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MUSIC

Market Uptake Support for Intermediate Bioenergy Carriers

Regional Bioenergy Settings in the Case study regions
WP5: Case Studies on Supply Chain Logistics

Deliverable 5.1

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EXECUTIVE SUMMARY

MUSIC aims to improve logistics and trade of biomass and intermediate bioenergy carriers (IBCs), specifically pyrolysis oil, torrefied biomass and microbial oil. In MUSIC, four case studies (CS) will be developed. These involve preparation of business and market development plans for four case study regions (Sweden/Finland, Italy, Greece, and International).

In the Sweden/Finland case studies, the aim is to investigate the logistics and feasibility of a long-distance value chain starting with pyrolysis oil production at various sites in Sweden and Finland and ending with pyrolysis oil upgrading to advanced marine biofuels at a site in the Netherlands. Both Sweden and Finland have large quantities of wood biomass available in the form of sawmill residues and fresh forest residues, which would be enough for an estimated 40 pyrolysis oil plants.

Logistic challenges include transport to ports in Sweden and Finland, followed by transport per ship to the Netherlands, where the pyrolysis oil can be upgraded to marine biofuels. Two case studies will be developed. An advanced case study which represents the minimum amount of pyrolysis oil needed for the upgrading plant will be investigated. A strategic case study with quantities of ca. 2 to 3 times as much will also be investigated.

In the Italy case studies, the advanced case study involves investigating a value chain concerning the production of charcoal/pyrogas of regional biomass for use in the Arcelor Mittal steel mill in Taranto (Puglia, South of Italy). The approach is to develop a network of biomass suppliers to several carbonisation units of ca. 35,000 tonne/year capacity. After carbonisation, transport to the steel mill is foreseen. Feedstocks to be considered include agricultural residue, olive pruning, olive oil production residues and potentially wood derived from infected olive trees.

The strategic case study will research the logistics and feasibility of a microbial oil (MO) value chain for large scale use at the ENI existing biorefineries in Porto Marghera (Veneto) and Gela (Sicily). Lignocellulosic residues are to be converted to sugars using the PROESA™ technology. This conversion step has been demonstrated already in the ENI cellulose ethanol plant in Cresentino (Italy). The sugars can subsequently converted to lipids by oleaginous yeasts. These lipids can then be used to as feedstock in the existing biorefineries of ENI. The microbial oil production step has not been demonstrated yet.

In the Greek case studies the logistics and feasibility of a torrefied biomass value chain supplying the DETEPA plant will be investigated in the framework of the advanced case study. In the strategic case study large-scale implementation at multiple regional (district) heating plants and relevant (cement, quick lime or magnesite) industries in the region will be investigated.

The focus of the advanced case study is a 30 MWth district heating pant (the Amyntaion district heating plant of DETEPA) that is being implemented at this moment. DETEPA plans to replace the lignite coal gradually by biomass. Torrefied biomass would minimise additional plant investment and facilitate logistics and storage. Part of the investigation could be a test with imported torrefied material. Biomass will be i.a. agricultural residues. A big challenge in these case studies will be to mobilise the biomass against acceptable costs.

In the International case study, torrefied material is to be used in the steel making mill of ArcelorMittal (AM) in Gent (Belgium). The advanced case study will assess a value chain broadening the range of biomass feed-stocks to be torrefied at the Ghent facility. Among others hybrid feedstocks including Solid Recovered Fuel (SRF), Refuse-Derived Fuel (RDF) and end-of-life plastics mingled with on-spec waste wood will be evaluated.

The strategic case study will investigate the logistics and feasibility of torrefied biomass made from various feedstocks for use at a range of AM steel mills including e.g. facilities in Belgium, North/South France, North Spain, North Germany, Poland & Italy.

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Abbreviations

AM(G)	ArcelorMittal (Ghent)
BTG	BTG Biomass Technology Group BV
BTG-BTL	BTG BioLiquids BV
CHP	Combined Heat and Power
CPM	Copenhagen Malmö Port
CS	Case Studies
DETEPA	District heating company of Amyntaion (NW Macedonia, Greece)
DM	Dry matter
FAME	Fatty Acid Methyl Esters
GFN	Green Fuel Nordic
GHG	Green House Gas
HBE	Bernieuwbare BrandstofEenheden (Renewable Energy Units)
HVO	Hydrotreated Vegetable Oil
IBC	Intermediate Bioenergy Carriers
MO	Microbial Oil
PO	Pyrolysis Oil
NFI	National Forest Inventory
OQDS	Olive Quick Decline Syndrome
PCI	Powdered coal injection
PFAD	Palm Oil Fatty Acid Distillate
RED II	Renewable Energy Directive
RDF	Refuse-Derived Fuel
SEK	Swedish Crown (conversion rate March 2020: 0,095 Euro/SEK)
SRF	Solid Recovered Fuel
TB	Torrefied Biomass
TEU	Twenty-foot Equivalent Units
VIGOR	Vegetable oil Initiative for Green Oil Refinery

1 Background and introduction

The MUSIC project

Intermediate bioenergy carriers (IBCs) are biomass that is processed to energetically denser materials, analogous to oil, coal and gaseous fossil energy carriers. This means they are easier to transport, store and use.

The MUSIC project will support market uptake of three types of Intermediate Bioenergy Carriers (IBCs) by developing feedstock mobilisation strategies, improved cost-effective logistics and trade centres. IBCs covered in MUSIC include pyrolysis oil, torrefied biomass and microbial oil.

IBCs are formed when biomass is processed to energetically denser, storable and transportable intermediary products analogous to coal, oil and gaseous fossil energy carriers. They can be used directly for heat or power generation or further refined to final bioenergy or bio-based products. IBCs contribute to energy security, reduce greenhouse gas emissions and provide a sustainable alternative to fossil fuels in Europe.

Industry-led case studies on supply chain logistics

WP5 covers industry-led case studies (CS) on supply chain logistics in four case study regions (Sweden/Finland, Italy, Greece and International) where intermediate bioenergy carriers are not yet (fully) introduced and where the objective is to introduce their large scale production.

In each case study region both a concrete advanced case study and a more strategic case study for the market up-take of intermediate bioenergy carriers will be developed. Advanced and strategic case studies will take a holistic look and broad view at cost-effective logistics, feedstock mobilisation strategies and trade-centres) at the broadest sense.

<u>Scope of the current document</u>

This document presents the regional bioenergy settings for the four MUSIC case study regions. This includes a description and assessment of:

- The case study (advanced CS in more detail, strategic CS in broader terms only)
- Regional biomass availability
- National framework conditions, relevant support schemes
- Physical infrastructure: presence of road/rail/waterways; biomass terminals etc.

A chapter is dedicated to each of the four regions.

The purpose of this document is:

- To learn and provide base data for MUSIC case study partners in the development of the advanced and strategic case studies;
- To provide information to all other stakeholders about local conditions, opportunities and framework conditions related to wider implementation of IBC.

This document does not intend to give a complete overview of the bioenergy settings in the region. The focus is on information that will enable/stimulate the case studies and the wider implementation of the relevant IBC. For more detailed description and discussion of selected topics the reader is advised to also check other public MUSIC Deliverables. For example, national framework conditions in the case study countries will be covered in substantially more detail in MUSIC D2.3 "*EU and national regulatory framework: present and future developments*", scheduled for release in autumn 2020.

2 Bioenergy Setting Sweden/Finland

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In recent years the first plants producing pyrolysis oil (PO) on commercial scale have started operation. PO market development currently concentrates on Sweden and Finland. Due to the changing structure of the industry the Nordic forest industry generates increasing amounts of unused sawdust and other residues. This underutilised biomass is excellent feedstock for PO production.

In the advanced case study, the logistics and feasibility of a long-distance value chain starting with PO production at various sites in Sweden and Finland and ending with PO upgrading to advanced marine biofuels at a site in the Netherlands will be assessed in detail.

In the strategic case study, an expansion strategy comprising additional PO production at multiple sites in Sweden and Finland, and PO upgrading at one or more sites in the Netherlands or a neighbouring country will be researched.

2.1 Case study description Sweden/Finland

Pyrolysis oil production

Pyrolysis is a conversion technique where biomass is heated rapidly to a high temperature in an oxygen free environment. The high temperature evaporates the biomass in long carbon chains. These gasses are then cooled to obtain a liquid oil. Approximately 60 to 70% of the energy content of the biomass ends up in the oil. The remainder is mainly converted to steam. The Intermediary Bioenergy Carrier Pyrolysis Oil (PO) can be used for energy production or could be further upgraded to a range of higher value products.

Figure 1: Pyrolysis oil

MUSIC partner BTG has successfully implemented a pyrolysis oil production plant in Hengelo, the Netherlands in 2015. This plant can produce 24,000 tonne of pyrolysis oil from wood residues annually. The amount of biomass input needed for that amount of pyrolysis oil is 37,500 tonne (dm[1])/year, or 75,000 tonne/year at a moisture content of 50%.

[1] 'dm' stands for dry matter and means an amount of biomass as if it had zero moisture content.

In 2019, the sister company of BTG – MUSIC partner BTG-BTL – signed contracts to implement a pyrolysis plant in Finland (in cooperation with MUSIC partner GFN) and another one in Sweden (with the company Pyrocell). Both plants will have a similar capacity as the one in Hengelo.

Pyrolysis oil application
Current application of the PO produced in the Hengelo plant is the co-firing with natural gas to produce industrial heat at the FrieslandCampina dairy plant in nearby Borculo. Several more advanced (energy and material) applications are under development. These include:

- Co-feeding into fossil refineries to produce drop-in advanced transport fuels
- Upgrading in a dedicated facility to produce drop-in advanced marine transport fuels
- Fractionation to produce high value bio-based products, such as wood modification chemicals, resins, etc.

In November 2019 biomass conversion technology developer BTG and sustainable marine fuel pioneer GoodFuels publicly announced their intention to collaborate on the first refinery in the world converting crude pyrolysis oil into diesel fuel suitable for the shipping sector. For this reason, the second application above – upgrading PO to produce drop-in advanced marine transport fuels – was selected to be the focus of the Nordic case study.

Scope of the case study
Both the advanced and the strategic case study will focus on the production of pyrolysis oil in several plants in Sweden and Finland, followed by sea transport to the Netherlands, where it will be upgraded to a drop-in advanced marine biofuel. The advanced case study will focus on the minimum capacity that is required to operate the upgrading plant economically. This capacity is foreseen to be equivalent to the output of thee pyrolysis plants of the size implemented in Hengelo. For the strategic case study, a substantially (indicatively: 2-3 times) larger capacity will be considered.

Pyrolysis oil will be produced at multiple locations in Sweden and Finland and transported to one or several ports in the Gulf of Bothnia (northern part of the Baltic sea). The exact locations for the pyrolysis plants in Sweden and Finland are not yet known. There it will be put on a ship and transported to a port in the Netherlands. An alternative transport option is to bring Swedish pyrolysis oil to Gothenburg (located on the Kattegat, the shallow sea between Sweden and Denmark), and further transport the pyrolysis oil from there.

Case study team
Case study partners are all members of the MUSIC consortium. They are:

- BioFuel Region (Case Study Lead) - a Swedish non-for- profit member organisation. Members are municipalities and companies in Sweden's four northernmost counties. A goal of the organisation is to stimulate business related to renewable biofuels. Access to feedstock – wood residues – is essential for implementing more pyrolysis plants.

- GoodFuels is a supplier and developer of advanced and sustainable biofuels for heavy road-based applications and water-borne applications. Goodfuels has an interest into access to their own renewable advanced drop-in marine biofuels.
- BTG is an SME with as focus biomass for energy and materials. Having successfully commercialised biomass pyrolysis technology, it now seeks to develop technology to produce drop-in advanced marine transport fuels from pyrolysis oil.
- BTG-BTL's mission is to realise commercial pyrolysis oil production plants (in cooperation with TechnipFMC).
- Green Fuel Nordic is a Finnish biorefining company. Its business concept is based on utilizing commercially proven, innovative pyrolysis technology to produce renewable fuel.

2.2 Biomass availability

Types of biomass needed for pyrolysis

Pyrolysis can be carried out in the laboratory with about any type of biomass, but for the commercial plants implemented by BTG-BTL woody biomass is best suited. Since fast pyrolysis technology involves rapid heating; dry and small particles are required. When they are entering the pyrolysis plant, biomass particles need to adhere to the following conditions:

Table 1: Biomass specifications for pyrolysis[2]

Parameter	value	unit
Size	3 mm length. Width and height are not limited	mm
Moisture content	< 6 - 8%	-

From the table above its clear that the pyrolysis plant requires relatively small particles (regular wood chips are too big and need to be made smaller).

This table does not mean that woody biomass that does not meet these specs is unsuitable per se; off-spec feedstock can be sized and dried at additional costs, which may be justifiable based on low feedstock prices.

[2] https://www.btg-btl.com/en/technology

2.2.1 Biomass availability in Sweden

Fresh biomass

The total standing volume of Swedish forests is currently around 3,200 million m^3, with annual growth of about 120 million m^3. In 2012 the annual gross felling volume amounted to 84.8 million m^3s (solid) and the net felling volume to 68.9 million m^3 sub (excluding bark), of which sawlogs, pulpwood, fuelwood and other roundwood accounted for 32.0, 30.5, 5.9 and 0.5 million m^3 sub, respectively (Swedish Forest Agency 2013). In Sweden it has been estimated that the total energy content of annually produced logging residues, stumps and small-diameter thinning wood amounts to more than 100 TWh, of which approx. 40 TWh could potentially be extracted under present ecological, economic and technical restrictions. The current use of primary forest fuels (obtained directly from the forest) amounts to approx. 15-20 TWh. Forest-based fuels (including streams directly from the forest and industrial residues) contributed 132 TWh to the energy used in Sweden in 2012, 32% of the total (Swedish Energy Agency 2014).

A potential of 40 TWh/year and a current use of 15-20 TWh/year means that around 22,5 TWh/year of fresh biomass is potentially available for other applications such as pyrolysis. 22,5 TWh means (8 GJ/tonne and 50% moisture content assumed) 5 million tonne dm/year.

Forestry as co-production system

Forestry is a co-production system, i.e. several products are produced simultaneously, such as saw logs, pulpwood and logging residues (See Figure 2). Therefore, the potential amounts of the different assortments are not independent. Calculating production costs for one product in a co-production system is not straightforward. Generally, there is no unambiguous way to allocate costs between the different products in an operation. For example, costs of harvesting a tree and cutting it into pulpwood and saw logs cannot be easily split into costs of producing pulpwood and saw logs, although saw logs are the most valuable assortment in terms of revenues for the land owner. The supply of forest feedstock depends on numerous factors. In the short term, the quantity of feedstock supplied to the market depends on decisions of individual forest owners whether to perform harvesting operations or not. The existing forest stock also constrains amounts that can be supplied in the short term. Furthermore, forestry is regulated by legislation intended to secure the productivity of the forest land and environmental values with specific restrictions. In the longer term, factors influencing forest growth are important. In addition to domestic wood, imported wood can also contribute to amounts available on the market. Forest owners' decision-making is influenced by several factors, including market prices of forest products, their current financial circumstances and the strength of their desire to pass on a well-managed forest estate to the next generation. The main market driver for the forest owners desicion when to deliver to market is the timber prices. The price for wood energy Is no factor of importance (yet).

Forest Industy by-products

Sawn timber products and pulp and paper products have dominated the use over a long time but the use of forest biomass for energy purposes has grown rapidly over the past decades. Soon, the use of forest biomass in biorefineries is expected to increase rapidly. As a result of the existing forest industry production large amounts of industry by-products are produced. Although a potential energy source, these by-products are commonly left in the field due to their high transport costs. Conversion into denser intermediate bioenergy carriers (IBC) could change that, if IBC production plants are located close to the supply. Some regions have a surplus of forest industry products while regions hosting big combined heat and power plants (CHPs) sometimes experience a shortage, especially during cold winters. Market price will for this reason vary both regionally and seasonally.

An average price for sawmill by-products (sawdust and bark) during the past 10 years delivered to industry gate can be estimated to 200 SEK/MWh (effective heating value as received). 200 SEK/MWh means (at a conversion rate of 0,095 Euro/SEK) 19 Euro/MWh, or 5,3 Euro/GJ. This means prices of around 45 Euro per fresh tonne (50% moisture, so about 9,5 GJ/fresh tonne).

