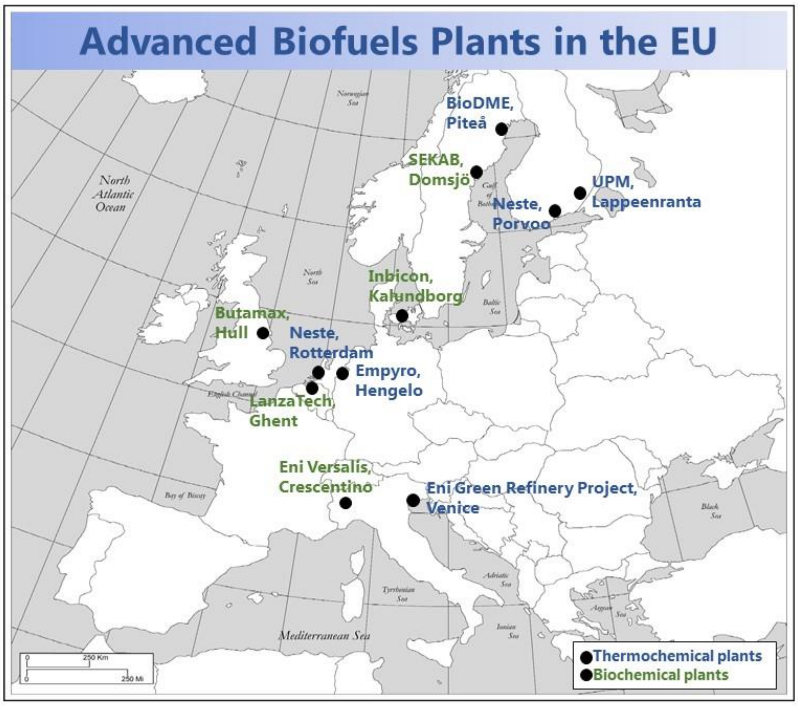
[4] FAO (2014) Good Practices template, www.fao.org/capacitydevelopment/goodpractices/gphome/en/

[5] Bretschneider, S., Marc-Aurele Jr., F. J., & Wu, J. (2004) ''Best Practices'' Research: A Methodological Guide for the Perplexed, *JPART*, 15:307–323.

2. Good practices in advanced biofuel plants

2.1. Overview of good practices

Map 1 below presents an overview of the selected plants that are presented in this report.



Map 1 European biorefineries with good practices (own compilation)

Ten (10) thermochemical and biochemical were selected as good practice cases, based on their merit of promoting the uptake of advanced biofuels for the European transport market. Plants were chosen to highlight all three kinds of development stages (pilot, demonstration and commercial), differing partnership structure, funding mechanism, time in operation, source of feedstock, conversion and product types and quantities, distribution possibilities and sustainability measures (Table 1).

Two (2) biochemical plants chosen are currently either closed or idle. They have been included in this report due to the innovative contribution they brought to their industrial area and invested companies. Along with the eight (8) other plants, all represent a good practice case at the time of operation in terms of environmental, economic and social performance, as well as transferability or replicability factors.

Table 1 Overview of thermochemical biorefineries

	BioDME	**Empyro**	**Neste**	**UPM**	**Eni Green**
Region/ country	Piteå, Sweden	Hengelo, Netherlands	Porvoo, Finland & Rotterdam, Netherlands	Lappeenranta, Finland	Venice, Italy
Partnership	CHEMREC, Delphi Diesel Systems, ETC research centre, Haldor Topsoe, Preem, Total, Volvo	Zeton and Tree Power; joint partnership with Twence Holding B.V.	Kilpilahti industrial area/Porvoo port and Port of Rotterdam collaboration opportunities	BNP Paribas, Leaders of Sustainable Biofuels, Zero Emission Resource Organisation, Technical Research Centre of Finland	Honeywell UOP, Bayern Oil, PCK and Ceska Rafinerska
Financing (private or public)	€28.4 million Funded by the European 7th framework programme (FP7) and The Swedish Energy Agency	€19 million Financing from the EU FP7, the Dutch government (TKI-BBE) and equity investments from the province of Overijssel (EFO) and a local investor	Porvoo : €100 million Rotterdam : €60 million Private	€179 million Private	€100 million Private
Development stage	Pilot	Demonstration	Commercial	Commercial	Commercial
Hours in operation	11,000	3,500		10,000	Continuous since 2014
Feedstock type(s) & capacity	Sulphate (kraft) black liquor; 3MW; 20t of dry BL per day	120t dry clean wood residues	Various vegetable oils and waste streams	Crude Tall Oil	Vegetable oils, animal fats and greases; 11,575 barrels/day

Conversion pathway	Chemrec gasification technology, HaldorTopsoe syngas technology with pyrolysis oil	Biomass Technology Group Biomass to Liquid Pyrolysis	NEXBTL: Own technology for hydrogenated vegetable oils processing	HaldorTopsoe hydro-treatment	Ecofining process: with deoxygenation, isomerization and product separation
Product (by-product)	4t/day DME	77t/day or 20 million litres/yr crude pyrolysis oil	Renewable diesel; 200,00t/yr; 1,000,000t/yr ; 40,000t/yr bio-propane	100,000t/yr	Hydrocarbon fuels (naphtha, LPG and jet fuel) and projected 420,000t/yr green diesel
Distribution and end use	Standalone with dedicated DME tanks, piloted for heavy trucking industry	Heat & power, automotive fuels after co-refining and Biorefineries	Renewable diesel for road vehicles, jet engine fuel compatible with existing jet fuel	Biodiesel can be blended with fossil diesel or used alone and it is compatible with vehicle engines and fuel distribution systems. Bio-naphtha can be used as a biocomponent in fossil gasoline	Blending 15% of the Green Diesel additive to a fossil diesel fuel
Sustainability measures	The biofuel produced uses a neighbouring sulphite mill by-product while yielding low PM matter and absence of soot	Energy efficiency using non-condensable pyrolysis gases to generate steam and power and excess heat used for drying; the plant uses clean woody biomass from local sources and recycles minerals back into soil	Significant reductions in tailpipe emissions while renewable diesel also reduces particle, hydrocarbon and nitrogen oxide emissions	UPM selected for climate change mitigation in UN Global Compact initiative; pulp and paper mill integration benefits such as no land use change and crude tall oil is classified as a residue	15% of the fuel is made of renewable “green” diesel and significantly reduces polluting emissions, cutting unburnt hydrocarbons and carbon monoxide

Table 2 Overview of biochemical biorefineries

	SEKAB	**Butamax (closed)**	**Inbicon (idle)**	**Eni Versalis**	**LanzaTech**
Region/ Country	Domsjö, Sweden	Hull, UK	Kalundborg, Denmark	Crescentino, Italy	Ghent, Belgium
Partnership	BioFuel Region, EuropaBio, F3, Företagsutbildarna, KOMTEK, Processum, Scania, Svebio, Taurus Energy, UNICA, Collaboration 2gen ethanol	Joint venture between BP and DuPont; consultancy for refiner and producer partners; working with leading companies across the existing U.S. biofuels industry; partnership with Early Adopters Group	Dong Energy; suppliers of Novozymes and Danisco Genencor; distribution to Statoil; partnership with Great River Energy and Otoka Energy for development in North Dakota	Joint venture with Mossi Ghisolfi Group	ArcelorMittal, Sulzer Chemtech
Financing (source & type of funds)		$50 million Private (BP & DuPont)	€54 million (construction), €10m of which was given from the Danish Energy Authority under Danish EUDP, €9m supported by FP7	€150 million Support from NER 300 and the FP7 framework program	€150 million Horizon2020
Development stage	Pilot	Demonstration	Demonstration	Commercial	Commercial
Hours in operation	50,000		15,000		8,000hr/yr
Feedstock type(s) & capacity	2t dry/d feedstock	0.2-0.3t/d unmodified yeast	96t/d; wheat straw	Agricultural and forestry residues, and energy crops	50,000Nm^{3}H$_2$+CO (carbon-containing gas from blast furnaces)
Conversion pathway	Own technology CelluAPP: heat treat-	Microbial production with a batch process	Biomass mechanical conditioning; hydrothermal pre-treatment; pre-enzymatic hydrolysis at high dry	Own technology: PROESA (heat treatment and enzymatic hydrolysis) to extract sugars	Microbes that feed on carbon monoxide produce ethanol

	ment and enzymatic hydrolysis with detoxing technology		matter consistency (up to 30% d.m.) for continuous liquefaction	from lignocellulosic biomass; 200,000t/y	
Product (by-product)	3.5 MWh/d ethanol; 4MWh/d lignin; 1MWh/d biogas	0.057-0.068t/d Bio-isobutanol	13t/d ethanol; 30t/d lignin ; 45t/d C5molasses	Ethanol; 25,000 – 40,000t/yr	143t/d bioethanol
Distribution and end use	Diesel engines; buses and lorries; E85 available in 1,500 locations in Sweden; and ED95 for adapted diesel engines	Drop-in biofuel that can be used in existing infrastructure or blended into gasoline	Ethanol produced is used by blending with conventional petrol; animal feed and lignin used as fuel for power plants	Competitive cost of product compared to oil	Transport fuel or potentially production of plastics
Additional information	Produces ED95, an ethanol fuel that reduces emissions of fossil CO2 by up to 80 per cent; created its own Verified Sustainable Ethanol Initiative	Bio-isobutanol yields a higher potential for replacing gasoline as it has a higher energy content than ethanol	The plant makes use of heat energy generated by Asnae coal-fired plant, a co-location which reduces CO2 emissions by 25,000t	20,000 tonnes of ethanol from a biorefinery saves 72,000 tons of CO2 through bioethanol production; this plant ensures complete water recycling and sources biomass locally	Operating at ambient temperature and pressure; 120,000 tonnes per year of CO2 reductions were reported for the first phase of the plant

2.2. Environmental, economic and social performance per plant and development stage

This section provides an overview of Good practices implemented by 11 plants, 5 thermochemical and 6 biochemical, and an initial characterisation of their performance based on environmental, economic and social indicators. These are respectively: i) greenhouse gas emissions reduction or other environmental safeguards, ii) production capacity, and iii) employment (direct and indirect) or other social partnership factors.

The work provides an overview of their performance as defined by these indicators firstly by comparing environmental achievement with targets from the recast of the Renewable Energy Directive (RED II)[6], which includes annexes listing default values for greenhouse gas reductions achieved through different advanced biofuel production pathways.

Secondly, the economic performance of the plants is described by the impact of their production capacity (or its potential) on national shares and mandates of biofuels. The sources for this information include:

- Eurostat Shares for Renewables[7] which provides the share of solid biofuels, other renewables (including biogas) and biofuels in transport per European country in 2017,
- the International Renewable Energy Agency[8] (IRENA) which provides data on energy power capacity for bioenergy (liquid biofuels, solid biomass and biogas) in 2017, and
- policy and statistic reports from EurObserv'ER, Renewable Energy Policy Factsheets for 2018 which highlight the share and trajectory of renewable energies for EU member states.
- The energy content of fuels listed in Annex III of the recast of the Renewable Energy Directive (RED II) and the International Energy Agency unit converter[9] used as a tool

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[6] COM/2016/0767 final/2 - 2016/0382 (COD)

[7] https://ec.europa.eu/eurostat/web/energy/data/shares

[8] IRENA (International Renewable Energy Agency) (2018) Country Rankings https://www.irena.org/our-work/Knowledge-Data-Statistics/Data-Statistics/Capacity-and-Generation/Country-Rankings, Last Visited on [13/04/2019]

[9] https://www.iea.org/statistics/resources/unitconverter/

- The prices of ethanol[10] and biodiesel (FAME)[11] are taken from the Independent Chemical Information Service (ICIS) for 2019 in € per cbm (cubic metre) FOB (free on board) Rotterdam

Finally, overall data describing the production activity and performance of plants (summarised in Table 1) was collected from the 2017 Technology status report from the Sub Group on Advanced Biofuels[12], including feedstock types and capacities, conversion types and production capacities, hours of operation and plant classification, and from official websites and publications advertised by the plant companies. Employment figures are primarily based on IRENA renewable energy employment data by country for liquid biofuels, published in 2017[13].

Each plant's performance and respective set of good practices is derived as a lesson for overcoming key barriers stated in D1.1 following stakeholder consultation[14]. The following analysis explores some of the ways in which these barriers are addressed or can be potentially overcome by good practices.

2.2.1.Thermochemical plants

I] Pilot Plants

The BioDME plant in Piteå, Sweden

The BioDME plant converts sulphate black liquor (which is the waste product from the kraft process of a paper and pulp mill) into methanol and dimethylether through gasification and

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[10] https://www.icis.com/explore/commodities/energy/ethanol/?intcmp=mega-menu-explore-commodities-energy-ethanol

[11] https://www.icis.com/explore/commodities/energy/biodiesel/?intcmp=mega-menu-explore-commodities-energy-biodiesel

[12] Landalv, I., Maniatis, K., Waldheim, L., van den Heuvel, E. & Kalligeros, S. (2017) Building up the future: Technology status and reliability of the value chains, *Sub Group on Advanced Biofuels, European Commission*

[13] IRENA (International Renewable Energy Agency) (2018) Irena jobs database, Renewable Energy Employment by Country, https://www.irena.org/ourwork/Knowledge-Data-Statistics/Data-Statistics/Benefits/Renewable-Energy-Employment-by-Country, Last Visited on [13/03/2019]

[14] Uslu, A., Detz, R. J. & Mozaffarian, H. (2017) Barriers to advanced liquid biofuels and renewable liquid fuels of non-biological origin, D1.1 Key barriers to advanced fuels, *ADVANCEFUEL*

syngas technology with pyrolysis oil. In 2013, the plant produced more than 500 tons of BioDME and trucks used for piloting the fuel accumulated more than 1 million km of operation[15].

Environmental performance

The plant absorbs a part of the black liquor coming from an existing facility producing pulp, which according to the plant's company Chemrec, makes the BioDME plant one of the highest land-use efficiencies in second generation biofuels.

The plant states that DME produced via biomass gasification and black liquor as pulp mill residue having the same greenhouse gas and energy consumption as Fischer-Tropsch from biomass, i.e. around **10 g CO2 eq/km for around 275 MJ/100 km**. By comparison, conventional fuels produce between 150 to 175 g CO2 eq/km for 200 MJ/100km[16].

As a reference point, according to RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from dimethylether (DME) from black-liquor gasification integrated with pulp mill and Methanol from black-liquor gasification integrated with pulp mill is 89%.

Additionally, the plant has reported positive feedback from driver perception from field tests due to locally produced fuel with good environmental properties and the absence of soot[17][18].

Economic performance

The full operational capacity of the pilot plant is 3MW which represents 20 tonnes of dry black liquor per day to produce **1.8MW of syngas** and **4 tonnes of DME per day**.

According to IRENA, installed capacity (MW) in 2017 for liquid biofuels in Sweden was 515.000 MW.

According to Eurostat Shares of Renewables, Sweden's share of compliant biofuels in transport in 2017 was 1,669.7ktoe. If operated every day of the year and not accounting for plant downtime or export/use in other countries, **the BioDME plant DME production represents 1ktoe** (total production in tonnes per year is multiplied by energy content [28 MJ/kg] of dimethylether cited in RED II).

There are no listed market prices for DME since the fuel for transport purposes is in nascent form. The fuel was tested on 10 Volvo trucks in the BioDME project and performed on an accumulated mileage of over 1 million km[19].

Social performance

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[15] Landalv, I., Gebart, R., Marke, B., Granberg, F., Furusjo, E., Lownertz, P., Ohrman, O. G. W., Sorensen, E. L. & Salomonsson, P. (2014) Two Years Experience of the BioDME Project—A Complete Wood to Wheel Concept, *Environmental Progress & Sustainable Energy*, 33 (3)

[16] Comparison of DME with other fuels with respect to emission of greenhouse gases and energy consumption, http://www.biodme.eu/about-dme/, Last Visited on [12/03/2019]

[17] http://www.biodme.eu/work-packages/veichle-field-test/, Last Visited on [12/03/2019]

[18] http://www.biodme.eu/work-packages/vehicle-procurement/, Last Visited on [12/03/2019]

[19] http://www.biodme.eu/work-packages/veichle-field-test/, Last Visited on [25/03/2019]

The plant employs **19 full-time staff members** as researchers and technicians at the plant[20]. According to IRENA, there are 7,600 direct and indirect jobs in the liquid biofuels industry in Sweden.

II] Demonstration Plants

The Empyro plant in Hengelo, Netherlands

The Empyro plant converts wood residues into crude pyrolysis oil through liquid pyrolysis, oil being the main product and pyrolysis gases are used to generate additional steam and power. The end-product is designed to be compatible with diesel and gasoline.
The plant is a located close to its raw material sources. This gives it the plant the potential to overcome the following barriers: difficulties in mobilising various feedstocks (technical), lack of clarity on land availability and environmental constraints (environmental), lack of knowledge from farmers (social).

Environmental performance
Empyro plant uses clean woody biomass from local sources while local decentralized production of pyrolysis oil extracts minerals in the biomass and recycles them back into soil.
Pyrolysis oil can replace natural gas in the production of process steam and thus can contribute to eliminating greenhouse gas emissions from conventional fossil-based gas[21]. According to the company's website, one dairy producer is saving 10 million m^3 of natural gas when co-firing pyrolysis oil. **The CO_2-eq/year reduction reported from the plant data is 24,000 tonnes[22]**.
The BTG-BTL group has published a summary of greenhouse gas emissions savings from the Empyro pyrolysis plant: total emissions from production while using forest residues amount to 8.70 g CO_2-eq/MJ pyrolysis oil, after attribution of emissions to co-production of heat and electricity. When placed against fossil fuel comparators, this figure represents an emissions savings of 90.4% when replacing electricity, 88.7% when replacing heat and 89.9% when replacing Combined Heat and Power[23].
According to the RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from waste wood Fischer-Tropsch diesel in free-standing plant is 85%.

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[20] Landalv, I., Gebart, R., Marke, B., Granberg, F., Furusjo, E., Lownertz, P., Ohrman, O. G. W., Sorensen, E. L. & Salomonsson, P. (2014) Two Years Experience of the BioDME Project—A Complete Wood to Wheel Concept, *Environmental Progress & Sustainable Energy*, 33 (3)

[21] https://www.btg-btl.com/media/cms_block/leafletempyro.pdf, Last Visited on [12/03/2019]

[22] Fast pyrolysis based advanced biofuels, New Delhi, 8th March 2018, Rene Venendaal, https://ec.europa.eu/energy/sites/ener/files/documents/19_renevenendaal-btg.pdf

[23] Btg-btl (2011) RED Greenhouse gas emission savings of pyrolysis oil produced by the Empyro pyrolysis plant: Summary, https://www.btg-btl.com/red_greenhouse_gas_emission_savings_of_pyrolysis_oil_produced_by_the_empyro_pyrolysis_plant.pdf

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Economic performance

The demonstration/commercial plant operates at a capacity of 120 tonnes per day of clean wood residues to produce **77 tonnes per day or 20 million litres per year of crude pyrolysis oil**, as well as 8MW of by-product. In 2017 the plant reached 100% capacity and passed the 20 million litre mark for fast pyrolysis oil, a figure which represents the replacement of 12 million cubic meters of natural gas, or the equivalent annual consumption of 8,000 Dutch households[24]. Pyrolysis oil can be stored for long periods of time and is therefore available when necessary.

According to Eurostat Shares of Renewables, Netherland's share of compliant biofuels in transport in 2017 was 303ktoe. Not accounting for plant downtime or export/use in other countries, the **Empyro plant production represents 17ktoe, which represents almost 6% of the national share** (total production in tonnes per year is multiplied by energy content [36 MJ/l] of co-processed oil of biomass or pyrolysed biomass origin cited in RED II).

The indicative price of pyrolysis oil is listed by the plant as 18-20€/GJ[25], which signifies a **gross added value of between €13 and €14 million per year**.

Social performance

The project creates approximately **100** person-years of work in Overijssel.

According to IRENA, there are 400 direct and indirect jobs in the liquid biofuels sector of the Netherlands.

III] Commercial Plants

The Neste plants in Porvoo, Finland and Rotterdam, Netherlands

Neste operates two advanced biofuels plants which convert various vegetable oils and waste streams into renewable biodiesel through hydrogenated vegetable oil processing.

The Port of Rotterdam is the largest port in Europe, provides opportunities for collaborating with neighbouring chemical plants[26] and has an integrated infrastructure connecting companies[27] while the Kilpilahti industrial area contains over 11 companies[28], and enacts air, sea water and surface water quality monitoring. Additionally, the Porvoo port is the largest in Finland

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[24] Btg World (2014) *Press* Release: Empyro breaks ground on biomass pyrolysis oil production plant in The Netherlands, http://www.btgworld.com/en/news/press-release-empyro-breaks-ground-persbericht-eerste-paal-empyro.pdf

[25] Fast pyrolysis based advanced biofuels, New Delhi, 8th March 2018, Rene Venendaal, https://ec.europa.eu/energy/sites/ener/files/documents/19_renevenendaal-btg.pdf

[26] https://www.neste.us/about-neste/who-we-are/production/rotterdam-refinery, Last Visited on [23/03/2019]

[27] Schouten, H. (2016) Site director of Neste Rotterdam, Port of Rotterdam, https://www.youtube.com/watch?v=ra896e-6GTg

[28] https://www.kilpilahti.fi/in-english/, Last Visited on [23/03/2019]

with approximately 1,100 to 1,400 ships passing every year[29]. These advantages have the potential of overcoming two significant barriers elicited from the stakeholder consultation: Concerns on stability/security of the industry (regulatory) and manufacturers unwillingness to change (economic).

Environmental performance

The Neste plants produce low-emission biofuels (significant reductions in tailpipe emissions) and have celebrated 10 years of reducing emissions, representing more than 33 million tons of traffic emissions reduction. Their renewable diesel also reduces particle, hydrocarbon and nitrogen oxide emissions[30].

Neste claims its Renewable Diesel is made from 100% renewable raw materials which achieve between **50% to a 90% reduction in greenhouse gas emissions** over its lifecycle compared to conventional fossil diesel[31].

In terms of the RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from waste cooking oil biodiesel is 84%.

Neste procures 36% of palm oil from mills with methane recovery systems or systems to prevent its formation. In 2017, it verified a 50% methane emission reduction from application of a belt filter press at palm oil mills[32].

According to RED II targets, pure vegetable oil made from palm oil (with a process with methane capture at oil mill) produces a default value of 57.2 g CO_2eq/MJ as total greenhouse gas emissions for cultivation, processing, transport and distribution.

Economic performance

Neste has invested approximately €1.5 billion in the renewable fuels production capacity in order to produce altogether some 2.7 million tonnes of renewables annually, which are suitable for high concentrations or even standalone products in all diesel engines, and have no special requirements for vehicles in terms of climates and storage[33].

The commercial Neste plants in Porvoo and Rotterdam produce **200,000 tonnes a year and 1,000,000 tonnes a year of biodiesel,** respectively, from various vegetable oils and waste streams.

According to Eurostat Shares of Renewables, Finland's share of compliant biofuels in transport in 2017 was 390ktoe. Without being adjusted for plant downtime or export/use in other countries, **the Porvoo plant production represents 171ktoe, almost half of the national share.** (total production in tonnes per year is multiplied by energy content [36 MJ/kg] of biodiesel of biomass origin cited in RED II).

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[29] https://www.neste.us/about-neste/who-we-are/production/finnish-refineries/porvoo, Last Visited on [23/12/2019]

[30] https://www.neste.com/what-difference-between-renewable-diesel-and-traditional-biodiesel-if-any, Last Visited on [12/03/2019]

[31] https://www.neste.com/companies/products/renewable-fuels, Last Visited on [12/03/2019]

[32] https://www.neste.com/neste-lead-project-verified-50-methane-emission-reduction-palm-oil-mills, Last Visited on [12/03/2019]

[33] https://www.neste.com/what-difference-between-renewable-diesel-and-traditional-biodiesel-if-any, Last Visited on [12/03/2019]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

According to Eurostat Shares of Renewables, Netherland's share of compliant biofuels in transport in 2017 was 303ktoe. Without being adjusted for plant downtime or export/use in other countries, **the Rotterdam plant production represents 859ktoe, almost triple the national share** (total production in tonnes per year is multiplied by energy content [36 MJ/kg] of biodiesel of biomass origin cited in RED II).

According to ICIS, EU fuel prices for FAME (fatty acid methyl ether) in January 2019 ranged between €737-754/tonne FOB Rotterdam[34]. The Neste Porvoo plant production represents a **gross added value of approximately €149 million (FOB) Rotterdam per year in fatty acid methyl ester terms,** while the Rotterdam plant represents a **gross added value of approximately €746 million (FOB) Rotterdam per year in fatty acid methyl ester terms.**

Social performance

According to IRENA, there are 2,900 direct and indirect jobs in the liquid biofuels industry in Finland and 25,400 in the solid biomass renewable energy sector. The Porvoo refinery is situated in the Kilpilahti industrial area which **employs** approximately **1900 workers**[35]. This represents almost ***half* of the national sector total**.

The Rotterdam refinery is located in the largest port of Europe, which is a major hub for trade, employment and partnership opportunities.

According to IRENA, there are 400 direct and indirect jobs in the liquid biofuels sector of the Netherlands.

The UPM plant in Lappeenranta, Finland

The UPM plant utilises crude tall oil which it extracts initially within the pulp and paper mill production process and converts it into biodiesel and naphtha through a hydrotreatment process.

UPM Lappeenranta is co-located with an industrial pulp and paper mill plant and benefits from strong feedstock sourcing thanks to managed nurseries, research and development, and trained forestry staff[36]. This gives UPM the opportunity to overcome the following barriers elicited from the stakeholder consultation: difficulties in mobilising various feedstocks, from remote regions (technical), high pre-treatment storage and transportation costs and unavailability of investments necessary for feedstock harvesting (economic).

Environmental performance

UPM BioVerno diesel tests publish results of tailpipe emissions (particle mass, hydrocarbon, carbon dioxide, nitrogen dioxide and carbon monoxide) as reduced by up to dozens of percent compared to conventional diesel fuel. The wood-based fuel was tested on a dredging

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[34] Europe biodiesel prices mixed on seasonality, January 25th 2019, *ICIS NEWS,* https://www.icis.com/explore/resources/news/2019/01/25/10311198/europe-biodiesel-prices-mixed-on-seasonality/

[35] https://www.neste.com/porvoo-refinery

[36] https://www.upm.com/responsibility/forests/our-forests/, Last Visited on [23/12/2019]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

vessel (maritime) as a 50% biofuel blend which represented a reduction of 600 tonnes in carbon dioxide emissions for the 6 months duration of the project. **UPM reports up to 80% lower greenhouse gas emissions than fossil diesel for both of its renewable biofuels**[37].

Crude Tall Oil is part of Annex IX, part A and therefore classified by the European institutions as residue and eligible for double-counting and is part of the sub-target for advanced biofuels. The use of crude tall oil in biofuel production does not increase wood usage and has been awarded with RSB (Roundtable on Sustainable Biomaterials) low iLUC (indirect land use change) risk certification[38].

According to RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving Fischer-Tropsch diesel from black-liquor gasification integrated with pulp mill is 89%.

Additionally, a bonus of 29 g CO2eq/MJ shall be attributed if evidence is provided that the land: (a) was not in use for agriculture or any other activity in January 2008; and (b) is severely degraded land, including such land that was formerly in agricultural use. UPM manages 570,000 hectares of forestry land in Finland which are semi-natural boreal forests, however 255,00 hectares in Uruguay have been established on formerly degraded grasslands[39], thus earning the RED II carbon capture and consumption reduction bonus.

Economic performance

The commercial plant in Lappeenranta produces **100,000 tonnes per year** (or 120 million litres per year) of biodiesel and bio-naphtha from crude tall oil.

Biodiesel can be blended with fossil diesel or used on its own, and is compatible with vehicle engines and fuel distribution systems. Bio-naphtha can be used as a biocomponent in fossil gasoline.

According to Eurostat Shares of Renewables, Finland's share of compliant biofuels in transport in 2017 was 390ktoe. Not accounting for plant downtime or export/use in other countries, **Lappeenranta's production represents 105ktoe, over a quarter of the national share** (total production in tonnes per year is multiplied by energy content [44 MJ/kg] of hydrotreated oil of biomass origin cited in RED II). According to ICIS, EU fuel prices for FAME (fatty acid methyl ether) in January 2019 ranged between €737-754/tonne FOB Rotterdam[40]. The UPM Lappeenranta plant production represents a **gross added value of approximately €74 million (FOB) Rotterdam per year in fatty acid methyl ester terms.**

Social performance

The UPM Lappeenranta plant employs **250 direct and indirect employees**[41].

