Market Uptake Support for Intermediate Bioenergy Carriers

D3.8: National strategies and recommendations

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Executive Summary

The importance of Intermediate Bioenergy Carriers (IBCs) is growing, as they can ensure a more efficient utilisation of biomass feedstocks from agricultural and forest residues (Thrän et al. 2019). Therefore, market uptake is foreseen for fast pyrolysis bio oil (FPBO), torrefied biomass (TB) and microbial oil (MO). It is crucial to develop adequate strategies and recommendations to support market implementation while paying attention to a changing macro-environment. We analysed several promising value chains in Sweden, Finland and The Netherlands (FPBO, Nordic Case Study, Figure 1), Italy (TB and MO, Case Study Italy, Figure 2), Greece (TB, Case Study Greece, Figure 3) and Belgium/Europe (TB, Case Study International, Figure 4) with an adopted PESTEL method (Achinas et al. 2018, Blümel et al. 2023). Enabling and hindering factors affecting the value chains collected during interviews, stakeholder workshops and from the literature were ordered into PESTEL+I categories (political, economic, social, technological, ecological, legal, infrastructural, Table 1, Table 3, Table 5, Table 7). The results were feed into a SWOT/TOWS matrix to combine enabling (E) and hindering (H) factors and to finally develop strategies supporting IBCs market uptake (Table 2, Table 4, Table 6, Table 8).

The results show that the market uptake of IBCs such as FPBO and subsequently produced biofuels is driven by the European Renewable Energy Directive II (RED II) (EU 2018/2001). In Annex IX, Part A (o) several forestry and agricultural residues are listed as potential feedstocks for advanced biofuels which can be double counted towards the 14% renewable energy share goal in the transport sector in 2030. These legal European obligations and their implementation into national law of EU member states create strong incentives for many downstream market actors to adopt advanced biofuel. However, technological challenges for some of the observed IBCs, ongoing standardisation processes and frequently changing regulatory guidelines specifically in regards to sustainability criteria (e.g. for specific biomass originating from forestry) still hamper fast market uptake.

Some of the strategies and recommendations in this report D3.8 might be helpful to stakeholders who are engaged in market uptake of IBCs to contribute to a more sustainable and independent resource base in Europe.

Table of Contents

List of Figures

List of Tables

Abbreviations

CCS	Carbon Capture and Storage
CCU	Carbon Capture and Usage
CHP	Combined Heat and Power
CS	Case Study
Dx.x	Deliverable
DRI-EAF	Direct Reduced Iron – Electric Arc Furnace
E	Enabler
EU	European Union
FPBO	Fast Pyrolysis Bio Oil
H	Hindrance
+I	Infrastructural
IBC	Intermediate Bioenergy Carrier
ICC	Intermediate Carbon Carrier
MUSIC	Market Uptake Support for Intermediate Bioenergy Carriers
PESTEL+I	Political, Economic, Social, Technological, Environmental, Legal and Infrastructural
RDF	Refuse-Derived Fuel
REDII	Renewable Energy Directive
SRF	Solid Recovered Fuel
SWOT	Strengths, Weaknesses, Opportunities, Threats
Tx.x	Task
TOWS	Threats, Opportunities, Weaknesses, Strengths
WPx	Work Package
WS	Workshop

1 Introduction

Intermediate Bioenergy Carriers (IBCs) are fast becoming a valid form of renewable energy for the replacement of fossil fuels and they could support the establishment of a sustainable bio-economy (Thrän 2015, Thrän et al. 2018). “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 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. [...] 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.” (WIP Munich 2021, Reumerman et al. 2021).