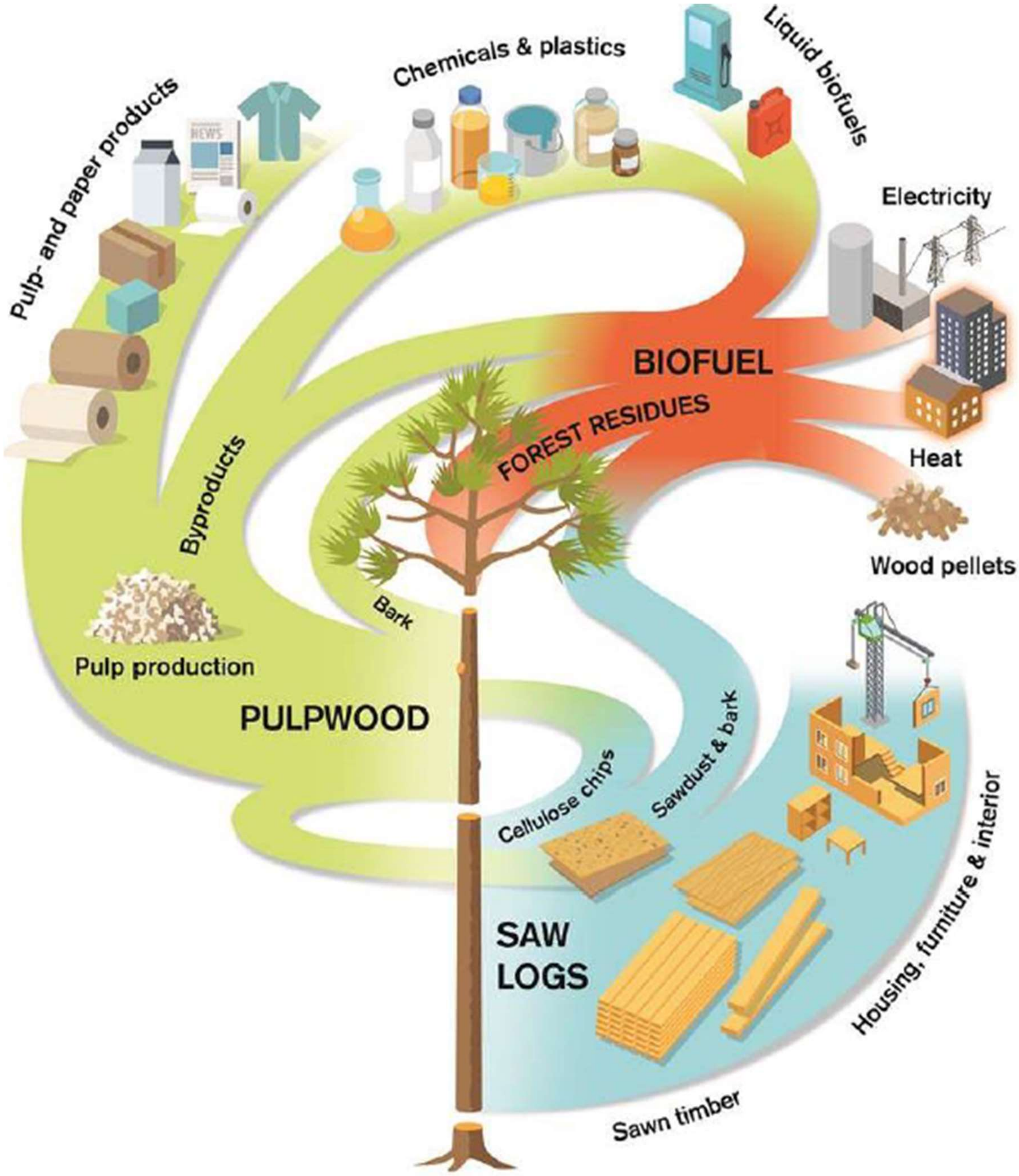

Figure 2: Illustration on how different parts of the tree are used by different industry segments (source: Sveaskog Sweden)

Sawmills

About half of the annually harvested roundwood (which stands at 37 million m^3 sub timber) in Sweden is fed into 104 bigger sawmills all over Sweden (Figure 3). About half of the logs being fed into a sawmill ends up as sawn goods. The rest of the log ends up us sawmill by-products. Some of the by-products can be used internally by the sawmills, mainly for drying of the sawn goods. Every cubic meter of wood being feed into a sawmill will result in:

- Sawdust - 20% of the wood - Today often used for pellet production and combustion
- Woodchips - 20% of the wood - Today often used by the pulp and paper industry
- Bark – 10% of the wood – Today often used for combustion to produce energy

Figure 3: Location of the bigger sawmills in Sweden

Of these sawmill residues, sawdust and wood chips are expected to be suitable for pyrolysis, whereas bark is likely not a priori suitable for pyrolysis due to a higher ash content. Based on the figures above, 3.7 million m^3 of sawdust is produced annually. Assuming a density of 400 kg/m^3 and a moisture content of 20% this means that 1.2 million tonne dm/year of sawdust is available.

Pulp and paper mills

About half of the annually harvested roundwood has dimensions considered too small for sawmills. This so-called pulpwood is used by the pulp and paper mills. In combination with imported pulpwood and sawmill by-products (woodchips), this wood was used to produce 11.9 million tonnes of pulp and 10.1 million tonnes of paper in 2016 (Facts and Figures, Swedish Forest Industries).

Besides this wood and paper, many other wood by-products are produced such as bark, black liquor, and tall oil. Most by-products are used to generate energy for internal use at the pulp mills, or to produce liquid (transport) biofuels. Therefore, it is not expected that the pulp and paper mills will be a source for pyrolysis feedstocks.

Estimation of biomass potential in Sweden for pyrolysis

The woody biomass that is available for pyrolysis in Sweden will come from either fresh woody residues or from sawdust as by-product of the sawmill industry. If we take the quantities identified earlier and assume that 10% of the fresh residues and 20% of the sawdust residues are available (own estimation) we can determine the amount to pyrolysis oil plants that can be implemented in Sweden. Assuming that a pyrolysis plant needs 37,500 tonne of dry matter annually, Table 2 shows the results:

Table 2: Estimation of the amount of pyrolysis plants that can be built in Sweden based on woody biomass residue availability

	Residues available (tonne dm/year)	**used for pyrolysis (%)**	**Potential amount of pyrolysis plants (-)**
fresh forest residues	5,062,500	10%	14
sawmill residues	1,184,000	20%	6

This is more than enough for the MUSIC advanced and strategic case studies, while leaving extra capacity open for wider market uptake.

Impact assessment

If we assume this potential amount of pyrolysis plants in Sweden, and furthermore that all pyrolyis oil from these plants is used to produce transport fuels, this can have the impact as given in Table 3.

Table 3: Estimated impact of renewable transport fuels produced from pyrolysis oil in Sweden

	Automobiles	**Trucks**	**Airbus 330**	**Ship**
Yearly transport fuel consumption in liters	1,250	25,000	28,350,000	65.625.000

Amount that can run:				
- with 3.5% advanced biofuels from pyrolysis	3,829,000	191,400	169	73
- with 10% advanced biofuels from pyrolysis	1,340,000	67,000	59	26
- with 15% advanced biofuels from pyrolysis	893,000	44,700	39	17

In this table the typical fuel consumption per year of a typical car, truck, plane or ship is shown. A typical ship is in this case a 4000 TEU[3] container ship (length approx. 300 meter). When taking into account that a typical PO plant produces 20 million liters of pyrolysis oil per year, and that it can be converted into about 8,5 million litres of transport fuels (in case of co-feeding), the impact can be determined. Using these values, the total amount of vehicles/planes that can be fuelled from the number of plants listed in Table 2 is shown for three scenario's: 3.5% advanced biofuels – this is the RED II[4] quotum for advanced biofuels in 2030 - , 10% advanced biofuels and 15% advanced biofuels. It should be noted that either the automobiles, the trucks, the planes or the ships can be fuelled this way, not all at the same time.

Advanced biofuels can be produced from pyrolysis oil by e.g. co-feeding in refineries. Transport fuels thus produced qualify as Advanced Biofuels according to the EU RED II regulation, Annex 9. This means also that these advanced biofuels can be double counted, which would mean for example if the 3.5% scenario is used, twice as many automobiles, trucks, planes or ships could be covered. Another advantage of these advanced transport fuels is that quota can be traded between countries, since the RED II quota are EU quota, and not national ones.

2.2.2 Biomass availability in Finland

Finland is one of the most forested countries in Europe. Three quarters of Finland (about 23 million hectares) is forest, representing about 10% of the forest area in Europe.

The growing stock in Finland has steadily increased over the last 50 years, being now 2,464 million cubic meters (annual increment 110 million cubic meters). Finland forests have been regularly monitored by the National Forest Inventory (NFI) since beginning of the 1920's. The volume of growing stock has increased by more than 60% since the early 1970's. The most common tree species are Scots pine (50% of growing stock), Norway spruce (30%) and birches (17%) (see Figure 4).

[3] Container ship capacity is measured in twenty-foot equivalent units (TEU)
[4] https://www.europex.org/eu-legislation/renewable-energy-energy-directive/

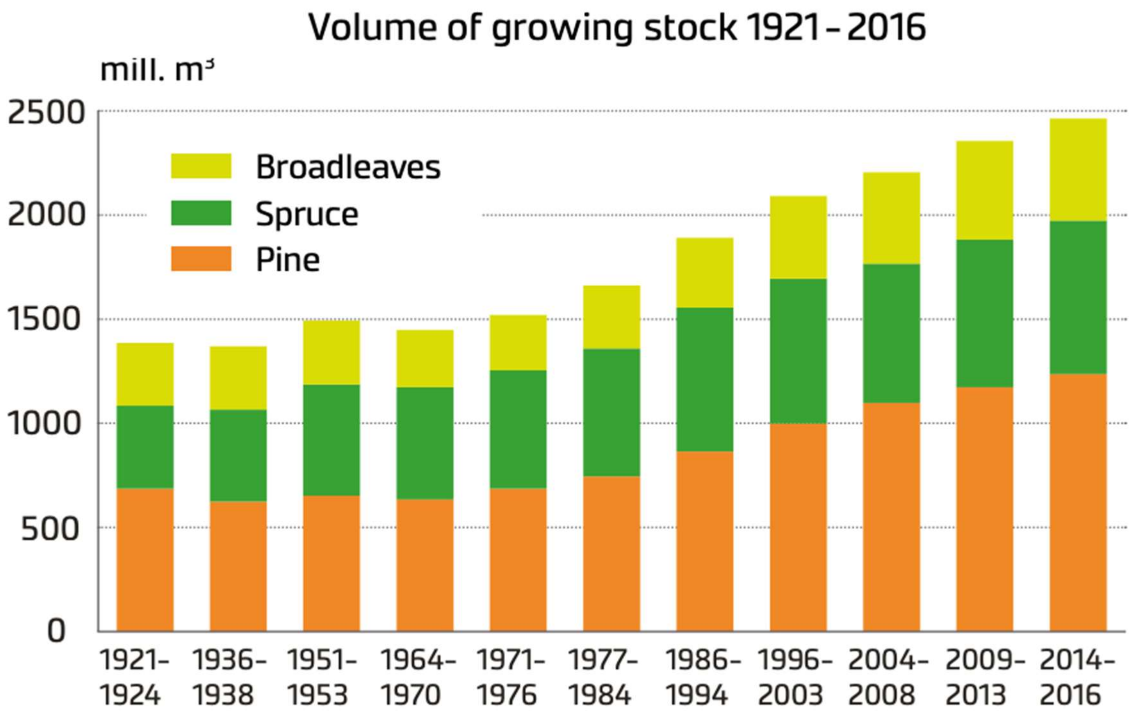

Figure 4: Volume of growing stock in Finnish forests

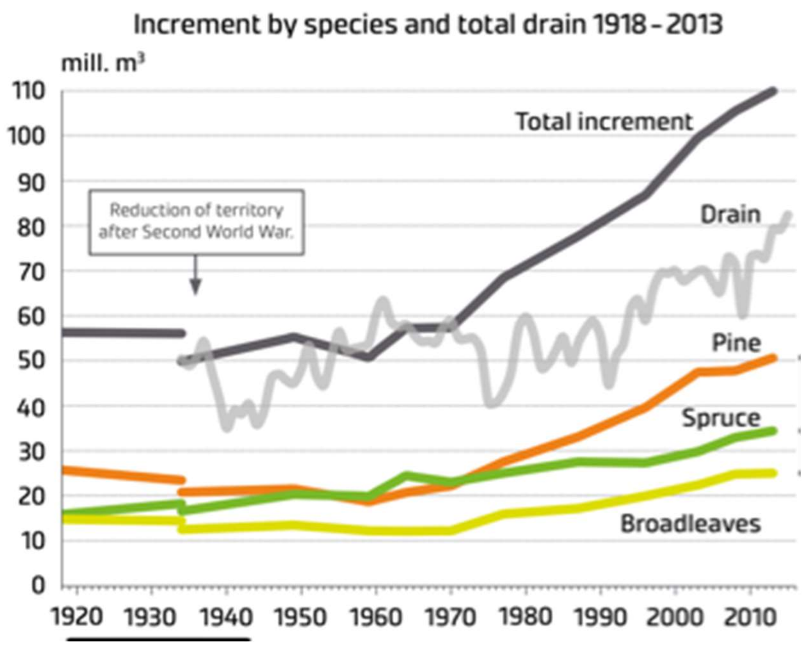

Figure 5: Evolution of increment by species in Finland in the last hundred years

Since the beginning of the 1970's each year the increments have been higher than the total drain (fellings and natural mortality). In recent years, the annual fellings have been on average 68 million cubic meter per year (62% of the increment) and the annual net carbon sink of forests has been about 38 million CO_2 equivalent tonnes. The sustainable felling potential of the Finnish forests would be 85 million cubic meters of stem wood per year for the years 2015-2024. The annual increment of the growing stock is 110 million cubic meters. The investments in forest management, started in the 1930's, are now producing increasing possibilities to use forest resources in a sustainable way.

The need for wood-based energy calculated in Finland Energy and Climate Strategy would be met with removals determined by the industry's demand in 2030 at the level of 79 million m3/year. This corresponds to the target of 80 million m^3 set in the National Forest Strategy.

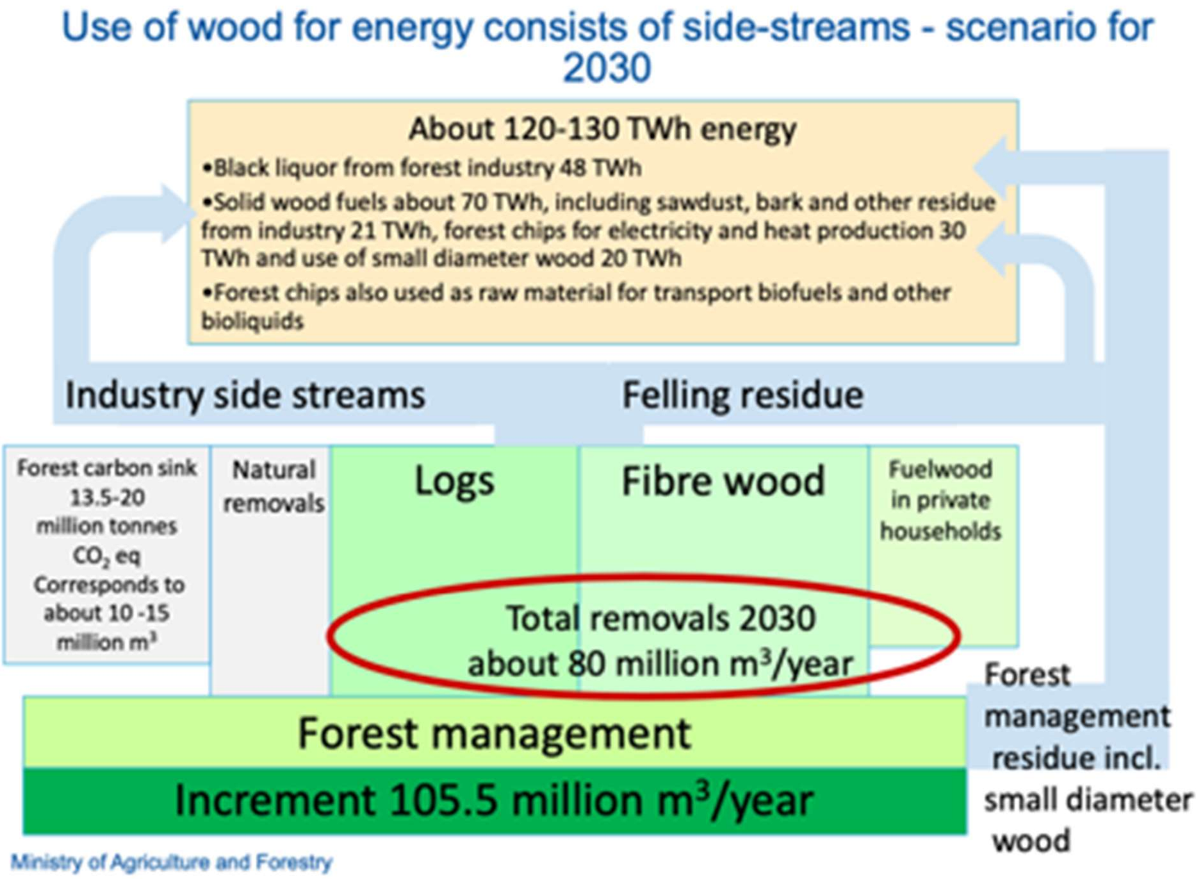

Figure 6: Use of wood for energy according to the national forest strategy - scenario for 2030

It is clear from this figure that from the about 120 – 130 TWh of wood energy available, about 48 TWh will be from black liquor from forest industry, and 70 TWh from sold wood fuels. The amount of sawdust available from sawmills is estimated elsewhere[5] to be 17.9 PJ, or 1.1 million tonne dm/year.