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[37] https://www.upmbiofuels.com/products/upm-bioverno-diesel/, Last Visited on [12/03/2019]

[38] Peters, D & Stojcheva V. (2014) Crude tall oil low ILUC risk assessment: Comparing global supply and demand, *Ecofys by order of UPM,* https://www.upmbiofuels.com/siteassets/documents/other-publications/ecofys-crude-tall-oil-low-iluc-risk-assessment-report.pdf

[39] https://www.upm.com/responsibility/forests/our-forests/, Last Visited on [12/03/2019]

[40] Europe biodiesel prices mixed on seasonality, January 25th 2019, *ICIS NEWS,* https://www.icis.com/explore/resources/news/2019/01/25/10311198/europe-biodiesel-prices-mixed-on-seasonality/

[41] https://www.upmbiofuels.com/about-upm-biofuels/production/upm-lappeenranta-biorefinery/, Last Visited on [12/03/2019]

According to IRENA, there are 2,900 direct and indirect jobs in the liquid biofuels industry in Finland. The plant's **share of employment in the national sector total is nearly 9%**.
UPM employees and contractors who works along the wood sourcing and forestry chain must be familiar with the UPM Code of Conduct and certification schemes. UPM has its own e-learning platform helping employees to complete the requisite courses.

The Eni Green plant in Venice, Italy

Eni's Green Refinery Project converts vegetable oils, animal fats and greases into hydrocarbon fuels, naphtha and LPG and jet fuel through an eco-fining process with deoxygenation, isomerization and product separation. This creates the Eni Diesel+ which comes from blending a 15% Green Diesel additive to a fossil diesel fuel.

Environmental performance

As a fuel which is 15 percent renewable (15% biodiesel added to conventional diesel), Eni Diesel **significantly reduces polluting emissions, and cuts unburnt hydrocarbons and carbon monoxide by up to 40 per cent**. In addition, a more sustainable production cycle helps to reduce CO_2 emissions by an average of 5 per cent[42].
According to RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from waste cooking oil biodiesel is 84% and hydrotreated oil from waste cooking oil is 83%.
The Green Diesel formulation allows for improved detergency of the fuel injection system in engines, which provides savings in consumption equal to 800km for every 20,000[43].

Economic performance

The Eni Green plant is projected to produce more than **420,000 tonnes per year of green diesel** from 11,575 barrels per day of feedstock. By 2021, Eni's Venice biorefinery will be able to process as much as 560,000 tonnes of feedstocks per year, using increasingly used cooking oils, vegetable oils and animal fats.
Green Diesel has higher heating value and energy density than fatty acid methyl ester, a very high cetane number, low aromatics content and can be blended with diesel without any limitation as a biocomponent[44].
According to Eurostat Shares of Renewables, Italy's share of compliant biofuels in transport in 2017 was 1,060.3ktoe. Not accounting for plant downtime or export/use in other countries, **the Eni Green plant production represents 441ktoe, which represents almost half of the national share** (total production in tonnes per year is multiplied by energy content [44 MJ/kg] of hydrotreated oil of biomass origin cited in RED II). According to ICIS, EU fuel prices

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[42] https://www.eni.com/en_IT/innovation/technological-platforms/bio-refinery/green-diesel.page, Last Visited on [12/03/2019]

[43] Giammarco Gioco & Corrado Fittavolini: Eni Diesel, *Eni Video Channel*

[44] https://www.eni.com/docs/en_IT/enicom/publications-archive/company/operations-strategies/refining-marketing/eni_Green-Refinery_esecutivo.pdf

for FAME (fatty acid methyl ether) in January 2019 ranged between €737-754/tonne FOB Rotterdam[45]. The Eni Green plant production represents a **gross added value of around €313 million (FOB) Rotterdam per year in fatty acid methyl ester terms.**

Social performance

Collaborative relationships have been established between the refinery and the academic community which have allowed several students to write theses on related topics, drawing on the experience and professionalism of the staff and the know-how of the company[46].

According to IRENA, there are 6,500 direct and indirect jobs in the liquid biofuels industry in Italy.

2.2.2. Biochemical plants

I] Pilot Plants

The SEKAB plant in Domsjö, Sweden

The SEKAB plant utilises its own CelluAPP technology to pre-treat feedstock with heat and catalyst, steam explosion, batch enzyme hydrolysis with detoxing technology, separation of sugars, and fermentation with yeast or bacteria for the production of 99% ethanol with a final distillation process. SEKAB's technology is able to process a wide range of raw materials, from wood chips and switchgrass from energy crops to wheat, cottonwoods, corn stover, paper, corn and sugarcane, and extract cellulose, hemicellulose and lignin[47].

The plant recycles raw material residues to fields, which gives it the opportunity to overcome the following barriers: technical uncertainties regarding input required to turn marginal land types to productive (technical), lack of profitability of dedicated energy crops in relation to current investments for fertilisation and weed control (economic), lack of clarity about environmental constraints (environmental).

Environmental performance

The bioethanol produced at the SEKAB plant minimizes toxicological effects and climate impacts thanks to advanced in-house conversion technology and the use of waste products from forestry and agriculture[48]. Outgoing process water is treated in an anaerobic wastewater

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[45] Europe biodiesel prices mixed on seasonality, January 25th 2019, *ICIS NEWS,* https://www.icis.com/explore/resources/news/2019/01/25/10311198/europe-biodiesel-prices-mixed-on-seasonality/

[46] https://www.eni.com/docs/en_IT/enicom/publications-archive/publications/brochures-booklets/countries/eni_Venezia-ENG.pdf

[47] http://www.sekab.com/biorefinery/, Last Visited on [12/03/2019]

[48] http://www.sekab.com/biofuel/, Last Visited on [12/03/2019]

treatment process. The **chemical plant (both the ethanol plant and cellulose annex) utilises green bioenergy for its process from its lignin production and energy input** in the form of vapour from Övik Energy's biomass-fired power and heating plant, processes **which help contribute to a lower carbon footprint**[49].

SEKAB plant location allows for economies of scale in transportation as it has access to main railways, maritime and road transportation networks. Integration with a pulp mill of Domsjö Factories means wasted raw material (sulphite lye) is captured and transformed into a viable advanced biofuel instead of discarded in nearby waterways.

Pure ethanol degrades rapidly in the environment and has near-zero particle pollution and low nitrogen oxide emissions[50].

SEKAB created its own sustainability criteria through the Verified Sustainable Ethanol Initiative and was awarded the Sustainable Bioethanol Award by Green Power Conferences at the World Biofuels Markets Conference in Brussels. Sustainability criteria involves at least 85% reduction of fossil carbon dioxide as compared to petrol and Zero tolerance for the felling of rainforests. It has also obtained the ISO 14001-certificate as a testament to safeguarding its environmental impact[51].

The RED II targets list sugarcane ethanol a default value for greenhouse gas emissions saving of 70% if produced with no net carbon emissions from land use changes.

Economic performance

The SEKAB plant has been operating for over 50,000 hours and as a **pilot plant produces 3.5 MWh per day of ethanol** from 2 tonnes per day of dry feedstock (representing 10.6 MWh per day). Additionally, it produces by-products of 4 MWh per day of lignin and 1 MWh per day of biogas.

According to Eurostat Shares of Renewables, Sweden's share of compliant biofuels in transport in 2017 was 1,669.7ktoe. Not accounting for plant downtime, **the SEKAB plant ethanol production represented 0.1ktoe**. According to ICIS, EU fuel prices for ethanol in February 2019 ranged between €568-573/cbm FOB[52]. The SEKAB plant production represents a **gross added value of around €128,000 (FOB) Rotterdam per year.**

Social performance

Although there are no public figures available for the direct employment at the SEKAB plant, the **company collaborates extensively with research institutes, universities, government agencies, vehicle manufacturers and other companies with the forestry and chemical industries**, as well as forestry and processing industry within the Domsjö industrial area[53].

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[49] http://www.sekab.com/sustainability/what-weve-done/plant-for-green-chemical-production/, Last Visited on [12/032019]

[50] SEKAB Product Sheet: Premium Pure Technical Ethanol 95%, http://www.sekab.com/wp-content/uploads/2013/10/Product-Sheet-Technical-ethanol.pdf

[51] DNV GL (2016) Management System Certificate ISO 14001:2004, http://www.sekab.com/wp-content/uploads/2012/11/SEKAB-BioFuels-and-Chemicals-AB.pdf

[52] EU fuel ethanol price range narrows as supply tightens, imports expected, February 14th 2019, *ICIS NEWS*, https://www.icis.com/explore/resources/news/2019/02/14/10319052/eu-fuel-ethanol-price-range-narrows-as-supply-tightens-imports-expected/

[53] http://www.sekab.com/about-us/cooperation-partners/, Last Visited on [24/03/2019]

According to IRENA, there are 7,600 direct and indirect jobs in the liquid biofuels industry in Sweden.

II] Demonstration Plants

The Butamax plant in Hull, UK (closed)

The Butamax joint venture demonstration plant, constructed by BP and DuPont, developed modified genes to expand enzyme conversion of sugar to biobutanol in higher quantities and more efficiently. The combined expertise of BP and DuPont's renowned industrial biotechnology capabilities and partnerships contributed to better prospects for product development and market uptake[54], which has the potential to address two highly-ranked economic barriers from the stakeholder consultation: high feedstock and conversion start-up costs.

The Butamax demonstration has proven its technology testing without any barriers reported and the plant has since closed. It has been chosen as a good practice case due to the innovative and successful testing of producing isobutanol, and the significance for the international corporate partnership of BP and DuPont: the commercialisation of bio-isobutanol production within its Kansas facility in the US[55].

Environmental performance
Feedstocks used included corn, sugarcane, wheat, cellulose and macroalgae.
According to RED II, butanol made from renewable sources yields an energy content of 33 MJ/kg, compared to petrol which is 43 MJ/kg. Butanol is thus closer to gasoline than ethanol is in terms of energy content, thus having a higher potential of replacing fossil fuel energy.
According to Butamax, **bio-isobutanol can displace 16% of every gallon of hydrocarbon gasoline**, **which means saving 17 billion gallons of gasoline per year** and replacing it with a renewable fuel[56].
Biobutanol degrades relatively quickly under both aerobic and anaerobic conditions while bioaccumulation in food webs is not expected.

Economic performance
The Butamax demonstration plant was able to convert 0.2-0.3 tonnes per day of unmodified yeast into **0.057-0.068 tonnes per day of isobutanol** in a continuous batch process.

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[54] http://www.butamax.com/history.aspx, Last Visited on [23/12/2019]
[55] "BP and DuPont joint venture, Butamax®, announces next step in commercialization of bio-isobutanol with acquisition of ethanol facility in Kansas", 2017, *Press Release,* https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-and-dupont-joint-venture.html, Last Visited on [24/03/2019]
[56] http://www.butamax.com/The-Bio-Isobutanol-Advantage/Higher-Value-Biofuel.aspx, Last Visited on [12/03/2019]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

Isobutanol has a higher energy content than ethanol and can be blended with gasoline at higher rates and directly at refineries and transported via existing fuel infrastructure. It does not require flex-fuel vehicle pipes and has about 4 percent less energy density than gasoline[57]. According to Eurostat Shares of Renewables, the United Kingdom's share of compliant biofuels in transport in 2017 was 1,016ktoe.

Social performance

38 experts in technology scale-up and operations were based at the demonstration facility[58]. This does not include the construction personnel needed.
According to IRENA, there are 10,000 direct and indirect jobs in the liquid biofuels industry in the United Kingdom.

The Inbicon plant in Kalundborg, Denmark (idle)

The Inbicon plant has demonstrated two process configurations: one converting wheat straw into second generation bioethanol, lignin and C5 molasses based on C6 fermentation and one based on C5 and C6 fermentation through biomass mechanical conditioning, hydrothermal pre-treatment and pre-enzymatic hydrolysis for continuous liquefaction.
Inbicon was co-located with an industrial plant, which gave it the opportunity to overcome the following barriers: difficulties in mobilising various feedstocks, from remote regions (technical), high pre-treatment storage and transportation costs and unavailability of investments necessary for feedstock harvesting (economic).

The Inbicon plant is currently idle however it was chosen as a good practice because of its location and role within the formation of a rapidly growing network of plants in Kalundborg. Inbicon received straw from Nordisk and Novozymes as an example of this industrial 'symbiosis'. Twelve (12) interconnected companies with 30 different waste streams turned into valuable inputs now populate the area, providing an innovative case for industrial-scale energy efficiency, circularity and emissions reduction[59]. Furthermore, waste bioethanol from the plant was used by the energy company Statoil, which provides used cooling water to the Danish energy company Dong[60].

Environmental performance

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[57] http://www.butamax.com/The-Bio-Isobutanol-Advantage/Higher-Value-Biofuel.aspx, Last Visited on [12/03/2019]
[58] http://www.butamax.com/biofuel-technology.aspx, Last Visited on [12/03/2019]
[59] Eine Symbiose von Gewinn und Gewissen, 2016, *Neue Zurcher Zeitung,* https://www.nzz.ch/wirtschaft/wirtschaftspolitik/daenemarks-industrie-cluster-kalundborg-eine-symbiose-von-gewinn-und-gewissen-ld.82293, Last Visited on [24/03/2019]
[60] "Circular cities are doing it for themselves", 2017, *Resource Magazine,* https://resource.co/article/circular-cities-are-doing-it-themselves-11754, [24/03/2019]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

Feedstock used for the Inbicon plant was wheat straw as an agricultural by-product while lignin as a by-product was used as a biofuel to replace coal in power and heat generation. Finally, C5 molasses replaced oil in transportation. Integration of the plant with a power station permits usage of heat energy in the form of steam while the power plant reduces over 25,000 tonnes of CO_2 by using the biofuel and **the plant reported a CO_2 reduction from using all three products of 85%**[61].

According to RED II targets, if produced with no net carbon emissions from land use change, the default value for greenhouse gas emissions saving from wheat straw ethanol is 83%.

Economic performance

The first demonstration plant was able to produce **13 tonnes per day of ethanol** (plus 30 tonnes per day of lignin and 45 tonnes per day of C5 molasses) with 96 tonnes per day of dry raw material using C6 fermentation. In energy terms this represents **98 MWh/day of ethanol**, 167 MWh/day of lignin and 104 MWh/day of C5 molasses from 386 MWh/d of straw.

The second demonstration produced 4.5 tonnes per day of ethanol (plus 9 tonnes per day of lignin and 7 tonnes per day of C5 molasses) with 24 tonnes per day of dry raw material and using C5 and C6 fermentation. In energy terms this represents 34 MWh/day of ethanol, 50 MWh/day of lignin and 10 MWh/day of C5 molasses from 97 MWh/d of straw.

In 2010, the technology was proven to produce over **5.4 million litres of ethanol per year**, 13,100 tonnes per year of lignin pellets and 11,250 tonnes per year of C5 molasses from 30,000 tonnes of wheat straw[62].

The Inbicon cellulosic ethanol process consumed less energy than it produced in the conversion of biomass, which resulted in energy efficiency and cost reduction for the plant.

According to Eurostat Shares of Renewables, Denmark's share of compliant biofuels in transport in 2017 was 218.4ktoe. Not accounting for plant downtime, **the Inbicon plant ethanol production represented 2.7ktoe** (total production in tonnes per year is multiplied by energy content [21 MJ/l] of ethanol produced from renewable sources cited in RED II).

According to ICIS, EU fuel prices for ethanol in February 2019 ranged between €568-573/cbm FOB[63]. The Inbicon plant production represents a **gross added value of around €3 million (FOB) Rotterdam per year.**

Social performance

30 employees worked at the demonstration plant, while Inbicon as a whole employed approximately 60 employees. As an example of integrated energy efficiency from a partnership, lignin pellets were sent to Dong Energy, which is Denmark's largest energy company transitioning to renewables and has more than 5,000 employees[64].

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[61] Persson, M. (2010) Inbicon demonstration plant, *European Biofuels Technology Platform, 3rd Stakeholder Plenary Meeting,* http://www.etipbioenergy.eu/images/Michael_Persson_Inbicon.pdf

[62] http://www.etipbioenergy.eu/images/Michael_Persson_Inbicon.pdf

[63] EU fuel ethanol price range narrows as supply tightens, imports expected, February 14th 2019, *ICIS NEWS,* https://www.icis.com/explore/resources/news/2019/02/14/10319052/eu-fuel-ethanol-price-range-narrows-as-supply-tightens-imports-expected/

[64] European Bioethanol Technology Meeting (2010) Inbicon Kalundborg Large Scale Demonstration Plant, http://www.agfdt.de/loads/bi10/stranabb

According to IRENA, there are 200 direct and indirect jobs in the liquid biofuels industry in Denmark. The **Inbicon demonstration plant thus represented 15%** of Denmark's liquid biofuel sector employment.

III] Commercial Plants

Eni Versalis plant in Crescentino, Italy

The Eni Versalis plant produces cellulosic ethanol, green electricity and biogas from agricultural residues (rice and wheat straw), energy crops (reed, switchgrass and woody crops) and forestry residues through the Proesa technology which handles the pre-treatment of biomass before enzymatic hydrolysis and fermentation.

The plant operates close to its raw material sources and recycles raw material residues to fields. This opens the door to overcome the following barriers from stakeholder consultation: uncertainties regarding input required to turn marginal land types to productive and difficulties in mobilising various feedstocks (technical), lack of profitability of dedicated energy crops in relation to current investments for fertilisation and weed control (economic), lack of clarity about environmental constraints (environmental), and lack of knowledge from farmers (social).

Environmental performance

Wheat straw and giant reed is grown within 70 km of the factory and the plant ensures 100% water recycling, while generating lignin to obtain energy as well as biogas for further energy efficiency[65].

According to IEA, 20,000 tonnes of ethanol from the **biorefinery saves 72,000 tons of CO_2** through bioethanol production which represents a >70% greenhouse gas reduction compared to gasoline[66].

According to RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from wheat straw ethanol is 83%. Additionally, the default value for total greenhouse gas emissions for cultivating, processing, transport and distribution of wheat straw ethanol is 15.7gCO_2eq/MJ.

Economic performance

The plant has a capacity of **40,000 tonnes of bioethanol per year** converted from over 200,000 tonnes of biomass[67].

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[65] Picciotti, P. (2017) GHG savings with 2G Ethanol Industrial Plant, *BetaRenewables,* https://www.bio.org/sites/default/files/0830AM-Pierluigi%20Picciotti.pdf

[66] IEA Bioenergy (2018) Bioenergy Success Stories: Crescentino Biorefinery – PROESA^{TM}, Italy, http://www.ieabioenergy.com/wp-content/uploads/2018/02/3-Crescentino-AdvancedEthanolBiorefinery_IT_Final.pdf

[67] European Biofuels Technology Platform, Biofuel Fact Sheet, Beta Renewables – commercial plant in Crescentino, Italy, http://www.etipbioenergy.eu/images/Factsheet_Beta%20Renewables_final.pdf

According to Eurostat Shares of Renewables, Italy's share of compliant biofuels in transport in 2017 was 1,060.3ktoe. Not accounting for plant downtime or exports to other countries, **the Eni Versalis plant ethanol production represents 25ktoe, which is 2.36% of the national sector total** (total production in tonnes per year is multiplied by energy content [26 MJ/kg] of ethanol produced from renewable sources cited in RED II). According to ICIS, EU fuel prices for ethanol in February 2019 ranged between €568-573/cbm FOB[68]. The Eni Versalis plant production represents a **gross added value of around €29 million per year (FOB) Rotterdam**.

Social performance

Employment at the Eni plant is of approximately 100 direct staff members and generates more than 200 indirect jobs[69].

According to IRENA, there are 6,500 direct and indirect jobs in the liquid biofuels industry in Italy and 32,600 in the solid biomass renewable energy sector. Thus, a total of 300 direct and indirect jobs generated by **the Eni plant employment represents almost 5% of the national sector total**.

The LanzaTech plant in Ghent, Belgium

The LanzaTech plant process involves biological conversion of carbon to products through gas fermentation in the form of microbes that grow on gases. As such it is able to convert waste gases such as hydrogen and carbon monoxide into bioethanol.

Environmental performance

The process operates close to ambient temperature and atmospheric pressure, resulting in reduced CO_2 emissions and minimizing heating and cooling costs: ethanol produced via recycling waste streams is expected to **reduce emissions by over 80%**[70]. **120,000 tonnes per year of CO_2 reductions were reported for the first phase of the plant**[71].

The project conducted a life cycle assessment in collaboration with the Roundtable on Sustainable Biomaterials and found a greenhouse gas emissions savings of over 60%.

The application of a microbial gas conversion system significantly advances the carbon capture, storage and utilisation potential.

Economic performance

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[68] EU fuel ethanol price range narrows as supply tightens, imports expected, February 14th 2019, *ICIS NEWS,* https://www.icis.com/explore/resources/news/2019/02/14/10319052/eu-fuel-ethanol-price-range-narrows-as-supply-tightens-imports-expected/

[69] Picciotti, P. (2017) GHG savings with 2G Ethanol Industrial Plant, *BetaRenewables,* https://www.bio.org/sites/default/files/0830AM-Pierluigi%20Picciotti.pdf

[70] Summary of the context and overall objectives of the project, https://cordis.europa.eu/project/rcn/195267/reporting/en, Last Visited on [12/03/2019]

[71] https://cordis.europa.eu/project/rcn/195267/results/en, Last Visited on [12/03/2019]

The commercial demonstration facility integrated with a steel plant is expected to produce 143 tonnes per day or **47,000 tonnes per year of bioethanol** from 50,000 Nm^3 per hour of waste gases such as hydrogen and carbon monoxide.

The resulting bioethanol will predominantly be used in gasoline blending and can also be further processed into other products such as drop in jet fuel. If scaled for a larger production, the technology can yield a production of 2.5 million tonnes of bioethanol in Europe[72].

According to Eurostat Shares of Renewables, Belgium's share of compliant biofuels in transport in 2017 was 465.1ktoe. Not accounting for plant downtime or export/use in other countries, **the LanzaTech plant production represents 29ktoe, which represents 6% of the national sector share** (total production in tonnes per year is multiplied by energy content [26 MJ/kg] of ethanol produced from renewable sources cited in RED II). According to ICIS, EU fuel prices for ethanol in February 2019 ranged between €568-573/cbm FOB[73]. The LanzaTech plant production represents a **gross added value of around €34 million (FOB) Rotterdam per year.**

Social performance

The new installation created 500 construction jobs over a period of two years while there are between **20 to 30 new permanent direct jobs** at the biorefinery[74].

According to IRENA, there are 900 direct and indirect jobs in the liquid biofuels industry in Belgium and 1,000 in the solid biomass renewable energy sector. The amount of permanent jobs generated by **the LanzaTech represents between 2.22% and 3.33% of the national total**.

2.3. Transferability of findings

Plant practices can be transferred elsewhere and either scaled-up or scaled-down depending on logistics, geography, and biomass availability. In this report, replication and scalability (defined here as transferability) at regional, national and international level are ranked as low, medium or high.

This section provides an overview of initial lessons per key asset and development stage that can be transferred to other regions/ countries. The objective is to help national, regional and local authorities in designing strategies to develop a competitive advanced biofuel sector.

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[72] https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-energy/biofuels/steelanol, Last Visited on [12/03/2019]

[73] EU fuel ethanol price range narrows as supply tightens, imports expected, February 14th 2019, *ICIS NEWS*, https://www.icis.com/explore/resources/news/2019/02/14/10319052/eu-fuel-ethanol-price-range-narrows-as-supply-tightens-imports-expected/

[74] "ArcelorMittal and LanzaTech break ground on €150million project to revolutionise blast furnace carbon emissions capture", 2018, https://corporate.arcelormittal.com/news-and-media/news/2018/june/11-06-2018, Last Visited on [24/03/2019]

Transferability[75] in this section is defined as the process in which knowledge about developing and operating a plant is used in the development of other ones in another setting and geographical area.

Table 3 below provides an overview of the main lessons learnt so far from the reviewed advanced biofuel plants, as well as their degree of transferability. Additionally, barriers based on the interviews and consultation with key stakeholders conducted during the period November 2018 to February 2019 are included.

Table 3 Lessons learnt, degree of transferability, examples of good practices in plants they can be related to and barriers which they can help removing

Lessons	**Development stage(s)**	**Supply chain stage**	**Degree of transferability**	**Example of good practice in plants**	**Barriers which lessons learned help to remove**
Location close to raw material is a key success factor	Pilot, demonstration, commercial	Feedstock provision	**Moderate to high** depending on project planning and geographic area	Eni Versalis sources its feedstock within a 70km radius; Empyro sources woody biomass locally	Difficulties in mobilising various feedstocks (technical), Lack of clarity on land availability and environmental constraints (environmental), lack of knowledge from farmers (social)
The scale and nature of supply & logistics is complex; it is therefore very important that local industry and regional feedstock suppliers have strong collaborations	Pilot, demonstration, commercial	Feedstock provision	**Moderate to high** depending on amounts of feedstock required and the feedstock availability in the region	UPM's Lappeenranta plant obtains its crude tall oil from its pulp and paper mill which sources its feedstock from Finnish forests which it manages through nurseries and trained staff	Difficulties in mobilising various feedstocks (technical), Lack of market transparency across regions (economic), cultural barriers or lack of information about introducing new crops (social), lack of clarity about environmental constraints (environmental)
Start up financing from the industry creates better prospects for product development and market uptake	Demonstration; commercial	Conversion	**High** depending on project planning and logistics	Butamax demonstration plant capital and operational formation benefited from a joint partnership between BP and DuPont	Access to project finance (economic); High production cost of RESfuels (economic)

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[75] PriceWaterhouseCoopers (2011), Regional Biotechnology: Establishing a methodology and performance indicators for assessing bioclusters and bioregions relevant to the KBBE area; via website: http://ec.europa.eu/research/bioeconomy/pdf/regional-biotech-report.pdf

Co-location with larger refinery	Demonstration; commercial	Conversion	**Moderate to high** depending on project planning and logistics	UPM is co-located with an industrial pulp and paper mill which supplies crude tall oil; Inbicon made use of heat energy generated by co-located coal-fired plant	Difficulties in mobilising various feedstocks, from remote regions (technical), high pre-treatment storage and transportation costs and unavailability of investments necessary for feedstock harvesting (economic)
Strengthen biorefinery concept, application and sustainability through integration and collaborations with neighbouring or partnering companies benefiting from or supplying energy and chemicals	Demonstration; commercial	Conversion End use	**Moderate to high** depending on project planning and logistics	Neste Porvoo and Rotterdam plants are located in their respective countries' largest port, offering integration and collaboration opportunities with neighbouring companies	Concerns on stability/security of the industry (Regulatory); Manufacturers unwillingness to change (Economic)
Applying energy or nutrient recycling for efficiency and emissions reduction	Pilot, demonstration, commercial	Conversion	**High** depending on project planning and logistics	SEKAB utilises green bioenergy for its process from its lignin production; Eni Versalis generates lignin to obtain energy as well as biogas for further energy efficiency	Technical uncertainties regarding input required to turn marginal land types to productive (technical), lack of profitability of dedicated energy crops in relation to current investments for fertilisation and weed control (economic), lack of clarity about environmental constraints (environmental)

2.4. Concluding remarks and future work

The work performed during this period has derived important highlights of European advanced biofuel plants as good practice cases, namely how they perform according to environmental, economic and social indicators.

10 (ten) plants, both thermochemical and biochemical, were presented as good practice cases for producing advanced biofuels through innovative conversion pathways, based on a set of environmental, economic and social performance measures. 6 (six) lessons were extracted from the described cases and placed against barriers elicited by stakeholders, as well as ranked in terms of their transferability to other regions. Nine (9) plant practices are included as examples of such lessons, drawing a link between practices and their performances. Below in the **Annex** can be found plant factsheet illustrating their respective value chains and summarising these performance indicators.

The deliverable representing the second version of this report (D5.6) shall use these good practice cases as a starting point for a more in-depth systems dynamic analysis, which will model for the optimisation of indicators in all three categories. Included in the **Annex** of this first report is the methodology behind the Vensim model building and optimisation and includes a preliminary presentation of the model.

The main objectives of this next report (due August 2020) are summarised below:

- Combine results from upcoming reports of the ADVANCEFUEL consortium to include data on feedstock sourcing (D2.2), management options (D2.3) and sustainability (D4.3), conversion pathways and feedstock suitability (D3.1), and end-product characteristics, as well as capital and operational expenditure averages across the value chain (D3.2)
- Consolidate quantitative and qualitative/participation-based data collection, whereby stakeholders will have the opportunity to provide their input regarding their own value chain optimisation needs while contributing data from their plants to validate model results
- Generate optimisation runs from a model that allows comparability across various value chains in the sector and provide evidence of good practices across multiple indicators

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.º764799.

3. Good practices in policies

This section provides an overview of Good practices in policy leading to relative success in nurturing the production of RESfuels while committing to the principles of sustainability. The work provides a comparative analysis of their performance across a set of key assets and addresses how this is reflected across the different market development stages. This version of the deliverable focuses on biofuels and advanced biofuels.