To facilitate IBCs market uptake, it is fundamental to engage different groups of stakeholders and to analyse the macro-environment of IBCs supply chains. Within the MUSIC project, Work Package 3 (Stakeholder engagement and mobilisation) focuses on engaging different groups of stakeholders, and assessing their views on IBC, with the aim of developing recommendations on supply chain development. Deliverable 3.8 aims to propose strategic recommendations to establish a positive environment for IBCs and to overcome hindrances. As the macro-environment differs across case study regions, tailor-made recommendations were proposed for each case study (CS) region (Nordic CS (Sweden, Finland), CS Italy, CS Greece, CS International (Belgium, Europe and beyond). The methodological framework which was applied for our research is based on an expanded PESTEL+I analysis as well as on a SWOT/TOWS analysis (Blümel et al. 2023). In a stepwise process, data were collected through stakeholder workshops, interviews and literature review (Siegfried et al. 2023a,b; Blümel et al. 2023). In a first step stakeholder factsheets containing information on important stakeholder groups of the value chain were prepared. During workshops the most important macro-environmental factors affecting the IBC value chains/solutions were defined by project partners/experts. These factors were categorized in a first preliminary PESTEL table (political, economic, social, technical, ecological, legal, infrastructural factors). Subsequently, the stakeholders relevant for a chosen value chain in each case study region were named by the project partners and expanded which resulted in preparation of regional maps of stakeholder settings (stakeholder maps) and a comprehensive stakeholder list. To verify data collected during the workshop and to supplement primary data collection by further market-relevant information, semi-structured interviews with experts (of all stakeholder groups) were held. Data triangulation was applied during the analysis process to avoid influence of a single perspective or bias. Factors collected within WP3 provided the baseline for determining and analysing hindrances and enablers along the IBC supply chain. Afterwards, hindrances and enablers for IBC market uptake were strategically combined in SWOT and TOWS matrices. Proposals for strategies and recommendations could be produced. Based on their unique regional macro-environment, recommendations tailored to each CS are presented in the four following sections.

2 The Nordic Case Study:

"Production of Fast Pyrolysis Bio Oil (FPBO) from sawdust and upgrading to advanced marine biofuel"

2.1 Introduction "The Nordic Case Study"

A value chain of converting woody biomass (sawdust, forest residues) into IBCs such as FPBO to produce biofuels in a Northern European region was the main object of investigation (D5.3, D5.5, Reumerman et al. 2021, 2022). FPBO can be used for replacement of fossil fuels in CHP plants (A), for co-processing in FCC units in refineries to produce advanced biofuels (B), for the upgrading to advanced biofuel for the marine transport sector (C), and for the fractionation in a biorefinery for bio-based materials and chemicals (D) (Figure 1, Siegfried et al. 2023b). Large quantities of sawmill residues and fresh forest residues available in Northern Sweden and Finland could be used for production of pyrolysis oil. This pyrolysis oil could be transported by ship to the Netherlands, were upgrading to marine biofuel would take place.

FPBO is already produced in several plants at commercial scale in the Netherlands. The FPBO here is used in a boiler to produce heat at a dairy plant in Borculo. In a similar highly efficient plant in Finland sawdust serves as the raw material for FPBO production, and steam released in the process is used internally for drying the biomass. When the feedstock is already dry, surplus steam is available for external users. The first plant in Lieksa, Finland will produce 20 million litres of FPBO per year that will be used for various offtake customers in Finland and Europe. In the commercial Pyrocell production plant in Sweden, FPBO produced is co-processed in a fluidized catalytic cracker (FCC) of Preem's Lysekil refinery to produce gasoline fuels (Fortum 2013). Several factors, however, are still limiting the further upscaling of FPBO production, which were elaborated in this report and elsewhere (Table 1 and 2, Siegfried et al. 2023b).