An average price for sawdust during the past 10 years delivered to industry gate can be estimated to 15 Euro/MWh (effective heating value as received).

Estimation of biomass potential in Finland for pyrolysis

[5] http://www.flexchx.eu/pdf/D2_3_Report_on_the_sustainably_available_feedstock_basis_Feb2019_110419.pdf

The woody biomass that is available for pyrolysis in Finland will come – like in Sweden - from either fresh woody residues or from sawdust from the sawmill industry. If we take the 'small diameter wood' quantity as the amount available (20 TWh), this would equal (assuming 8 GJ/tonne and 50% moisture content) 4.5 million tonne dm/year. If we take the sawdust quantities and assume like in Sweden that 10% of the fresh residues and 20% of the sawdust residues are available (own estimation) we can determine the amount to pyrolysis oil plants that can be implemented in Finland:

Table 4: Estimation of the amount of pyrolysis plants that can be built in Finland based on woody biomass residue availability

	Residues available (tonne dm/year)	Used for pyrolysis (%)	Potential amount of pyrolysis plants (-)
fresh forest residues	4,500,000	10%	12
sawmill residues	1,118,750	20%	6

Like with Sweden, this is more than enough for the MUSIC advanced and strategic case studies, while leaving extra capacity open for wider market uptake.

Impact assessment

If we assume this amount of pyrolysis plants in Finland, and that the pyrolyis oil from these plants is used to produced transport fuels, this can have the impact as given in Table 5.

Table 5: Estimated impact of renewable transport fuels produced from pyrolysis oil in Finland

	Automobiles	Trucks	Airbus 330	Ship
Yearly transport fuel consumption in liters	1,250	25,000	28,350,000	65.625.000
Amount that can run:				
- with 3.5% advanced biofuels from pyrolysis	3,486,000	174,300	153	66
- with 10% advanced biofuels from pyrolysis	1,220,000	61,000	54	23
- with 15% advanced biofuels from pyrolysis	813,000	40,700	36	15

In this table the typical fuel consumption per year of a typical car, truck, plane and ship is shown. A typical ship is in this case a 4000 TEU container ship (length approx. 300 meter). When taking into account that a typical PO plant produces 20 million liters of pyrolysis oil per year, and that it can be converted into about 8,5 million litres of transport fuels (in case of co-feeding), the impact can be determined. Using these values, the total amount of vehicles/planes/ships that can be fuelled every year using the amount of pyrolysil oil that can be produced from the number of plants listed in Table 4 is shown for three scenario's: 3.5% advanced biofuels, 10% advanced biofuels and 15% advanced biofuels. It should be noted that either the automobiles, the trucks, the planes or the ships can be fuelled this way, not all at the same time.

As mentioned earlier, transport fuels thus produced are Advanced Biofuels according to the EU RED II regulation, Annex 9. These can be double counted, meaning twice as many automobiles, trucks, planes or ships could be covered.

2.3 Framework conditions

2.3.1 Relevant framework conditions in Sweden

The use of bioenergy in Sweden has increased from 40 TWh/year in the 1970s to around 140 TWh/ year today. Biomass has a dominant position in the Swedish heat market as a fuel for CHP for district heating. Today, very little fossil fuels are used for heating. Biomass is also the main energy source for energy intense forest industries. Increased use of bioenergy is the main reason that Sweden has managed to decrease greenhouse gas emissions by 25% between 1990 and 2014. During the same time the total growing volume of forest has increased, storing more and more carbon in the forest every year. The main reason for this development is a broad political support for long term and stable energy policies starting with the introduction of carbon tax in 1991 and further developed with green electricity certificates introduced in 2003.

In Sweden, the parliament has decided that the vehicle fleet should be fossil independent by 2030. In connection with the decision on the climate policy framework 2017, the parliament decided that greenhouse gas emissions from domestic transport should decrease by at least 70 percent by 2030 compared to 2010. In 2018, Sweden had the largest share of renewable fuels for transport in the EU with a 23 % share. The main driver for this development is the exemption from energy and carbon taxes that was introduced in 2007. However, the tax exemption has been questioned by EU as state subsidy and permission to extend it has been granted during this time period 7 times. This has not created the long term and stable energy policy landscape required for investments in domestic production of biofuels. In 2018, 85 % of the biofuels used in Sweden were imported (imports mainly concerned hydrotreated vegetable oil, HVO).

In July 2018, Sweden introduced a new mandate on fuel distributors to reduce GHG emissions of the fuel mix supplied. This policy requires fuel distributors to decrease GHG emissions by 19.3% in the diesel supply and 2.6% in the gasoline supply by 2018. The reduction targets increase to 21% and 4.2% for diesel and gasoline, respectively, by 2020. Sweden has a longer-term target for a fuel mix that would achieve a greenhouse gas (GHG) emissions reduction of about 40% by 2030 corresponding to around 50% of biofuels blending. For the biofuels distributed as high blends (pure fuel HVO 100, high-blend E85 and biogas), the tax exemption still remains but is likely to be removed soon. The past 5 years there has been a huge increase in the use of HVO based on a palm oil by-product, PFAD (Palm Oil Fatty Acid Distillate). Because of concerns about palm oil related land use change, PFAD will be reclassified from waste to by-product meaning that it must fulfil the same sustainability criteria as other biofuels.

With the new quota in place, interest for domestic investments in biofuel production is on the rise. The quota for advanced biofuels within RED II is also a strong market driver. Investment support from the Swedish climate leap has been granted for production of PO in Kastet Sawmill in Gävle, now under construction. The climate leap budget has been increased this year and is likely to continue the coming years. Swedish oil refinery PREEM has set up a company goal to produce and distribute at least 3 million cubic meters of renewable fuel by 2030 and are involved in several investment plans, including the Gävle facility.

2.3.2 Relevant framework conditions in Finland

The National Energy and Climate Strategy outlines the actions that will enable Finland to attain the targets specified in the Government Programme and adopted in the EU for 2030, and to systematically set the course for achieving an 80%–95% reduction in greenhouse gas emissions by 2050. With minor exceptions, Finland will phase out the use of coal for energy. The share of transport biofuels will be increased to 30%, and an obligation to blend light fuel oil used in machinery and heating with 10% of bioliquids will be introduced. The minimum aim is to have 250,000 electric and 50,000 gas-powered vehicles on the roads. The electricity market will be developed at the regional and the European level. The flexibility of electricity demand and supply and, in general, system-level energy efficiency will be improved. Technology neutral tendering processes will be organised in 2018–2020, on the basis of which aid will be granted to cost-effective new electricity production from renewable energy. The share of renewable energy in the end consumption will increase to approx. 50% and the self-sufficiency in energy to 55%. The share of renewable energy use in transport will clearly exceed the Government Programme target. The domestic use of imported oil will be halved as planned. The greatest non-ETS sector reductions in emissions will be achieved in the transport sector, and this will be the foundation of the medium-term climate policy plan of 2017.

2.3.3 Relevant framework conditions in the Netherlands

The Netherlands is far behind most other EU countries in the production of energy from renewable sources. In 2018, only 7.4% of the energy used in the Netherlands came from sustainable sources, according to the European statistics agency Eurostat. (January 2020). As a result, the Netherlands is furthest from achieving its renewable energy targets for this year, since this share must be at least 14 percent by the end of 2020, according to the EU's rules.

To ensure targets are met the Dutch government in 2019 presented the Climate Agreement, with the key aspiration to reduce overall greenhouse gas emissions by 49% by 2030 (compared to 1990 emission levels). To achieve this, the Climate Agreement formulates a target of 65 PJ for renewable fuels to be used in the transport sector in 2030. The estimated emissions from transport in 2030 should be below the 25 Mt CO_2 target of the earlier Energy Agreement (the previous government programme to reduce fossil fuels). The 2030 target stated in the Climate Agreement will be partly filled in by the HBE system, a biofuel blending requirement. This system is aimed at companies that deliver fuels to the road transport sector in the Netherlands. The HBE system has set the target in 2020 for renewable energy in transport to 16.4%, increasing every year.

Renewable energy units (in Dutch: HBEs - hernieuwbare brandstofeenheden) are to be obtained by fuel suppliers when they blend biofuel into their fuel mix. One HBE represents 1 gigajoule (GJ) of renewable energy that is delivered to the Dutch transport market.

Currently, there are three types of HBE certificates based on the feedstocks used:

- HBE Advanced - biofuels from waste streams (Annex IX A Red II)
- HBE Conventional - food/feed crops or by-products of crops
- HBE Other - renewable electricity, oils and fats, (Annex IX B Red II)

With the RED II in place as of 2018 the Dutch government is investigating to add a fourth dedicated category for the biofuels produced from the feedstocks listed in RED-II Annex IX-B from 2021 onwards. The name of this HBE will be 'HBE Fats and Oils'. Currently, the biofuels from these feedstocks count towards HBE Other.

Feedstocks from Annex IX-A and B may be counted double their energy content towards the quota. This means twice the amount of HBEs will be obtained. This incentive is added in order to promote biofuels from advanced feedstocks. Biofuels produced from feedstocks not listed in this annex may only be counted once.

This system of HBEs enables the voluntary RED opt-in for the water transport sector. Dutch producers of biofuels used in this sector can generate HBEs when supplying these fuels to the Dutch market. As there is no obligation for the shipping sector, these HBEs can be sold to the obligated parties of the road transport obligation. With this money, the price premium between conventional fossil maritime fuels and biofuels can partly be bridged.

The reduction in CO_2 obtained by applying biofuels in the maritime sector does not count towards the national Climate Agreement targets. As a result, currently discussions are being held within the Ministry of Infrastructure and Water Management to exclude the marine opt-in from the new HBE system (2022-2030). Whether this will happen is highly uncertain.

With RED II for the 2021-2030 period currently being implemented the Ministry is considering the following changes:

- Gradually reduce the limit on Annex IX-B to 1.7% in 2030
- Growth in volumes must come from advanced biofuels and renewable fuels of non-biological origin
- Double counting of advanced and renewable fuels of non-biological origin
- Opt-in in aviation and shipping temporarily possible. To stop a few years before 2030 to attribute climate reduction of fuels to the Netherlands.

Apart from the HBE system the Dutch Government has the ambition by 2030 to close down all coal-fired power generation plants, make the tax system greener and more sustainable, increase off-shore wind energy, make buildings more energy efficient and have only new passenger cars with zero emissions being sold by 2030.

2.4 Physical infrastructure

2.4.1 Physical infrastructure in Sweden

The costs of harvesting, transporting, storing and handling of the biomass are prime determinants of overall biorefining costs. Thus, it is vitally important to develop local forest biomass supply systems that can efficiently supply biorefineries with sufficient raw material that meets their specific quality and seasonal demands. Low hanging fruits are forest industry by-products as they are available in large amounts in a single place. To maximize possible synergies, refineries are preferably integrated and located just next to existing forest industries. However, most of the forest industry by-products are already used, either internally, or by pellet producers or CHP plants. In the near future, new processes are likely to be developed to upgrade by-products like sawdust both into high value products and into different types of biofuels. It is likely that competition for forest industry by-products, especially those with a well-defined quality, like sawdust will increase in the near future.

In the inland of northern Sweden, large amount of forest energy assortments (logging residues and young trees) are available that are hardly utilized at all. In this region forest energy has low commercial value because the forest lands are located far away from most existing end consumers. Upgrading of this biomass into IBC has a great potential for mobilizing these biomass assortments. After upgrading, the increased energy density will make logistics to end consumers more economic. Geographical accessibility of such forest biomass is not well known. Thus, it is important to acquire detailed information about both current and anticipated extractable biomasses around key locations (biomass terminals) during specified timeframes (e.g. 20 to 50 years from now). A biomass terminal can have several functions, one of them is to increase long distance biomass supply efficiency. These terminals often have railroad connection and they are situated close to well-maintained road network, in order to utilize transport modes of higher payloads such as trains and high capacity-trucks, e.g. 74 t gross weight. ⅓ of the Swedish productive forest land is located within a 50 km radius from the inland railway (see Figure 7).

Several biomass terminals are located along this railway that can be suitable locations for production of IBC. In cooperation with Inlandsbanan, advanced raw material supply analysis for young trees and logging residues will be carried out around the Storuman terminal and possible 1-2 more locations.

Figure 7: The Inland Railway with major communities

Ports in Sweden

For the purpose of transporting pyrolysis oil in large quantities to the Netherlands, there are two main harbours in the south of Sweden: CPM Malmo and Gothenburg. There are many other ports (see a map in Figure 8[6]), which may be of interest, but for now it is considered prudent to focus on these larger two:

CPM Malmö

[6] https://www.cockettgroup.com/PortsMapAssets/region-sweden.html

CPM Malmö stands for Copenhagen Malmö Port AB. It is the operator of two nearby ports, namely Copenhagen in Denmark, and Malmö in Sweden. The ports are located on either side of the waterway (called the Øresund), and also connected by a bridge. CMP is one of Scandinavia's largest port operators, handling more than 15.1 million tonnes of freight in 2018. Every year around 4,500 ships dock in the two harbours. They have liquid bulk facilities.

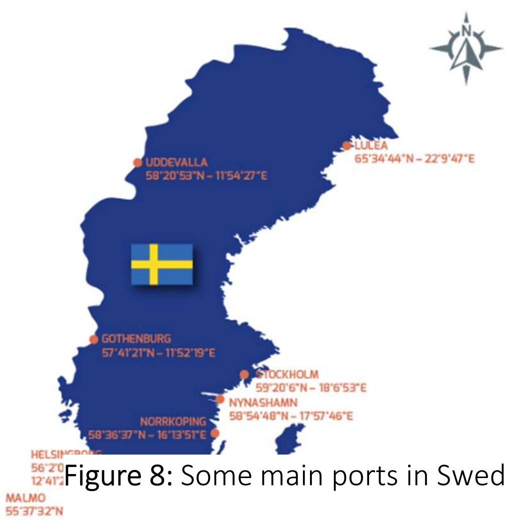

Figure 8: Some main ports in Sweden

Gothenburg

The municipally owned Port of Gothenburg is the largest port in the Nordic countries. It is located around 250 km north of Malmo.

Gothenburg has 11,000 ship visits per year. It handles nearly 30% of the country's foreign trade, comprising 39 million tonnes of freight per year. It has a specialised section[7] dealing with energy and bulk liquid. 2,500 tankers per year and 20 million tonnes bulk liquids are going through this port.

2.4.2 Physical infrastructure in Finland

According to Laihanen[8], road transportation with trucks is currently the most cost-effective and flexible option if no railway connection or deep-water harbour exists near the production plant. Main advantages for road transport are constant transportation flow from production to end-users and the most extensive coverage.

For transport over long-distances, rail transport can be an attractive option, provided no (costly) extra loading and unloading is needed.

Average transportation costs can be estimated to be 2.5-3.5 Euro/MWh/100 km. This figure is an expert estimation based on transport of woody biomass (for energy); for pyrolysis oil the figure could be lower because of the higher energy density (energy content per unit of volume).

Ports in Finland

[7] https://www.portofgothenburg.com/terminals-and-services/bulk-liquid/
[8] http://www.besustainablemagazine.com/cms2/requirements-for-transportation-of-fast-pyrolysis-bio-oil/

Like with Sweden, there are many ports in Finland[9], but for case studies it is considered prudent to focus on larger ports. Larger ports are ports with more infrastructure, that are able to service larger ships, compared to smaller ports.