The policies analysed in ADVANCEFuel refer to renewable fuel programs and strategies that have good performance in the following key assets:

i) *Include a mix of policy mechanisms* (regulatory, financing and information provision) which are *integrated across the value chain*,

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.

3.1. Overview of policy landscape for advanced biofuels

A set of twelve good practices in policy for advanced biofuels are presented in this report. They refer to ten countries (Denmark, Finland, Germany, the Netherlands, Italy, Slovakia, Sweden, United Kingdom, Brazil, Canada), the European Union and the state of California in the US, which have specific policy measures for advanced biofuels within their policy regimes.

Table 5 provides an overview in terms of the policy mechanisms employed and respective special provisions for aviation, marine and heavy-duty road transport.

Policy formation for new innovative market sectors and their sub-segments progresses through three main stages, typically taking a few years to reach maturity. The challenges at the initiation of the market development differ from those during the mature stage. Advanced fuels are a new sector that entails high innovation across the value chain development. Hence it makes sense for the analysis performed in this report to distinguish the phases and analyse the respective operational mechanisms that are in place for successful market development.

The considered development stages are:

1. Initial market development: Introducing advanced biofuels in transport, fuel and/ or energy policy for RESFuels.
2. Early markets: Advanced biofuels are produced and sold to the market. The value chains grow with the addition of new companies, regional infrastructure has improved, and the activities attract both private and public funding.
3. Mature markets: Advanced biofuels are produced at an extensive scale and operate with well-functioning market mechanisms. Policy steers their uptake to sub segments with fewer low carbon alternatives such as aviation, marine and heavy-duty road transport.

The individual policy mechanisms are grouped in regulatory, financing and information provision as described in Table 4 below.

Table 4 Policy mechanisms for advanced biofuels per value chain step, type of policy and market stage development

	Mechanism	**Biomass supply**	**Conversion**	**End Use**
Regulatory	Mandate		Early markets Mature markets Sustain markets	Mature markets Sustain markets
	Quotas			
	Standards	Mature markets Sustain markets	Mature markets Sustain markets	
	Targets/ Obligations	Mature markets Sustain markets		Mature markets Sustain markets
	Green Procurement			
Financing	Carbon tax			Mature markets Sustain markets
	Subsidies	Early markets	Early markets	
	Carbon/ GHG certificates			Mature markets Sustain markets
	Tax exemptions		Mature markets	
	Research funds	Early markets	Early markets	
Information provision	Strategy		Early markets	Early markets
	Promotion	Early markets	Early markets	Early markets
	Capacity building	Early markets Mature markets Sustain markets		Early markets Mature markets Sustain markets
	Networking			

Table 5 Policy landscape in the countries analysed

	Regulations					Financing					Information provision							
	Mandate	Quota	Standards	Targets	Green procurement	Carbon tax	Subsidies	Certificates	Tax exemption	Research funds	Strategy	Promotion	Capacity building	Networking	Aviation	Marine	Heavy duty	Development stage
Denmark	X	X	X	X		X	X		X	X	X			X				
Finland	X	X	X	X		X					X				X		X	
Germany	X		X	X		X		X	X		X							
Italy	X	X	X	X			X	X										
Netherlands			X	X				X			X				X		X	
Slovakia	X		X						X									
Sweden		X	X			X			X		X							
United Kingdom	X	X	X	X				X										
European Union	X		X	X							X							
Brazil						X	X				X							
California			X			X					X		X					
Canada			X			X					X		X					

Denmark

Liquid biofuels are exempted from the carbon tax as well as other energy taxes.

The carbon tax is operational in Denmark since 2012 and its 2018 value was equal to €23.2 per ton CO2e[76].

From the time the tax started all fuel companies are obliged to have at least 5.75 percent of biofuels in their total annual fuel sales. They are also encouraged by the Danish Energy Agency to use the voluntary certification schemes.

Since 2012, biomethane has received an additional direct premium tariff, which is updated annually. In 2018, the tariff was equal to €0.6 per litre of diesel equivalent when injected into the natural gas grid or to €0.4 per litre of diesel equivalent when sold directly as a transportation fuel[77].

In 2016 Denmark transposed the EU iLUC Directive and introduced a 0.9% mandate for advanced biofuels starting in 2020[78]. Following, the 2018 Energy Agreement[79] further disaggregates the strategic aims on widespread electrification for road transport, aiming at a long-term strategy where biofuels will be used mainly in heavy-duty vehicles and in aviation.

The Danish Biofuel Act is to be amended in order to enable mixes with 10 % biofuels by 2020, subject to an analysis of alternative methods of meeting the renewable energy target for transport.

Finland

Finnish policy promotes biofuels as a cost-effective way to reduce CO_2 and acts synergistically to the strong commitment of Finnish industries to low carbon economy and innovation as well as the domestic availability of raw materials.

Early in 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.

The Finnish policy framework has a variety of mechanisms that can ensure the successful delivery of the set targets but also efficient monitoring and updates when required. As a result, the country exhibits one of the longest and consistent renewable fuel programs in Europe and worldwide.

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[76] "Carbon Pricing Dashboard", The World Bank, accessed November 8, 2018, https://carbonpricingdashboard.worldbank.org/map_data.

[77] Danish Energy Agency, "The Danish subsidy scheme for the use of biogas" (2018), https://ens.dk/sites/ens.dk/files/Bioenergi/the_danish_subsidy_scheme_for_the_use_of_biogas_and_current_subsidy_ levels.pdf.

[78] Bekendtgørelse om biobrændstoffers bæredygtighed m.v. (Order on the sustainability of biofuels, etc.), BEK nr. 1044 af 07/09/2017, https://www.retsinformation.dk/Forms/R0710.aspx?id=192647.

[79] "New Danish energy agreement secured: 50 percent of Denmark's energy needs to be met by renewable energy in 2030," State of Green, accessed November 8, 2018, https://stateofgreen.com/en/partners/state-of-green/news/new-danish-energy-agreement-a-green-focus-towards-2030/.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.º 764799.

There is strong, consistent and continuous collaboration across all governmental bodies that are involved in biomass supply, environmental protection, economy and energy.

Germany

In 2015, Germany moved from an energy mandate to a GHG reduction quota with the goal of achieving a 6% GHG reduction in the transportation fuel mix by 2025. Double-counting towards the mandate stopped. This gives HVO and UCO competitive advantages only based on their higher GHG reduction compared to first generation biofuels[80].

There is an advanced biofuel mandate and in 2017 legislation introduced a sub-target for advanced biofuels, increasing it from 0.05% of energy used in road and rail transportation (for companies supplying more than 20 PJ of fuels), up to 0.5% for all suppliers by 2025[81].

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[82] 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%).

The 2018 mandate includes an obligation for advanced biofuels starting at 0.6% in 2018 and rising to 1.85% in 2022. This target is further divided 75% must be met with advanced biomethane and 25% by other advanced biofuels[83].

In addition to the above, a support scheme has been introduced in March 2018[84], 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.

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[80] 37c (2) Federal Act on Protection against Air Pollution (Bundes-Immissionsschutzgesetz) http://www.gesetze-im-internet.de/bimschg/__37c.html

[81] https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl117s3892.pdf%27%5D__1552823660323

[82] Decreto 10 Ottobre 2014, Aggiornamento delle condizioni, dei criteri e delle modalita' di attuazione dell'obbligo di immissione in consume di biocarburanti compresi quelli avanzati (14A08212). (Updating the conditions, criteria and implementation modalities of the obligation to release biofuels, including advanced ones, for consumption), Gazzetta Ufficiale Serie Generale n.250 del 27-10-2014, http://www.gazzettaufficiale. it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2014-10-27&atto.codiceRedazionale=14A08212&isAnonimo=false&normativi=false&tipoVigenza=originario&tipoSerie=seriegenerale&currentPage=1.

[83] Giuntoli. 2018. Advanced biofuel policies update in selected Member States: 2018 updates. ICCT policy updates

[84] http://europa.eu/rapid/press-release_IP-18-1441_en.htm

Netherlands

In 2018, the Dutch government raised the biofuel mandate to 16.4% by 2020, including double-counting[85]. 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[86].

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[87]. It includes a priority to use sustainable biomass for fuels in heavy road transportation, aviation and shipping, while favouring electrification and hydrogen for other transportation modes. Legislation to implement the Climate Agreement is still being discussed[88].

Slovakia

Slovakia amended its Act no. 309/2009 on Support of Renewable Energy Sources. The amendment no. 181/2017 came into force as of August 1, 2017.

It updated the overall blending percentage and introduced mandates for 2nd generation biofuels, as well as targets for 2020 – 2030.

Sweden

Sweden has no mandate for advance biofuels. The main support mechanism for biofuels has been exemptions from its energy and carbon taxes, which apply to fossil fuels[89]. In 2018, the carbon tax was 1150 SEK per ton CO2 (€109 per ton CO2)[90].

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[85] (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

[86] Dutch Emissions Authority, "Brandstoffen in het REV – Augustus 2018). (Fuels in the register for transport energy – August 2018)" (2018), https://www.emissieautoriteit.nl/onderwerpen/register-energie-voorvervoer/documenten/publicatie/2018/08/14/brandstoffen-in-het-rev---augustus-2018.

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

[88] Giuntoli. 2018. Advanced biofuel policies update in selected Member States: 2018 updates. ICCT policy updates

[89] Susanne Åkerfeldt, "How to design a cost-effective carbon tax on motor fuels and be in line with EU state aid rules," (Ministry of Finance of Sweden, 2017), https://www.government.se/492fd9/contentassets/18ed243e60ca4b7fa05b36804ec64beb/170925-aakerfeldt-carbon-tax-on-motor-fuels-gcet-tucson.pdf.

[90] "CarbonPricingDashboard, The World Bank, https://carbonpricingdashboard. worldbank.org/map_data.

Long term Swedish targets forecast that by 2030, 50% of passenger vehicles could be fuelled by biofuels and 20% by electricity[91].

United Kingdom

The UK introduced the Renewable Transportation Fuel Obligation (RTFO)[92] in 2008, setting a biofuel mandate that started at 2.6% by volume in 2009 and increased up to 6% in 2018.

The RTFO has a market-based credit trading system. One Renewable Transport Fuel Certificate (RTFC) is allocated for each litre of liquid renewable fuel produced. Renewable fuels produced from specific wastes and other feedstocks listed by the UK government are counted double and awarded two RTFCs for each litre of fuel[93].

New blend mandate legislation and accompanying policy came into force in the UK on April 15, 2018. This aims to double the use of renewable fuels in the transport sector in the next 15 years.

The 2018 amendment differentiates certificates into three categories of renewable fuels: relevant crop, development fuel, and general RTFCs.

Advanced biofuels are in the category of “development fuels”, have a sub-mandate and each litre is double-counted. A development fuel must be one of the following fuel types: hydrogen, aviation fuel, substitute natural gas (i.e. renewable methane) or a fuel that can be blended to give 25 percent or more renewable fraction in the final blend while still meeting fuel technical and quality standards.

European Union

The climate objectives of the European Union for 2030 include a target for greenhouse gas (GHG) reduction of at least 40% and a minimum of a 32% share of renewable energy consumption across all sectors[94]. GHG emissions in the European transportation sector have declined by only 3.8% since 2008, compared to an 18% decrease, or more, in all other sectors, indicating that the decarbonization of transportation should be a priority for the future[95].

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[91] Jacopo Giuntoli, Final recast Renewable Energy Directive for 2021-2030 in the European Union, (ICCT: Washington, DC, 2018), https://www.theicct.org/publications/final-recast-renewable-energy-directive- 2021-2030-european-union

[92] Department for Transport, “Renewable Transport Fuel Obligation (RTFO) order [Collection 2018]” (2018), https://www.gov.uk/government/collections/renewable-transport-fuels-obligation-rtfo-orders.

[93] Department for transport, “RTFO Guidance – Feedstocks including wastes and residues” (2018), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/731027/rtfo-guidance- feedstocks-including-wastes-and-residues-year-11.pdf

[94] Jacopo Giuntoli, Final recast Renewable Energy Directive for 2021-2030 in the European Union, (ICCT: Washington, DC, 2018), https://www.theicct.org/publications/final-recast-renewable-energy-directive- 2021-2030-european-union

[95] EUROSTAT (Greenhouse gas emissions by source sector (env_air_gge), accessed November 2018), https://ec.europa.eu/eurostat.

Incentives for biofuels have been in place since 2009, with the Renewable Energy Directive (RED) mandating that by 2020, 10% of energy used in the transportation sector should come from renewable energy sources (RES)[96]. In 2015, the RED was amended by the EU Indirect Land Use Change (ILUC) directive[97], which introduced a 7% cap on the contribution that conventional food and feed-based biofuels could make to the RES-transport target. The ILUC directive introduced a further a non-binding 0.5% target for advanced biofuels in 2020[98].

In 2018, the Renewable Energy Directive (REDII)[99] introduced a 14% RES-transportation energy target and a 3.5% advanced biofuels sub-target by 2030. Conventional food-based biofuels will be capped at each member state's 2020 level with a maximum of 7%. This implicitly creates a minimum 7% target for advanced, non-food-based alternative fuels[100]. Similarly to the 2020 RED, advanced biofuels, as well as biofuels produced from used cooking oil and animal fats, can double- count towards the 14% RES-transport target.

The aviation and maritime sectors are excluded from the obligation, but if, in the future, they opt in, each unit of biofuel will count at 1.2 times toward the target.

Brazil

Brazil has a long history in policy for renewable fuels which started as a mechanism to support domestic production for energy security in the oil crisis of 1970. Since then it has been consistent and coherent with the economic challenges in the country including increased investment to create jobs and income.

The new Brazilian programme, RenovaBio, was introduced in 2017. The programme creates a system that allows the certification of biofuels by measuring the exact contribution of each biofuel producer to greenhouse gas emissions reductions, in relation to their fossil substitute.

The law also creates a decarbonization credit that combines the emissions reduction targets and the live cycle assessment of each biofuel producer. The credits are described as a financial asset that can be traded on a stock exchange. The credits are issued by the biofuel producer following the sale of product. Fuel distributors will meet required targets by acquiring these credits.

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[96] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, L 140/16, April 23, 2009, https://eur-lex.europa. eu/legal-content/EN/ALL/?uri=celex%3A32009L0028.

[97] Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources, Official Journal of the European Union, L 239/1, September 15, 2015, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L151 3&from=EN

[98] Jacopo Giuntoli, Final recast Renewable Energy Directive for 2021-2030 in the European Union, (ICCT: Washington, DC, 2018), https://www.theicct.org/publications/final-recast-renewable-energy-directive- 2021-2030-european-union

[99] Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources - Analysis of the final compromise text with a view to agreement, accessed November 2018. https://www.consilium.europa.eu/register/en/content/ out?&typ=ENTRY&i=LD&DOC_ID=ST-10308-2018-INIT.

[100] Jacopo Giuntoli, Final recast Renewable Energy Directive for 2021-2030 in the European Union, (ICCT: Washington, DC, 2018), https://www.theicct.org/publications/final-recast-renewable-energy-directive- 2021-2030-european-union

California (USA)

The Californian Low Carbon Fuel Standard (LCFS) programme has as primary target to reduce GHG emissions. It has been established in 2009, amended in 2011 and re-adopted 2015 due to legal challenge.

It is fuel neutral, accounts for Life Cycle and ranks fuels with Carbon Intensity (CI) scores according to the greenhouse gas emissions resulting from each fuel's production and consumption.

Flexible-Regulated parties can comply by: i) innovating to reduce the CI of their fuels, ii) buying lower-CI fuels from other producers, or iii) trading credits.

Current exempted fuels and applications are: i) aviation, ocean-going marine, locomotives, military tactical vehicles; ii) propane and other liquefied petroleum gas.

The government considers inclusion of propane, and aviation in 2019. California has also established carbon trading. Credit trading offers valuable flexibility, but it introduces the complexity of overseeing a multimillion-dollar environmental commodity market. 7.0 million credits produced in California's LCFS from Sept. 2016-August 2017. At a $88/credit, that's $616 million in credit value created annually. In Dec 2016 alone $94 million in credits changed hands.

Canada

The Clean Fuel Standard (CFS) is the main legal framework for advanced biofuels. The goal is to reduce 30 Mt of GHGs by 2030 and it will be performance based requiring a percentage reduction in carbon intensity (based on lifecycle analysis).

Unlike a traditional low carbon fuel standard, the CFS will apply to liquid, gaseous and solid fuels used across the transportation, buildings and industrial sectors in Canada – the first of its kind. It will be a non-prescriptive, market-based approach that includes a crediting and trading system aiming to provide maximum flexibility to fuel suppliers.

3.2. Good practice performance in policies

This section describes the good practice performance of the policies included in the analysis. It is based on a preliminary assessment done jointly with the interviewed stakeholders.

This is measured against three key assets:

i) policy mix which is well integrated in the national policy,
ii) individual targets for advanced biofuels and special provisions/ strategic considerations for the use of advanced biofuels in transport market segments with low or limited available alternatives for decarbonization, and
iii) active stakeholder engagement from industry and policy.

Why a policy mix?

Advanced biofuels form part of the energy products that derive from biomass within the overall biobased economy concept. As such they should be supported with policy frameworks that account for innovation and resource efficiency across the value chain. Individual sector targets which do not account for improved value chain efficiency and cross sector implications have been partly successful and, in many cases, have resulted in conflicts and market imbalances. A balanced approach for future policy formation at all governance levels is to ensure there is an appropriate policy mix that is integrated along the value chain components (biomass supply, conversion, end use).

Integration for developing an advanced biofuel policy framework can based on a three-pillar approach[101]:

- Integration of specific policy mechanisms in the RESfuel value chain components. The mechanisms have been selected, based on benchmarking previous policies and several consultations with national policy makers, so that they can work complementary to enhance resource efficient feedstock uptake and secure supply for efficient conversion technologies.
- Integration of various types of policy mechanisms by combining a set of regulatory, expenditure and information provision policy mechanisms that are applied across value chains and sectors to ensure resource efficient uptake, successful market development and maintenance of existing capacities in the country of analysis.
- Integration of sectorial policy which reflects both the upstream and downstream policies required within specific value chains to ensure both resource and energy efficiency.

The policy mix varies per development stage (see Table 7).

Why individual targets are essential for advanced biofuels and provisions for aviation, marine, heavy- duty?

The sector is relatively new, and most value chains are at pilot and pre-commercial stage. Their scale up and commercialisation implies high investment risks. Without a dedicated and

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[101] Panoutsou, C., Singh, A., Uslu, A., van Stralen, J., Kwant, K., Muisers, J., Pelkmans, L. & N. Devriendt. (2016) Lessons and recommendations for EU and national policy frameworks. Deliverable 4.4. Biomass Policies project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.º764799.

consistent policy in place there industrial and investment confidence is reduced and this results in low market uptake. Future policy should have clarity, quantitative targets and trajectories for advanced biofuels. It should also be in line with the long- term decarbonisation plans that foresee a shift of their use from light duty vehicles to heavy duty vehicles, aviation and marine.

Why stakeholders' engagement and bottom up solutions work best?

Stakeholders are critical for the successful market uptake of advanced biofuels. Their active and continuous involvement, consultation and approvals during policy formation, implementation and monitoring is critical for the future of the sector.

The following issues have been examined per key asset:

Policy mix

- number and type of policy mechanisms (regulatory, financing and information provision)
- integration across the value chain (feedstock production, conversion, end use)

Target setting

- specific target for advanced biofuel
- steer and support for aviation, marine and heavy-duty road transport
- adequate sustainability targets

Network of stakeholders from policy and industry

- Information provision mechanisms
- Cross ministerial collaboration
- Industrial engagement

Table 6 illustrates the performance of each country in each of these issues.

In the policy mix category, all countries score high except Slovakia and European Union which have average performance as their policy has only one specific mechanism on advanced biofuels which is still not complemented with other ones across the value chain and this may limit the future market uptake. Italy has an average score in the integration of policy mechanisms across the value chain as well.

With regards to target setting all countries have individual targets for advanced biofuels and include sustainability in their legislation. Except Slovakia, all other countries have specific provisions for market sub-segments as aviation, marine and heavy duty.

Finally, in networking of stakeholders, all countries score high in information provision mechanisms except Slovakia and India that are at the initial market development stage. In terms of cross Ministerial collaboration only Italy, Slovakia, European Union and India have average performance which indicates their cross-sector collaborations at decision making level and is also reflected in the policy integration issue. Industrial engagement scores high across all the countries analysed.

Table 6 Good practice performance for the understudy countries, EU and California

	Denmark	**Finland**	**Germany**	**Netherlands**	**Italy**	**Slovakia**	**Sweden**	**United Kingdom**	**European Union**	**Brazil**	**California**	**Canada**
Policy mix												
Number & type	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟨	🟩	🟩	🟩
Integration	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟨	🟨	🟩	🟩	🟩
Target setting												
Advanced biofuels	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Aviation, marine, heavy duty	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩
Sustainability	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Stakeholders												
Information provision	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩
Cross ministerial	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩
Industrial engagement	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Green: high performance; yellow: average performance;

3.3. Transferability of findings

This section provides an overview of initial lessons per key asset and development stage that can be transferred to other regions/ countries. The objective is to help national, regional and local authorities in designing strategies to develop a competitive advanced biofuel sector.

Transferability[102] in this analysis is defined as the process in which knowledge about policies in one political and administrative or geographic setting (past and present) is used in the development of policy in another setting and geographical area.

Table 7 below provides an overview of the main lessons learnt so far from policy formation in the field of advanced biofuels. These are based on the interviews and consultation with key stakeholders conducted during the period November 2018 to February 2019.

Table 7 Lessons learnt, degree of transferability, examples of good practice policies they can be related to and barriers which they can help removing.

Lessons	**Key asset(s)**	**Development stage(s)**	**Degree of transferability**	**Example of good practice policies**	**Barriers which lessons learned helps to remove**
Strategy and vision should be carefully discussed and analysed with the local community and the industrial actors who are likely to invest in advanced biofuels	Stakeholders	Initial	**High** since this is one of the first steps in the communication of policy makers and industries in order to agree on the focus of the strategy and introduce relevant policy mechanisms	Denmark has a €67 million plan for sustainable transportation development between 2020 and 2024 and a long-term strategy in place where biofuels will be mainly used in heavy-duty vehicles and aviation, this sends a positive message to the market players and security.	High capital costs, high risk investment and lack of long-term and unstable policy environment makes it difficult for the investors to invest. Difficulty to access the existing support schemes.
Policy must ensure wide acceptance and endorsement of the measures by local stakeholders	Stakeholders	Initial	**Low to moderate** as public acceptance is subject to change after certain periods of time so the process	Finnish policy has wide acceptance by the public as there is high awareness of biomass, bioenergy and biofuels.	Lack of policy mechanisms which bridges the gap between conventional and advanced biofuels. Not enough information provisions which

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[102] PriceWaterhouseCoopers (2011), Regional Biotechnology: Establishing a methodology and performance indicators for assessing bioclusters and bioregions relevant to the KBBE area; via website: http://ec.europa.eu/research/bioeconomy/pdf/regional-biotech-report.pdf

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			requires continuous attention, adaptation and communication of consistent messages.		raises the awareness and share information about the innovative technologies.
Quota have been a successful measure for the increase of the overall biofuels share in transport	Policy mix Target setting	Initial Early	**High** since this is one of the most applied mechanism in the biofuels sector and it has led to high market uptake	Obligatory biofuel quota system with tradable or non-tradable green certificates. DE, FI, DK, IT, SK, NL and UK.	Lack of dedicated policy support to promote biofuel share among all renewable sources.
Set up mechanisms to attract capital	Policy mix	Early	**Low to moderate** as it is strongly reliant to the economic situation and competitiveness of individual countries and regions as well as investment environment	Investment subsidies and support schemes. DK has subsidy schemes. NL has subsidy programmes targeted for market players and producers like IBB for innovative Biofuels and TAB for installing filling stations.	Lack of policy support to provide security for the industry
Policy must account for the local context under which the measures would be best suited and fit to local needs and infrastructures	Policy mix Target setting	Initial Early Mature	**Moderate** as local context is subject to many socio-political forces through time so careful planning and monitoring systems must be in place to ensure the successful longevity of a certain sectorial policy.	UK started a 'development fuels' mandate to promote the feedstocks which can contribute in second generation advanced biofuels. SK has legislative measures to promote the woody biomass resources from both agricultural and forestry sector. DE expired their double counting but increased their GHG mandate in 2014 to make more competitive environment for advanced biofuels.	Lack of harmonised regulations on sustainable farming practices for residual biomass, dedicated energy crops and forest management practices Lack of harmonised regulations throughout EU concerning fuel taxes, biofuel tax reductions, obligation systems, RESFuel Blends and fuel standards
Taxation of fossil fuels is considered a strong indirect support measure for the uptake of biofuels	Policy mix	Early Mature	**Moderate** as it depends on the overall taxation system and whether there is already a suitable mechanism from which advanced biofuels can be exempted	Energy and CO2 tax reduction mechanisms in place to subsidise the advanced biofuels compared to fossil fuels. SE, SK, DK, NL, FI and DE	Lack of policy mechanisms to make RES more competitive compared to the fossil fuels.

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Tailored financing support allows for innovative and high efficiency technologies to be implemented.	Policy mix	Early Mature	**Low to moderate** as it is strongly reliant to the economic situation and competitiveness of individual countries and region and investment environment	NL has training and certification facilities for new innovative technologies under their Clean and Efficient Strategy.	Lack of policy support to provide stability and security for the industry.
Policy should ensure long term consistency and high clarity of strategic messages	Policy mix Target setting	Mature	**Moderate** as long term policies are quite hard to implement and maintain; they require strong commitment from governments, regional authorities and administrative bodies.	All countries under study here have target set for the share of RES in transport sector in line with EU RES-T target. Some of the countries like NL, It, DE, DK, SK have national mandate for advanced fuel share by 2020 and 2030	Lack of harmonised policy support with dedicated targets for each sector.
Secure business commitment from industries	Stakeholders	Mature	**Moderate** as long term commitment requires economic and political stability, trust from investors and funding bodies as well as good success stories with high replication potential.	Finland and Sweden have a long collaboration with their advanced biofuel industries.	Lack of policy support to provide stability and security for the industry.

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3.4. Concluding remarks and future work

The work performed during this period has derived important highlights for future policy formation to support RESFuels market uptake.

All policies reviewed for the work under the task 5.2, show that the respective countries and regions are actively implementing sustainability provisions and have national mandates and targets in place to support the growth of advanced biofuels. However, their market shares are at different scale and countries need to introduce new financial and provisional measures to build and sustain their national capacity. This can be achieved by introducing tailored financial incentives to facilitate market uptake and provide security for industry and business investments.

Future policy agendas must be developed considering the development stage of the national markets as well as the existing and planned operational capacities.

The main remarks are summarised below:

- At initial market development, targets and policy must be discussed with all stakeholders and ensure wide acceptance and endorsement.
- At early market stage, all relevant policy mechanisms and tailored financing should be tailored to fit the national value chains and available infrastructures.
- At mature development stage, policy should ensure long term consistency, provide high clarity of strategic messages and secure long-term industrial commitment.

Future work incorporating results from this report will come in the form of Deliverable D5.6 (due in August 2020) where a cost benefit analysis will be performed to practices that contribute most to policy targets and market uptake. Furthermore, D2.3 shall present upgrading strategies of lignocellulosic supply chains.