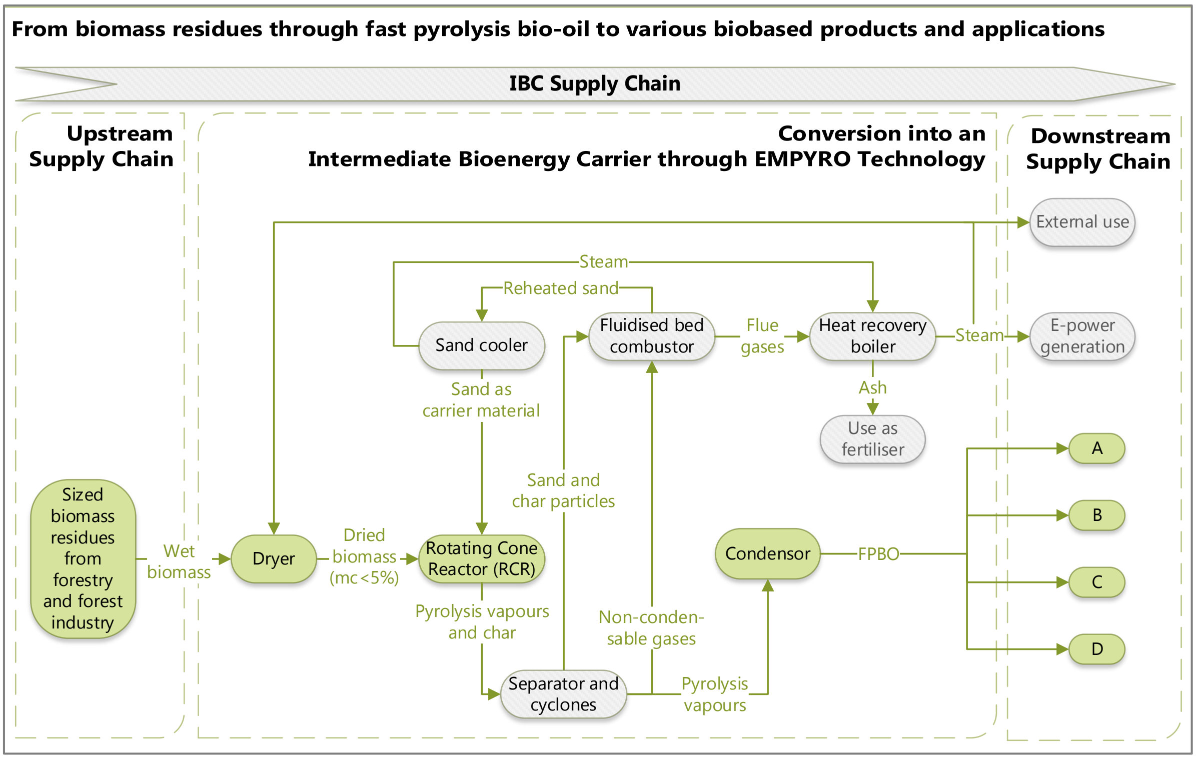

Figure 1. Potential supply chain of converting forest residues (sawdust) to Fast Pyrolysis Bio-Oil (FPBO, Siegfried et al. 2023b)

2.2 Macro-environment of “The Nordic CS” – PESTEL+I

Table 1. Macro-environmental factors affecting the potential value chain of the Nordic case study (H-Hindrance, E-Enabler)

PESTEL category/code	Nordic
Political (P)	Sawdust as a forest residue widely abundant in parts of Northern Sweden and Finland is included in RED II Annex IX Part A (o) (EU 2018) (E) Advanced maritime and aviation fuels can be multiplied 1.2x towards the mentioned targets. (E) Advanced biofuels made from forest residues and FPBO can provide a sustainable and environmentally friendly option to replace unsustainable biofuels based on palm oil. (E) Today, potential investors may not support FPBO upscaling because of more cost-efficient alternatives still available on the market. (H) In the Netherlands from 2025 onwards, the generation of so-called HBEs (hernieuwbare brandstof eenheden=renewable fuel units) by blending fossil maritime and aviation fuels with biofuels may not be supported anymore. (H)