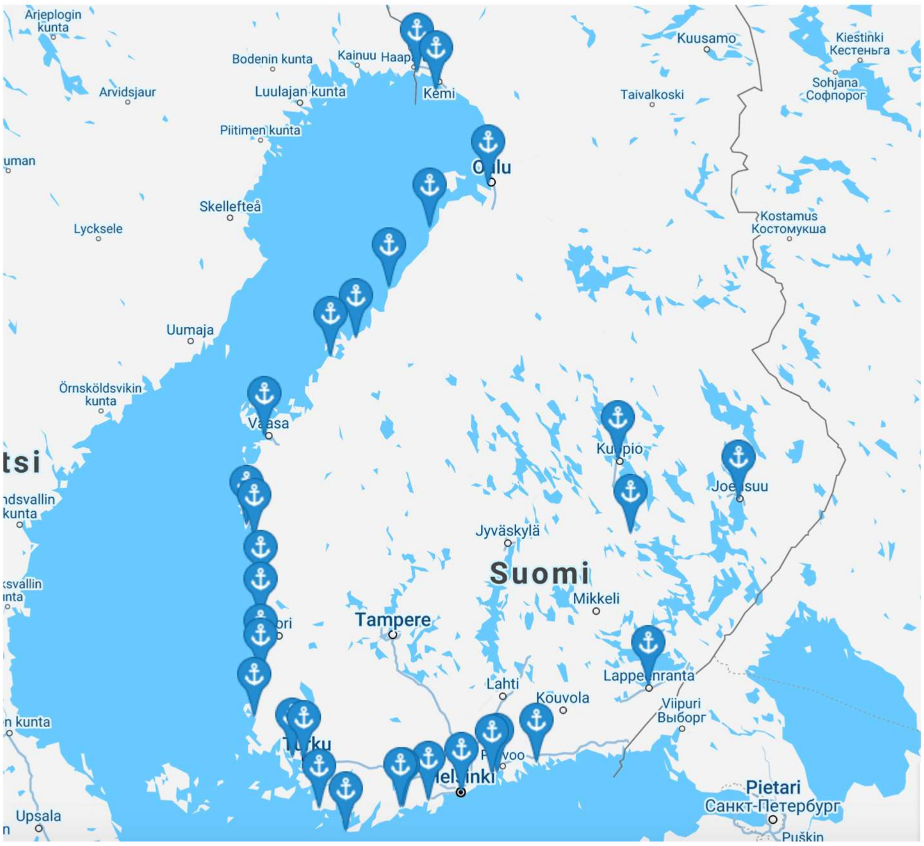

Figure 9: The ports in Finland[10]

2.4.3 2.4.2 Physical infrastructure in the Netherlands

The Netherlands is home to world-class, deep-water ports, many rivers and a dynamic network of canals. Dutch ports move more than 580 million metric tonnes annually.

[9] https://www.vtt.fi/inf/pdf/workingpapers/2011/W164.pdf
[10] http://www.satamaliitto.fi/fin/organisaatio/jasenet-kartalla/

Figure 10: Main ports in the Netherlands

Ports in The Netherlands

n Figure 10 an overview is given of the main ports in the Netherlands. There are four major seaports: the port of Rotterdam, the port of Amsterdam, Zeeland Seaports, and Groningen Seaports. Specifics about these seaports are given in Table 6.

Table 6: Main seaports in the Netherlands

Port	Description
Port of Rotterdam	In terms of port size Rotterdam now takes a third place after Shanghai and Singapore with an annual cargo tonnage of about 400 million tonnes. Every year 34,000 sea-vessels and 133,000 inland-traveling vessels cast anchor in Rotterdam. Cargo most often shipped include chemicals, fruit, grain, coal, ores, oil, fodder and fertilizer.
Port of Amsterdam	The port of Amsterdam is the second largest port in the Netherlands and ranks fifth in Europe. It has a rich seafaring history, and, whereas the port of Rotterdam is almost purely industrialized, Amsterdam is also popular with cruise ships. The port of Amsterdam is connected to the North Sea by the North Sea Canal. It is an important port for oil, grains, coals, and ores.
Zeeland Seaports	Zeeland Seaports, in the southern part of the Netherlands, is a joint venture of the ports of Vlissingen and Terneuzen. It is strategically located between the port of Antwerp and the port of Rotterdam. Situated at the mouth of the Scheldt and the Gent-Terneuzen canal, it will

	become even more strategic in the future. At this moment the "water highway" to Paris is under construction at Zeeland that connects the Seine with the Scheldt. Thus, it is expected to gain great significance for inland shipping.
Groningen Seaports	The Groningen Seaports combines the management of Eemshaven and the port of Delfzijl and is thus the largest Seaport in the northern part of the Netherlands. The port is connected to the Eems river in northwestern Germany.

Transport of Pyrolysis oil between Sweden/Finland and The Netherlands

Transport of pyrolysis oil in reasonably large quantities (say more than 30 tonne) via international or inland waterways has not been performed so far. As pyrolysis oil is a new type of liquid biofuel, no commercial data can be found. Therefore, this section looks at the hypothetical options and barriers.

First of all, it is important to notice that pyrolysis oil is generally acidic; unstable at high temperatures or over long storage periods; highly polar; and mainly non-volatile, containing a large amount of chemically dissolved emulsified water. It is important. Considering this there are two ways how pyrolysis oil could be transported over sea. The first option is in a bulk ship and the second option is a container ship with tank containers (see Figure 11).

The advantage of a bulk ship is its higher volume compared to a tank container. Therefore, the operational costs of loading, unloading and cleaning of the tanks will decrease. However, the downside is that the acidity of pyrolysis oil requires a bulk container which is able to handle acid liquids. These ships exist but are more expensive to charter than conventional fuel bulk ships.

An advantage of the bulk container is its flexibility to be used for road, railway and seaway transport. This means that the tanks can be filled at the pyrolysis plant in Sweden or Finland and can directly be transported to the upgrading plant in the Netherlands. There is no need for (costly) transferring and pumping pyrolysis oil from one type of tank to another.

Figure 11 Tank container

For waterway transport pyrolysis oil will also need IMO classifications which is written in the IBC code. The IBC Code provides an international standard for the safe carriage in bulk by sea of chemicals and noxious liquid substances listed in chapter 17 or 18 of the Code. At the moment, it is not clear if pyrolysis oil fits to an entry in this code, which means it not clear yet if it is allowed to transport pyrolysis oil on seaways. It could also be the case that pyrolysis oil is not listed in chapter 17 or 18 of the Code, which would make transport easier.

There are two legal possibilities to transport pyrolysis oil by water in chemical tankers. It can be transported in a tanker under a tripartite contract or upon the product's listing in the IBC Code list. A tripartite contract is the fastest way to transport pyrolysis oil between two countries. The tripartite contract is temporary and is valid for three years. This contract is made among the authorities of the country of export, the importing country and the flag state of the vessel. The process related to the IBC Code, which involves permanent permission for the product's maritime transport, is more complicated and time consuming than is handling a tripartite contract. In Finland, the process for the IBC list is handled in co-operation with the Finnish Transport Safety Agency. The IMO validation committee calls a meeting once a year.

The last barrier of transporting pyrolysis oil by seaways is that ports with sufficient storage capacity are required. Whether the ports in Sweden, Finland and the Netherlands that will be used in this case study are all able to handle chemical fluids remains to be investigated.

3 Bioenergy Setting Italy

Contributor/s: Marco Buffi

3.1 Case study description

The case studies in Italy will focus on the use of locally sourced agricultural, agro-forest and agro-industrial residues as well as industrial crops. They will address two different IBC production pathways, driven by large industries as end-users that are partners of the MUSIC consortium:

For the advanced case study, a value chain concerning the production of charcoal/pyrogas of regional biomass for use in the Arcelor Mittal steel mill in Taranto (Puglia, South of Italy) will be researched. Feedstocks to be considered include agricultural residue, olive pruning, olive oil production residues and potentially wood derived from infected olive trees.

The strategic case study will research the logistics and feasibility of a microbial oil (MO) value chain for large scale use at the ENI existing biorefineries in Porto Marghera (Veneto) and Gela (Sicily). Lignocellulosic biomass residues could be used as feedstock for oleaginous yeasts to produce lipids that could be used as substitute feedstock for co-processing in ENI's existing industrial biorefineries.

3.1.1 Advanced Case Study Description: charcoal/pyrogas for use in steelmaking plants

General description

Italy hosts the EU's largest company of steelmaking, Ilva, which has been recently acquired by Arcelor Mittal Corporation. The Ilva steel plant is located in Taranto (Apulia, Italy), a site that serves as a hub for the local community and an important player in the regional economy. One of the main pillars of the new property is the environmental sustainability of the plant, thus the use of biomass (as carbon source) in steelmaking process is particularly attractive.

In order to provide a share of renewable carbon as coke/coal substitute in the steel sector, charcoal and torrefied material have been considered for this scope. This material can be added up to high quantities to replace the fossil carbon-source and has a huge potential of CO_2 emission reduction, with economic benefits in the short- and medium-term scenario[11]. Biomass will be sourced from the Apulia Region in the south of Italy. It is the most important olive oil producing area in Italy. However, many trees are infected, and need to be removed.

[11] C. Wang, P. Mellin, J. Lövgren, L. Nilsson, W. Yang, H. Salman, A. Hultgren, M. Larsson, Biomass as blast furnace injectant - Considering availability, pretreatment and deployment in the Swedish steel industry, Energy Convers. Manag. 102 (2015) 217–226. doi:10.1016/j.enconman.2015.04.013.

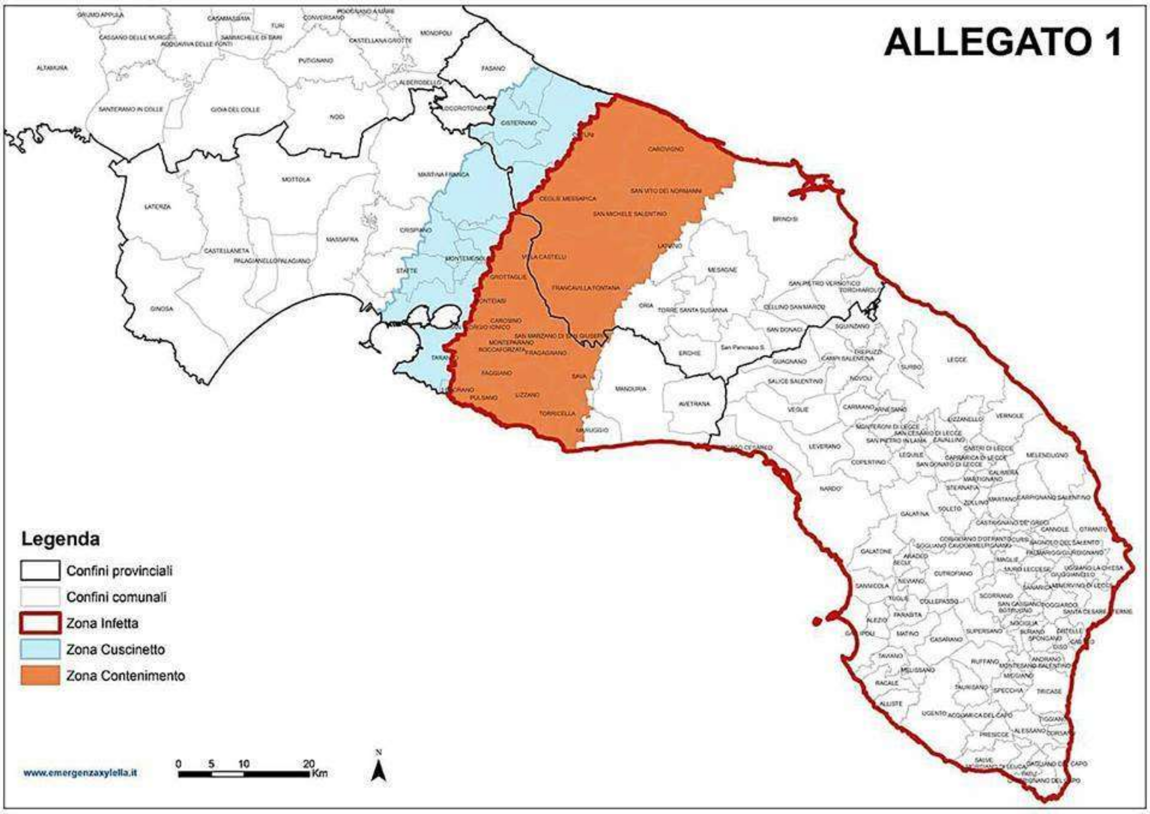

Figure 12: Apulia area infected by Xylella (inside the red line), including Taranto district area where the Arcelor Mittal plant is located (www.emergenzaxylella.it)

In the short-term, the advanced CS is developed in the surroundings of the Arcelor Mittal steel making plant in Taranto (Apulia, South of Italy), where the selected biomass are olive pruning, residues and wood derived from the trees infected by the xylella fastidiosa. In October 2013, xylella fastidiosa was found infecting olive trees in southern Italy. The olive quick decline syndrome (OQDS; in Italian: *complesso del disseccamento rapido dell'olivo*) was causing a rapid decline in olive plantations. By April 2015 the disease had infected up to a million trees in the southern region of Apulia, affecting the whole Province of Lecce and other zones (see Figure 12).

The proposed approach is to develop a network of biomass suppliers to the pyrolysis unit to produce charcoal/pyrogas for the steel making industry (Arcelor Mittal). Regarding biomass supply, the stakeholder engagement plan involves local farmers, industrial producers, farmer associations and public institutions of Apulia region, in proximity of Taranto district.

Case study development

The envisaged value chain is shown in Figure 13. The agronomic actors will be involved during the study of the geographical territory in terms of biomass potential, which will be carried out by means of a GIS software, CropSyst. This tool consists in a daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. The model will be implemented with additional information collected from farmers surveys/interviews in the territory of interest. Olive-derived biomass is collected in decentralized sites and immediately pre-processed to be easily transportable to a centralized site, where the torrefaction conversion plant is located.

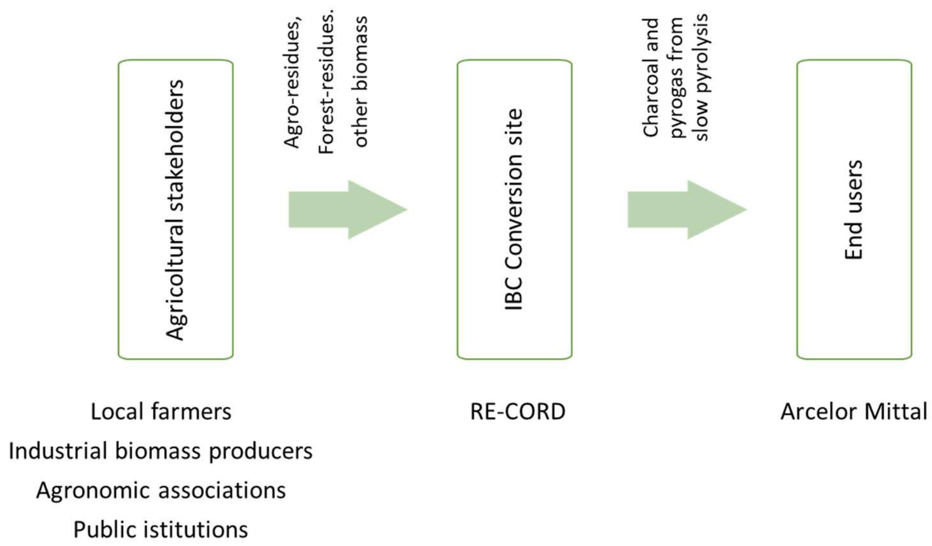

Figure 13: Layout of the proposed case study for the Italian advanced CS

From the International case study, the technology of torrefaction and pelletizing of Torr-Coal (multiple units of 35,000 tonnes/y each) and the coal demand of Arcelor Mittal plant (8 million tonens per year of steel) will provide a first indication of how to build the value chain. In the case study, RE-CORD will evaluate the potential use of the slow pyrolysis (carbonisation) process, which could produce charcoal with different properties than torrefied material (favourable than torrefied material for steel making industry). The impact of the study is directly reflected on the local territory with the development of concrete value chains. As outcome, the CS has a promising development of olive residuals market at regional level (with fixed prices and constant demand).

Case Study Team

The case study team is composed by RE-CORD and Arcelor Mittal, with the potential engagement of stakeholders from biomass production side and logistics.

3.1.2 Strategic Case Study Description: Microbial Oil for co-processing in biorefineries

General description

All microorganisms are capable of producing lipids but only few species can accumulate more than 20% of their weight in oil: this category been classified as oleaginous. ENI has developed a very innovative technology to produce MO from oleaginous yeasts as alternative lipids sources for their biofuel production sites. The process consists in the production of lipids from sugar fermentation by oleaginous yeasts. These micro-organisms can accumulate up to 36% (dry weight) of fatty acids inside their cells at high concentration in water (>100 g/l)[12]. Currently the process has been tested in pilot reactors at the Renewable Energy and Environmental R&D Center of ENI in Novara (North Italy), but has a high potential to be scaled-up at demo-level of approx. 100,000 t/y of microbial oil production, which is the object of the present case study.

Figure 14: Oleaginous yeast cultivated in the laboratory of ENI.