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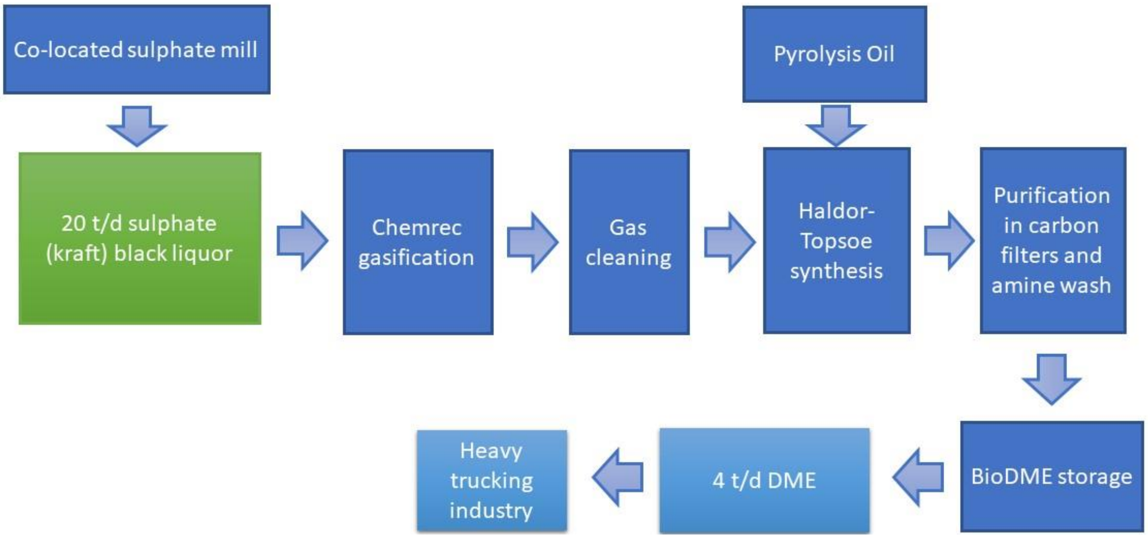
4. Annexes

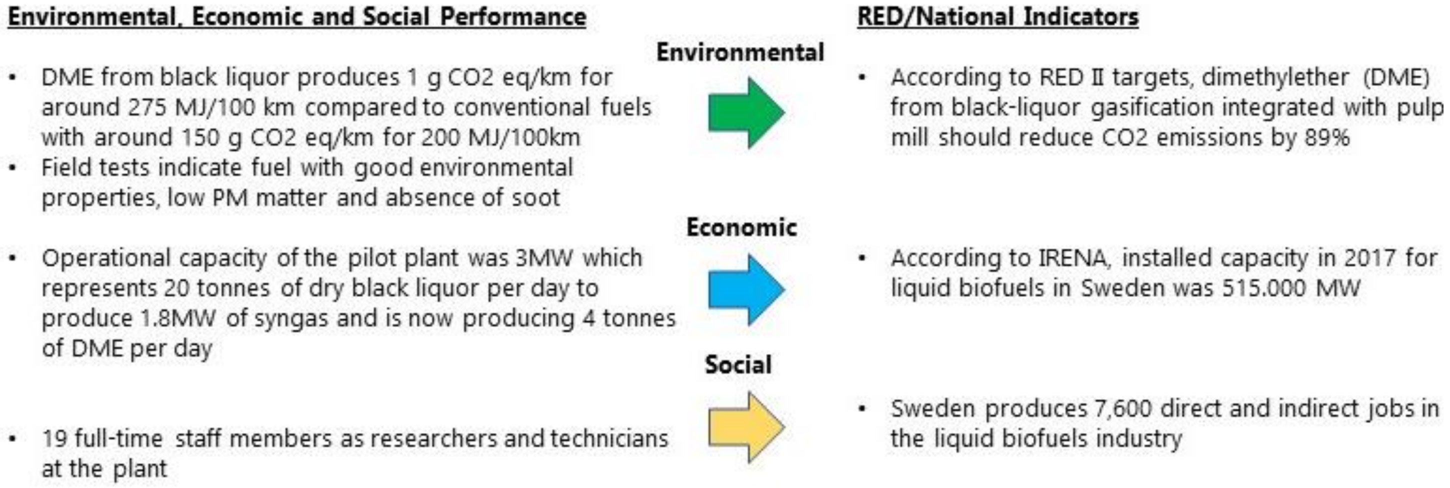
4.1. Individual plant factsheets

BioDME Thermochemical Pilot Plant Factsheet

Plant Description: The BioDME plant in Piteå, Sweden, converts sulphate (kraft) black liquor from a nearby sulphate mill into methanol and dimethylether (DME) through the Chemrec engineered gasification and Haldor-Topsoe syngas technology with pyrolysis oil. It is able to produce 4 tons per day with an investment cost of €20 million for the construction of the plant. DME has similar properties as LPG with very low particle emissions and has been tested a on 10 different Volvo trucks.

BioDME Piteå Value Chain





Environmental, Economic and Social Performance		RED/National Indicators
• DME from black liquor produces 1 g CO2 eq/km for around 275 MJ/100 km compared to conventional fuels with around 150 g CO2 eq/km for 200 MJ/100km • Field tests indicate fuel with good environmental properties, low PM matter and absence of soot	**Environmental** ➡	• According to RED II targets, dimethylether (DME) from black-liquor gasification integrated with pulp mill should reduce CO2 emissions by 89%
• Operational capacity of the pilot plant was 3MW which represents 20 tonnes of dry black liquor per day to produce 1.8MW of syngas and is now producing 4 tonnes of DME per day	**Economic** ➡	• According to IRENA, installed capacity in 2017 for liquid biofuels in Sweden was 515.000 MW
• 19 full-time staff members as researchers and technicians at the plant	**Social** ➡	• Sweden produces 7,600 direct and indirect jobs in the liquid biofuels industry

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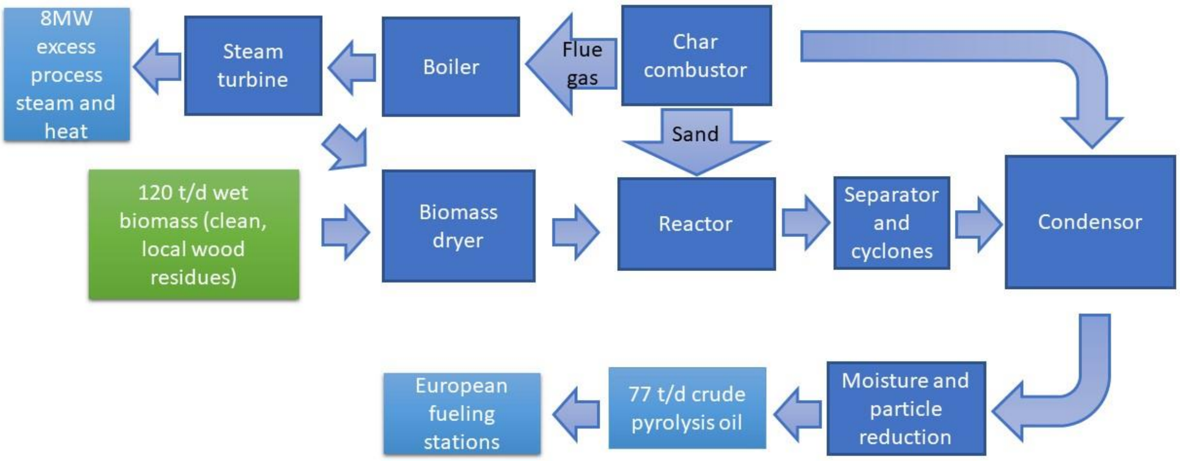
Empyro Thermochemical Demonstration Plant Factsheet

Plant Description: The Empyro plant in Hengelo, Netherlands, converts wood residues into crude pyrolysis oil through liquid pyrolysis, oil being the main product and pyrolysis gases are used to generate additional steam and power. The end product is designed to be compatible with diesel and gasoline.

Empyro Hengelo Value Chain

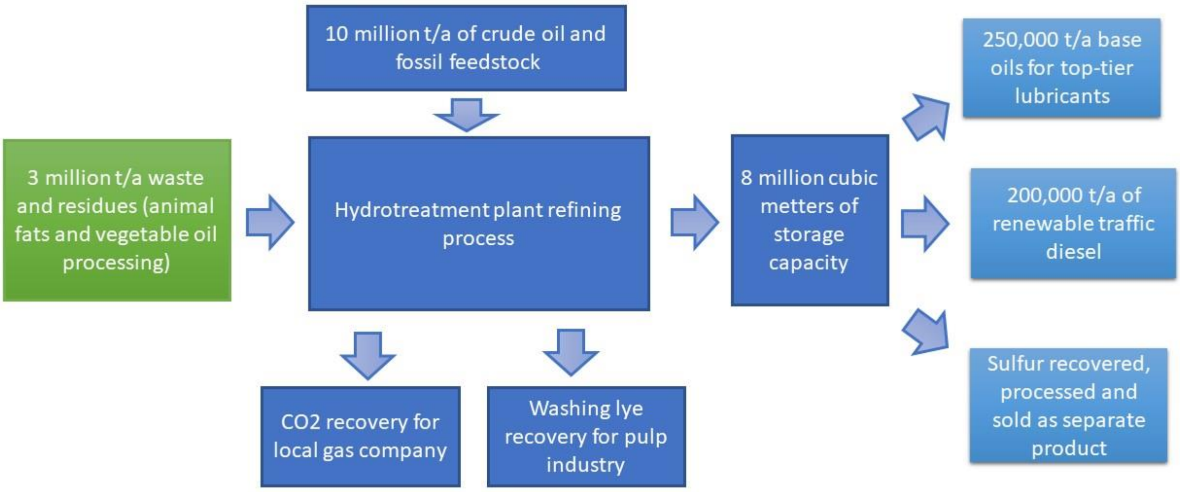


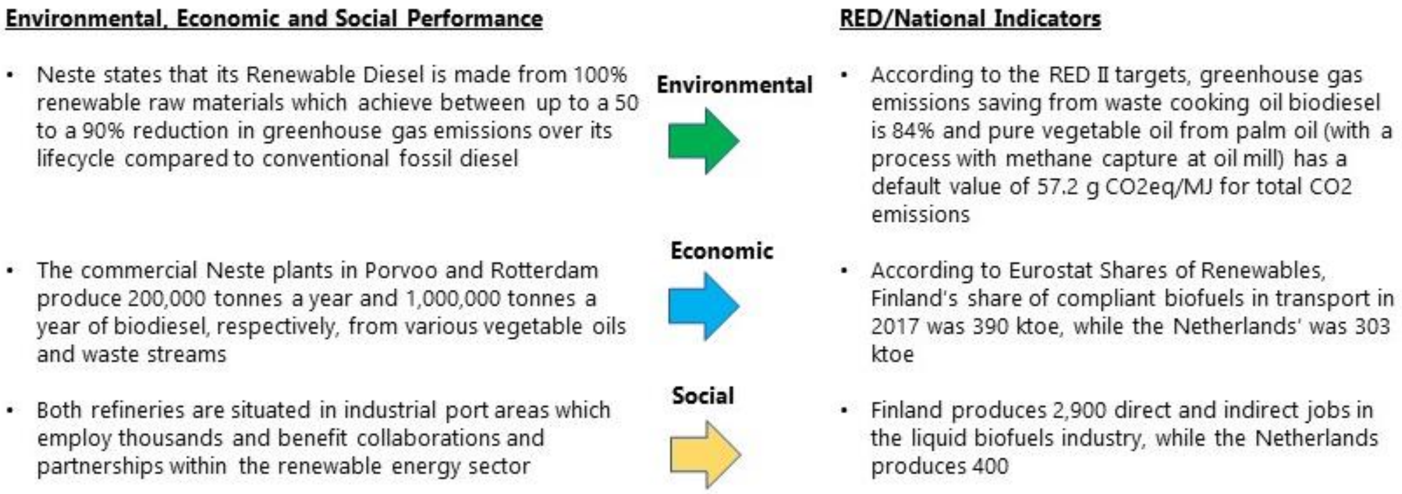
Environmental, Economic and Social Performance		RED/National Indicators
- The plant uses clean woody biomass from local sources recycles extracted minerals back into soil - Total emissions from production while using forest residues amount to 8.70 g CO2-eq/MJ pyrolysis oil, when placed against fossil fuel comparators, this figure represents an emissions savings of 90.4% when replacing electricity	**Environmental**	- According to the RED II targets, greenhouse gas emissions saving from waste wood Fischer-Tropsch diesel in free-standing plant is 85%
- The demonstration/commercial plant operates at a capacity of 120 tonnes per day of clean wood residues to produce 77 tonnes per day of crude pyrolysis oil, as well as 8MW of by-product	**Economic**	- According to Eurostat Shares of Renewables, the Netherlands' share of compliant biofuels in transport in 2017 was 303 ktoe
- The project creates approximately 100 person-years of work	**Social**	- The Netherlands produces 400 direct and indirect jobs in the liquid biofuels industry

Neste Thermochemical Commercial Plant Factsheet

Plant Description: The Neste Porvoo, Finland, and Rotterdam, Netherlands, plants convert various vegetable oils and waste streams into renewable biodiesel through hydrogenated vegetable oil processing.

Neste Porvoo Value Chain





Environmental, Economic and Social Performance		RED/National Indicators
Neste states that its Renewable Diesel is made from 100% renewable raw materials which achieve between up to a 50 to a 90% reduction in greenhouse gas emissions over its lifecycle compared to conventional fossil diesel	**Environmental**	According to the RED II targets, greenhouse gas emissions saving from waste cooking oil biodiesel is 84% and pure vegetable oil from palm oil (with a process with methane capture at oil mill) has a default value of 57.2 g CO2eq/MJ for total CO2 emissions
The commercial Neste plants in Porvoo and Rotterdam produce 200,000 tonnes a year and 1,000,000 tonnes a year of biodiesel, respectively, from various vegetable oils and waste streams	**Economic**	According to Eurostat Shares of Renewables, Finland's share of compliant biofuels in transport in 2017 was 390 ktoe, while the Netherlands' was 303 ktoe
Both refineries are situated in industrial port areas which employ thousands and benefit collaborations and partnerships within the renewable energy sector	**Social**	Finland produces 2,900 direct and indirect jobs in the liquid biofuels industry, while the Netherlands produces 400

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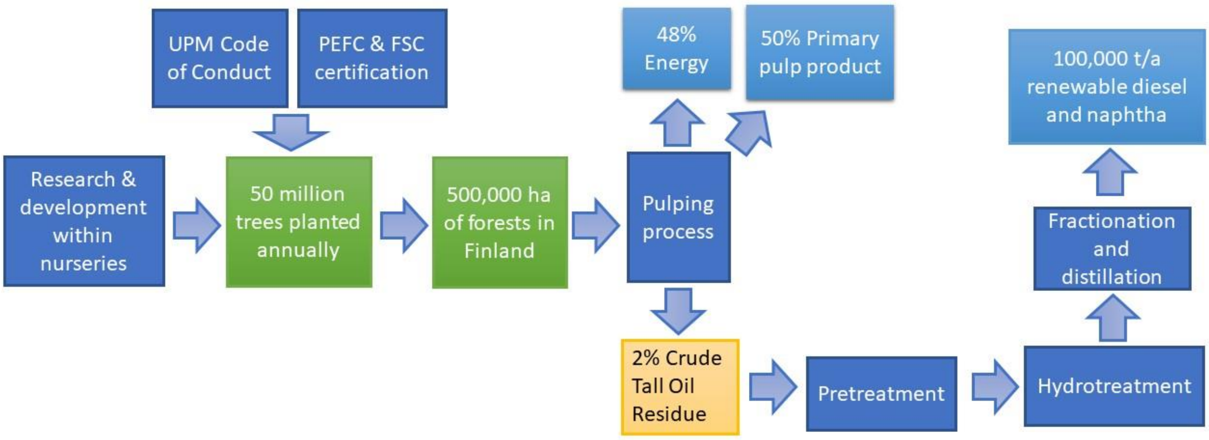
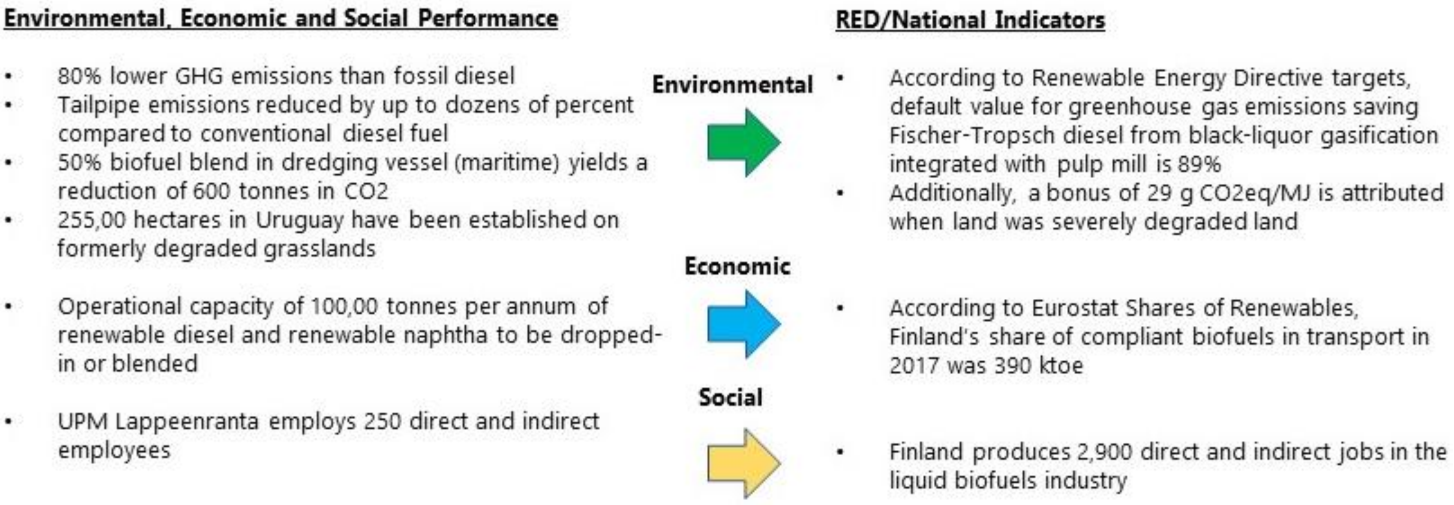
UPM Thermochemical Commercial Plant Factsheet

Plant Description: UPM's biorefinery in Lappeenranta, Finland, produces 100,000 tonnes per year of renewable diesel and renewable naphtha, both drop-in fuels compatible within the existing European distribution network and without any limits to blending with either diesel or gasoline, respectively. The production pathway of these advanced biofuels is possible because of the plant's co-location with a pulp and paper mill factory, which produces a certain surplus amount of crude tall oil. The plant is at a commercial development stage thanks to a financing of €179 million and has been in operation for more than 10,000 hours.

UPM Lappeenranta Value Chain





Environmental, Economic and Social Performance

- 80% lower GHG emissions than fossil diesel
- Tailpipe emissions reduced by up to dozens of percent compared to conventional diesel fuel
- 50% biofuel blend in dredging vessel (maritime) yields a reduction of 600 tonnes in CO2
- 255,00 hectares in Uruguay have been established on formerly degraded grasslands

- Operational capacity of 100,00 tonnes per annum of renewable diesel and renewable naphtha to be dropped-in or blended

- UPM Lappeenranta employs 250 direct and indirect employees

Environmental

Economic

Social

RED/National Indicators

- According to Renewable Energy Directive targets, default value for greenhouse gas emissions saving Fischer-Tropsch diesel from black-liquor gasification integrated with pulp mill is 89%
- Additionally, a bonus of 29 g CO2eq/MJ is attributed when land was severely degraded land

- According to Eurostat Shares of Renewables, Finland's share of compliant biofuels in transport in 2017 was 390 ktoe

- Finland produces 2,900 direct and indirect jobs in the liquid biofuels industry

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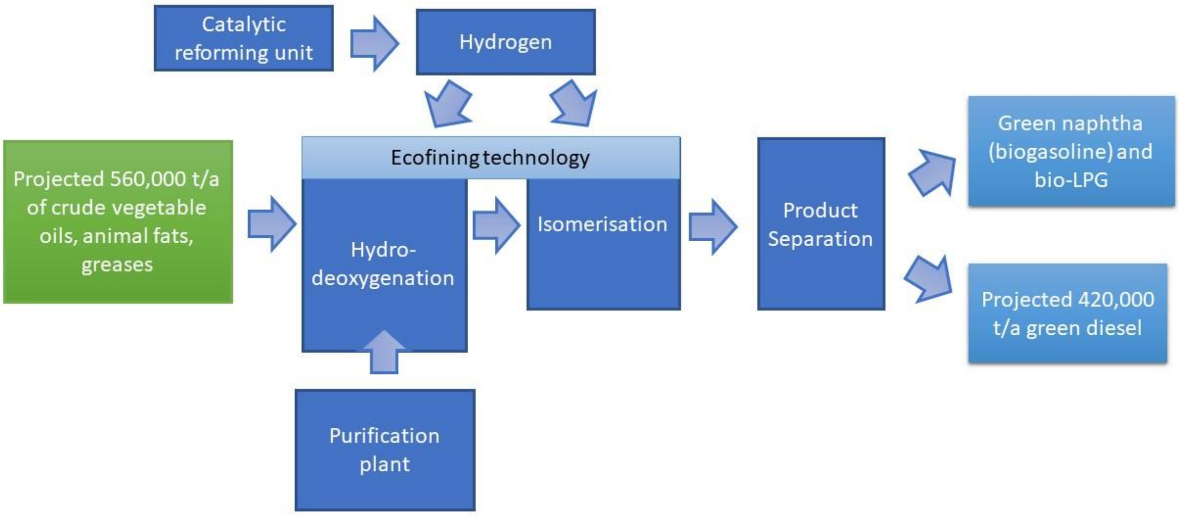
Eni Green Refinery Thermochemical Commercial Plant Factsheet

Plant Description: Eni’s Green Refinery Project in Venice, Italy, converts vegetable oils, animal fats and greases into hydrocarbon fuels, naphtha and LPG and jet fuel through an ecofining process which involves deoxygenation, isomerization and product separation. The produced green diesel is of high-quality, free of aromatic compounds and high cetane levels which makes it entirely compatible with diesel.

Eni Green Value Chain



Catalytic reforming unit

Hydrogen

Projected 560,000 t/a of crude vegetable oils, animal fats, greases

Ecofining technology

Hydro-deoxygenation

Isomerisation

Purification plant

Product Separation

Green naphtha (biogasoline) and bio-LPG

Projected 420,000 t/a green diesel

Environmental, Economic and Social Performance		**RED/National Indicators**
- Eni Diesel is 15 percent more renewable than regular diesel, and cuts unburnt hydrocarbons and carbon monoxide by up to 40 per cent. - Production cycle helps to reduce CO2 emissions by an average of 5 per cent	**Environmental**	- According to RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from waste cooking oil biodiesel is 84% and hydrotreated oil from waste cooking oil is 83%
- The Eni Venice Green plant is projected to produce more than 420,000 tonnes per year of green diesel amount from 11,575 barrels per day of feedstock	**Economic**	- According to Eurostat Shares of Renewables, Italy's share of compliant biofuels in transport in 2017 was 1,060 ktoe
- Eni Green Project has established collaborations with the academic community including the sponsorship of masters and PhD theses	**Social**	- Italy produces 6,500 direct and indirect jobs in the liquid biofuels industry

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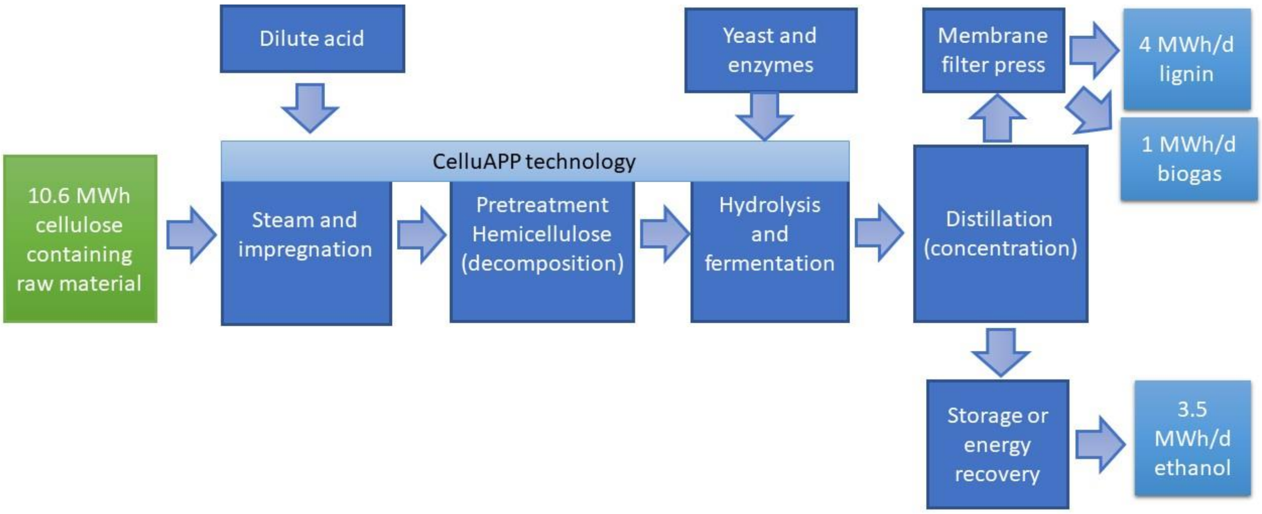
SEKAB Biochemical Pilot Plant Factsheet

Plant Description: The SEKAB plant in Domsjö, Sweden, utilises its own CelluAPP technology to pretreat feedstock with heat and catalyst, steam explosion, batch enzyme hydrolysis with detoxing technology, separation of sugars, and fermentation with yeast or bacteria for the production of 99% ethanol with a final distillation process.

SEKAB Domsjö Value Chain



Environmental, Economic and Social Performance

RED/National Indicators

Environmental

- Pure ethanol represents a greenhouse gas emissions reduction of 87% compared to sugarcane-based ethanol and has near-zero particle pollution and low nitrogen oxide emissions
- SEKAB's own sustainability criteria involves at least 85% reduction of fossil carbon dioxide as compared to petrol and zero tolerance for the felling of rainforests

- According to RED II targets, default value for greenhouse gas emissions saving from sugarcane ethanol is 70%

Economic

- The SEKAB plant produces 3.5 MWh per day of ethanol from 2 tonnes per day of dry feedstock.
- Additionally it produces by-products of 4 MWh per day of lignin and 1 MWh per day of biogas

- According to IRENA, installed capacity in 2017 for liquid biofuels in Sweden was 515.000 MW

Social

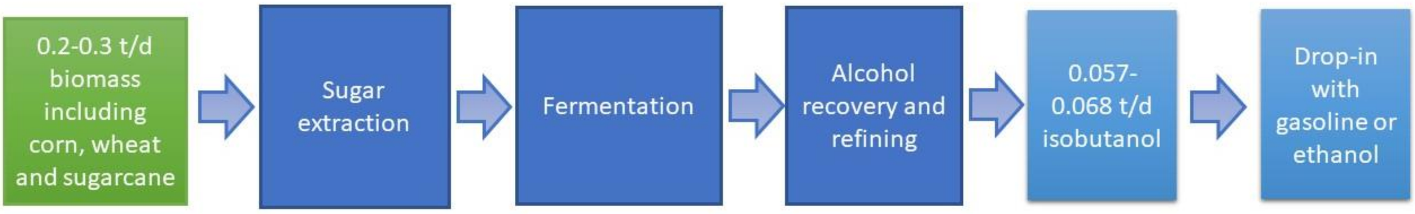
- Extensive collaborations with research institutes, universities, government agencies, vehicle manufacturers and other companies with the forestry and chemical industries, as well as forestry and processing industry

- Sweden produces 7,600 direct and indirect jobs in the liquid biofuels industry

Butamax Biochemical Demonstration Plant Factsheet

Plant Description: The Butamax joint venture pilot demonstration plant in Hull, UK, constructed by BP and DuPont, developed modified genes to expand enzyme conversion of sugar to biobutanol in higher quantities and less time, producing

Butamax Hull Value Chain



Environmental, Economic and Social Performance		RED/National Indicators
- Total CO2 reduction from using bioethanol, lignin and C5 molasses is 85% - Integration of the plant with a power station permits usage of heat energy in the form of steam while the power plant reduces over 25,000 tonnes of CO2 by using the biofuel	**Environmental** ➡	- According to RED II targets, default value for greenhouse gas emissions saving from wheat straw ethanol is 83%
- The Inbicon plant produces a total of 5.4 million litres per annum of ethanol from 30,000 tonnes per annum of feedstock - Additionally it produces 11,250 tonnes per annum of C5 molasses and 13,100 tonnes per annum of lignin	**Economic** ➡	- According to Eurostat Shares of Renewables, Denmark's share of compliant biofuels in transport in 2017 was 218 ktoe
- 30 employees at the plant and 60 employed at Inbicon	**Social** ➡	- Denmark produces 200 direct and indirect jobs in the liquid biofuels industry

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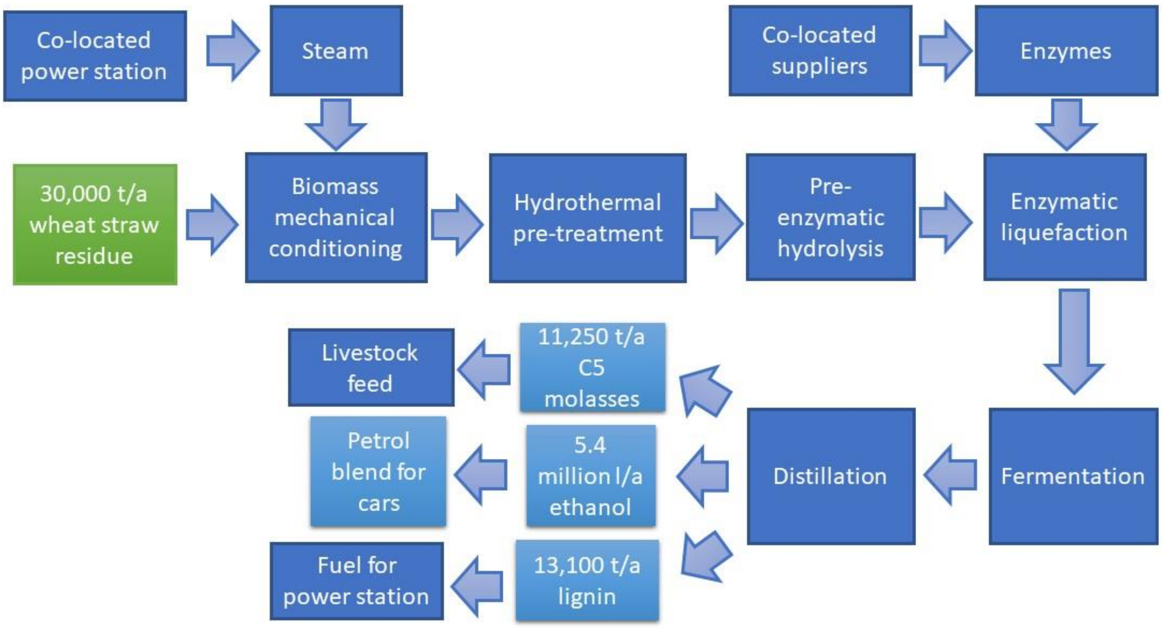
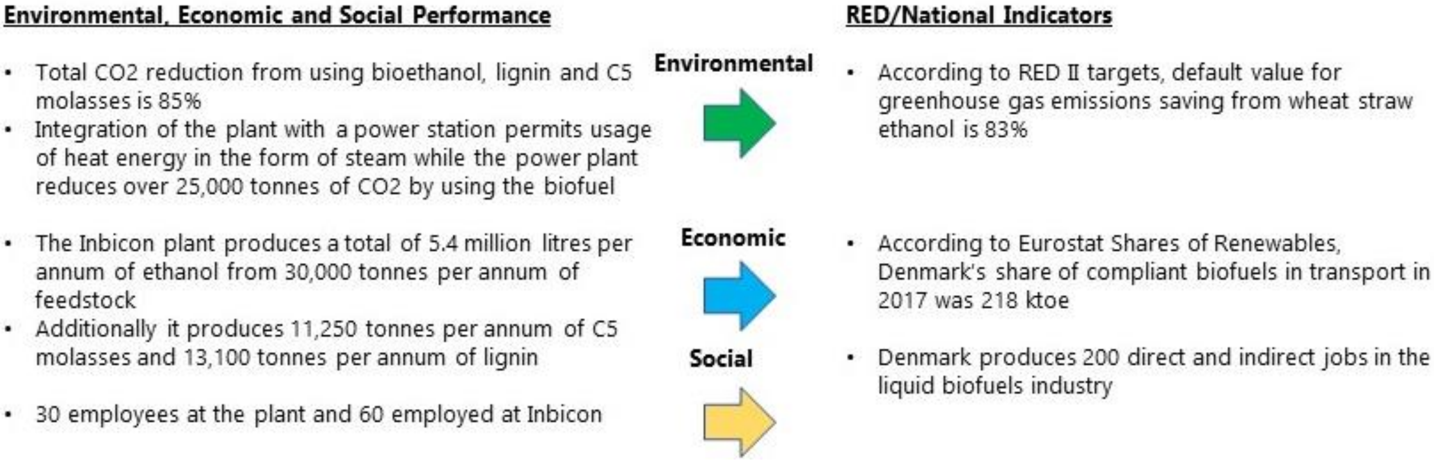
Inbicon Biochemical Demonstration Plant Factsheet

Plant Description: The Inbicon plant in Kalundborg, Denmark, has demonstrated two process configurations: one converting wheat straw into second generation bioethanol, lignin and C5 molasses based on C6 fermentation and one based on C5 and C6 fermentation through biomass mechanical conditioning, hydrothermal pre-treatment and pre-enzymatic hydrolysis for continuous liquefaction.