Economic (E)	FPBO as an IBC enables cost-efficient and climate-friendly transport of energy resources from regions with abundant resources and low energy demand to countries with low biomass availability and high energy demand (e.g. energy consumption inland water-ways and domestic maritime transport per year is in Sweden 3.8 PJ, and in Germany 9.7 PJ (EU 2021). (E) CAPEX and OPEX for pyrolysis plants are mostly high and such high capital investment requires a certain security and reliable forecast of market profits and price stability, which is not given at the moment. (H) POME, PFAD, UCO are likely to first meet the demand of customers because of low price, easy handling (H) Currently, prices for renewable advanced biofuels made from FPBO estimated at 1,750 €/t (Van de Beld & Muggen 2015) would be in the range of prices of conventional biofuels (e.g. SME biodiesel 1,500-1,600 €/t, FAME biodiesel 1,700-1,800 €/t, (NESTE/Platts 2022) and more than double the current fossil fuel prices. (E)
Social (S)	The new biofuel industry and related value chains will create new employment opportunities, support rural development and helps to protect the climate if certified sustainable and ecologic forest and feedstock management practices are implemented (E). Limited amount of skilled labour is available in remote areas (H). Decreasing public acceptance of usage of woody feedstocks for biofuels production. (H) Contrary, some studies mention more nuanced results of management intensity, species composition and close-to-nature forest management concepts (Bauhus et al. 2017, Bollmann et al. 2013, EOS 2018). (E)
Technological (T)	Deoxygenation of FPBO by hydrogenation yields so-called hydrotreated Pyrolysis Oil (HPO), which can be blended directly with common fuels such as diesel (use as marine fuels, aviation fuels) (E) Fast pyrolysis increases bulk density (BD) (sawdust 280 kg/m3 to FPBO 1,200 kg/m3) (E) 6-fold increase in the energy density by fast pyrolysis of biomass compared to sawdust (E).
Ecological (E)	Saw dust must originate from certified sustainable managed forests (H) Increasing competition and large-scale demand for saw dust could lead to unsustainable forest management (H)
Legal (L)	REACH registration, Import/Export EU permitted (E) Several standardisation processes and guidelines define the market framework for FPBO and derived fuels. The ISO 8217:2017 and the IMO guidelines (IMO 2018) are setting the quality standards and benchmarks for fuels used in ships and the marine sector. (H) FPBO as a flammable liquid will be likewise classified as a hazardous substance with additional costly safety measures. (H) Guidelines defining the transportation/shipping of fuels are set by the Economic and Social Council (ECOSOC) Committee of Experts on the Transport of Dangerous Goods. The IMO is responsible for maritime transport and the Intergovernmental Organisation for International Carriage by Rail (OTIF) for rail transport. (H)
Infrastructural (I)	320,000 raw tonnes (t/yr) of sawdust could be potentially available from several sawmills near the cities of Piteå and Sundsvall. A number of about 12 sawmills in Lieksa (North Karelia), Lisalmi (North Savo) as well as in Kainuu regions in Finland could potentially provide approx. 263,000 raw tonnes (t/yr) of sawdust (E)

	Produced amounts of sawdust varies and depends on produced amounts of sawn wood for other applications (H) FPBO conversion reduces transport costs compared to bulky biomass such as sawdust. (E) Investment and purchase of large volumes of FPBO is discouraged by recent in-adequate production capacities of only 6 commercial-scale plants in the EU (the Netherlands, Sweden, and Finland) and Canada with a total capacity of 180,000 kt/yr which equals approximately 2.9 PJ (Prussi et al. 2022) (H) The lower energy content of pyrolysis oil of about 18-20 GJ/ton (Reumerman et al. 2021) compared to fossil crude oil with 40-46 GJ/tonnes leads to higher transportation and storage costs for FPBO compared to fossil oil. (H) In the past decades the pulp and paper industry from Northern Sweden and Finland has moved further south and closer to larger cities, which created an economic and social de-cline in some Northern areas. (E) The construction of FPBO production and upgrading units and transport and storage infrastructure in remote regions of Northern Sweden and Finland will create new value chains and markets for regional companies and the local forest industry (E). Missing infrastructure in remote regions, which needs to be built by skilled labour (H). Heating of storage tanks is required in cold regions and seasons to keep the temperature of FPBO > 0°C. (H) Continuous stirring of FPBO required to keep a homogeneous quality (H). To prevent corrosion, stainless steel should be used as the storage tank material be-cause of the acidic character of the FPBO. (H)