Technological background

In order to assume lignocellulosic biomass as feedstock for IBC plants, the case study considers the biomass pre-treatment technology of 2nd generation cellulosic ethanol to produce lignocellulosic derived-sugars, i.e. feed of the oleaginous yeasts.

Italy hosts the largest European lignocellulosic ethanol plant in Crescentino (Vercelli, Piedmont). The demo-plant based on PROESA™ technology allows the use of the sugars extracted from lignocellulosic biomass to convert these in an alcohol fuel. It is the result of large industrial investment, started by Mossi & Ghisolfi group in 2006. Recently M&G activities around the production of lignocellulosic sugars and ethanol have been taken over by ENI-Versalis, the chemical company of the ENI group, which is also leader in the HVO (hydrotreated vegetable oils) technology, named UOP/ENI Ecofining™. This conversion pathway consists in a commercial alternative to biodiesel (Fatty acid methyl esters, FAME), where bio-based pure hydrocarbon (diesel- and kerosene-like) fuels are produced. The process can be fed also by non-edible or residual oils, once that contamination level is within the acceptable ranges.

[12] R. Davis, L. Tao, E.C.D. Tan, M.J. Biddy, G.T. Beckham, C. Scarlata, J. Jacobson, K. Cafferty, J. Ross, J. Lukas, D. Knorr, P. Schoen, Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute-Acid and Enzymatic Deconstruction of Biomass to Sugars and Biological Conversion of Sugars to Hydrocarbons, 15013 Denver West Parkway Golden, CO 80401, 2013. doi:10.2172/1107470.

In Italy, two fossil refineries have been converted to HVO processing: (1) Porto Marghera, Venice site, is the world's first fossil refinery converted to bio-refining, which can process up to 560,000 t/y of vegetable oil per year (currently running at 360,000 t/y), of which around 15 per cent is used and purified cooking oil, while the rest is refined and certified vegetable oil (also certified sustainable); (2) Gela, Sicily bio-refinery (in operation from September 2019) will process up to 750,000 t/y of lipids per year, with an annual production of around 500,000 t/y of HVO diesel. The position inside an agronomic map of each biorefinery is reported in Figure 15.

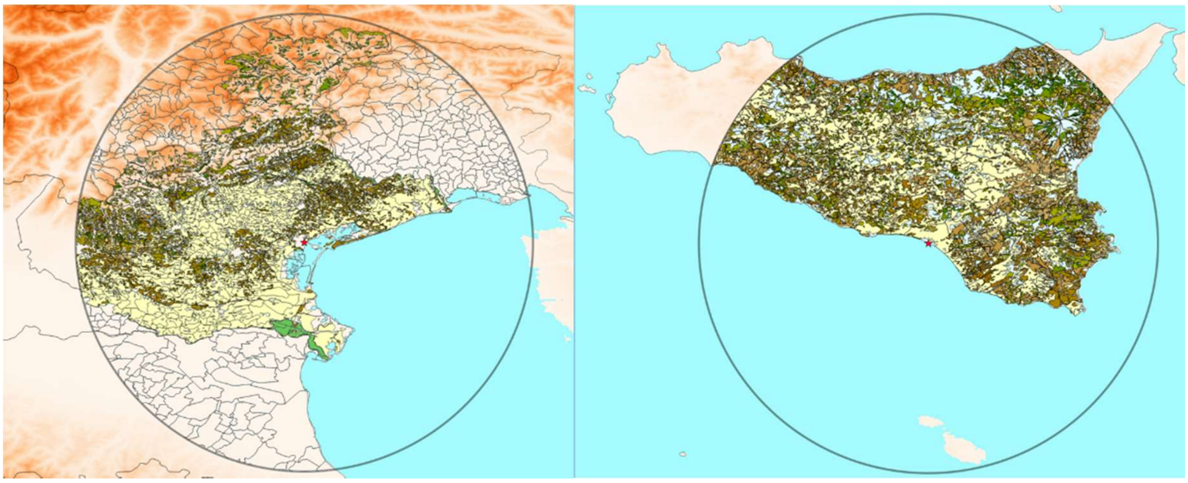

Figure 15: Agronomic map of the use of soil in the surroundings of ENI' biorefineries (left – Porto Marghera, right – Gela).

Case study development

Combining the pre-treatment technology developed by M&G/Biochemtex, now ENI, for producing sugars from lignocellulosic biomass (TRL 8) with the MO production pathway, a high triglycerides potential can be leveraged to supply the feedstock to the Italian bio-refineries (TRL 9). Based on the existing pilot units (TRL 4-5) the microbial reactor can be scaled up to a capacity of 100,000 t/y of microbial oil production.

The Italian experience of cellulosic ethanol production is crucial in the development of the present value chain. Besides technology development, extensive agronomic studies have been conducted, accompanied by a logistics modelling. The large scale (approx. 200,000 tDM/y) biomass supply has been one of the most challenging task in plant development. The supply of uniform biomass (qualities and quantities) from a large number of suppliers required a detailed monitoring of biomass availability, quality at plant gate and supply costs. Cleaning and treating biomass before the actual steam explosion pre-treatment system was also found as a major bottleneck of the route. This experience is fundamental in the development of the present value chain.

Case Study Team

The case study team is composed of RE-CORD and ENI, with the potential engagement of stakeholders from biomass production sites and logistics (as shown in Figure 16).

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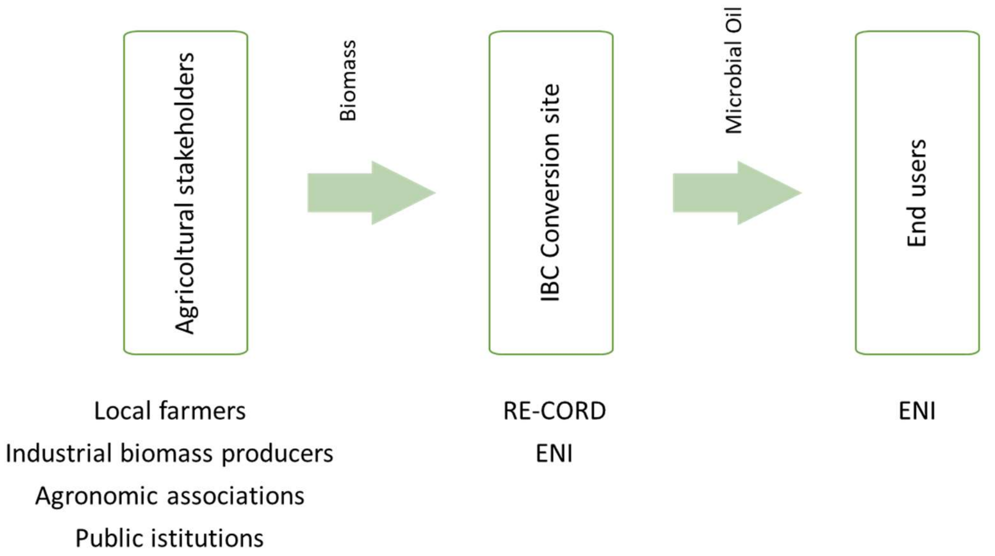

Figure 16: Layout of the proposed case study for the Italian strategic CS.

3.2 Biomass availability

3.2.1 Charcoal/pyrogas for use in steelmaking plants

The Apulia Region is the largest olive oil production area in Italy. Today, Italian olive production covers approximately 1,700,000 ha, with 80% of this area located in southern Italy. Apulia represents the most important region with about 370,000 ha of olive trees[13], thus olive tree pruning consists in a huge biomass source of the area. Moreover, in the last years the southern part of the Region has been infected by Xylella fastidiosa, a pathogen that dried and killed a very high number of olive trees, in particular the older ones. More than 5,000 km^2 of land – an area almost three times the size of London – has been classified as "infected", and 11 million olive trees could be uprooted[14]. Thus, the selected biomass feedstocks are olive pruning, residues and wood derived from the infected trees by the xylella fastidiosa.

[13] G. Fontanazza, Importance of olive-oil production in Italy, FAO L. Water Bull. (2005) 36. doi:10.1684/bdc.2007.0526

[14] Tondo, Italy's farmers turn to cow dung to save beloved olive trees, Guard. (2018). https://www.theguardian.com/world/2018/jul/22/italy-farmers-olive-trees-xylella-blight-cow-dung-Apulia.

3.2.2 Microbial Oil for co-processing in biorefineries

Possible and generally available biomasses in both Northern and Southern Italian territory are sorghum, corn, triticale, or also Arundo (if planted) and agricultural residues. The scheme of biomass supply is developed in the same way as for the Apulia case study, adopting GIS software (Cropsyst). From the VIGOR project, a private contract between RE-CORD and ENI to evaluate the potential of oleaginous and lignocellulosic crops in the areas of interest (further discussed in MUSIC D2.1), it has been estimated the following biomass potential production and costs (e.g. around ENI' biorefineries):

Site	***Distance, radius [km]***	***Cost [Euro/tonnes]***	***Potential availability [tonnes]***
Porto Marghera (Veneto, Italy)	250	21	2,201,846
Gela (Sicily, Italy)	250	21	2,706,843
Porto Marghera (Veneto, Italy)	100	15	1,769,533
Gela (Sicily, Italy)	100	15	1,384,785

The simulations assumes the biomass potential as «energy crops» and not as «agro-residues». For the development of a concrete biomass supply chain, the proposed scheme will implement the work of the above mentioned VIGOR project (Vegetable oil Initiative for Green Oil Refinery). The proposed scenario will be improved by farmers and agricultural companies' surveys to assess the real feedstock potential and to promote a guaranteed market with fixed prices, thanks to pre-commercial agreements between ENI and private farmers/associations.

3.3 Framework conditions

3.3.1 Charcoal/pyrogas for use in steelmaking plants

Renewable energy into the steel making industry is possible replacing the current fossil derived coking coal by renewable carbon sources at reasonable cost. This would be a significant step forward in reducing GHGs emissions from the industrial sectors. Despite the use of renewable carbon sources generates incentives in terms of CO_2 saving, today this strategy is not yet widespread enough.

Environmental issues at the Taranto steel making plant ate hotly debated, and constitute both an opportunity as well as a potential showstopper for plant upgrading. The blast furnaces in Taranto consist in old technologies, which require special authorizations to be operated due to the heavy pollutions vs the current Italian emission limits. The Italian government' promised legal shield would have given Arcelor Mittal immunity from possible costly prosecution related to a planned clean-up at the plant, in order to avoid the layoff of over 8,000 workers. Today, Arcelor Mittal and Italian government are negotiating for a deal, which could allow a partial plant operation, in parallel with a modernization of the factory, to meet at least the minimum sustainability criteria and preserving the job positions. In addition, the upcoming European Green Deal consists in a true opportunity to create a bioeconomy in the industry aimed to the transition to carbon-neutral future.

3.3.2 Microbial Oil for co-processing in biorefineries

A key driver to build the Italian case study on microbial oil production stems from recent EU policies of biofuels. According to the transport objective of the new RED II, the EU institutions agreed to reduce the consumption of high ILUC risk[15] feedstock to produce biofuels, as palm oil, starting in 2023 and reaching a complete phase out by 2030. According to the legislative scheme, ENI is going to substitute palm oil that currently is main feedstock for biorefineries with other lipid sources (as shown in Figure 17).

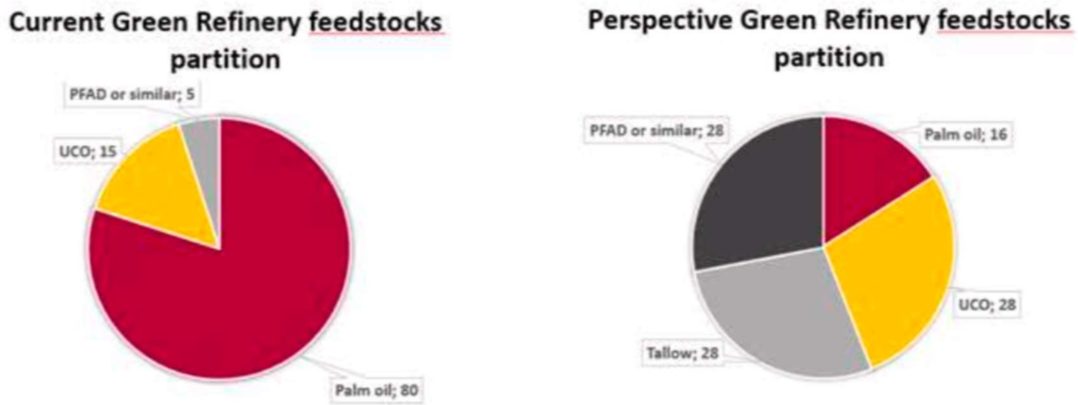

Figure 17: Current situation and perspectives in the mid-term scenario in terms of lipid feedstock for HVO (courtesy of ENI).

Thus, the present Italian case study offers an integrated package for the existing HVO biorefineries that assumes lignocellulosic biomass as feedstock for oleaginous yeasts, including biomass pre-treatment technology from 2nd generation cellulosic ethanol to produce lignocellulosic derived-sugars. In order to combine the MO technology with two commercially available conversion pathway (both owned by ENI) for both upstream and downstream process, this approach has a very large potential for advanced biofuels production.

3.4 Physical infrastructure

3.4.1 Charcoal/pyrogas for use in steelmaking plants

The scope of MUSIC focuses on building optimized value chains through cost-effective logistics, using the optimisation tools previously mentioned. During the Kick-Off Meeting the evaluation

[15] ILUC = Indirect Land Use Change. High ILUC risk fuels, under the EC definition, are fuels produced from feedstock with a significant expansion into land with high carbon stock.

of the best quality feedstock for the steel making industry has been discussed, resulting in charcoal for the blast furnaces. Inside these reactors, charcoal demonstrated the highest potential for partial substitution of top charged coke and full substitution for PCI (Pulverized Coal Injection system, typical for blast furnaces)[16]. In order to evaluate a different scenario than the International Case Study (Arcelor Mittal' plant in Ghent, BE), the use of slow pyrolysis as conversion technology was selected for the Taranto plant. The proposed approach differs from torrefied pellets production since consider a centralized production of renewable carbon in form of charcoal and pyrogas into the steel making plant facilities (Figure 18). Here the heat generated by pyrogas could be directly used into the steel making processes.

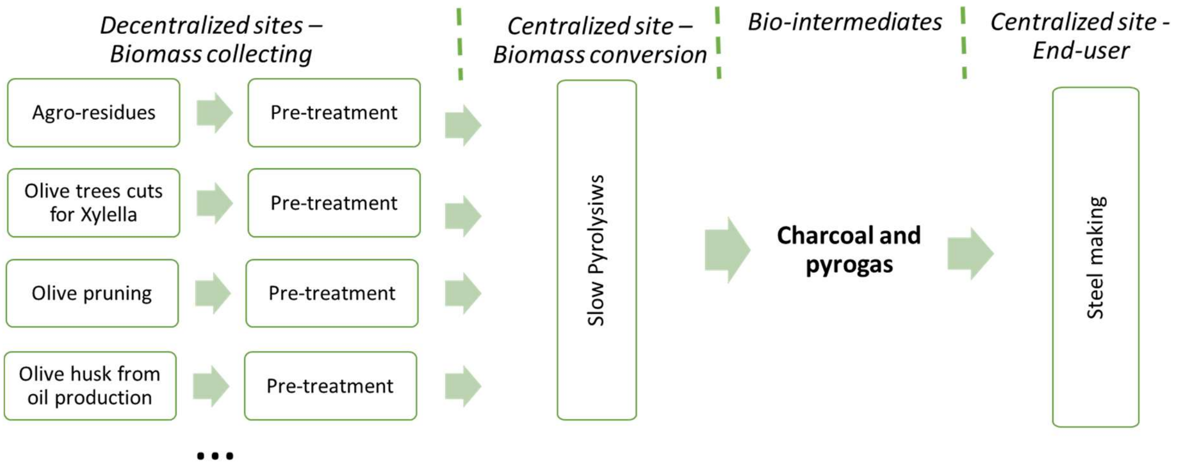

Figure 18: Centralized approach to produce bio-intermediates from slow pyrolysis.

On the other hand, the alternative approach (reported into the project proposal) focused on torrefied pellets production in "decentralized" spots where the biomass was collected. Despite this approach offered a substantial cost-effective logistics, due to biomass energy densification in proximity of the biomass sources, the conversion pathway requires an additional process to produce pellets. However, in the "centralized" approach, agro- and forest- residuals biomass are however collected in decentralized sites, therefore immediately pre-processed to be easily transportable to the centralized site, where the slow pyrolysis conversion plant is located.
Combining the technology of slow pyrolysis (multiple units of 4-5 ktonnes/y each one for a total production of 32.4 ktonnes/y, about the same size of Torr-Coal plants[17]) and the coal demand of Arcelor Mittal plant (8 million tonnes per year of steel), the case study is developed. RE-CORD

[16] E. Mousa, C. Wang, J. Riesbeck, M. Larsson, Biomass applications in iron and steel industry: An overview of challenges and opportunities, Renew. Sustain. Energy Rev. 65 (2016) 1247–1266. doi:10.1016/J.RSER.2016.07.061.