Inbicon Kalundborg Value Chain





Environmental, Economic and Social Performance		RED/National Indicators
• Total CO2 reduction from using bioethanol, lignin and C5 molasses is 85% • Integration of the plant with a power station permits usage of heat energy in the form of steam while the power plant reduces over 25,000 tonnes of CO2 by using the biofuel	**Environmental**	• According to RED II targets, default value for greenhouse gas emissions saving from wheat straw ethanol is 83%
• The Inbicon plant produces a total of 5.4 million litres per annum of ethanol from 30,000 tonnes per annum of feedstock • Additionally it produces 11,250 tonnes per annum of C5 molasses and 13,100 tonnes per annum of lignin	**Economic**	• According to Eurostat Shares of Renewables, Denmark's share of compliant biofuels in transport in 2017 was 218 ktoe
• 30 employees at the plant and 60 employed at Inbicon	**Social**	• Denmark produces 200 direct and indirect jobs in the liquid biofuels industry

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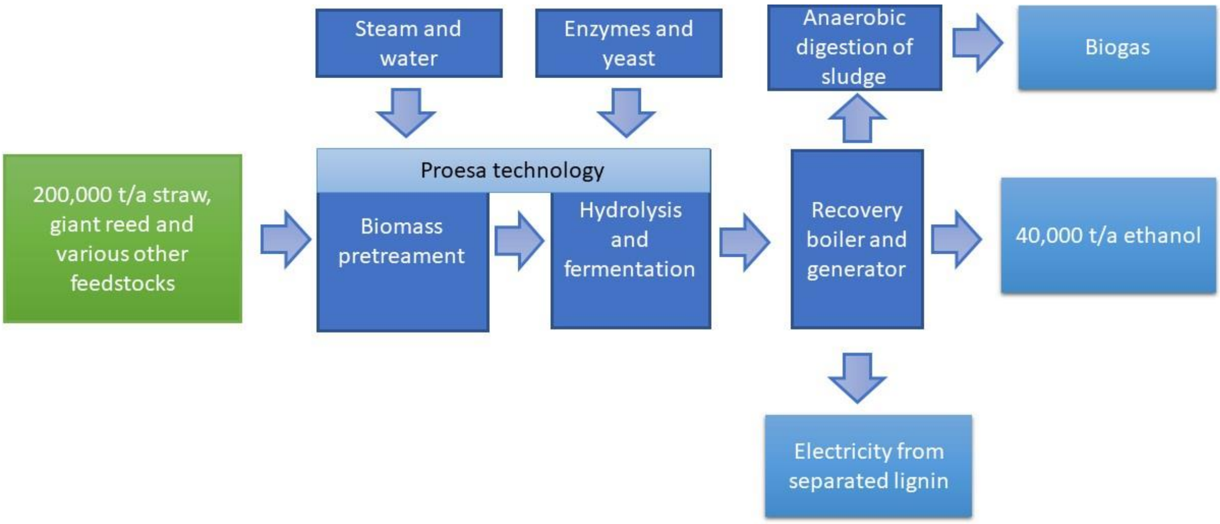
Eni Versalis Biochemical Commercial Plant Factsheet

Plant Description: The Eni Versalis plant in Crescentino, Italy, produces cellulosic ethanol, green electricity and biogas from agricultural residues (rice and wheat straw), energy crops (reed, switchgrass and woody crops) and forestry residues through the Proesa technology which handles the pretreatment of biomass before enzymatic hydrolysis and fermentation.

Eni Versalis Crescentino Value Chain



Environmental, Economic and Social Performance

Environmental

- 20,000 tonnes of ethanol from a biorefinery saves 72,000 tons of CO2 through bioethanol production which represents a >70% GHG reduction compared to gasoline
- Wheat straw and giant reed grown within 70 km of the factory

Economic

- The plant converts over 200,000 tonnes of biomass to produce a capacity of 40,000 tonnes of bioethanol per year

Social

- The Eni Versalis plant generates approximately 100 direct and 200 indirect jobs

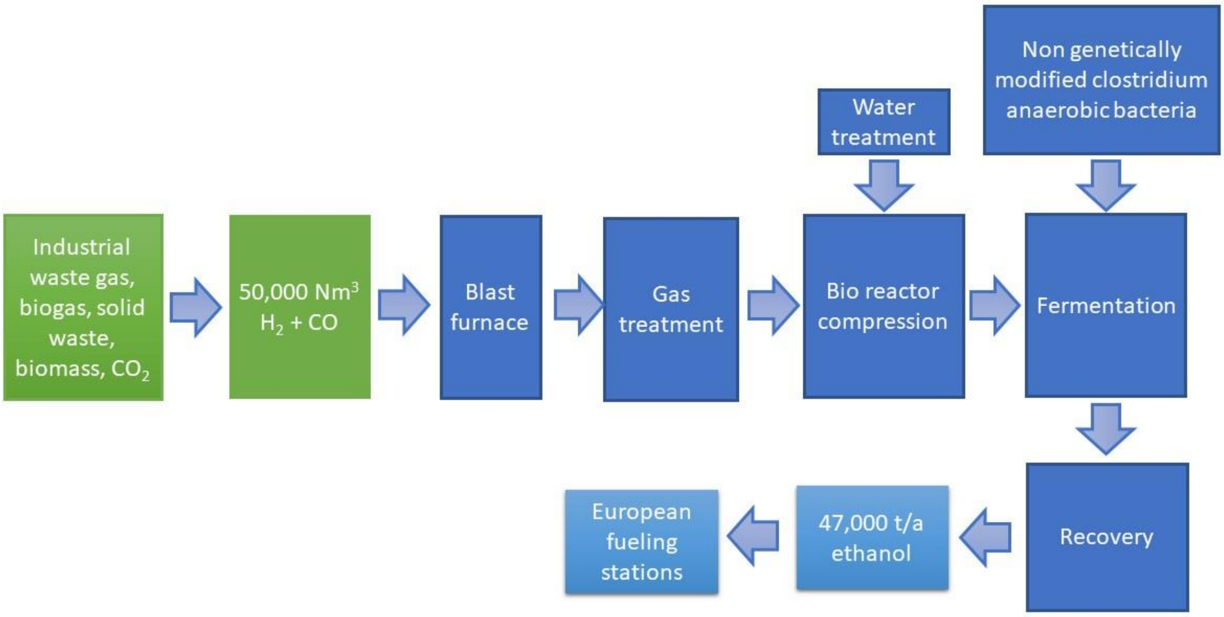
RED/National Indicators

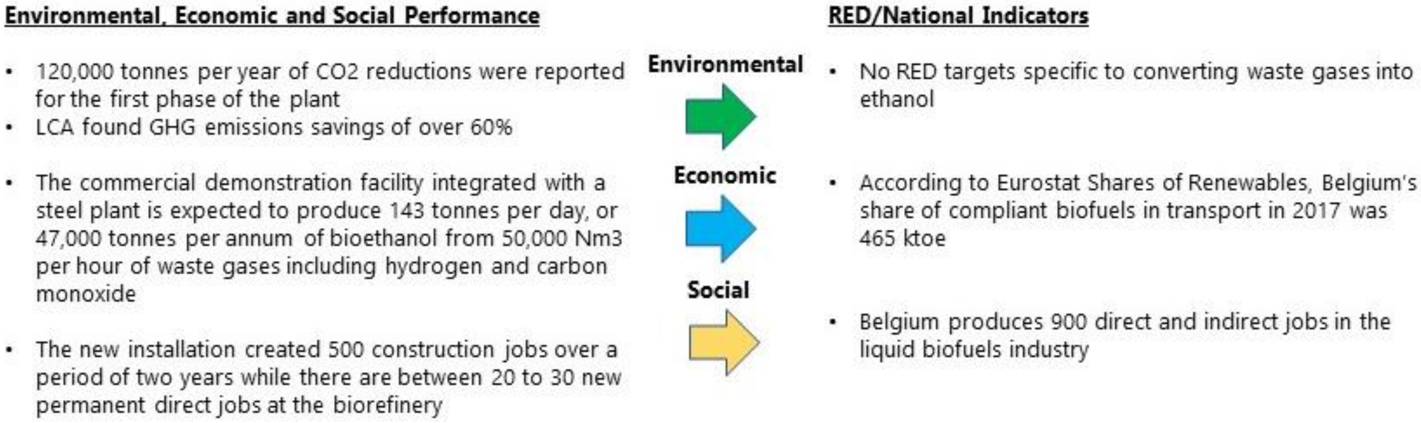
- According to RED II targets, if produced with no net carbon emissions from land use change, default value for greenhouse gas emissions saving from wheat straw ethanol is 83%
- According to Eurostat Shares of Renewables, Italy's share of compliant biofuels in transport in 2017 was 1,060 ktoe
- Italy produces 6,500 direct and indirect jobs in the liquid biofuels industry

Lanzatech Biochemical Commercial Plant Factsheet

Plant Description: The LanzaTech plant in Ghent, Belgium involves a process of biological conversion of carbon to products through gas fermentation in the form of microbes that grow on gases. As such it is able to convert waste gases such as hydrogen and carbon monoxide into bioethanol, ready for blending with gasoline or drop in jet fuel.

Lanzatech Ghent Value Chain





Environmental, Economic and Social Performance

- 120,000 tonnes per year of CO2 reductions were reported for the first phase of the plant
- LCA found GHG emissions savings of over 60%
- The commercial demonstration facility integrated with a steel plant is expected to produce 143 tonnes per day, or 47,000 tonnes per annum of bioethanol from 50,000 Nm3 per hour of waste gases including hydrogen and carbon monoxide
- The new installation created 500 construction jobs over a period of two years while there are between 20 to 30 new permanent direct jobs at the biorefinery

Environmental

Economic

Social

RED/National Indicators

- No RED targets specific to converting waste gases into ethanol
- According to Eurostat Shares of Renewables, Belgium's share of compliant biofuels in transport in 2017 was 465 ktoe
- Belgium produces 900 direct and indirect jobs in the liquid biofuels industry

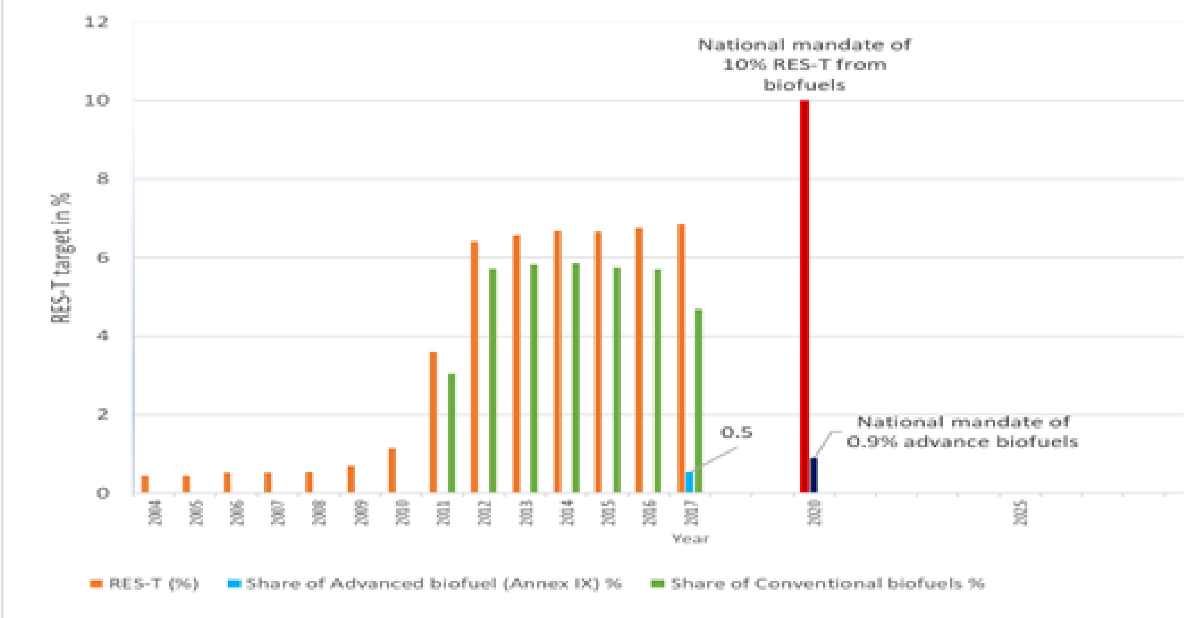
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.º764799.

4.2. Individual country factsheets

Denmark (DK) Policy Factsheet on Advance Biofuels

Current State of Art[103]: Denmark is leading by example and have surpassed their national binding target for 2020 in 2015 and aims to be 100% carbon neutral by 2050. Denmark implemented the biofuel mandate of 5.75% for road and rail transportation starting from 2009. Following this we can see the consumption trend of biofuel increased from 0.69% in 2009 to 6.41% in 2012[2]. However, looking at the consumption trend of renewable transport fuels (RES-T) from 2012 to 2017, it has not increased significantly. In 2017 the RES-T share is 6.85% and advance biofuel share of RES-T is only 1% which shows that they need to push the consumption of RES-T to reach the EU mandate. 90% of the total biofuel consumption in 2017 comes from conventional biofuels and 10% comes from advanced biofuels (Eurostat, SHARES 2017), which means there is lot of room for advanced fuel to increase their contribution. There national mandate for RES-T is 10% by 2020 and they also introduced a mandate for advanced biofuels, which is 0.9% starting from 2020.

Overall RES share for 2017: 35.77% **Overall RES-T share for 2017: 6.85%** **RES target for 2020: 30%**



Barriers to uptake advance biofuel:

- Transport sector of Denmark will most likely import ethanol up to 2020 as there are concerns of environmental sustainability in using energy crops to produce biofuel. (Danish Energy Agency (DEA), March 2017, Analysis of Bioenergy in DE)
- Danish energy companies who imports wood residues and wood pellets will face challenges related to the environmental sustainability with RED II sustainability criteria (DEA, March 2017, Analysis of Bioenergy in DE)

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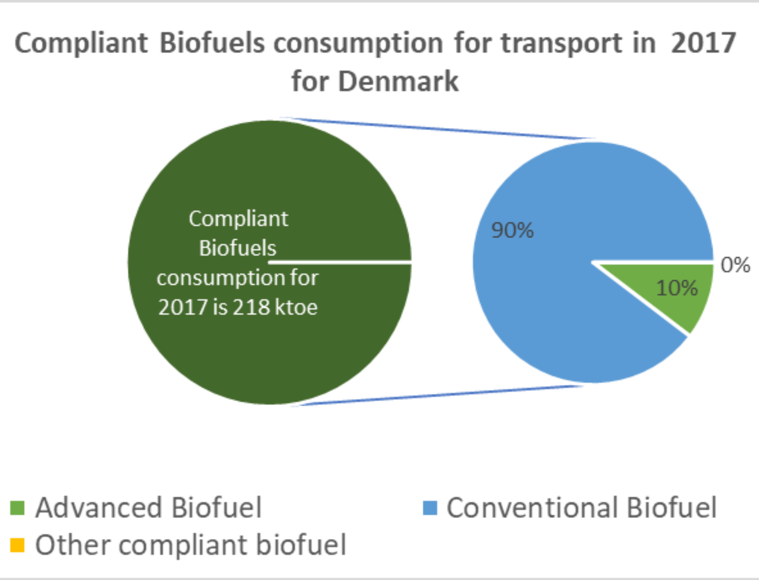
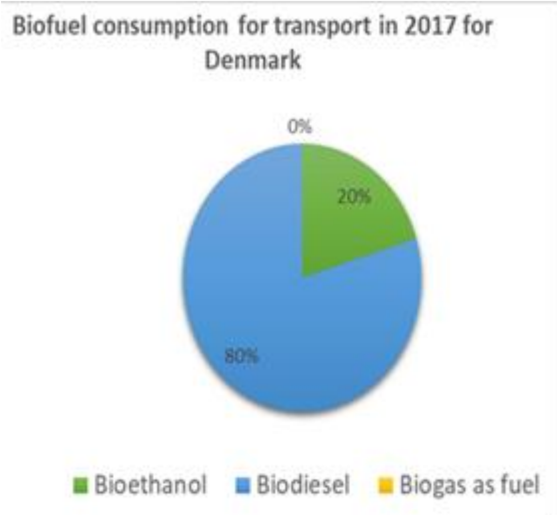
[103] All the number and facts in these factsheets are from Eurostat, SHARES, 2017; Denmark's NREAP Report; ICCT report Advanced Biofuel Policies in Select EU Member State: 2018 Update



Source : SHARES Renewable 2017, Eurostat

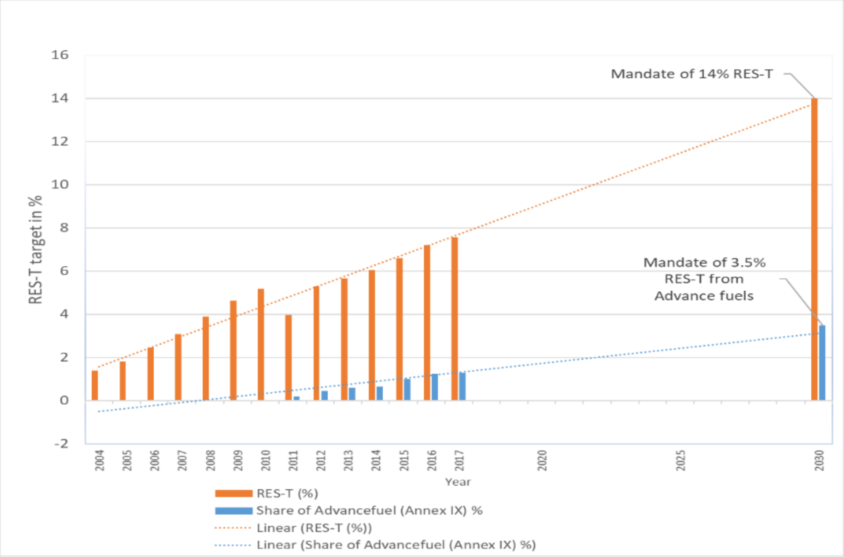


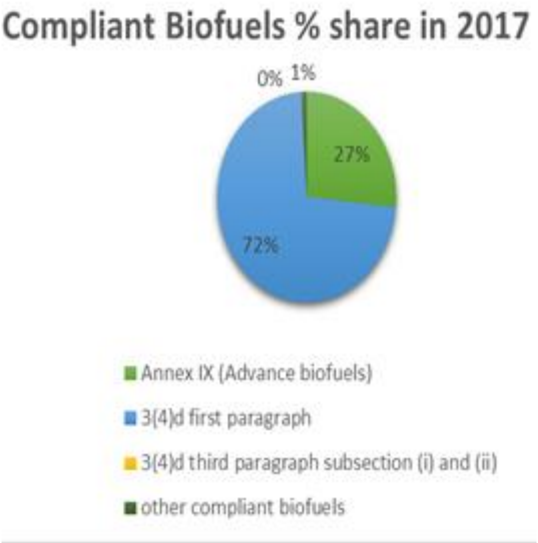
Source : EurObserv'ER 2017

Enabling policy instruments in place for 2030:

- DK has biofuels quota scheme
- Liquid biofuels exempted from carbon as well as energy tax whereas fossil GHG emissions has carbon tax €23.3 per ton CO2e in 2018.
- Direct subsidies and support schemes.
- Biomethane receives feed-in premium tariff which in 2018 as €0.6 per litre of diesel equivalent when injected into the natural gas grid or to €0.4 per litre of diesel equivalent when sold directly as a transportation fuel.
- Long-term strategy introduced in 2018 place where biofuels will be mainly used in heavy-duty vehicles and aviation. Under this strategy 530 million is allocated for biogas expansion for the period up to 2030 and €67 million plan for sustainable transportation development between 2020 and 2024.
- Danish Energy Agency works with public support which is very important for the information provisions mechanisms and establishing collaboration among stakeholders from different sectors.
- Act on Sustainable Biofuels to regulate the sustainability criteria of biofuels
- The Danish Energy Agency also encourages the voluntary certification schemes.

Current State of Art: The Renewable Energy Directive (RED) has mandates set for 2020 and aims to achieve 27% of the final energy consumption across all sectors to come from for Renewable Energy Sources (RES). With the new RED II, EU target has been raised to 32% by 2030. In addition to that RED II introduced a sub-target of 14% RES-transportation and 3.5% for advanced biofuels by 2030. Advanced biofuels (Annex IX) will be double-counted towards both these targets. Fuels used in the aviation and maritime sectors are excluded from the 14% obligation, but these sectors can opt to contribute to the target. The consumption trend of the compliant biofuels (biofuels which meets the sustainability criteria defined under Articles 17 and 18 of RED 2009/28/EC) as renewable transport fuels (RES-T) plotted from 2004 to 2017 for EU 28 shows that there is a steady increase every year. GHG emissions in European transportation sector have declined by only 3.8% since 2008 therefore RED II defines a series of sustainability and GHG emission criteria that liquid biofuels and bioliquids used in transport must comply with to be counted towards the overall RES target. There is no mandatory GHG savings threshold before 2021 but after 2021 GHG savings threshold is 65% for transport biofuels. Consumption of advance biofuels was accounted from 2011 as a separate category within the compliant biofuels which includes only the non-food and feed feedstocks listed under Annex IX. The consumption trend of advance biofuels is also increasing steady. If this growth rate continues in linear manner, EU28 can still meet the targets set for 2030 for RES-T and share of advance biofuels with the total target. Some of the countries in EU28 are also considering increasing the biofuel incorporation rates by energy content or by volume to meet the target. Country wise biofuel incorporation rates by energy content for 2020 are 8.5% for Spain, 8.5% for Poland, 8.75% for Austria, 8.81% for Croatia, 10% for Greece, 10% for Italy, 10% for the Netherlands, 10% for Portugal and 20% for Finland[104].





Source : SHARES Renewable 2017, Eurostat

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[104] Facts and numbers are from Eurostat SHARES, 2017, Biofuels Barometer September 2018 by EurObserv'ER.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

Enabling strategy and programme in place for 2030:

- **2030 Framework for Climate and Energy**
- The **Clean Energy for All Europeans Package** is the new energy policy framework in place which is intended to be adopted from 2019.
- A robust governance system is set up for the Energy Union and Climate Action under which a 10 year **Integrated National Energy and Climate Plans (NECP)** is defined for 2021 to 2030.
- To support RES there are other instruments like: The **EU Emission Trading Scheme (ETS),** Research, development and innovation funding programmes such as **Horizon 2020, the Innovation Fund, the NER300 programme,** the regional development funds from **European Investment Bank** and from the **European Fund for Strategic.**
- **Climate neutral Europe by 2050** is a long-term strategy which will build on energy policy framework established under the Clean Energy for All European package.
- **The EU Effort Sharing Regulation 2021-2030** to establishes binding emission reduction targets for each Member State in the non-ETS sectors like transport.

Enabling Regulatory Frameworks in place:

- **Alternative Fuels infrastructure Directive 2014/94/EEU**
- **Renewable Energy Directive RED I and RED II**
- **Fuel Quality Directive (Dir 2009/30/EC); Biofuel Directive (2003/30); iLUC Directive (EU 2015/1513; Clean Vehicles Directive (2009/33/EC); Energy Efficiency Directive (Dir 2012/27/EU)**
- **European Norm for biofuels -FAME EN14214; EN590; EN228**

Enabling environment created by the policy framework:

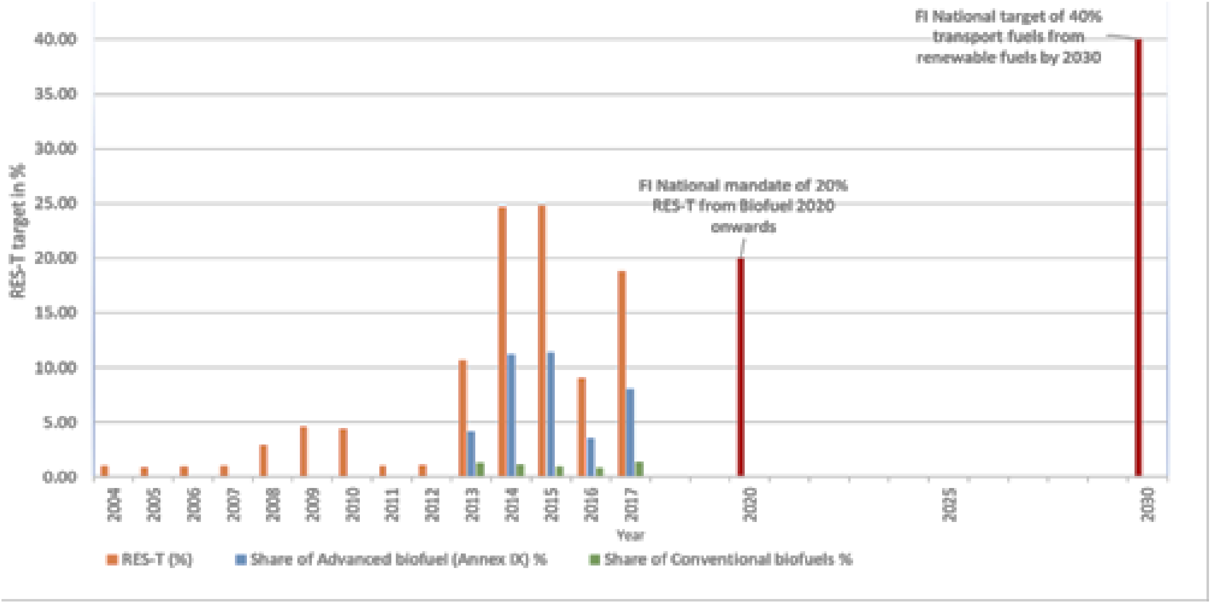
- Under RED II Member states has flexibility on implementation choices of transport mandate and sustainability criteria compared to RED.
- Provides long-term certainty for investors
- Puts the consumer at the centre of the energy transition with a clear right to produce own renewable energy
- Increases competition
- Accelerates the uptake of renewables in transport sectors
- Strengthens the sustainability
- Promotes the innovative technologies provides long-term certainty for investors

Key barriers for the uptake of advance biofuels identified based on the stakeholder consultation[2]

- Lack of harmonised regulations on sustainable farming practices for residual biomass, dedicated energy crops and forest management practices
- Lack of harmonised regulations throughout EU concerning fuel taxes, biofuel tax reductions, obligation systems, RESFuel Blends and fuel standards.
- Absence of structural mechanism to bridge the gap between renewable and fossil-based fuels
- Absence of dedicated policy support for RES-T in the form of incentives and dedicated national and EU level targets
- Long term policy support to provide stability and security for the industry (including pricing and regulation of (competing) fossil fuels).
- Lack of certification required to ensure market share of CO2 as feedstock for renewable fuels.