2.3 Strategies and Recommendations for "The Nordic CS" – SWOT/TOWS Matrix

Table 2. SWOT/TOWS Matrix for the "Nordic CS" (+I = Infrastructural factor)

INTERNAL FACTORS / EXTERNAL FACTORS	**S (Internal Strength) – enablers:** **(S1)** Sawdust included in RED II Annex IX Part A **(S2)** FPBO enables biomass transport to low biomass countries (+I) **(S3)** FPBO conversion reduces transport cost (+I) **(S4)** Fast pyrolysis increases bulk density (+I) **(S5)** 6fold increase of the energy density of (saw dust) biomass (+I) **(S6)** Large abundance of sawdust in Northern EU (+I) **(S7)** Currently a hazard assessment classification of FPBO is prepared **(S8)** REACH registration of FPBO enables trade and import in EU	**W (Internal Weakness) – hindrances:** **(W1)** Investment discouraged by few commercial scale plants (+I) **(W2)** High CAPEX and OPEX for pyrolysis plants **(W3)** Low energy content pyrolysis oil compared to fossil fuels (+I) **(W4)** Heating of storage tanks required in cold regions (+I) **(W5)** Continuous stirring of FPBO required during storage (+I) **(W6)** Acidic character of the FPBO causes corrosion, metal content interferes with catalysts during upgrading in Fluid Catalytic Cracker **(W7)** Classification and certification process not finalised of what?
O (External Opportunities) – enablers: **O1)** Decline of the pulp and paper industry in the North creates unused feedstock potential (+I) **(O2)** FPBO industry creates new value chains for regional companies and the local forest industry (+I) **(O3)** Upgraded FPBO (FCC and/or deoxygenation) could serve demand for sustainable aviation ad maritime fuels	**Strategy 1:** International stakeholders and industry should form associations to promote forest residues use for advanced biofuel production and inter industrial sector communication. **Strategy 2:** Feedstock quality and advancing biofuel production technology opens up new markets for the biomass that is converted into FPBO. **Strategy 3:** Further investigate technological possibilities along with certification processes to upgrade FPBO to advanced sustainable aviation fuels. **Strategy 4:** Forestry industry/refineries should invest increasingly in the installation of a FPBO plant because they could use their own resources of own plants nearby, establish regional value chains, reduce dependence on imports. **Strategy 5:** Additional feedstock types should be exploited: looking for adequate partners should be one of the first steps; e.g. (a) from wood and waste chains; (b) first thinning ground, raw wood; (c) remnants of natural disasters and similar.	**Strategy 6:** Missing long-term operation of only 6 FPBO plants indicates investment insecurity. Incentives can only be provided by further nationally initiated funding programs; FPBO must be included in new business concepts combined with other renewables. **Strategy 7:** Producing advanced biofuels nearby the FPBO plant and exporting the final fuel to other countries may be the easier option compared to exporting FPBO as an intermediate. **Strategy 8:** Therefore, it needs to be elaborated if FPBO-based biofuels may have a competitive advantage over biofuels based on residues of palm oil production in terms of costs in the future. **Strategy 9:** Construct FPBO plant near planned green hydrogen production sites and other industrial installations (pulp mills, refineries) to use synergies.
T (External Threat) – hindrances: **(T1):** POME part of RED II Annex IV, part A, will serve demand **(T2)** In the Netherlands from 2025 onwards blending fossil maritime and aviation fuels with biofuels may not be possible anymore **(T3)** Currently, prices for renewable advanced biofuels made from FPBO higher than other biofuels **(T4)** Decreasing public appreciation of usage of woody feedstocks for biofuels **(T5)** Supply of sawdust from sustainably managed forests must be regularly audited and certified	**Strategy 10:** Creation of a long-term database, which continuously provides information about the availability of sustainable forestry feedstock, based on reliable data and controlled by independent institutions. **Strategy 11:** Prevailing misunderstanding of different biofuel generations; campaigns are needed in which it is clarified that (a) advanced biofuels do not compete with food production chains, (b) feedstock used has to undergo certification processes, (c) assessment of the biofuels life cycle is made, (d) biodiversity issues are considered.	**Strategy 12:** Further R&D activities on FPBO quality, adapt characteristics according to the requirements of the engines that represent the most promising application field (e.g. eliminate metal content because already small contents are problematic for FCC units in refineries). **Strategy 13:** FPBO quality determines application, always investigate the best fitting purpose in order to reach the highest value, clearer allocation of specific feedstock to specific applications/processes, e.g. lower quality FPBO could serve as a fuel for CHP plants in Sweden. **Strategy 14:** ASTM standardisation requirements, currently prevent the application of FPBO in SAF -> Further R&D activities on FPBO, adapt characteristics according to the requirements of plane engines.