[17] C. Hilgers, Still more future hope than reality, BIOENERGY - Sun Wind Energy 5 - Torrefaction Co-Firing. (2012) 241–242. http://www.sunwindenergy.com/system/files/SWE_0512_241-242_Bioenergy_Torrefaction_for_co-firing.pdf.

will evaluate the advantages of using charcoal compared to torrefied material, which is in general more challenging for steel making industry[18 19].

3.4.2 Microbial Oil for co-processing in biorefineries

The proposed approach is a network of decentralized pre-treatment sites to produce an energy-dense transportable feedstock to a centralized enzymatic hydrolysis and microbiological conversion plant (in proximity of the HVO plant). A very schematic value chain is shown in Figure 19.

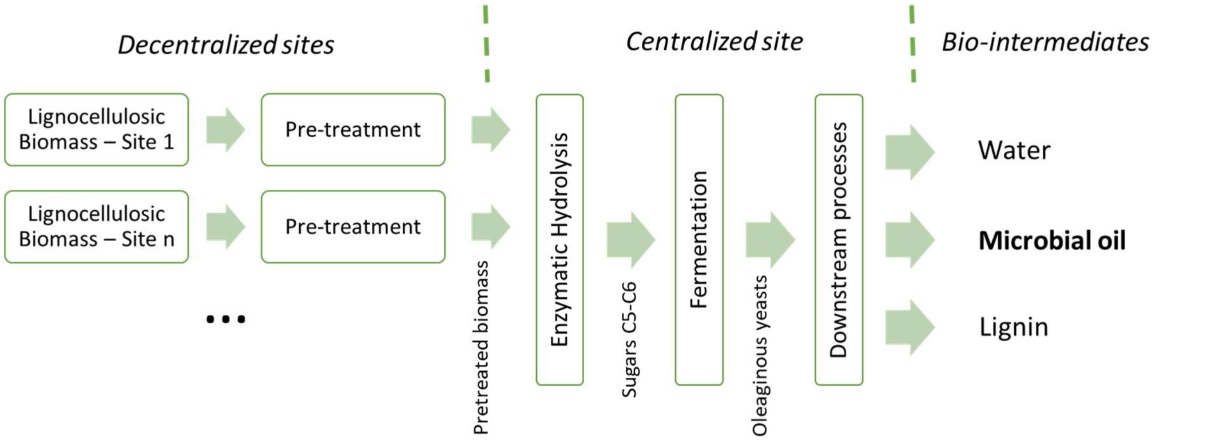

Figure 19: Scheme of bio-value chain of microbial oil production to HVO.

Logistics will be developed as well, proposing one or several pre-treatment units, each probably around 25-50 ktons per year of biomass in capacity, installed in a decentralized scheme. The pre-treated biomass is delivered to a centralized site of 50,000 t/y of microbial oil (or more) production to the industrial HVO site.

[18] IEA TASK 34, PyNe 45 - Direct Thermochemical Liquefaction, (2019) 33. http://task34.ieabioenergy.com/iea-publications/newsletters/ If

[19] V. Sahajwalla, S. Maroufi, G. Bell, P. Bell, I. De Bari, Alternative sustainable carbon sources as substitutes for metallurgical coal, Paris (France), 2019. http://task42.ieabioenergy.com/

4 Bioenergy Setting Greece

Contributor/s: Kyriakos Panopoulos, Giorgos Kardaras

In Western Macedonia (Greece) district heating supply to local communities uses excess heat from lignite-fired thermal power stations. Today, the operation and expansion of these power stations is at a great risk as the post-lignite era is approaching. The district heating company DETEPA has started building a 30 MW_{th} biomass combustion plant in Amyntaio, that could be fuelled using nearby biomass, including corn stalks, corn cobs and tree pruning. These locally available biomasses are currently not exploited due to challenging logistics. Applying torrefaction will help mobilising biomass at lower transport costs.

In the advanced case study, the logistics and feasibility of a torrefied biomass value chain supplying the DETEPA plant will be investigated,
In the strategic case study, large-scale implementation at multiple regional (district) heating plants and relevant (cement, quick lime or magnesite) industries in the region will be investigated.

4.1 Case study description

The main focus and starting point of the case study is the case of the Amyntaion district heating (DETEPA company) which is currently implementing a 30 MW_{th} biomass-based combustion plant to completely cover the heating demands of the 3,000-5,000 residents of this area. DETEPA plans to gradually replace lignite with corn residues and wood chips (up to 100%) in the fuel mix. The boiler technology is based on grate firing – able to operate with high-ash and/or low-ash fuels. The selected technology presents distinct advantages: it has a strong potential to use both biomass and lignite, as well as torrefied material.
The nominal capacity of the designed plant is 50,000-60.000 MWh/yr and could be covered by utilising local corn residues and wood chips.
A critical parameter is the handling and storage costs of biomass. More specifically a great problem of the logistics of corn stalk baling, large capacity handling and storage and crushing requirements currently rules out this biomass fuel option. Torrefaction could be greatly beneficial increasing the density and minimizing storage capacity of this locally available residue (available on fields for approximately three months per year).

Case study Team

Intra Music partners: CRES, CERTH, DBFZ, CLUBE

Potential External Partners for the case study:

- DETEPA (district heating company of Amyntaion), http://detepa.gr/
- DETIP (district heating company of Ptolemais), http://tpt.gr/
- DEYAK (district heating company of Kozani), http://www.deyakozanis.gr/

The case study has to include several implementation steps such as:

- Meeting with first of a kind stakeholder – most eminent users (DETEPA, local farmers etc)
- Arranging for a proposed test with imported torrefied material (with DETEPA)
- Technoeconomic appraisal of application of torrefaction
- Greater inclusion of other potential customers such as the municipalities of Kozani (company DEYAK) and Ptolemais (company DETIP).

To summarize, the Western Macedonia **advanced case study** and the implementation of biomass intermediates to this region is characterized by the following aspects/targets:

- Biomass potential in the region is huge, as determined in earlier research projects including https://agrowchain.eu/, and http://disheat.gr/
- Great potential due to costs associated with replacement of fossil fuels.
- Reduction of CO_2 emissions that are currently rising, whereas district heating plants that continue to operate on lignite will be required to reduce them.
- Reduction of the large costs associated with agricultural residues.
- Break the limited experience with torrefaction in Greece
- Explore potential investing in the technology by Greek based companies
- Solving issues related to legislative approach for torrefaction material.
- Prove reduction of storage capacity and seasonality of residues
- Prove the alignment of the Greek Scheme for Integration of Renewable Energy Sources (RES) into the energy system.
- Prove the Industry and employment development potential.

Finally, towards a **strategic case study**, the interest of further potential customers such as the Public Power Corporation PPC will be explored. PPC has started building a +40% efficiency steam cycle based power plant that will need to source an alternative feedstock replacing lignite fuel. Other prospective consumers come from the calcination processing sector (companies Greek Magnesite and CaOHellas). Notably some of the above companies could invest in the torrefaction process (torrefaction technology providers attracted by the MUSIC project) and provide biomass intermediate to various interested end users, including:

- CaOHellas S.A. (Quicklime producer) https://caohellas.gr/
- Grecianmagnesite S.A. (Magnesite producer) http://www.grecianmagnesite.com/
- Public Power Corporation (DEI S.A) https://www.dei.gr/en

4.2 Biomass availability

Bioenergy can be generated from a wide range of biomass sources, including dedicated energy crops and residues. Most commonly used as energy crops are grasses like arundo, miscanthus, switchgrass, short rotation forestry, as well as, annual crops like sorghum, etc. On the other hand, biomass residues include harvesting residues from forest and agricultural operations on-site (e.g., straw, fellings and branches, etc.); pruning from tree crops (olive trees, fruit trees, vineyards, etc.) and urban green wood residues; waste biomass from agricultural and forest industries and cattle breeding farms (e.g., olive kernels, saw dust, etc.); woody wastes from buildings, renovations or demolitions; as well as, the biodegradable part of municipal wastes.

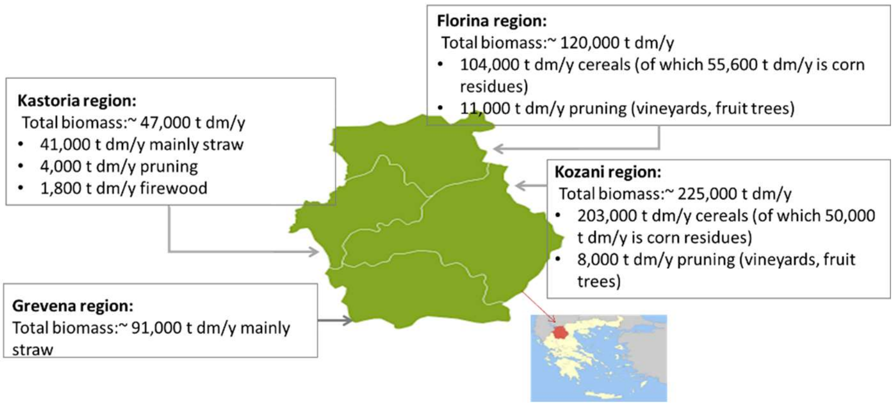

Figure 20: Biomass availability by region and type, Western Macedonia

Western Macedonia presents a significant amount of biomass potential as shown in Fig. 18, particularly Kozani and Florina region, where DETEPA's district heating plant is located. Residual cereal biomass is a by-product of agricultural activities and only a small part is collected and utilized, mostly as fodder, the rest is chopped and left on the field or usually burnt.

Corn and straw residues are available in the form of bales, with average prices of 2 €/small bale and 10€/big square or cylinder bale.

Table 7: Corn/straw residues and bales characteristics

Bulk density of straw (kg/m³)	Type of bales	kg/bale	Volume of bales (m³)	Dimensions (m)		
				Length	Width	Height
95.83	Small square bale	23	0.24	1.20	0.50	0.40
154.32	Big square bale	300	1.94	2.40	0.90	0.90
124.66	Big cylindrical bale	215	1.72		1.30	1.30
Type of residues	**Dry matter (t/ha)**	**Moisture after harvest (%)**		**Number of bales/tonne**	**Number of bales/ha**	**Mean weight (t/bale)**
Wheat straw	2.17	5		4.65	10.09	0.215

Barley straw	1.2	5	4.65	5.58	0.215
Cotton stalks	2.54	39.9	4.17	10.58	0.24
Corn stalks	10.1	14.7	3.45	34.83	0.29

Annual pruning is a necessary agricultural practise in vineyards and fruit trees to ensure optimal and continuous production. On eliminating branches, the number of fruits per plant is reduced and the nutrients are better distributed. The amount of residual biomass to draw from vineyards and tree orchards depends on its cultivation characteristics, thus, table 5 presents the average dry biomass that can be obtained from pruning operations. Tree branches are collected loose within each field and are mostly burned on the spot.

Table 8: Biomass potential from pruning

Type	Average dry matter (t/ha)	Moisture after harvest (%)
Vineyards for fresh fruit production	2.5	36
Vineyards for wine production	1.7	36
Apple trees	5.6	39
Pear trees	5.8	39
Peach trees	2.9	39
Apricot trees	1.6	39
Cherry trees	2	39

Western Macedonia has a continental climate with severe winters and a yearly heating season that lasts 8-9 months. Large municipal corporations in this region offer district heating to local communities, by using excess heat from the lignite-fired Greek Public Power Corporation (PPC) power stations. Despite that biomass is largely available near the district heating plants it is still not exploited due to the challenging logistics.

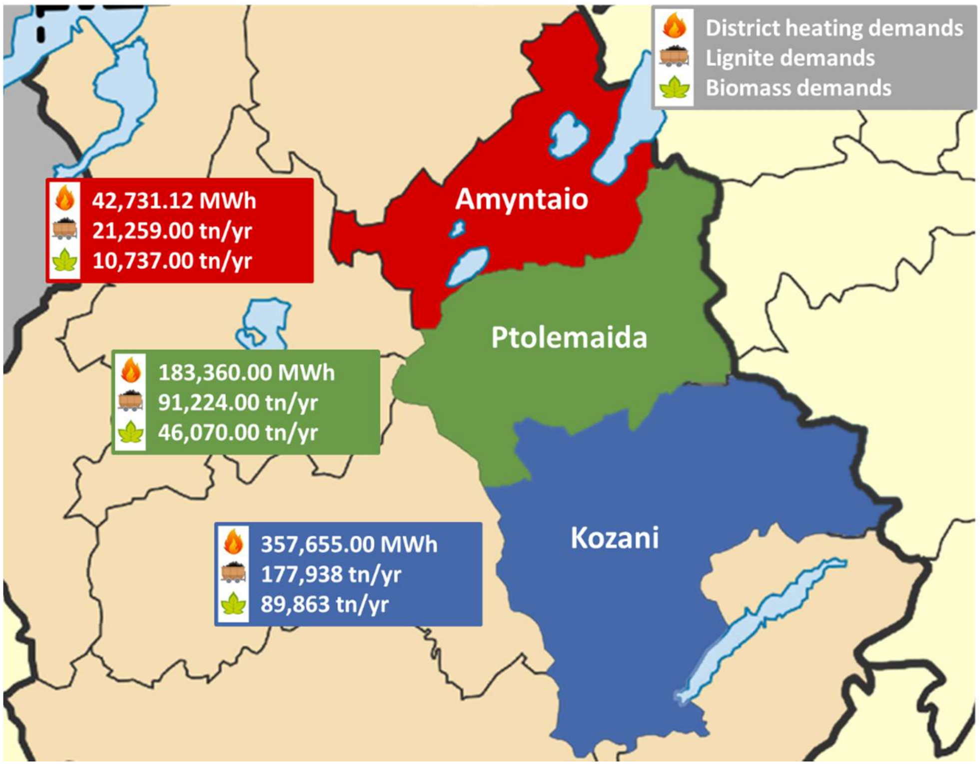

Figure 21: District heating demands for the municipalities of Kozani, Ptolemaida and Amyntaio, presently covered by lignite and potentially covered by biomass.

The application of torrefaction will contribute to mobilising biomass sources at lower transportation costs and at the same time address the seasonal availability of biomass .

Table 9: Biomass seasonal availability, for the rest of the year biomass has to be stored

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Wheat straw												
Corn stalks												
Tree pruning												
Forest harvesting												
Forest industries' residues												

4.3 Framework conditions

Following the EU and national legislations and directives, Greece has recently developed the new National Energy and Climate Plan 2021-2030 to enhance the use of Renewable Energy Sources (RES) and to promote energy savings by 2030.
Main targets of this action plan, are:

- Reduction in the mining of lignite and its use for power generation purposes. A direct and indirect impact on growth and employment in lignite-producing areas will be felt by the local communities. Therefore, specific transition policies will have to be developed.
- About 65% of the gross final electricity consumption, compared to previous 55%, must derive from RES. In practice this means that – for bioenergy - from approximately 6 GW today, we will have to reach 14.5 GW.
- E-mobility maintains the target of 10% of all passenger cars in Greece in the year 2030 to be electrically driven.
- Promotion of bioenergy, implementation of biomass projects of in total 320 MW capacity, to produce final energy from biomass equal to 0.27-0.41 Million Tonnes of Oil Equivalent (Mtoe), to strengthen the available district heating installations, especially those using renewable energy sources and to take advantage of the biomass produced from agricultural and agro-food industries.

In the region of Western Macedonia (NW Greece) the lignite fired power plants are set to close operation. In September 2019 Greece announced it would will close all majority state-owned lignite-fired power plants by 2028 at the latest. .

4.4 Physical infrastructure

Intermediate Bioenergy Carriers (IBCs) are formed when biomass is processed to energetically denser, storable and transportable intermediary products analogous to coal, oil and gaseous fossil energy carriers Such IBCs can significantly contribute in reducing the cost of logistics, by enabling long range transportation from several regionally distributed plants to a few centralized large-scale plants, easy storage, transportation and conversion, and the decoupling of production and final use. In this context, the case-study performed in Greece, aims to convert agricultural residues, such as straw and tree pruning, to torrefied materials and, subsequently, utilize them in district heating plants and non-district heating networks.

The three main cities in Western Macedonia with district heating (DH) plants are:

- Kozani – receiving a total of 137 MW_{th} nominal capacity of heat from Agios Dimitrios Power Plant Units 3 & 4 (and Unit 5 in standby) (power plant scheduled to be closed by 2028);
- Ptolemais receiving a total of 100 MW_{th} nominal capacity of heat from Kardia Power plant Units 3 & 4 (power plant scheduled to be closed in 2023);
- Amyntaion receiving a total of 30 MW_{th} nominal capacity of heat from Amyntaion power plant (power plant to be closed in 2020).