Current State of Art[105]: Finland achieved their 2020 renewable energy target under 2009 RED by 2014 and set new target of 38% by 2020. The Finnish Government set target to reduce their GHG emission by 80-95% by 2050 compared to 1990 levels under the Climate Change Act under their national Energy and Climate Strategy 2015. This strategy supports the non-ETS (emission trading scheme) sectors like transport to use waste streams in the production of transport fuel and investment subsidies are in place promote commercialisation of new technologies to produce advanced transport biofuels. For the road transport, the share of biofuel distribution obligation is increased from 13.4 % to 30% by 2030. According to the National Energy and Climate Strategy 2030[2] the additional demand for transport biofuel is expected to come from advanced biofuels produced in Finland. 80% of this demand will be fulfilled by those biofuels which has the largest production volumes which are defined a as drop-in biofuels.

Overall RES share for 2017: 41.01%   **Overall RES-T share for 2017: 18.33%**   **RES target for 2020: 38%**



Barriers to uptake advance biofuel:

- Advanced biofuel offers a potential for increasing the FI's share of renewable energy in transport sector first for road and then for aviation and freight. However, the increase in biofuel use will also be restricted by the demand for biomass in other applications. Imports of raw materials will be an alternative, but sustainability criteria introduced by RED II will introduce some challenges.

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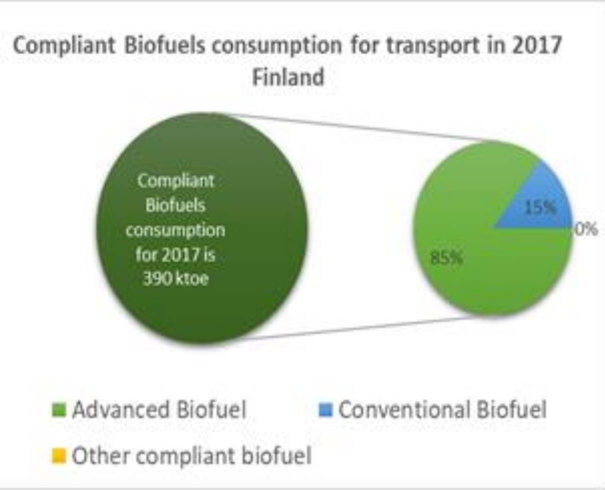
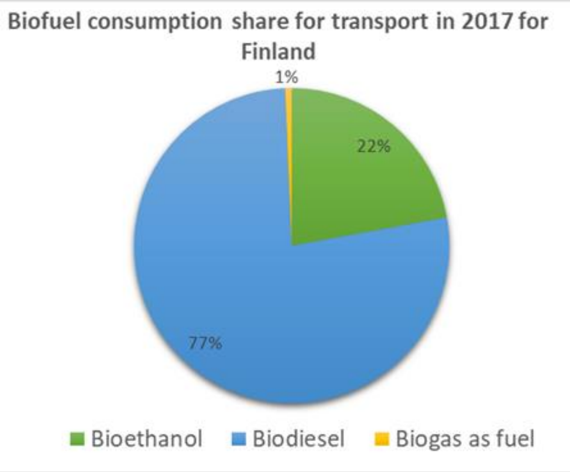
[105] All the numbers and facts here are referenced from 'Government report on the National Energy and Climate Strategy for 2030' Publications of the Ministry of Economic Affairs and Employment 12/2017. Eurostat SHARES, 2017 and EurObserv'ER, 2017





Source : SHARES Renewable 2017, Eurostat

Source : EurObserv'ER 2017

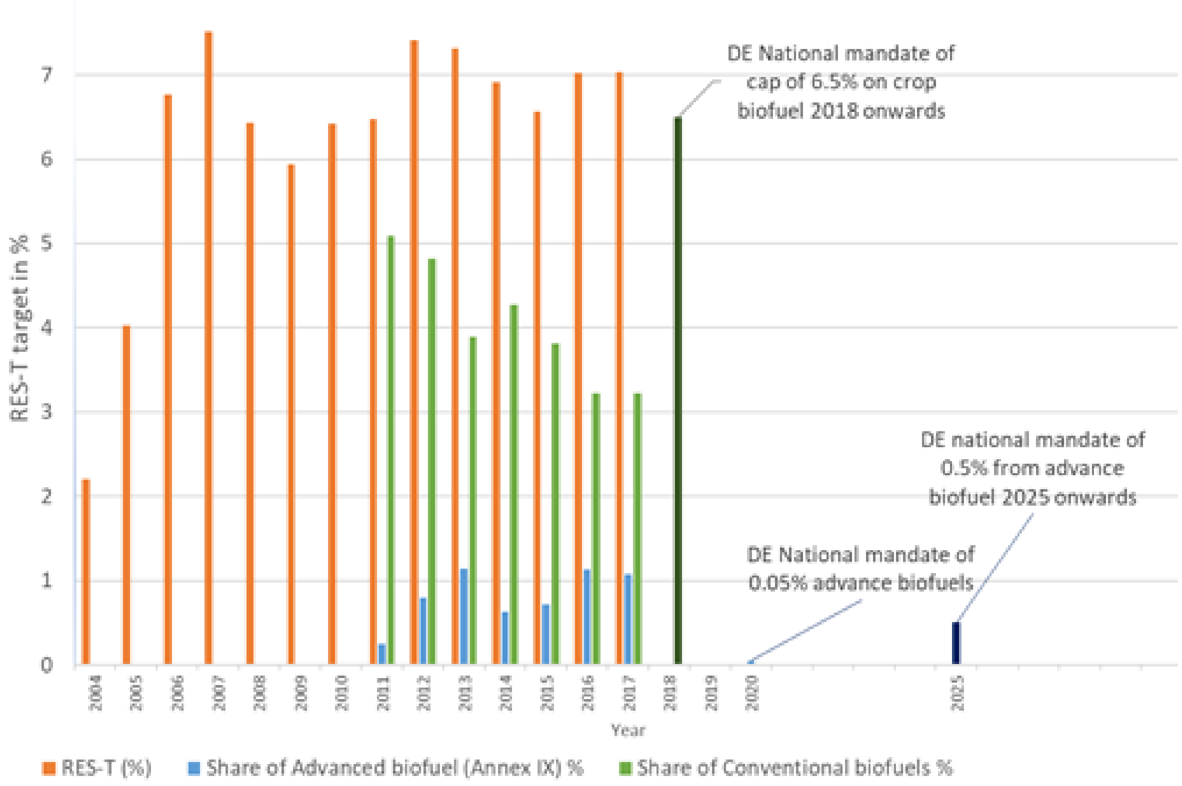
Enabling policy instruments in place for 2030:

- The Finnish Act on the promotion of the use of biofuels for transport (446/2007)
- FI has biofuel quota obligation system makes sure that make up a certain percentage of the total annual sale of fuels.
- Sustainably sourced biofuels are subject to 50 % less CO2 tax
- Biofuels which can be double-counted under the RES Directive are not subject to any CO2 tax.
- FI has the effort sharing target of 16% reduction by 2020 and 39 % reduction in GHG emissions by 2030 compared to 2005. The low-carbon economy roadmap is proposed by the Commission in 2011.
- FI National Energy and Climate Strategy 2030, focuses on sector specific plans for reducing their carbon emissions. FI transport sector accounts for approx. 40 % of effort sharing sector emissions, estimated 2.6–3.6 Mt emission reduction by 2030. The Strategy emphasizes that since transport plays a key role in achieving the emission reduction target, this creates market opportunities for the promotion of the technology of liquid biofuels and biogas which are advanced biofuels produced in Finland.

Germany (DE) Policy Factsheet on Advance Biofuels

Current State of Art[106]: Germany is one among top 10 consumers of transportation biofuels in EU. Together with Italy, the Netherlands, Sweden and the United Kingdom they consumed 46% of the total EU biofuels in 2016. GHG emissions from transport is recorded as 163mtoe in 1990 and has roughly remained similar until 2017 which is 171mtoe. This is because improved energy efficiency was able to balance out the increased volume of emission from transport but not enough to reduce. Under the Climate Action Plan 2050, Germany has emission targets set for all (Energy, Buildings, Transport, Industry, Agriculture, Waste and other). The target set for transport sector is reduction by 40-42% by 2030 compared to the level of 1990. To achieve these climate targets, Germany has established a GHG reduction quota of currently 4% and 6% from 2020. The average GHG savings of biofuels in the German market in 2017 was 81%[107]. There will be a mandate for advance biofuels starting from 2020.

Overall RES share for 2017: 15.45% **Overall RES-T share for 2017: 7.03%** **RES target for 2020: 18%**



Barriers to uptake advance biofuel:

- GHG savings mandate has forced the biofuel producers to improve their industrial processes to enhance GHG efficiency, which reduces the biofuel incorporation by volume for fuel suppliers.

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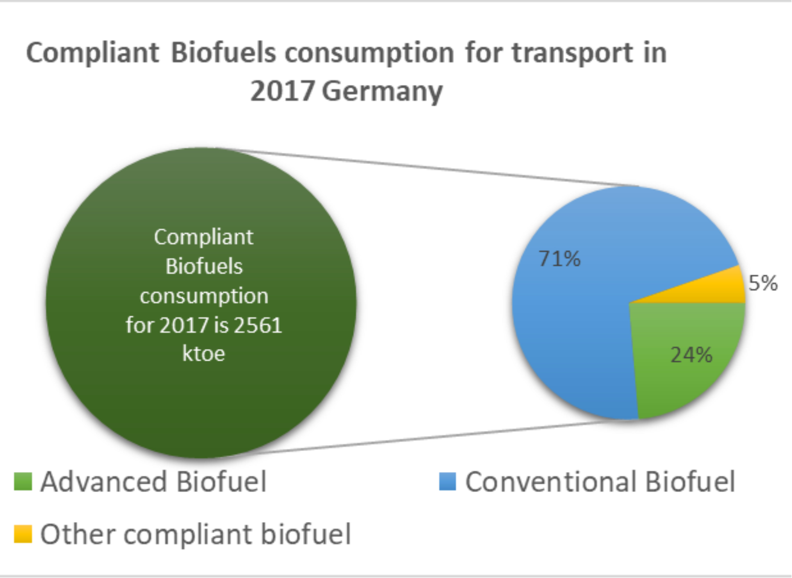
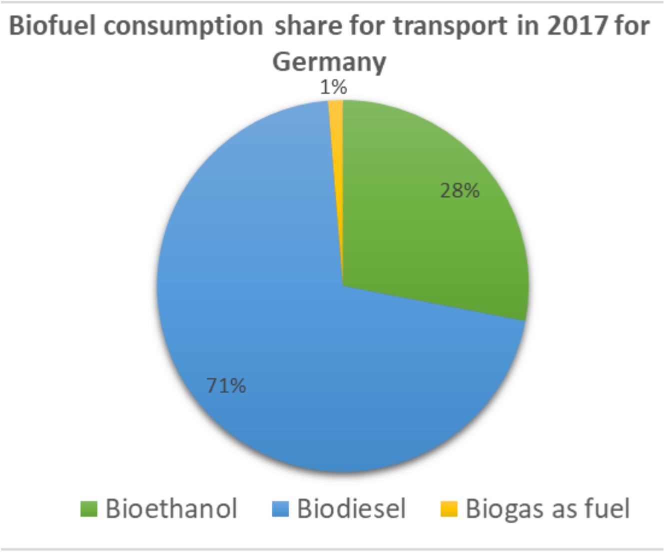
[106] All the facts and numbers are referenced from Eurostat SHARES 2017 and EurObserv'ER 2017; ICCT report Advanced Biofuel Policies in Select EU Member State, 2018 Update

[107] http://www.gesetze-im-internet.de/bimschg/__37a.html, Last Visited on [22/03/2019]



Source : SHARES Renewable 2017, Eurostat



Source: EurObserv'ER 2017

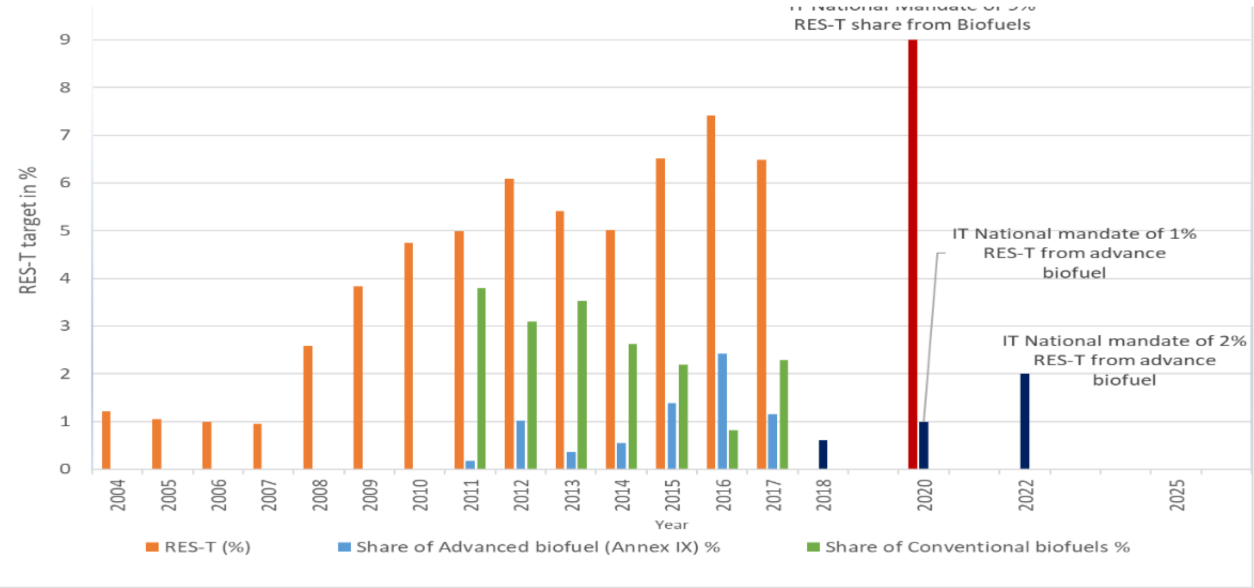
Enabling policy instruments in place for 2030:

- Double counting mandate expired in 2014 and introduced GHG savings mandate of 6% by 2025 which created a competitive environment for advanced biofuels like HVO and UCO compared to conventional biofuels, although the most performing biofuels are incentivised since all fall under the GHG quota. There is no double counting towards the mandate.
- German national cap on first generation biofuel is 6.5% and this was set under the ILUC Directive and new RED II which set a limit of 7% blending of conventional biofuels and this gave an advanced biofuel an opportunity to contribute towards to overall RES-T target of 14% by 2030
- Penalty for fuel suppliers failing to meet the biofuel mandate were subjected to penalties of €0.7 per litre of diesel equivalent for biodiesel and €1.55 per litre of diesel equivalent for ethanol. Beginning in 2015, the penalty switched to €470 per ton of CO2e of GHG savings not achieved.
- Germany has national mandate of 0.05 % share of advanced starting from 2020 and slowly move up to 0.5% by 2025
- For biodiesel and bio gasoline used in transport Germany has quota obligation with Tradable Green certificates and tax regulation mechanisms II (BioKraftQuG)
- Under the Federal Emission Control Act, starting from 2017 Germany increased their GHG savings mandate from 3.5% (2015) to 4%, which will go up to 6% from 2020 onwards.

Italy (IT) Policy Factsheet on Advance Biofuels

Current State of Art[108]: Italy has achieved their overall EU renewable and GHG emission reduction targets for 2020. They were the first member state to mandate the use of advanced biofuels. The Ministerial Decree of October 10th, 2014 encourage the use of advanced biofuels that comes from waste and non-food origin and the new regulations encourages its adoption with gradual increase over the years[2].In 2014 they had the mandate of at least 1.2% advance biofuels, which is now increased to 2% by 2022. 66% of the total share of compliant biofuels comes from conventional biofuel sources and rest 34% comes from advanced biofuel. Italy's biofuel share is dominated by biodiesel 97%. They have increased the overall consumption of biofuel but reduced the share of conventional biofuel and increased the share of advanced biofuels.

Overall RES share for 2017: 18.26% **Overall RES-T share for 2017: 6.48%** **RES target for 2020: 17%**



Barriers to uptake advance biofuel:

- Transport sector in Italy consumes the highest share of final energy consumption (FEC), therefore the highest savings are expected from this sector. Excepted FEC saving in 2020 is 5.50 mtoe/yr

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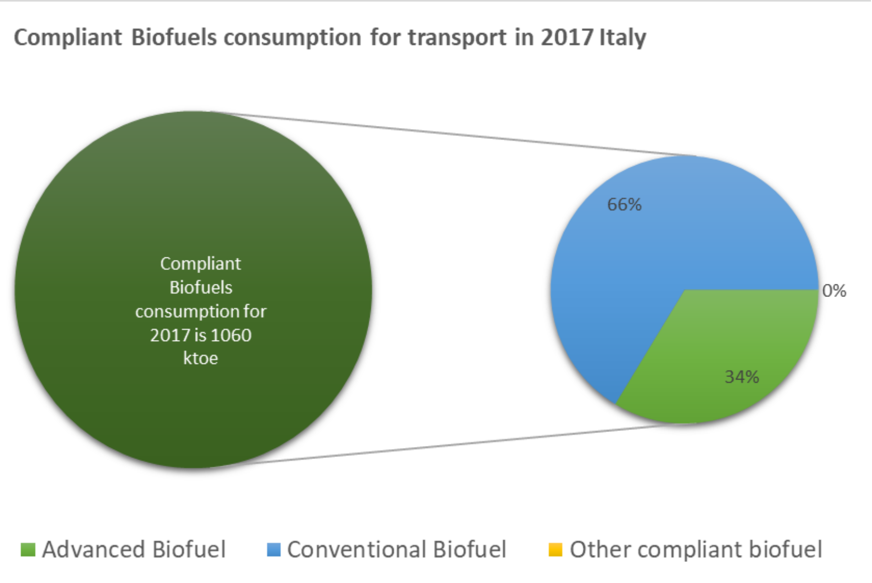
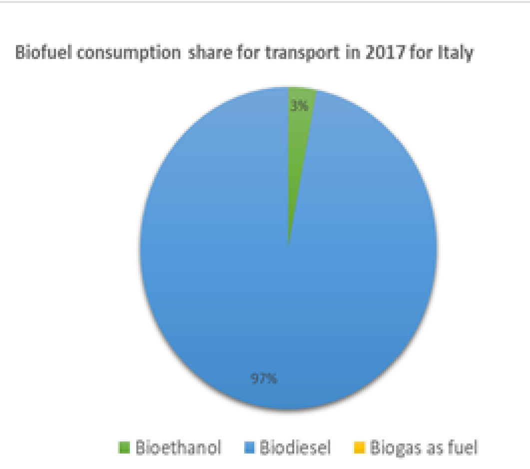
[108] All the number and facts in these factsheets are from Eurostat, SHARES, 2017; Italy's NREAP Report; ICCT report Advanced Biofuel Policies in Select EU Member State: 2018 Update and Biofuels Mandates in the EU-Report 2018





Source : SHARES Renewable 2017, Eurostat

Source : EurObser'VER 2017

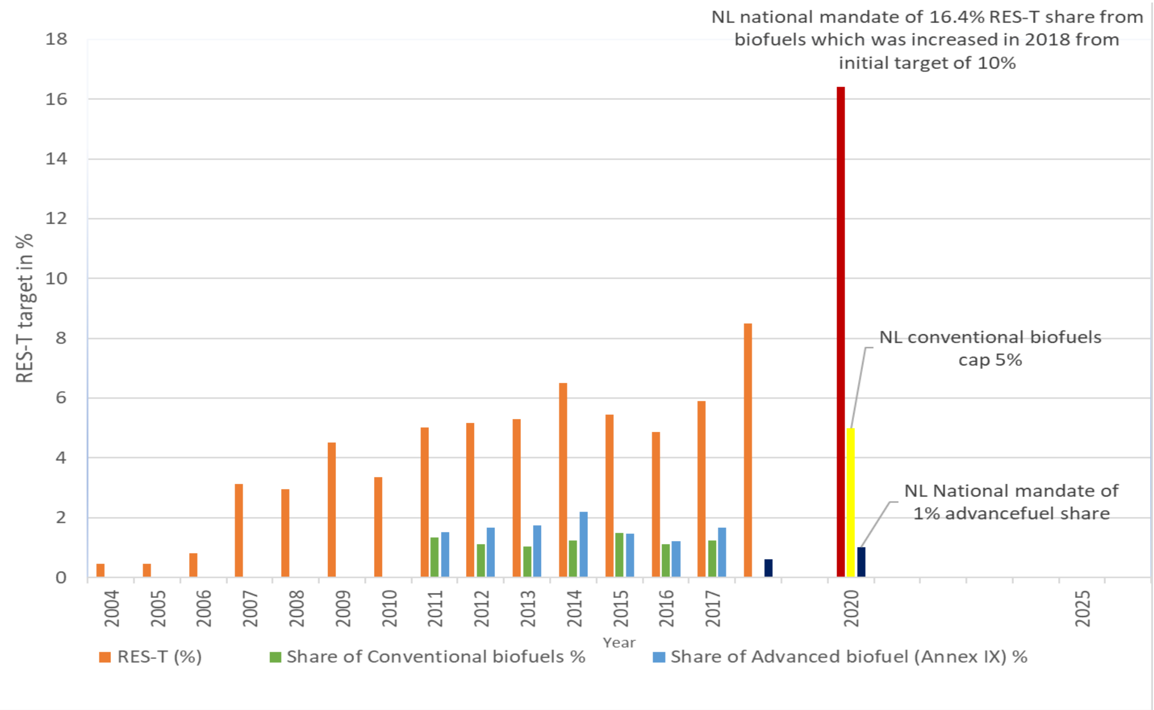
Enabling policy instruments in place for 2030:

- The main incentive for renewable energy use in transport is a quota system. These quota obligations that are issued annually without the tradable green certificates. The quota is to gradually increase from 5% in 2014 to 10% by 2020.
- In 2018 a new decree was published which included an obligation for advanced biofuels starting at 0.6% in 2018, 1% in 2020 increasing to 1.85% in 2022.
- There is cap set for conventional biofuels under EU ILUC Directive.
- The decree has introduced an emission certificates (CIC) for producers of biofuels. 1 CIC is assigned for 10 Gcal of conventional biofuels but for just 5 Gcal of advanced biofuels. The decree also has fixed subsidy for each advanced CIC.
- There is increase in subsidy for plants which produces biomethane for transport instead of electricity.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

Current State of Art [109]: Netherlands is on right path to achieve their national mandates as well as EU mandates for both renewable energy and GHG emission reduction targets for 2020 and 2030. In 2018 they increased their RES-T share from biofuels mandate to 16.4%. Their advanced biofuel mandate was also increased from 0.6% in 2018 to 1% in 2020. The physical volume of biofuel blended is not as large because of double counting. If we look at the consumption trend of conventional as well as the advanced biofuels we can see that share of advanced biofuels is higher until 2017 and is on track to meet the target set for 2020.

Overall RES share for 2017: 6.60% **Overall RES-T share for 2017: 5.91%** **RES target for 2020: 14%**



Barriers to uptake advance biofuel:

- There is no legislation in place to implement the Climate Agreement even though it was signed in 2017.

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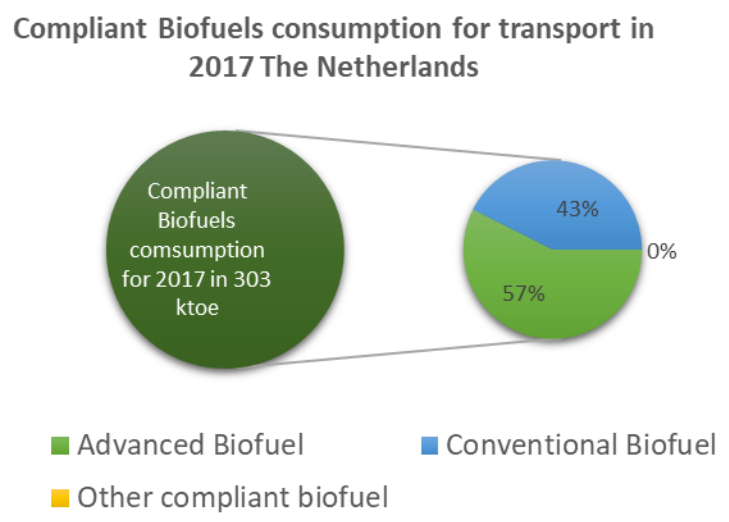
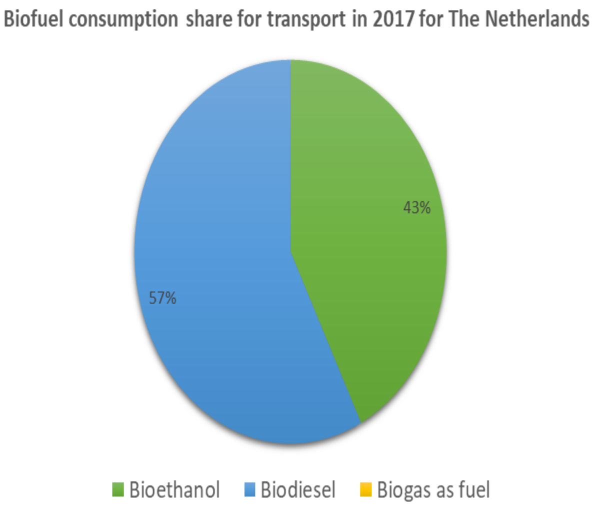
[109] All the number and facts in these factsheets are from Eurostat, SHARE tool, 2017; Netherland's NREAP Report; ICCT report Advanced Biofuel Policies in Select EU Member State: 2018 Update



Source : SHARES Renewable 2017, Eurostat



Source : EurObserv'ER 2017

Enabling policy instruments in place for 2030:

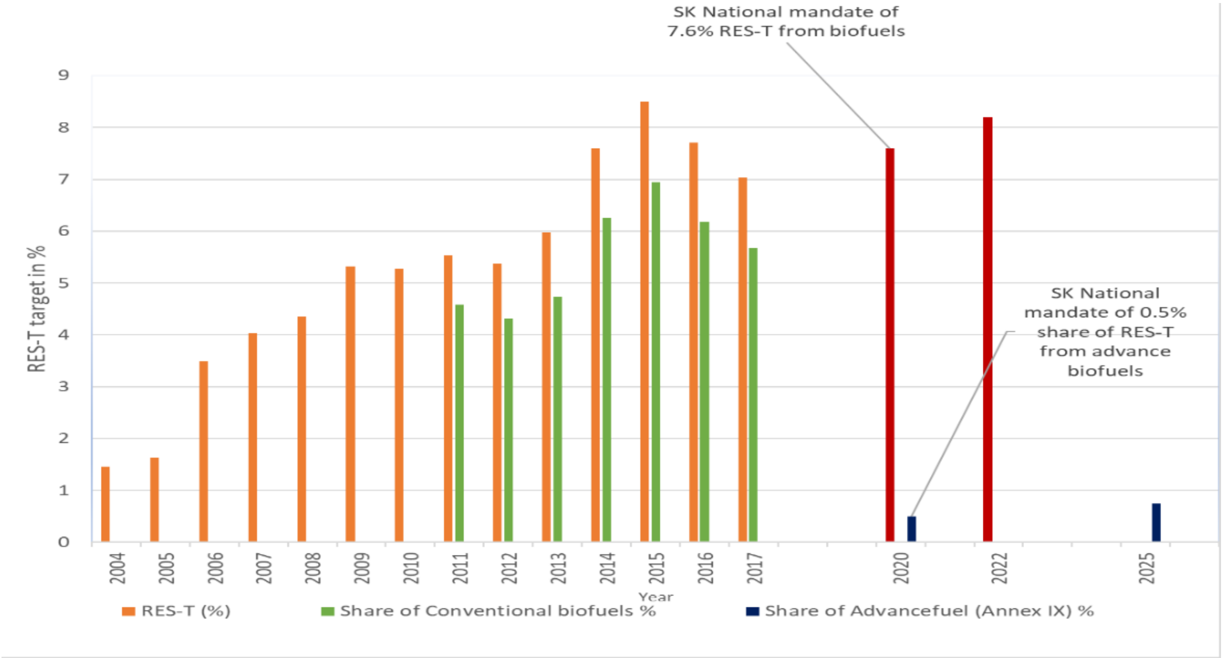
- Biofuel quota obligation with tradable Green certificates. Biofuel traders of transport fuels need to adopt an obligation scheme which should result in a 10% RES share of energy consumption in the transport sector.
- Tax credits exist for biofuel and hydrogen related RES-T investments.
- GHG emission reduction goal of 7.3 million tons by 2030 under Climate Agreement signed in 2017.
- Under the Climate Agreement NL agreed to prioritize the use of sustainable biomass for fuels in heavy road transportation, aviation and shipping. Aviation biofuels are eligible to obtain green certificates.
- IBB subsidy programme: This subsidy programme supports market players that improve or renew the process for supplying innovative biofuels to the transport.
- TAB (Tankstations Alternatieve Brandstoffen) subsidy filling stations for alternative fuels. Under the voluntary scheme, sellers of the transport fuels can apply for subsidy to install a filling stations for an alternative fuel such as E85 (bioethanol) and B30 (biodiesel).
- Additionally, the Netherlands Enterprise Agency facilitates market parties and specific organizations to establish training and certification facilities for RES installers and installations. Innovation in energy is supported through innovation contracts between private companies, universities, R&D institutes.
- Clean and Efficient Strategy in place to support the new innovative technologies and policy instruments in place.
- Priority to energy produced from renewable source in network connection RED Directive 2009 Article 16(2)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

Slovakia (SK) Policy Factsheet on Advance Biofuels

Current State of Art[110] : Slovakia's National Energy Action Plan (NREAP) states that the overall national mandate for renewable energy share in transport sector to be 7.6% by 2020 and 0.5% of the total share to come from the advanced biofuels. When you look at the consumption trend of biofuels (Eurostat SHARES 2017) we can see that there is no account of advanced biofuels but conventional biofuels is quiet high. However, Slovakia's NREAP [111] estimated that in 2018, their share of advanced fuel is expected to grow up to 14 ktoe in 2018 and up to 60 ktoe by 2020. Slovakia amended its Act no. 309/2009 on Support of Renewable Energy Sources and it updated the overall blending percentage and introduced mandates for advanced biofuels, as well as targets for 2020 which is 0.5% and increases to 0.75% by 2025. The contribution from the advanced biofuels will be double counted.