3 The Case Study Italy:

"Microbial oil production from agricultural residues and dedicated crops grown on marginal lands"

3.1 Introduction "The Case Study Italy"

The "Case Study Italy" as an advanced case elaborated on the collection of agricultural residues (olive tree, vine prunings) and *Arundo donax*, conversion of these biomasses by slow pyrolysis and subsequent application in steel mills to partly replace coal coke. The research findings were reported previously in detail in deliverable reports of the MUSIC project (D5.3, D5.5, Reumermann et al. 2021, 2022). The value chain is to some extend similar to the "International Case Study" described below.
As a strategic case study, the production of microbial oil by converting ligno-cellulosic agricultural residues and dedicated crops grown on marginal lands to sugars via enzymatic hydrolysis, successively fed to specific microorganisms was investigated (Figure 2). The microbial oil should be further used in biorefineries as a feedstock for biofuel (i.e. HVO diesel) production. The following findings are based on investigations of the value chain concentrating on microbial oil as a final IBC product (Table 3 and 4, strategic case study, D5.5, Reumerman et al. 2022).

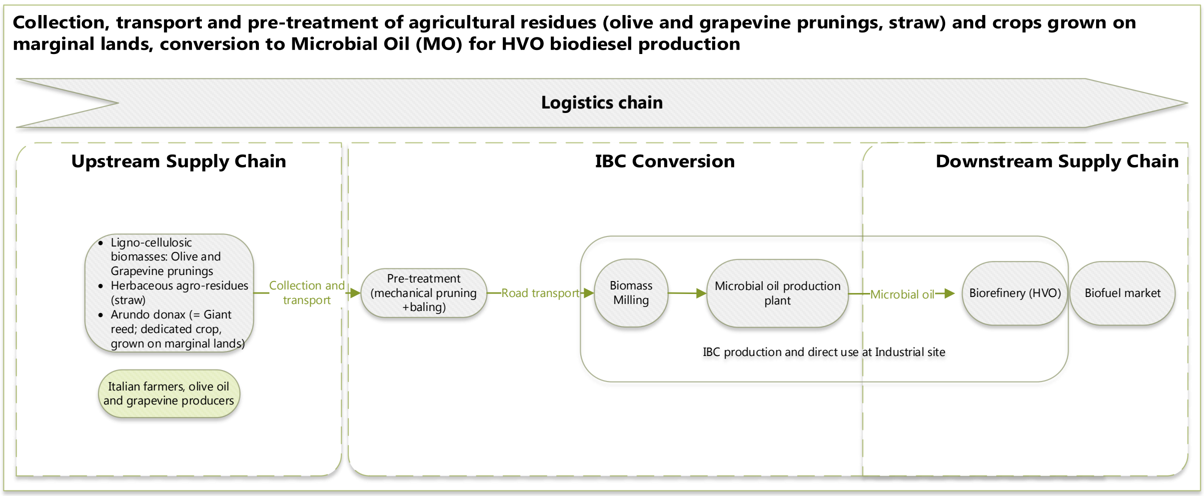

Figure 2. Potential supply chain of converting agricultural residues and dedicated crops grown on marginal lands to Microbial Oil (MO).