District heating company **DETEPA** runs the smallest of the district heating plants which is the most eminent to run out of heat supply when the PPC lignite-fired power plant in Amyntaion is shutting down. DETEPA is currently building a 30 MW_{th} biomass-based district heating plant that is scheduled to start operation in 2020. In particular the boiler combustion grate can handle the combination of lignite and biomass. The technology is based on grate firing – able to operate with high-ash and/or low-ash fuels. A schematic representation of a grate fired boiler system is shown in Fig. 20.

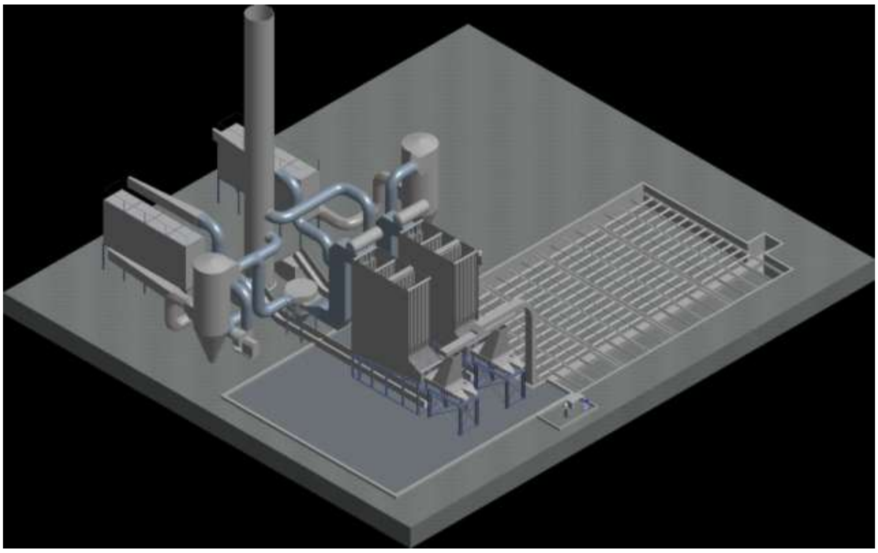

Figure 22: Schematic of the grate fired boiler system

The combustion unit is designed for mixtures of lignite and biomass with typical moisture rates of 25% and 45%, respectively. Each of the two 15 MW boiler units will produce superheated water with the following data:

- Nominal thermal power: 15,000 kW.
- Operating pressure: 16 bar; design pressure: 19 bar.
- Operating temperature: 130-180 °C; water inlet temperature: 70 °C; minimum exhaust temperature: 145 °C.
- Boiler thermal efficiency: 88% (min).
- Exhaust gas cleaning system and ash removal system.
- Complete fan system (exhaust fan, primary air fan, secondary air blower, exhaust gas recirculation).
- A chimney with a height of less than 35 m.
- Control system comprising 2 cabins (one per boiler).
- Analytical instruments to measure: water input, water output and exhaust gases temperatures, pressure in the combustion chamber, oxygen content in exhaust gases, NO_x, SO_x and CO_2 emissions.

Thermal energy consumption from district heating stood at 42,732 MWh in 2015 and 44,220 MWh in 2016. Anticipating a population increase in the near future, the plant will have a nominal design capacity in the range 50,000-60.000 MWh/yr.

Introduction of Biomass Intermediates

The current design of the biomass utilization is summarized in Table 5:

Table 10: Lignite fuel and biomass demands of district heating boiler (in tonne/year)

Lignite	Min	0	100% covered by biomass
	Max	14,623	50% of total fuel demands
Wood Chips	Min	0 6,571	Only lignite and corn residues are used 50% covered by lignite and 50% by wood chips
	Max	13,143	100% covered by wood chips
Corn residues	Min	0 7,414	Only lignite and wood chips are used 50% covered by lignite and 50% by corn residues
	Max	14,828	100% covered by corn residues

In order for DETEPA to secure a net return on its investment of about 15 million euros, the district heating plant needs to find a fuel that is competitive with lignite, priced at 25 €/tonne (2.01 MWh/tonne). Corn residues cost about 34-86 €/ tonne (3.97 MWh/tonne) and wood chips about 70 €/tonne (4.48 MWh/tonne).

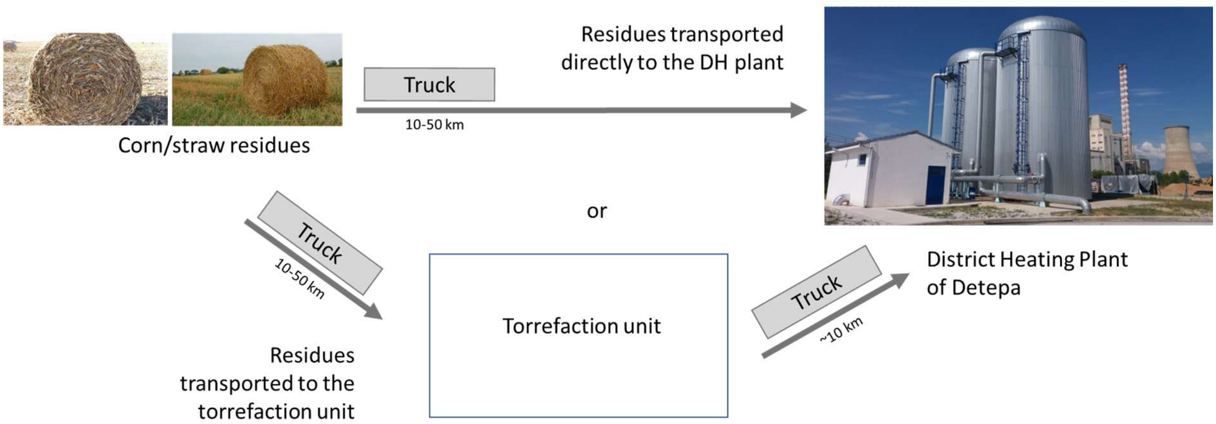

Figure 23: Potential value chain of straw/pruning of the Greek case study

Apart from the above district heating plant there is a great number of calcination processing companies in the greater region with a large capacity. Furthermore, the Public Power Corporation is currently building a new power plant of 550 MW_e (that has not operated yet and phases eminent phase out almost once it will be completed because of lignite fuel availability due to the stop of lignite extraction operations).

5 Bioenergy Setting International case study

Contributor/s: Wim Van Der Stricht

In Europe, only a few plants producing torrefied biomass at significant scale are in operation or being developed today. One of these plants is the Torero waste wood torrefaction facility that is under development at the ArcelorMittal (AM) steel mill in Ghent (Flanders, Belgium). The Torero facility[20], co-funded by the European Commission, will demonstrate a cost-, resource-, and energy-efficient technology concept for producing bioethanol from a wood waste feed-stock, fully integrated in a large-scale, industrially functional steel mill (see Figure 24).

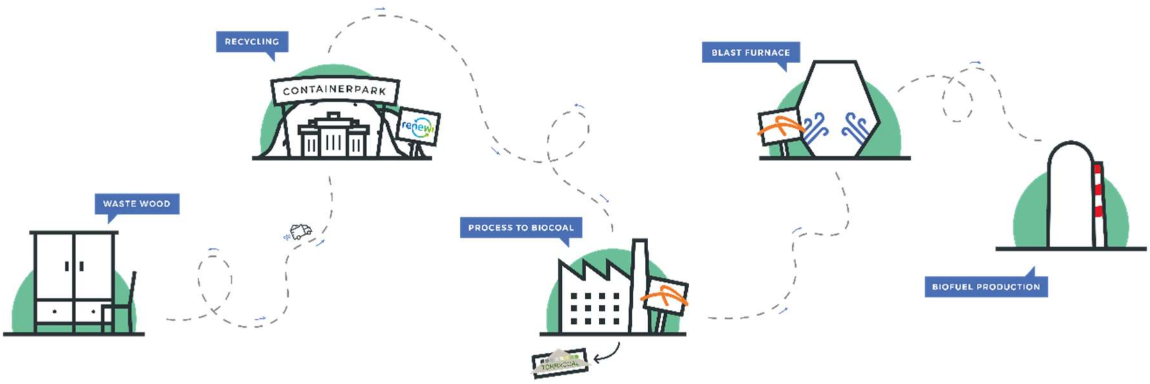

Figure 24: Torero technology concept

Torero is add-on technology that can be used to upgrade existing facilities of the steel sector, and ArcelorMittal anticipates good opportunities and a substantial potential to expand the use of torrefied biomass at its various steel mills.

In the MUSIC project, the **advanced case study** will assess a value chain broadening the range of biomass feedstocks to be torrefied at AM's Ghent facility. Among others hybrid feedstocks including Solid Recovered Fuel (SRF), Refuse-Derived Fuel (RDF) and end-of-life plastics mingled with on-spec waste wood will be evaluated.

The **strategic case study** will investigate the logistics and feasibility of torrefied biomass made from a various feedstocks for use at a range of AM steel mills including e.g. facilities in Belgium, North/South France, North Spain, North Germany, Poland & Italy.

5.1 Case study description

[20] http://www.torero.eu

5.1.1 Blast furnace process

ArcelorMittal aims to reduce the consumption of fossil fuels by substituting blast furnace feedstock with renewable alternatives. The blast furnace (see Figure 25) is fed by two different types of fuel: cokes and powdered coal.

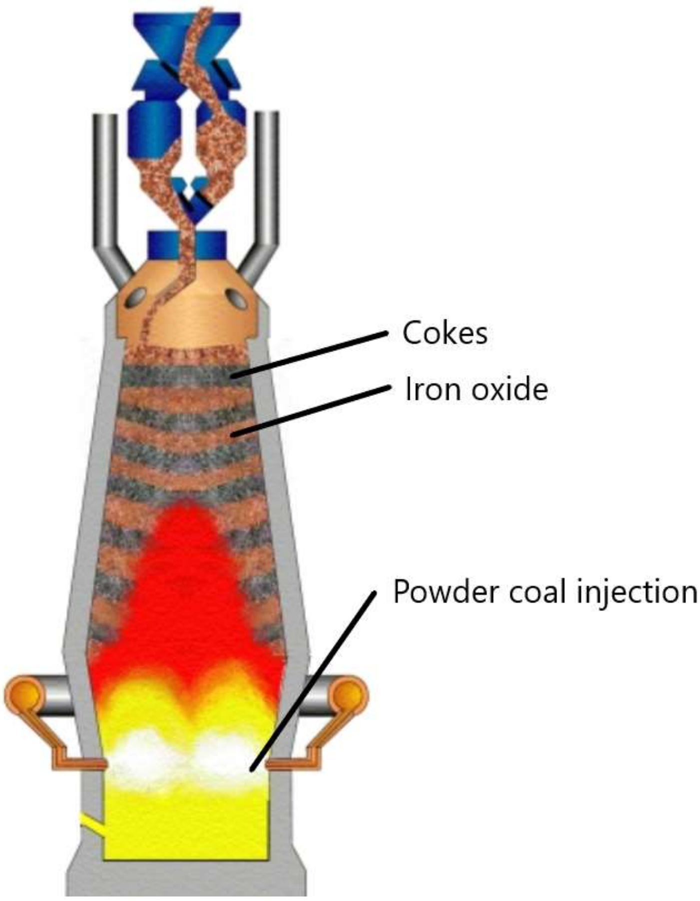

Figure 25: Blast furnace

Cokes are loaded alternatively with the iron-rich load at the top of the blast furnace. The function of cokes is triple; it acts as a reductant, whereby the carbon atoms react with oxygen atoms bound to iron oxide and oxygen atoms from the injected air. During these oxidation reactions heat is released, resulting in the heating and melting of the reduced iron. As such cokes can be seen as an energy carrier. The last function of cokes is as a structural element in the load, due to its very high strength, permeability of the load is ensured, thereby increasing productivity and preventing the collapse of the load. Powdered coal is injected (PCI) at the bottom of the blast furnace and only serves as reductant and energy carrier.

Due to the high demands on the strength of cokes, no form of biomass or treated biomass qualifies as a substitute for this form of feedstock. As a result powdered coal was identified as the material to be replaced by a bio-based feedstock.

5.1.2 Need for torrefaction

Several constraints on the feedstock which can be injected into the blast furnaces are in place, both chemical and physical in nature. The chemical composition of the feedstock must be as close to a pure hydrocarbon as possible. Deviations from this (higher ash content, higher oxygen content) result in production and energy loss. On the physical side, the feedstock must be brittle so that it can be ground finely, allowing for pneumatic transport. Untreated bio-based feedstocks do not fulfil these constraints and as such a thermochemical treatment was selected to prepare the feedstock for injection. As a result, the TORERO project was set up to convert biomass to a suitable replacement for PCI using torrefaction.

Torrefaction is a mild thermochemical treatment of biomass at 200 to 320 °C. It is carried out under atmospheric pressure and in the absence of oxygen. During the torrefaction process, the water and the volatiles contained in the biomass are released. Due to the high temperatures, biopolymers will (cellulose, hemicellulose and lignin) partly decompose, which leads to the formation of volatiles. The process thus yields two products: a gas with high caloric value (torrgas) and a residual solid. The residual solid is dry, blackened material which is referred to as bio coal. The carbon content of the bio coal after torrefaction should be greater than 61.5 wt % on dry basis. Commissioning and startup of the Torero plant is planned for the summer of 2021. The process was co-developed with MUSIC partner Torr-coal, which is the supplier of the torrefaction reactor and which has performed preliminary testing. Torr-Coal currently has an operating production plant in Dilsem-Stokkem (Belgium).

5.1.3 Waste wood as a feedstock

ArcelorMittal aims to operate the torrefaction process on type B waste wood. By doing so, three problems are tackled simultaneously. Firstly, fossil feedstock is replaced by renewable feedstock; secondly, waste wood is given a more valuable application than energy recovery from combustion, which is its current state of the art application; and thirdly, part of the carbon oxides leaving the blast furnace are biogenic in nature, which allows for the production of bioethanol by gas fermentation in the Steelanol plant[21].

5.1.3.1 Type B waste wood

The recycling level in the waste hierarchy, depicted in Figure 26, can be split in mechanical recycling and chemical recycling, where the former is more valuable than the latter due to lower overall process losses. The torrefaction of waste wood, followed by the gasification in the blast furnace and the conversion to bioethanol in the steel plant falls under chemical recycling. As such it is a more favorable application for waste wood than incineration with energy recovery. The categorization as chemical recycling is important as legislation is moving

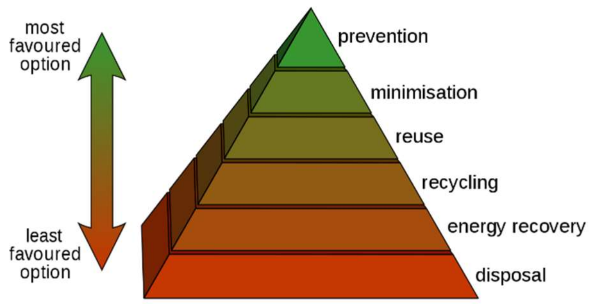

Figure 26: Waste hierarchy

[21] At the Steelanol plant, ArcelorMittal will transform the carbon-containing gases from its blast furnaces into bioethanol to be used as fuel for transportation or even for the production of synthetic materials. This will be the first industrial installation of its kind in Europe, producing 80 million litres of bioethanol annually. Source: http://www.steelanol.eu/en

towards higher recycling targets for this type of streams. As a result recycling initiatives are promoted and it is expected that energy recovery initiatives will be impaired.

Once the Torero project has proven the feasibility of waste wood torrefaction, a broader range of biomass feedstocks will be evaluated. For this evaluation, constraints on the specifications of the end product must be taken into account. The primary feedstock, being woody biomass, had been selected for its relative high carbon content after torrefaction compared to other types of biomass.

5.1.3.2 Hybrid feedstocks

Type B waste wood is defined as uncontaminated treated wood. Next to this category of waste wood, two other categories exist. Type A waste wood is defined as untreated wood and type C waste wood is defined as contaminated treated wood. While types A and B can be processed in Torero, only type B is selected even though type A has a chemical composition which is better suited for injection in the blast furnace. The reason for this is that waste wood type A is preferably used in material recycling purposes such as the production of chipboard. Waste wood type B cannot be used in material recycling and as such is better suited for chemical recycling.

Accounting for this, waste-derived residues were selected as a potential alternative feedstock. These residues consist of different types of materials, with waste biomass and plastics as most abundant fractions. Due to the presence of plastics, the carbon content of these hybrid feedstocks can be higher than that of biomass feedstocks. Hybrid feedstocks that will be evaluated in the MUSIC project include: Solid Recovered Fuel (SRF), Refuse-Derived Fuel (RDF) and end-of-life plastics mingled with on-spec waste wood.