Overall RES share for 2017: 11.49% **Overall RES-T share for 2017: 7.03%** **RES target for 2020: 14%**



Barriers to uptake advance biofuel:

- There were no dedicated policy instruments to support advanced biofuels until now.

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[110] All the number and facts in these factsheets are from Eurostat, SHARE tool, 2017; Slovakia's NREAP Report; ICCT report Advanced Biofuel Policies in Select EU Member State: 2018 Update

[111] Table 4b in NREAP Slovakia report

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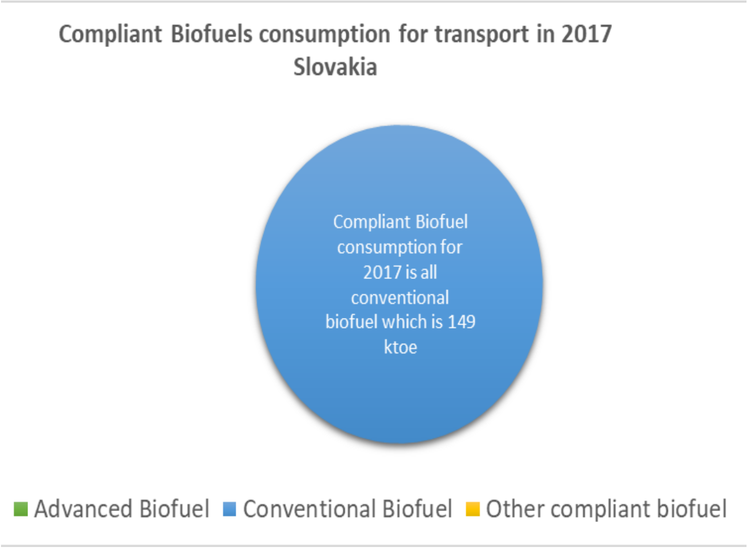


Source : SHARES Renewable 2017, Eurostat

Source : EurObserv'ER 2017

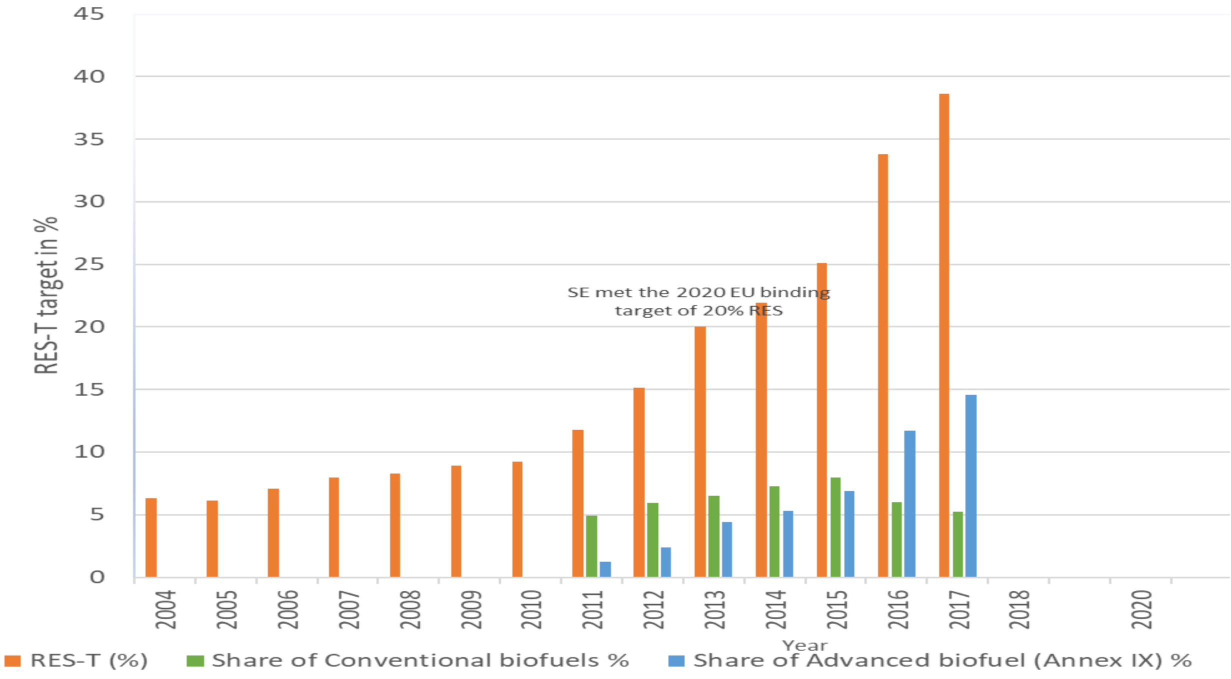
<u>Enabling policy instruments in place for 2030:</u>

- Biofuel quota scheme: SK has compulsory blending obligations of biofuels in place since 2006.
- SK has national mandate for share of advanced biofuels starting from 2020 at 0.5% to 0.75% by 2025.
- SK has tax credit mechanisms II which are fiscal incentives the biofuel producers can apply for. Biofuels are fully exempted and blended transport fuels are also partially exempted which is proportionate to their blend percentage.
- SK has legislative and regulatory measures in place to promote the production of woody raw materials to increase the supply of biomass from both agricultural as well as forestry holdings since 2011.
- Biofuels sustainability certification scheme in place in accordance with Article 15 of Directive 2009/28/EC.

Sweden (SE) Policy Factsheet on Advance Biofuels

Current State of Art[112] : Sweden has been on a good track record for biofuel consumption. The total share of advanced biofuel is 74% which is 1669 ktoe in 2017 (Eurostat, SHARES 2017). In 2017 they set a new record and this rise is attributed to the HVO biodiesel, according to the Swedish Bioenergy Association. If we look at the percentage of biofuel consumed in 2017, biodiesel makes up 87% of the total share. Sweden has no national mandate set for advanced biofuel but they are have already surpassed the EU28 mandate. SE has national target of 70% GHG emission reduction from transportation sector by 2030 compared to 2010 level. It is expected that 50% of passenger vehicles could be fuelled by biofuels and 20% by electricity to achieve this reduction target.

Overall RES share for 2017: 54.5% **Overall RES-T share for 2017: 38.63%** **RES target for 2020: 49%**



Barriers to uptake advance biofuel:

- There is no specific barrier as their uptake started since 2011 has been increasing consistently until 2017.

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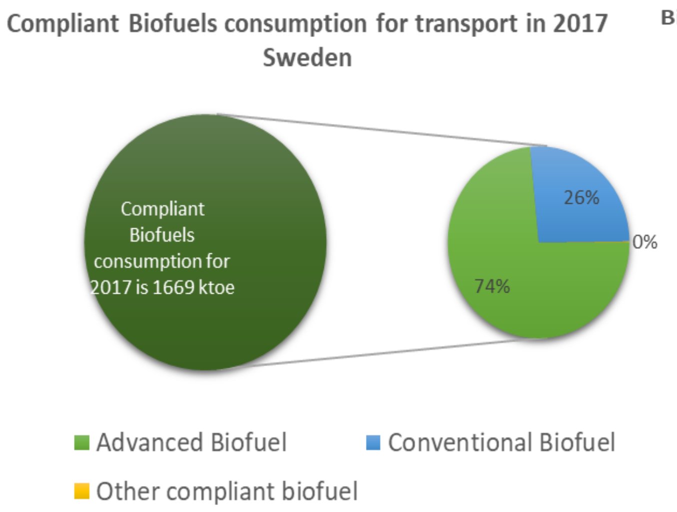
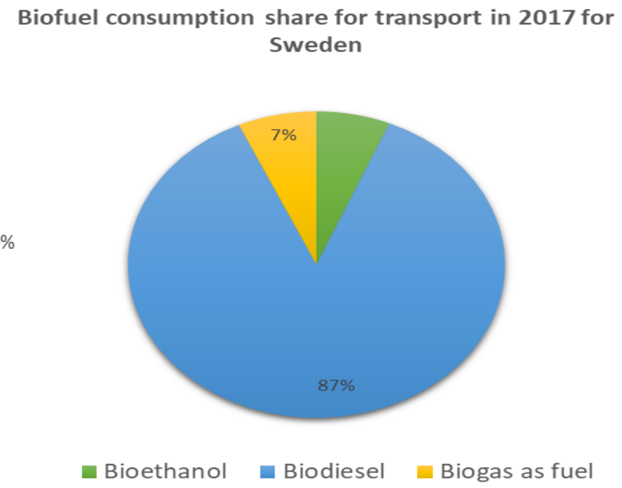
[112] All the number and facts in these factsheets are from Eurostat, SHARE tool, 2017; ICCT report Advanced Biofuel Policies in Select EU Member State: 2018 Update

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.º764799.





Source : SHARES Renewable 2017, Eurostat

Source : EurObserv'ER 2017

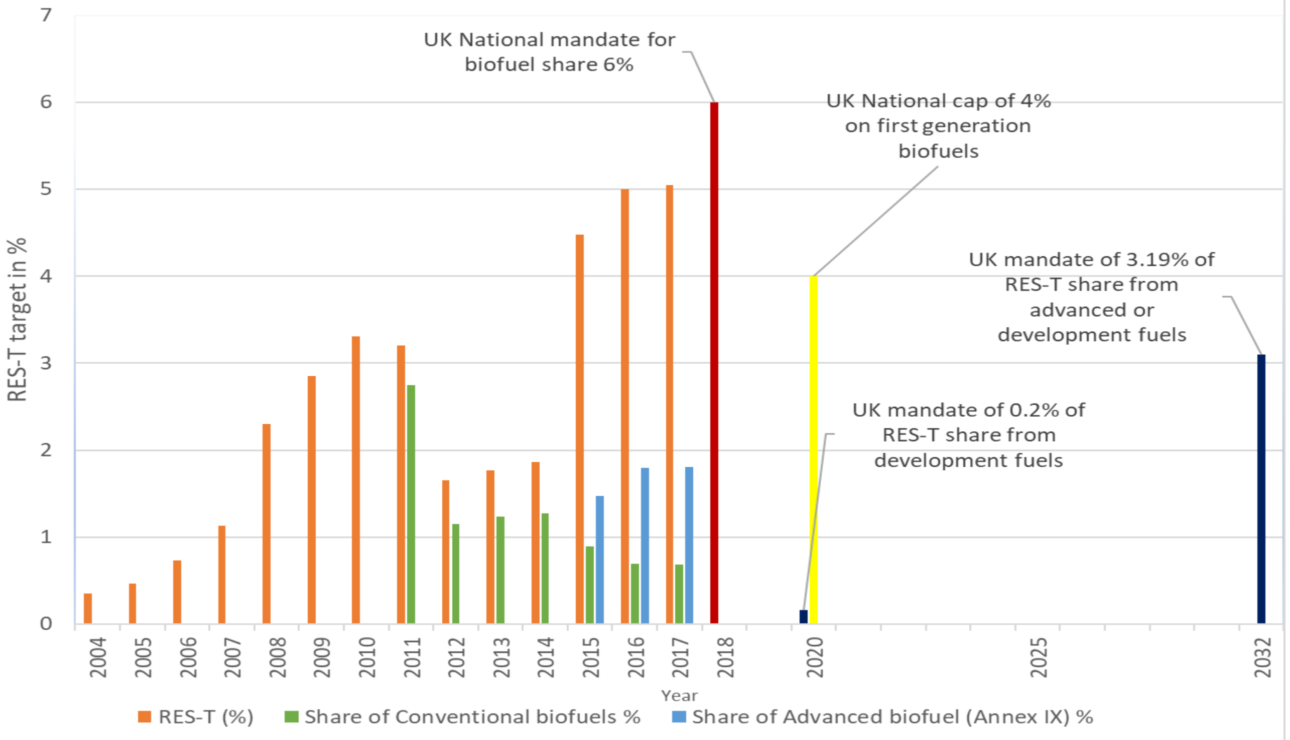
Enabling policy instruments in place for 2030:

- Energy and Carbon tax exemptions are the main incentives in place to promote the biofuels for transport. In 2018, the carbon tax was 1150 SEK per ton CO2 (€109 per ton CO2).
- In 2018 a new mandate was introduced in SE for fuel distributors to reduce GHG emissions of fuel supplied. The mandate is 19.3% reduction in diesel and 2.6% in gasoline by 2018. These targets increase to 21% and 4.2% by 2020 and up to 40% by 2030.
- SE Government has long term strategy to reduction 70% of GHG emission from transportation sector compared to 2010 level.
- Biofuel blending target is set for 50% by 2030.

The United Kingdom (UK)   Policy Factsheet on Advance Biofuels

Current State of Art[113] : UK has set a very high national mandate of 10.63% share of advanced biofuel in total RES-T consumption by 2020. Their overall RES-T share for UK in 2017 is accounted as 5.05% whereas the EU mandate for RES-T share by 2030 is 14% which a quite a big gap to fill. If you look at the consumption trend of conventional biofuels for the UK from 2011 to 2017 we can see a declining trend. UK has also set a national cap of 4% share from conventional biofuels by 2020 which will be reduced to 2.33% by 2030. Therefore, there is an opportunity for advanced biofuels to fill that gap.

Overall RES share for 2017: 10.21%   **Overall RES-T share for 2017: 5.05%**   **RES target for 2020: 15%**



Barriers to uptake advance biofuel:

- UK has long-term mandates for advanced biofuels not the challenge is to mobilize technologically and commercially available innovations to achieve this mandate.

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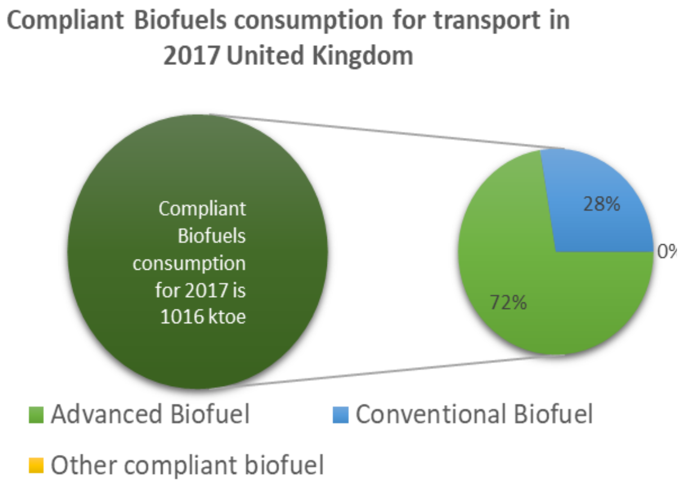
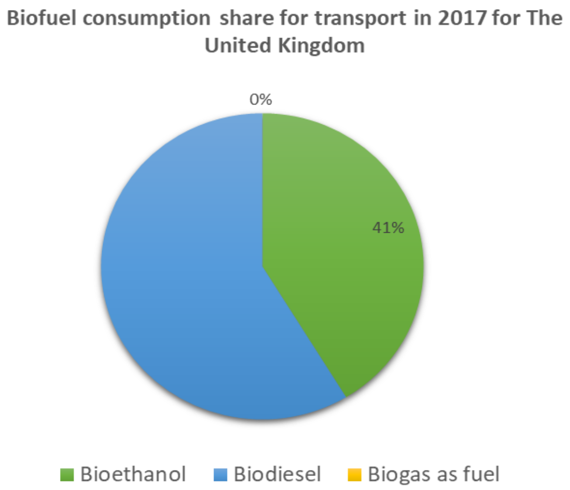
[113] All the number and facts in these factsheets are from Eurostat, SHARE tool, 2017; UKs NREAP Report; ICCT report Advanced Biofuel Policies in Select EU Member State: 2018 Update

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.º764799.



Source : SHARES Renewable 2017, Eurostat



Source : EurObserv'ER 2017

Enabling policy instruments in place for 2030:

- The UK introduced RTFO (Renewable Transport Fuel Obligation) in 2008 and RTFC (Renewable Transport Fuel Certification) allocated for advanced biofuels. 2 RTFCs are awarded for each litre of fuel.
- Aviation fuel qualifies for development fuel RTFCs
- There is a cap set on the maximum amount of RES-T share from first generation biofuels. This will be a maximum of 4 percent by volume in the period 2018 to 2020, and then must reduce incrementally to reach 2 percent in 2032.
- UK has cap on conventional biofuels starting from 2020 at 4% up to 2% in 2032.
- Advanced biofuels are categorised as 'Development fuel' and a mandate started from 2019. It is double counted. The aim is to double the use of renewable fuels in the transport sector in the next 15 years. A development fuel must also be one of the following fuel types: hydrogen, aviation fuel, substitute natural gas (i.e. renewable methane) or a fuel that can be blended to give 25 percent or more renewable fraction in the final blend while still meeting fuel technical and quality standards. (From the Renewable Transport Fuels and Greenhouse Gas Emissions Regulations 2018)

4.3. Interviewed stakeholders

Mrs Geradine Kutas, Brazil
Dr Kyriakos Maniatis, European Union,
Dr Nils Olof Nylund , VTT
Dr David Chiaramonti, Italy
Dr. Pauliina Uronen, Neste
Dr Pekka Tuovinen, Neste
Dr Mika Aho, St1
Dr Marko Janhunen, UPM
Mrs Liisa Ranta, UPM
James Cogan, EERL
Dieter Bockey, UFOP

4.4. Questionnaire for plants

This questionnaire focuses on the first type of practices and addresses environmental, economic and socio-economic aspects that characterise the development path of the good practices and case study advanced biofuel plants in a structured way.

1) ***Which plant and region is the good practice being implemented in?***

Discuss the profile and key facts and figures of the region, the nature/ type of advance biofuel plant, the key elements of the value chain and the good practice (is it across the value chain or in one of the stages, e.g. feedstock production?).

2) ***What is the development stage of the plants?***

The development of an advanced biofuel value chain passes through different stages, typically taking a few years to reach maturity. The challenges at the initiation of the chain differ from that during a mature stage. Hence it makes sense to distinguish the phases in the development path and analyse the respective operational capacities that should be in place for successful implementation.

Please describe the value chain:

- Land used (ha)- locality (EU, non-EU)

3) ***What land is being used for feedstock production?***
4) ***Is it marginal, abandoned, or contaminated? Is it a high nature value area?***

- Feedstock used (tonnes) -(type)- Locality (EU, imported)

5) ***What kind of feedstocks do you use***
6) ***How much of it gets processed?***
7) ***What are your priorities when it comes to feedstock quality?***

	Low Priority	Medium Priority	High Priority
Yield			
Moisture Content			
Heating Value			
Calorific Value			
Ash Content			
Volatile Matter			

8) ***What makes this feedstock better than others?***

	Low	Medium	High
Feedstock Cost			
Energy Efficiency			
Storage Efficiency			
Transportation Efficiency			
Air Quality			
Water Quality			
Soil Quality			

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- Value chain development stage (initial, drive to maturity, maturity)

9) *Where do you think you have made the best improvements in the value chain?*

- Scientific base (e.g. sources of scientific/ technical support- Universities, technology providers, consultancies, in-house R&D department, etc.)

10) *Have you benefited from scientific or technical support for your plant operations?*

- Industrial base (is there industrial involvement; is the plant co-located with other refineries; etc.)

11) *Is your plant operating at full capacity? If not, why? When will the plant be able to run in full capacity?*
12) *Is your plant co-located or co-owned with other refineries? How does this benefit your overall supply chain?*

- Financial base (source and type of funds – private, public, loans, etc.)

13) *What determines the price of feedstock when you purchase it from farmers at the gate? How much are you willing to pay given the market outlook?*
14) *What was the amount of total investment (M€ and or k€/MW installed) and what cost categories does this include? How did you secure the financing?*

- Partnership: Describe the partnership and how it works**.** Is there an inter-regional dimension?

15) *Are you engaged in regional or inter-regional partnerships?*
16) *What actors are part of this partnership? Do they represent the whole value chain? What is the level of cooperation, trust or potential conflict among actors?*

- Future outlook for biofuels: how does your industry see the future of advanced biofuels?

17) *Do you see a demand rising for methanol and butanol in the transport sector? How about for other biofuels?*

- Impact of the project on the region

18) *What has been the impact of the project in the region, locality or urban area? What are the activities and results that can be attributed to the initiative, i.e. which would not have happened without it? Are there new (business) activities emerging from the project?*

- Policy support that helps or that is needed

19) *What kind of policy support do you benefit from or wish you had for lack thereof?*

- Performance Indicators

20) *Which of the following performance indicators apply to your case and how do they measure?*

Environmental

	Feedstock supply	Conversion	Distribution & end use

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.°764799.

Land footprint			
Energy footprint			
Water footprint			
Well-to-wheel system efficiency			
Life cycle greenhouse gas emissions			

Comments:

Economic

	Feedstock supply	Conversion	Distribution & end use
Energy crop production cost reduction (% reduction in costs €/t or €/GJ)			
Net added value (market price minus production costs) per tonne			
CAPEX needed to increase the TRL of selected technologies (M€)			
CAPEX and OPEX reduction due to opportunities for greening the fossil fuel infrastructure (%)			
Levelised life cycle costs			
Net added value			

Comments:

Socio- economic

	Feedstock supply	Conversion	Distribution & end use
Employment in agriculture (fte/t biomass; fte/ha)			
Employment footprint: Full direct job equivalents (fte/t of bio-based product across value chain; fte/PJ)			

Comments:

21) ***Key lessons/ learning points***

This section draws a set of key lessons and learning points from the analysis of the specific case that can serve as exemplars/ guidelines for the future plants.

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4.5. Questionnaire for policy

This questionnaire focuses on the third one and addresses environmental, economic and socio-economic aspects that characterise the development path of the good practices and RES fuel policies in a structured way.

1) ***What is the country/region of the practice?***

Discuss profile and key facts and figures of the region, the nature/ type of RES fuel policy, the key elements of policy mechanism and the good practice.

2) ***Why has government intervention been necessary?***
3) ***Which have been the key issues under consideration in the understudy region for RES fuel policy formation?***
4) ***What are the policy objectives and intended effects?***
5) ***What evidence has been used for developing the policy?***

Please describe datasets, modelling capacities, etc.

6) ***What mechanisms have been included in the policy?***
7) ***What are some of their limitations?***

The policy interventions are categorised in the groups as described in the table below:

Regulations		**Financial support**		**Information provision**	
Quotas		Grants/ feedstock premium		Best Practices/ Lessons learnt	
Product standards		Feed in Tariffs/ Feed in premium		Promotion	
Targets & qualifying criteria for incentives		Tax incentives		Capacity building	
Green procurement		User charges		Awareness raising	
		Research funds			

Please describe the selected ones

8) ***Is the policy well integrated within the national legislation across relevant sectors (e.g. agriculture, environment, energy, transport, etc.)?***

The following are considered as integration options:

- Integration of specific policy mechanisms in the biomass value chain components. The mechanisms have been selected, based on benchmarking previous policies and several consultations with national policy makers, so that they can work complementary to enhance resource efficient feedstock uptake and secure supply for efficient conversion technologies.
- Integration of various types of policy mechanisms by combining a set of regulatory, financial support and information provision policy mechanisms that are applied across value chains and sectors to ensure resource efficient uptake, successful market development and maintenance of existing capacities in the country of analysis.
- Integration of sectorial policy which reflects both the upstream and downstream policies required within specific value chains to ensure both resource and energy efficiency.

9) *Which of the following performance indicators are included to your policy and how?*

Environmental

	Feedstock supply	Conversion	Distribution & end use
Land footprint			
Energy footprint			
Water footprint			
Well-to-wheel system efficiency			
Life cycle greenhouse gas emissions			
Other (please add/ describe)			

Comments:

Economic

	Feedstock supply	Conversion	Distribution & end use
Energy crop production cost reduction (% reduction in costs €/t or €/GJ)			
Net added value (market price minus production costs) per tonne			
CAPEX needed to increase the TRL of selected technologies (M€)			
CAPEX and OPEX reduction due to opportunities for greening the fossil fuel infrastructure (%)			
Levelised life cycle costs			
Net added value			
Other (please add/ describe)			

Comments:

Socio- economic

	Feedstock supply	Conversion	Distribution & end use
Employment in agriculture (fte/t biomass; fte/ha)			
Employment footprint: Full direct job equivalents (fte/t of bio-based product across value chain; fte/PJ)			
Other (please add/ describe)			

Comments:

10) *Key lessons/ learning points*

This section will draw a set of key lessons and learning points from the analysis of the specific case that can serve as exemplars/ guidelines for the future policy formation.

4.6. Methodology for Modelling Analysis Using Systems Dynamics Software

The second version of this report (D5.2 v2 to be submitted August 2020, M19-M36) will use a combination of qualitative and quantitative data from the reported good practices and to integrate within a full value chain analysis with Vensim[114], which will allow the identification of i) practices that contribute the most to policy targets and market uptake and ii) indicators that best illustrate these good practices in each step of the value chain (feedstock production, conversion, end use) and can be further used in the future for effective policy formation.

The following methodology describes the main characteristics of biomass supply chains and preliminary work produced by reports from the ADVANCEFUEL consortium: these will permit the combination of results from feedstock sourcing (D2.2), management options (D2.3) and sustainability (D4.3), conversion pathways and feedstock suitability (D3.1), and end-product characteristics, as well as capital and operational expenditure averages across the value chain (D3.2). The model will perform a cost benefit analysis from this data through optimisation of selected performance indicators. The methodology then presents a brief literature review on decision-making capabilities, key performance indicators as optimal targets underpinning this decision-making, and optimisation of biomass supply chains and systems dynamics applications. The model shall be built upon both by value chain configurations presented throughout this literature as potential good practices, as well as by plant data information from chosen good practice cases in this report version. Finally, the methodology gives an overview of input data, which will come in part from quantitative input data, in part from qualitative/participation-based data from stakeholders who will have the opportunity to provide their input regarding their own value chain optimisation needs while contributing data from their plants to validate model results. There are preliminary overviews of the model structure and illustration.