3.2 Macro-environment of "The Case Study Italy" - PESTEL+I

Table 3. Macro-environmental factors affecting the potential value chain of the case study Italy (H-Hindrance, E-Enabler)

PESTEL category/code	Italy
Political (P)	ENI commitment to phase-out palm oil by 2023 in the frame of EU directive high-ILUC + net zero emissions by 2050, including the feedstock switch in biorefinery production (E) Policy implementation and bureaucracy are crucial barriers of Italian legislation (H)
Economic (E)	Veneto as a potential region for MO production is one of the richest, most productive and well-developed regions in Europe, holds a high GDP and presents a widespread transport infrastructure network. Veneto holds the 10 % share value of the Italian agricultural production (E) Main sectors are industrial crops, viticulture and meat livestock. (E) MO biorefinery are not as productive in terms of cost-benefits and technology up-scaling is still in an early stage (H)
Social (S)	Rural development (biomass job opportunities, new biomass business models could be successful and support local (energy) resources supply (E) Unsustainable traditional agricultural practices and beliefs are rooted in agricultural production and hence hard to modify (H)
Technological (T)	Uncertainties about biomass availability (H) Agricultural residues that are burnt are the ones that are difficult to handle/process, cost benefit of collection, storage and conversion by fermentation may not be favourable (H)
Ecological (E)	Optimized management of forested lands and re-cultivation of marginal lands could lead to reduction of wildfires and improve water storage and climate change resilience (E) Illegal wood market prevents regulation and management of residues use for IBC production (H) Water scarcity and a poor water infrastructure system in southern Italian regions hamper the cultivation of bioenergy crops and it may negatively affect tree crops and derived amounts of biomass residues (H)
Legal (L)	Ban on burning agricultural residues. Art. 256 Legislative Decree 152/2006 opens up new usage options (E) Existence of forest owner associations and agricultural associations in some Northern Italian regions beneficial for IBC supply chains (E)
Infrastructural (I)	The Porto Marghera bio-refinery is the first conventional refinery to be converted into bio-refinery in 2014. Future upgrades planned, including an increased processing capacity to 560,000 t/a (E) Wine industries and other farms (olive) are rather small (ca. 3 ha) and scattered + the concept of reusing agricultural residues recently not applied anymore or is inefficient (H) Unavailability of biomass collection and transport logistics, storage and trading centres (H)

3.3 Strategies for "The Case Study Italy" – SWOT/TOWS Matrix

Table 4. SWOT/TOWS Matrix for "The Case Study Italy"