5.1.3.3 Sourcing and pre-processing

To procure on-spec waste wood, ArcelorMittal is working together with MUSIC partner Renewi. Renewi is a leading supplier of secondary raw materials and the market leader in the Benelux[22] area. They are responsible for sourcing the waste wood and processing it to specifications provided by ArcelorMittal. Renewi will collect the waste wood at different sites and process it with mobile installations so that it can be transported more easily. The processed wood will then be transferred to Renewi's Ghent facility where they will further process the wood in a new installation so that it fulfills the technical specifications requested by ArcelorMittal. The on-spec wood will then be sent to the pre-handling facilities at ArcelorMittal Ghent.

[22] Benelux is a portmanteau formed from joining the first few letters of Belgium, Netherlands, Luxembourg.

5.1.3.4 Sourcing and pre-processing

Three industrial partners of the TORERO project will collaborate in the international case study. All are members of the MUSIC consortium:

- ArcelorMittal is the world's leading steel producing company and has an industrial presence in 19 countries around the globe, implementing torrefaction technology at its steel mill in Ghent.
- Renewi, a leading waste management service provider, recycler and supplier of secondary raw materials. Renewi collects, treats and processes waste, from which valuable raw materials are generated.
- Technology provider Torr-Coal, a SME specialized in the torrefaction process.

5.2 Biomass availability

5.2.1 Waste wood

Renewi is one of the bigger waste management companies in the UK and the Benelux. Waste wood belongs volume wise to the bigger waste streams Renewi is dealing with. The biggest waste streams are residual waste, polluted soils and inerts. The activity of Renewi consists of the collection, transport, sorting and pretreatment to generate raw materials with appropriate qualities for the market. Renewi is transforming towards a raw materials supplier for which qualities become more and more important. It is the ambition to generate more and more end products. Some examples of biomass end products are cat litter from wood, wood pellets for stoves, compost, etc.

The most valuable waste wood quality is called A-wood as indicated above. It consists of untreated wood such as pallets. A-wood quality is collected and pretreated (size reduction, removal of metals, removal of non A-wood particles) to generate an appropriate quality for panel board industry, cat litter and wood pellets. A special grade of pellets is sold to the biomass pyrolysis plant in Hengelo (Netherlands), discussed in Chapter 2 of this document. The amount of pure A-wood collected in Benelux is limited.

B-wood consists of treated wood such as the different types of panel board, fiber board, painted wood, multiplex, tropical hard wood, … Most waste wood is collected as a mixture of B-wood with a limited amount of A-wood. This so called AB-quality is treated to sort as much as possible A-wood from the mix. The total waste wood market in Belgium and the Netherlands is considered to be around 2.5 million ton/a. Renewi has 25% of the Belgium market and more than 30% of the market in the Netherlands.

C-wood consists of wood treated with harmful wood preservation products. The total volume of C-wood as waste is small compared to the above mentioned mix.

The division into different waste wood qualities is due to legal restrictions in the use of the different waste wood qualities. C-wood is considered hazardous and can only be treated in installation certified for the treatment of hazardous waste. B-wood contains paints and different types of glues. Only certified installations can treat this type of waste wood. B-wood is not suitable to make pellets that can be used by households. However, it can be used to generate heat and power in certified power plants.

Renewi collects and treats wood and transports the wood to various customers within and outside Benelux. Most customers do not use stringent specifications for which much screening efforts are required. If screening is required, up to now this did not generate an outlet problem for the one or the other fraction. Also for the volume of fines obtained as a result of screening, a market outlet was available.

As for indicative quantities, annually about 900 ktonne (2012) of waste wood is used in Flanders for the products of energy (power, heating, cooling) and about 500 ktonne (2012) is used for chipboard and engineered wood. Flanders imports waste wood from other European countries (2012: 510 ktonne) and from other parts of Belgium (2012: 110 ktonne). The bulk of the imported waste wood is used for energy production. Flanders exports waste wood to 3 countries only: Germany, Netherlands and Sweden (2012: 115 ktonne)[23].

5.2.2 Waste-derived residues

Besides waste wood, several other interesting wastes can be used as carbon feedstock. Renewi is the biggest green waste collection and treatment partner in Belgium and the Netherlands with over 400 ktonne of greenery waste collected and treated. Green waste is converted into compost. Around 50% of the input results in compost. The remaining branches and trunks are used for energy recovery. Green waste is a local market.

Paper and cardboard waste is also a potential carbon feedstock. Paper and cardboard waste is of course recycled for its fiber and used in the production of new paper and cardboard with various applications. Most paper and cardboard is collected separately and the quality is good enough for sale to the paper and cardboard mills. Recycling percentages of paper and cardboard are high reaching up to 90% depending on the country. However, still part of the waste ends up in the residual waste fraction or is too dirty for recycling. Paper and cardboard are collected locally but the sale of waste paper and the sourcing by paper mills is a global market. More than 30 million tons of paper and cardboard are used annually for packaging purposes in Europe.

A new and growing separately collected waste stream is the organic waste fraction from cooked food and food scraps. This wet fraction is treated and send to digestion facilities to generate bio-methane for power and heat production. Other technologies use this fraction for oil extraction. Specific companies target the collection of specific fractions such as peels of oranges to generate essential oils.

[23] VIL, Flanders Recycling Hub: Rapportage Marktschets (werkpakket 1), URL: https://vil.be/wp-content/uploads/2017/04/Flanders-Recycling-Hub-Rapportage-marktschets.pdf

Other carbon containing wastes that are collected separately are sludges, manure, oils and animal waste.

5.3 Framework conditions

5.3.1 Plants using waste wood as feedstock

Several energy plants that will use waste wood are under development in the direct or wider surroundings of the ArcelorMittal Ghent site. Among the energy plants that are anticipated to be commissioned between 2020 and 2022 are:

- Unilin - Wielsbeke (a producer of flooring, panels and insulation material) will use energy generated from waste wood to drive its processes. The necessary amount of waste wood is expected to be 160 ktonne/year.
- Belgian Eco Energy - Ghent (a local energy company) will generate energy from waste wood. The necessary amount of waste wood is expected to be 135 ktonne/year.
- Indaver - Antwerp (a waste processer and recycler) will generate heat and electricity from waste wood. The necessary amount of waste wood is expected to be 150 ktonne/year.
- Two energy plants in Germany and one in the Netherlands, close to the Belgian border. These plants would need a total amount of waste wood of 390 kton/year.

The energy plants in Wielsbeke, Ghent and Antwerp are the last ones of this type that will receive financial support from the Flemish government. Additionally, in the same period, the material recycling capacity of waste wood is expected to increase with 200 ktonne/year. Due to these developments a local shortage of waste wood is expected. Case study partners ArcelorMittal and Renewi will explore alternative sources of biomass feedstock. This will include sourcing similar feedstock (waste wood) from other nearby regions and using alternative feedstock (like SRF, RDF, and wood-plastic mixes).

5.3.2 Legislation on waste wood treatment

In Flanders, the regional government intends to actively steer the usage of waste wood by employing policy instruments. In 2020, a new action plan regarding biomass treatment for the next years will be published. This action plan will favor recycling processes over energy recovery processes. Furthermore, there is a possibility that incineration of waste wood will be taxed.
These measures, combined with the recent investment in new facilities mentioned above result in an uncertain, unpredictable market situation for waste wood in Flanders.
The new energy related and financially supported (*Groenestroomcertificaten*; in English: renewable electricity certificates) initiatives in Flanders will disturb the waste wood market. The regional Flemish market will change from an exporting market towards an importing market of

B-wood. The market will change from a push towards a pull market. It will become more difficult to compete against these new infrastructures to collect wood for other purposes.
The energy policy of the Flanders government is not always in line with the materials policy of the Flemish waste agency. Future energy plants using waste wood will in general no longer receive renewable electricity certificates. The mentioned energy plants will be the last of their kind qualifying for renewable energy production grants.

5.4 Physical infrastructure

5.4.1 Transport connections for AMG site

ArcelorMittal Ghent (AMG) is well connected by railroad and waterways. The figures below show the connection of AMG to the railroad network and the waterways respectively. As can be seen from Figure 28, the Ghent site is connected to the North Sea via the sluice system at Terneuzen.

Figure 27: Railroad network of Belgium

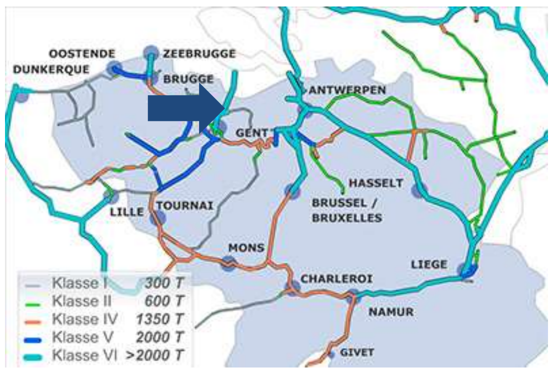

Figure 28: Waterways of Northern Belgium

For the Torero project, Renewi will supply AMG with clean shreds. The distance between the Ghent sites of the two companies is just 3.5 km. Both sites are located on the Ghent loop (R4) and easily accessible for transport by road as they are located near the E17, E34 and E40 major highways.

5.4.2 Biomass sourcing

Renewi operates over 200 waste collection and treatment sites. A large part of these sites are used to collect waste wood. The current pretreatment of waste wood for existing customers consists of local shredding with mobile systems to generate wood with a particle size in line with the specifications of the customer. Wood is transported to local customers by trucks. Exports of wood (longer distance) to Scandinavia or Germany are performed by boat from Renewi sites having a quay.

The torrefaction process and the application of bio coal in the blast furnace requires additional screening of waste wood. Additional screening will remove the small fraction which contains most of the inerts. The resulting product is called the clean shreds. The required waste wood capacity no longer allows to operate with mobile systems. A dedicated facility for the production of clean shreds production will be established at Renewi's Ghent site. The facility will consist of a wood storage area, pre-shredder, high capacity mill and sieving infrastructure. The product will directed be loaded in walking floors and transported to the AMG site. Wood will come from the different Renewi sites nearby their Ghent site.

5.4.3 Torrefaction installation

5.4.3.1 Pre-handling and drying

The pre-handling section at the AMG site (see Figure 29) mainly serves as a buffer capacity to ease the transition from a batch wise supply to continuous operation. Furthermore, a screening installation is in place, which ensures that the feedstock material falls within the design specifications. Before the feedstock is transported to the reaction section it passes a drying installation.

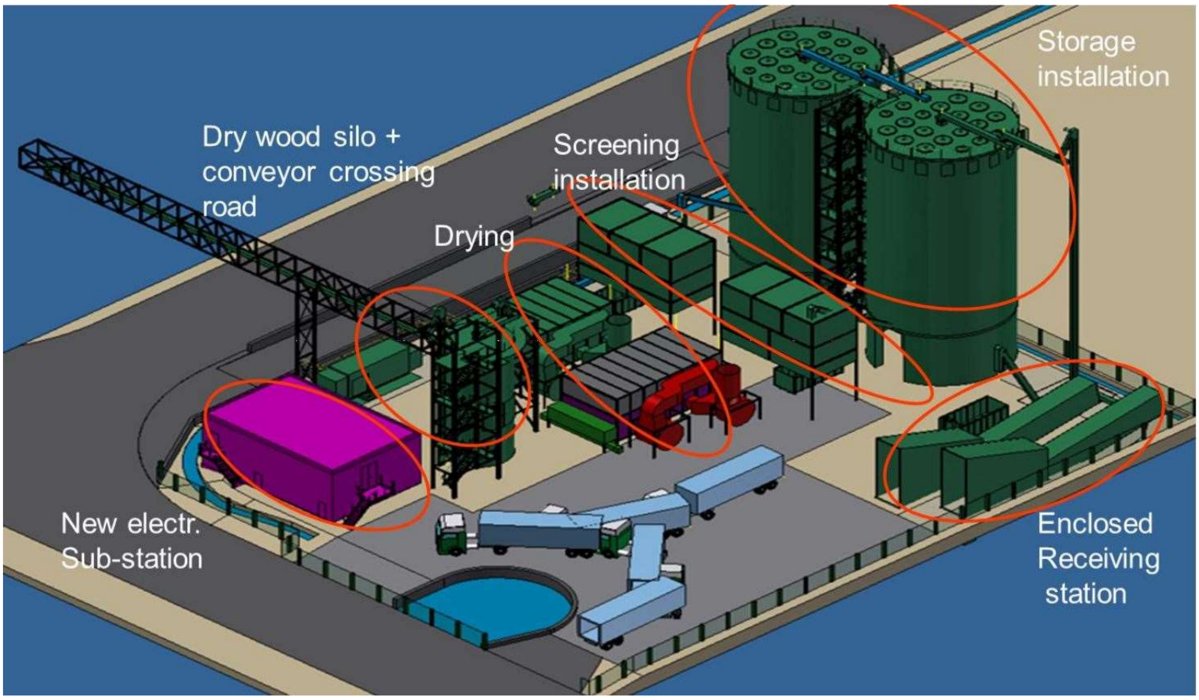

Figure 29: Pre-handling and drying section at the ArcelorMittal site in Gent (Belgium)

5.4.3.2 Torrefaction and grinding

The pilot testing of the torrefaction of waste wood will be performed on Torero 1. This installation will have an input capacity of 7.5 ton/h, thereby producing 4.6 ton/h of bio coal. The bio coal will be simultaneously evacuated and cooled by a cooling screw. The reaction section will be coupled to a grinding installation, as shown in the figure below. The pulverized bio coal will be transported to the powdered coal bunkers, from where it will be injected in the blast furnaces. After successful tests on Torero 1, commissioning on Torero 2 will start, enlarging the intake capacity of the plant to around 100 kton/year.

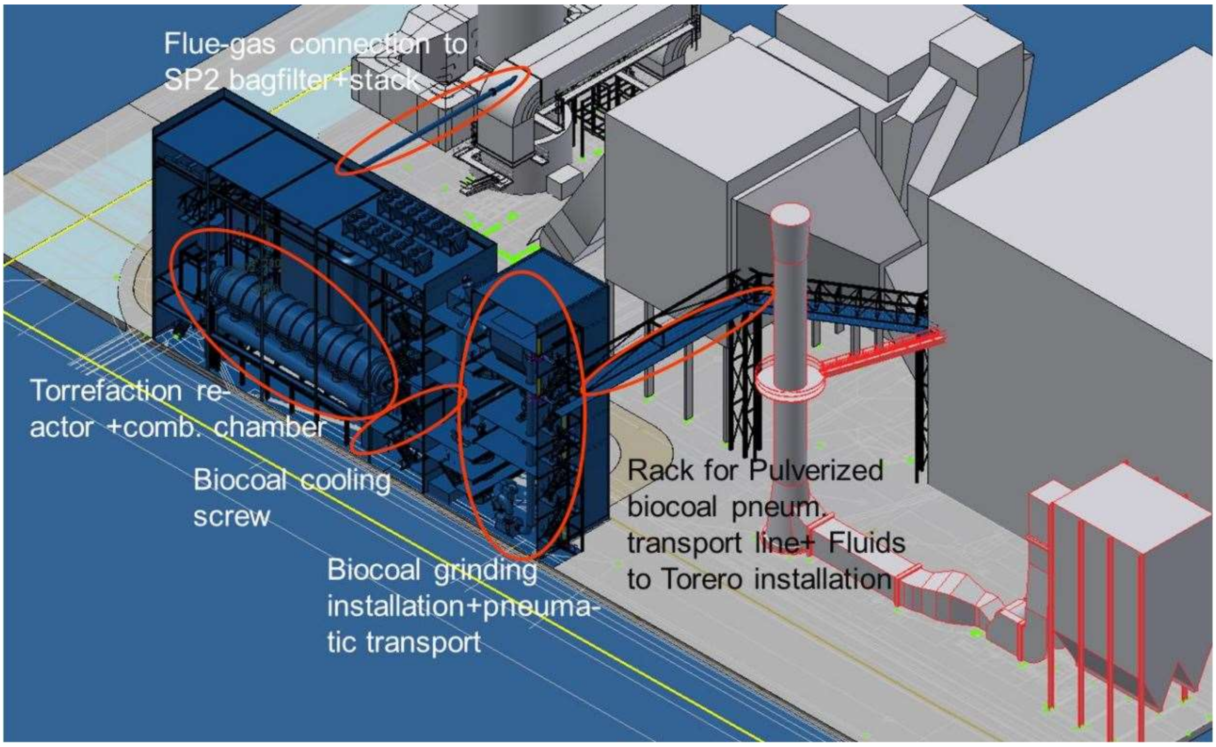

Figure 30: Torrefaction and grinding at the ArcelorMittal site in Gent (Belgium)

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