I] Biomass Supply Chains

Technological Readiness Level

ADVANCEFUEL D2.1 report includes the feedstock categories studied in this report. Biofuels are defined as energy obtained through a process of biological carbon fixation in a short (maximum one year) period of time, are mainly second-generation, non-edible crops such as feed crop

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[114] Vensim is an industrial-strength simulation software built to improve the performance of real systems. Vensim's rich feature set emphasizes model quality, connections to data, flexible distribution, and advanced algorithms. https://vensim.com/vensim-software/

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residues, forest by-products, industrial wastes, considered as lignocellulosic crops[115]. They include biomass from landscape management, processing crop residues, grassy energy crops, oil crops, low-value woods, primary forest residues and woody energy crops, among others (see table 1 below). ADVANCEFUEL D2.1 has outlined the link between feedstock and technological readiness level, in other words the extent to which feedstock is suitable for a certain level of conversion technology[116]. The development of an industrial feedstock production and conversion plant for the production of renewable biofuels passes through three main stages. It is estimated to take between 3 to 5 years to progress one TRL level[117]. The considered development stages are: 1) **Initial stage and take off, or pilot stage plant,** 2) **Drive to maturity**: **demonstration/flagship stage plant** 3) **Maturity: commercial stage plant.**

Feedstock and Conversion Types

Feedstock Types for advanced biofuels		
Biogenic wastes	**Agriculture**	**Forestry**
Biomass from roadside	**Processing crop residues**	**Processing residues**
Organic waste from industry	**Harvesting crop residues**	**Low-value woods**
Biomass from landscape management	**Lignocellulosic fractions of agroforestry systems**	**Primary forest residues**
Biomass fraction of mixed municipal solid waste	**Grassy Energy crops**	**Industrial round wood and pulpwood**
Animal and mixed food waste	**Starch and sugar crops**	**Woody Energy Crops**
Organic waste from agriculture	**Oil crops**	

Table 1 Feedstock types in ADVANCEFUEL

ADVANCEFUEL D3.1 defines a range of biomass conversion technologies suitable for lignocellulosic feedstock conversion into advanced biofuels[118], while D.3.2 presents averages for capital and operational expenditures for different conversion pathways.

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[115] Zandi Atashbar, N., Labadie, N. & Prins, C. (2018) Modelling and optimisation of biomass supply chains: a review, *International Journal of Production Research*, 56 (10): 3482-3506

[116] Hoefnagels, R., Germer, S. & Panoutsou, C. (2018) Report on lignocellulosic feedstock availability, market status and suitability for RESfuels, *ADVANCEFUEL*

[117] Mawhood, R., Gazis, E., de Jong, S., Hoefnagels, R., & Slade, R. (2016) "Production Pathways for Renewable Jet Fuel: A Review of Commercialization Status and Future Prospects." Biofuels, Bioproducts and Biorefining 10 (4). doi:10.1002/bbb.1644.

[118] Papadokonstantakis, S. & Johnsson, F. (2018) Report on definition of parameters for defining biomass conversion technologies, *ADVANCEFUEL*

Value chains for the production of renewable fuels for road, maritime and aviation sectors sourced from lignocellulosic feedstock are characterised in the following way[119]: 1) upstream: cultivation, harvesting, collection (baling, loafing, chopping), transport, pre-processing operations (drying, pelletising, torrefaction, pyrolysis), storage, transport, 2) midstream: conversion for biofuel production in biorefinery and 3) downstream: transport/distribution to demand zones. Strategic decisions and practices with long-term implications include the selection of biomass cultivation sites, the locations and capacities of biorefineries, and the supply networks from biomass resources to refineries and from the latter to biofuel blending and distribution terminals, with decision variables such as numbers, types and capacities of storage and production facilities, production rates of biofuels, inventory levels at each facility, and transportation flows[120].

Biomass storage can be accessible from multiple points within a supply chain network or sited locally and next to a conversion plant. Different storage types can lead to reductions in biomass to energy supply chain costs. There are various types of biomass pre-treatment and depending on the supply chain and feedstock, they can lead to more efficient biomass in terms of handling and transportation cost, as well as conversion technology. Transportation logistics have a significant impact on total biomass supply cost, energy consumption and environmental emissions.

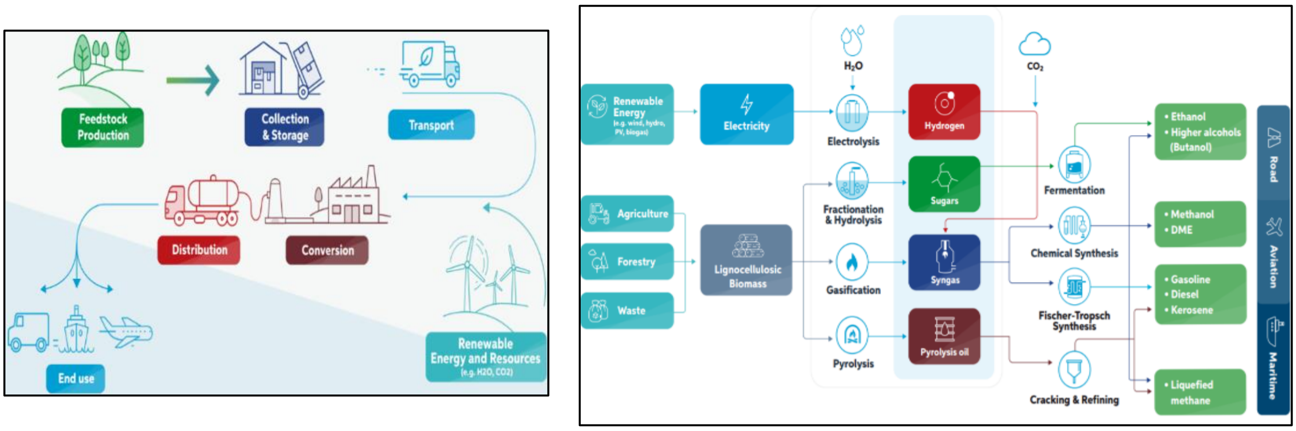

Figure 1 & 2 Advanced Biofuels Value Chain from Lignocellulosic feedstock with different sourcing, conversion and production options

II] Decision-Making Capacities

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[119] Zandi Atashbar, N., Labadie, N. & Prins, C. (2018) Modelling and optimisation of biomass supply chains: a review, *International Journal of Production Research*, 56 (10): 3482-3506

[120] Nguyen, D. H., Chen, H. & Wang, N. (2017) Modeling and optimization of biomass supply chain with two types of feedstock suppliers, *7th International Conference on Industrial Engineering and Systems Management*, Saarbrücken, Germany

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Stakeholders can enact decisions over their choice of conversion process, such as gasification or combustion for generating power, and associated technological equipment, such as updraft, downdraft or crossdraft gasifiers[121]. Decision-making affects long-term choices such as facilities' capacity and location, the optimal configuration of logistics networks and the establishment of long-term contracts with suppliers[122]. According to one optimisation model[123], the best supply chain configurations are implemented by domestically cultivating and selecting highly productive raw materials, coordinating transportation network on various decision-making levels, using efficient biomass to energy conversion technologies while reducing economic and environmental cost, choosing the right capacity and location for conversion facilities and storages, as well as the right design of distribution network.

Changes in biomass production capacity level and facilities can have an impact on transportation costs due to the possibility of intermediate densification and thus more efficient bulk density[124]. From an operational perspective, biomass composition can yield higher costs and degradation rate for long-distance transport because of its low energy density, thus, there is a potentially major tradeoff in biofuel supply chains between the costs of transportation and the capital and production costs of production facilities[125]. Additionally, intermodal versus remote transportation capabilities can influence transportation costs depending on where the plant is located since proximity to major transport hubs is a factor for cost optimisation. Proximity to natural gas grid is equally key for a supply chain either importing or exporting energy and resources, essential utilities such as natural gas, water or hydrogen. Plant co-location or integration within an existing infrastructure and supply chain for the added production of a co-product creates shared feed and handling infrastructure and can yield significant reductions in production cost and emissions.

Storage facilities for biomass resources can be cheaper as ambient storage leading to significant cost reduction however, this may accelerate biomass degradation in terms of heating value reduction due to a higher water content. In addition, pretreatment processes of raw biomass

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[121] Balaman, S. Y. (2018) *Decision-Making for Biomass-Based Production Chains: The Basic Concepts and Methodologies*, Academic Press, 165

[122] Nguyen, D. H., Chen, H. & Wang, N. (2017) Modeling and optimization of biomass supply chain with two types of feedstock suppliers, *7th International Conference on Industrial Engineering and Systems Management*, Saarbrücken, Germany

[123] Papapostolou, C., Kondili, E., Kaldellis, J.K. (2011) Development and implementation of an optimization model for bio-fuels supply chain, *Energy*, 36:6019-6026

[124] De Jong, S., Hoefnagels, R., Wetterlund, E., Pettersson, K., Faaij, A. & Junginger, M. (2017) Cost optimization of biofuel production – The impact of scale, integration, transport and supply chain configurations, *Applied Energy*, 195: 1055-1070

[125] Yue, D., You, F. & Snyder, S.W. (2013) Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges, *Computers and Chemical Engineering*, 66: 36-56

materials can be adopted in different practices. Thermal and chemical treatments can be applied to reduce moisture content, remove contaminants, and improve feedstock quality, stability, and processing performance[126].

III] Key Performance Indicators

Key performance indicators act as a measure for good practices and highlight the technical, environmental, economic and socio-economic functioning of the value chain. They represent quantitative and qualitative variables of a system and provide a base for assessing its performance based on acceptable standards of sustainability and achievements[127]. As factors of quality, safety and efficiency, indicators are a measure of good practices. Plant operators and policymakers can support innovation, resource use efficiency, ecosystem service nurturing, smooth business and market operations, and increased job opportunities and rural development impacts by optimising such indicators. All stages of the value chain, from land to primary biomass production, conversion and end-use are relevant as impact categories. Key performance indicators can link all these practices as well as form a bridge between European-level legislation and value chain components.

Key performance indicators are selected to be **specific** (with a widely-accepted definition), **measurable**, **achievable**, **relevant** and **time-specific**. A comprehensive list relevant for the advanced biofuels production features in the ADVANCEFUEL D1.2, the Biomass Futures project[128] and the Biomass Policies project[129]. In this report, one indicator per each of these categories has been chosen and integrated in the model as a proposed target to maximise: **life cycle greenhouse gas emissions** (in t CO2eq./MJ), **levelised life cycle costs** (in €/GJ or tonne of output), and **employment footprint** (in full direct job equivalents, fte/t of bio-based product across value chain; fte/PJ). These are important measures of success in many of the cited literature in this report as well as in key European legislation. Renewable biofuels as energy sources have been cited as contributors to reducing emissions, improving energy efficiency and creating employment[130]. Employment creation in low-carbon, renewable energy economies is a major factor[131].

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[126] Yue, D., You, F. & Snyder, S.W. (2013) Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges, *Computers and Chemical Engineering*, 66: 36-56

[127] Balaman, S. Y. (2018) *Decision-Making for Biomass-Based Production Chains: The Basic Concepts and Methodologies*, Academic Press, 91

[128] U. Fritsche et al. (2012). Sustainable bioenergy: key criteria and indicators. Deliverable D4.1 of the Biomass Futures project (IEE).

[129] www.biomasspolicies.eu

[130] European Commission. "Clean energy for all Europeans" – Winter package. Brussels; 2016

[131] UNEP. Green jobs: towards decent work in a sustainable, low-carbon world. United Nations Environment Programme and International Labour Organisation, 2011; 2008.

IV] Value Chain Optimisation

Many systems analysis tools and methods are available for biomass supply chain optimisation across different temporal and spatial scale, and accounting for several integers. At the whole supply chain level, modelling tools can play a key role in optimising the supply chain network structure and improving installation and operations. Decision makers can determine optimal design from choosing feedstock types, candidate suppliers, facility locations, technology options and transport modes[132]. In this model[133], a multi-period mixed integer programming model was used to account for the main changes in a biomass supply chain including feedstock supply, storage, transportation and conversion, results demonstrate the importance that transportation costs play in biomass supply chains, accounting for around 24% of total cost. Similarly, a geographically-explicit cost optimization model was used[134] to analyse five different types of scenarios: reduced maximum capacity (economies of scale), centralized system, distributed system, no integration, low biomass supply, high demand and road transport only. Key factors for optimising cost reduction include intermediate densification, intermodal transportation and co-location of facilities.

Another study[135] used mixed integer linear programming for supply chain optimization to investigate the full supply chain performance of a technology co-gasifying black liquor with pyrolysis liquids, modelling for four supply chain configurations with different economic conditions, accounting for trade-offs between biomass conversion efficiency, economic performance and CO_2 emissions. A sensitivity analysis accounting for significant changes to prices of energy carriers and to transportation costs was conducted and found the case of Black Liquor gasification with high conversion efficiency to be the most economically favourable compared to co-gasification cases with larger facilities. It was also the most favourable regarding total CO_2 mitigation potential, however with limited total methanol production potential. Difference in emission levels between cases depend largely on emissions related to transport within the supply chain. Availability of investment for replacing boilers has a large impact on supply chain methanol production cost: this is linked to the benefit of industrial integration.

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[132] Yue, D., You, F. & Snyder, S.W. (2013) Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges, *Computers and Chemical Engineering*¸ 66: 36-56

[133] Nguyen, D. H., Chen, H. & Wang, N. (2017) Modeling and optimization of biomass supply chain with two types of feedstock suppliers, *7th International Conference on Industrial Engineering and Systems Management*, Saarbrücken, Germany

[134] De Jong, S., Hoefnagels, R., Wetterlund, E., Pettersson, K., Faaij, A. & Junginger, M. (2017) Cost optimization of biofuel production – The impact of scale, integration, transport and supply chain configurations, *Applied Energy*, 195: 1055-1070

[135] Zetterholm, J., Pettersson, K., Leduc, S., Mesfun, S., Lundgren, J. & Wetterlund, E. (2018) Resource efficiency or economy of scale: Biorefinery supply chain configurations for co-gasification of black liquor and pyrolysis liquids, *Applied Energy*, 230: 912-924

This paper[136] provides a model capturing environmental impacts of large-scale, regional biofuel supply chains by estimating CO_2 emission due to transportation, biorefinery location and operations, as well as the social impacts of biofuels by estimating the number of jobs created along the value chain. Results combine findings of the relative cost of cellulosic ethanol production, unit emissions and number of new jobs created in the industry, thus providing insights for policymakers. In this work[137], a mixed-integer linear programming model is developed to find the optimal design and operations of cellulosic ethanol supply chains under economic, environmental and social criteria, to address the need for novel production, storage and transportation strategies for the physical and chemical properties of cellulosic biomass feedstocks and fuel ethanol while accounting for temporal and spatial integration of facilities.

V] Systems Dynamics Modelling

Systems dynamics is a tool used for building models of whole systems and their functionalities, and subsequently study interrelationships at play simultaneously and the impacts on the system when enacting different scenarios or configurations. As a systems dynamics tool, Vensim® creates integrated models for any given value chain while having the possibility to test for various scenarios, sensitivity analyses and optimisation runs. It utilises stocks that can be calculated with a time-based function, corresponding flows and their rates, converters linking stocks and flows, and visualises whether sources of parameters fall outside of the system boundary. Interrelationships among key elements are represented as arrows between stocks, flows and convertors.

In their model studying the sustainability extent of a forest residues to energy system based on the economy, environment and job market, Jin et al[138] predict simultaneous changes in CO_2 savings, cost savings and employment generating when modelling for the adoption of co-firing systems, the impact of carbon sequestration, residue recovery and bioenergy operations growth. One study developed a bioenergy technology sustainability model to identify the need for developing biodiesel production in the Eastern Cape Province of South Africa[139]. A sub-model for the cost of production of biodiesel was built and includes capital costs and operational costs such as feedstock, water, and energy. Another sub-model for the functional capacity of the biodiesel plant was developed.

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[136] Roni, M. S., Eksioglu, S. D., Cafferty, K. G. & Jacobson, J.J. (2017) A multi-objective, hub-and-spoke model to design and manage biofuel supply chains, Annals of Operations Research, 249 (1-2): 351-380

[137] You, F., Tao, L., Graziano, D. J. & Snyder, S. W. (2012) Optimal design of sustainable cellulosic biofuel supply chains: Multiobjective optimization coupled with life cycle assessment and input–output analysis, *AIChE Journal*, 58 (4): 1157-1180

[138] Jin, E. & Sutherland, J. W. (2018) An integrated sustainability model for a bioenergy system: Forest residues for electricity generation, *Biomass and Bioenergy*, 119: 10-21

[139] Musango, J.K., Brent, A.C., Amigun, B., Pretorius, L. & Muller, H. (2011) Technology sustainability assessment of biodiesel development in South Africa: A system dynamics approach, *Energy*, 36 (12): 6922 - 6940

In Deliverable D5.6, Vensim® shall be used to optimise for several performance indicators at the same time and conclude which practices or value chain configurations represent good ones.

VI] Input and Baseline Data

Energy content averages of fuels and biofuels, typical and default values of greenhouse gas savings from certain production pathways as well as per stage of production, and detailed calculation of greenhouse gas emissions for the entire biofuel production process will be provided by the Recast of the Renewable Energy Sources (RES) Directive of the European Parliament and of the Council[140].

Inputs will also be taken from the EU guidelines for the calculation of land carbon stocks[141], with equations and data useful for determining land use change and carbon sequestration in a biofuel supply chain.

Direct job creation from a certain amount of MW will be estimated using employment data taken from the combination of Eurostat Labour Force Survey[142], Structural Business Statistics[143] and Agri-environmental indicators[144].

VII] Vensim® Model

In the next version of this deliverable, systems modelling software will be used to analyse changes and different configurations in a RESfuels value chain and identify which contribute to maximizing three chosen indicators: levelized supply chain costs, greenhouse gas emissions, and employment footprint. The aim will thus be to compare different value chains and their configurations and how they impact these indicators, as well as identify where policy mechanisms can have the most impact in the value chain.

A model will be built using Vensim® Pro to minimise the production costs and greenhouse gas emissions, and optimise employment, while taking into account different configurations along

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[140] COM/2016/0767 final/2 - 2016/0382 (COD)

[141] Commission Decision 2010/335/EU of 10 June 2010 for the purpose of Annex V of the Directive 2009/28/EC (OJ L 151, 17.6.2010, p. 19)

[142] http://ec.europa.eu/eurostat/web/lfs/data/database

[143] http://ec.europa.eu/eurostat/web/structural-business-statistics/data/database

[144] https://ec.europa.eu/eurostat/web/agriculture/agri-environmental-indicators

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the whole value chain. The model will follow a generic biomass supply chain production structure taken from literature outlining basic concepts in this topic[145] in a stock and flow format: with stocks, rates, variables as convertors and arrows. In the preliminary model shown below and built for the purposes of this deliverable, stocks are represented as boxes and are calculated by rates (flows) which are time-based functions and represented as pipes with arrows and valves. Cloud symbols are sources of flows and stocks which lie outside of the model scope. Variables are additional factors or convertors which link or relate to stocks and flows. Finally, arrows are the interrelationships among elements of the model.

The main model features stocks of biomass/biofuel with flows either increasing or decreasing these quantities, as dependent on the supply chain stage pathway and transportation nodes. Biomass growth and biofuel growth rates are influenced by functional capacity levels of biomass production and conversion. The model will aim to optimise key performance indicators as the main outputs, namely greenhouse gas emissions reduction, cost optimisation and job employment whose performance varies depending on key variable interrelationships from different possible value chain configurations. Some external factors such as policy-led support and investment as well as exogenous market forces determining a lower or higher market price value of biofuel are included in the model. Inputs to the model such as production and conversion capacity, conversion rates, energy contents, equivalences and sequestration rates will be provided by plant data, policy guidelines and from literature review sources. The main model will be supplemented by sub-models which will detail the supply chain respective to the optimisation of one indicator. Below are featured Figure 3 and Figure 4 which give an initial illustration of the main model and sub-models.

Model value chain configurations will be chosen from a literature review of biomass supply chains, decision-making capabilities, and supply chain optimisation, as well as qualitative data from stakeholder consultations. Structural validity of the model will be proven by comparing the model’s consistency with knowledge of the real system relevant to the purpose[146] in this case advanced biofuels development. The model will use both case specific data, and will translate optimisation scenarios and configurations from the literature into systems dynamics as well as mathematical relationships outlined in European Commission guidelines for calculating emissions, cost and jobs. Finally, tests will be carried out to ensure the model conforms to basic physical conservation laws.

Each separate sub-model, greenhouse gas emissions reductions, cost optimisation and employment generation, will mirror the same basic value chain configuration as well as illustrate pathways which contribute solely to those indicators. The sub-models will generate value outputs of these performance indicators along the full supply chain, which can be inserted into the main

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[145] Balaman, S. Y. (2018) *Decision-Making for Biomass-Based Production Chains: The Basic Concepts and Methodologies*, Academic Press, 56

[146] Musango, J.K., Brent, A.C., Amigun, B., Pretorius, L. & Muller, H. (2011) Technology sustainability assessment of biodiesel development in South Africa: A system dynamics approach, *Energy*, 36 (12): 6922 - 6940

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model as the same outputs. The main model will however feature all pathways which *simultaneously* affect all three indicators, on top of the sub-model independent pathways.

Below are two snapshots of preliminary models showing first a full value chain model and optimisation pathways for all three indicators, and a second sub-model showing the full value chain and optimisation pathway for greenhouse gas reduction.

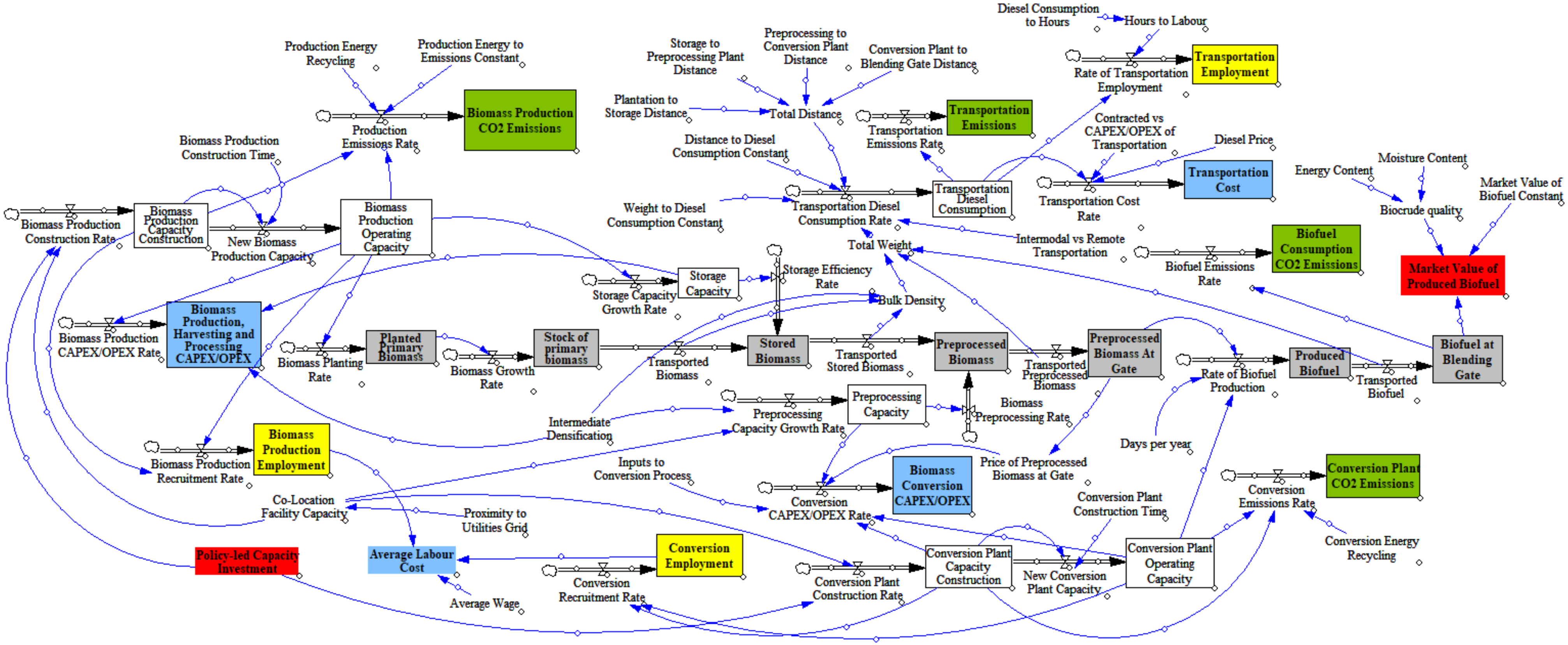

Figure 3 Main model value chain system with three indicator optimisation (grey boxes represent biomass to biofuel supply chain stock and flow, coloured boxes represent indicator outputs (green = emissions, blue = cost, yellow = jobs) as well as exogenous inputs (red))

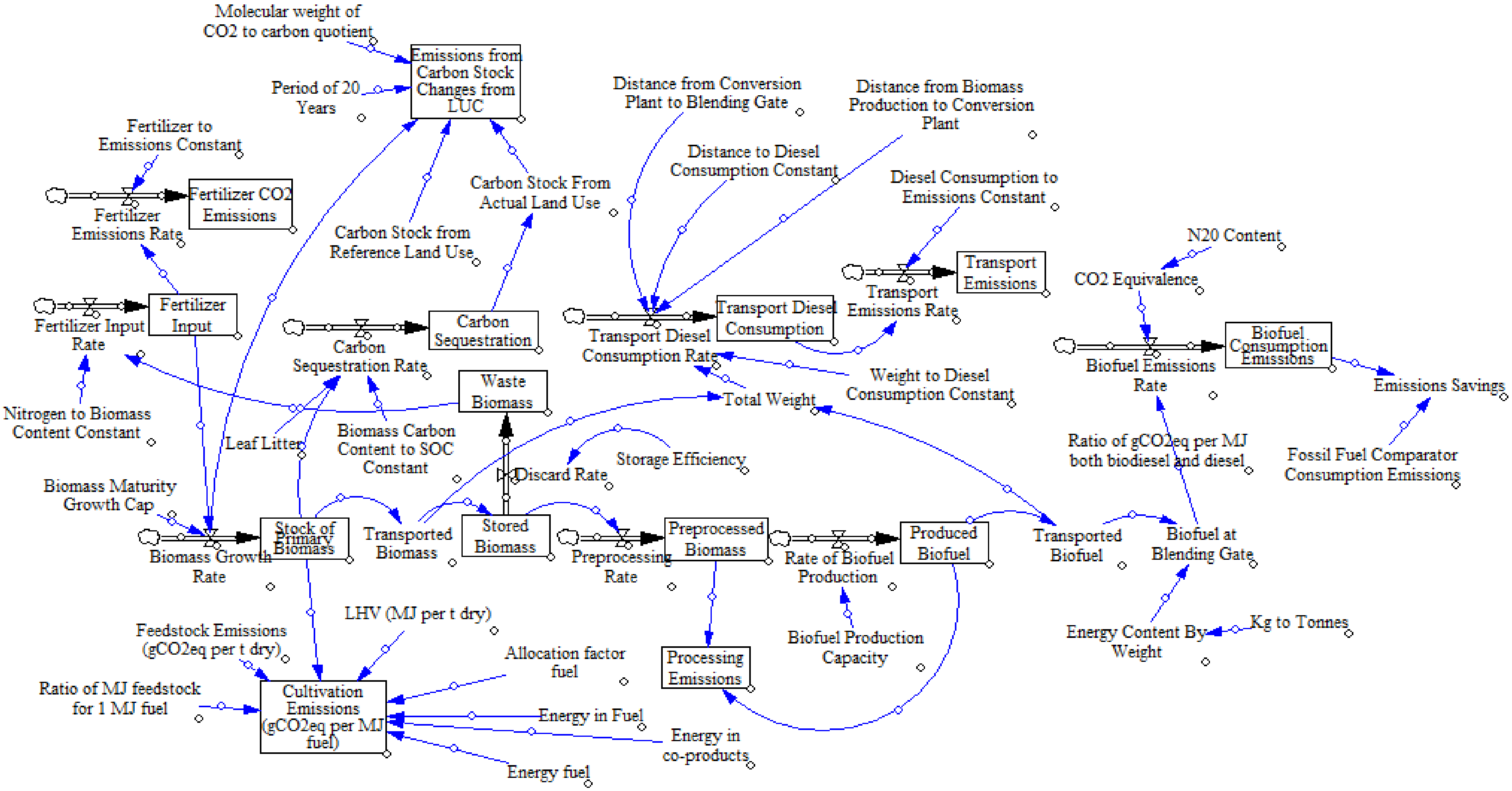

Figure 4 Sub-model value chain system for greenhouse gas emissions optimisation