INTERNAL FACTORS / EXTERNAL FACTORS	**S (Internal Strength) – enablers:** **S1:** Producing MO is convenient because some of the upstream processes are already being used i.e. for bioethanol production **S2**: Adding value to by-products and wastes, creation of new value chains/economic opportunities, generating profit for rural areas can extend farmer's business opportunities **S3:** The valorisation of lignin as a by-product, Lignin is normally burnt and therefore reduces electricity costs. Yet, it has a high revenue potential	**W (Internal weakness) – hindrances:** **W1**: MO biorefinery are not as productive in terms of cost-benefits and technology upscaling is still in an early stage **W2**: Uncertainties about biomass availability Agricultural residues that are burnt are the ones, that are difficult to handle/process, cost benefit is not favourable **W3:** *Arundo Donax* bears the emissions from the cultivation process. **W4**: Feedstock is scattered and therefore difficult to collect all at once **W5:** Cost benefit calculation not done yet, not clear if feedstock supply and usage in MO production plant is rentable, detailed data about business model, logistics, capex, opex to be communicated to market
O (External Opportunities) – enablers: **O1**: The new ban on burning agricultural residues. Art. 256 Legislative Decree 152/2006 **O2**: Existence of vineyards in Veneto and Northern Italy **O3**: Rural development (biomass job opportunities, new biomass business models could be successful and support local (energy) resources supply. **O4**: The Porto Marghera bio-refinery was the first conventional refinery to be converted into bio-refinery in 2014. Future upgrades, including an increased processing capacity to 560,000 t/a.	**Strategy 1**: A Biomass purchasing platform should be invented to bring farmers (i.e. wine or oil producers) and end users (biofuels and biochemicals industry) together. **Strategy 2**: Lignin based value chains from lignocellulosic residues must be investigated for different products and applications. **Strategy 3**: Veneto has the infrastructural and agricultural potential for first implementation of the proposed MO biomass value chain.	**Strategy 4**: Policy to support bringing back unused/abandoned land into usage, incentives are needed. Promote rural development and ecological valorisation. **Strategy 5**: Specific cropping systems invention could increase soil fertility, biodiversity and water retention (leguminous crops, agroforestry) **Strategy 6**: Re-cultivation of land through crop cultivation for MO Production. **Strategy 7**: Involvement of the wine industry, wine makers as investors, jointly develop new value chains for residues.
T (External Threats) – hindrances: **T1:** Policy implementation and bureaucracy are crucial barriers of Italian legislation **T2**: Water sources are limited, water scarcity and a related high risk of fires and droughts. **T3:** Wine industries are rather small (ca. 3 ha) and scattered + the concept of reusing agricultural residues recently not applied anymore **T4:** There is a low social acceptance to cultivate crops suitable for biomass/biofuel production, such as *Arundo Donax*	**Strategy 8**: Upscaled IBC conversion/MO refineries should be installed at/near existing industrial and chemical sites, e.g. in Porto Marghera or Gela. **Strategy 9**: Further increase of collaborative technology development activities to accelerate TRL level of MO and support upscaling activities. **Strategy 10**: Found investment hub. Engage and invest in innovative start-ups involved in IBC value chains. **Strategy 11**: Biomass availability must be defined for all Italian regions by application of calculation models for biomass residues. **Strategy 12**: Involvement of associations of agricultural stakeholders (found biomass trade association and centres; e.g. Coldiretti as initiator) Auctions/contracts (long term) **Strategy 13**: Development of specific logistical concepts (e.g. usage of the produced biofuel by trucks that are collecting the agricultural biomass) **Strategy 14**: Small farms, specific/adequate machinery is needed -> organise competition event/pitch with machinery students to develop ideas.	**Strategy 15**: Marginal lands have to be classified regarding their ecological conditions/status and ownership.

4 The Case Study Greece:

“Torrefaction of agricultural residues to replace lignite coal”

4.1 Introduction “The Case Study Greece”

In the “Case Study Greece” it was investigated if agricultural residues (corn residues and straw) could be collected, converted to torrefied biomass and further used as feedstock for district heating plants in Northern Greece in the region Western Macedonia to partly replace lignite coal (Figure 3).

In order to be supplied without any hazzle into feeding systems of district heating plants, corn residues and straw, due to their physical properties, require additional pre-treatment.

To this purpose, the conversion of agricultural residues to Intermediate Bioenergy Carriers (IBC) such as torrefied biomass was considered. IBCs are produced from biomass (forest biomass, agricultural biomass, energy crops, and waste). Biomass is processed via different conversion routes, namely, thermo-chemical conversion, physical-chemical conversion and bio-chemical conversion to energetically denser, storable and transportable intermediate products, analogous to coal, oil and gaseous fossil energy carriers, for easier transport, storage and use than biomass residues. IBCs such as torrefied biomass could contribute to energy security, reduce greenhouse gas emissions and provide a sustainable alternative to lignite in Western Macedonia (Table 5 and 6).

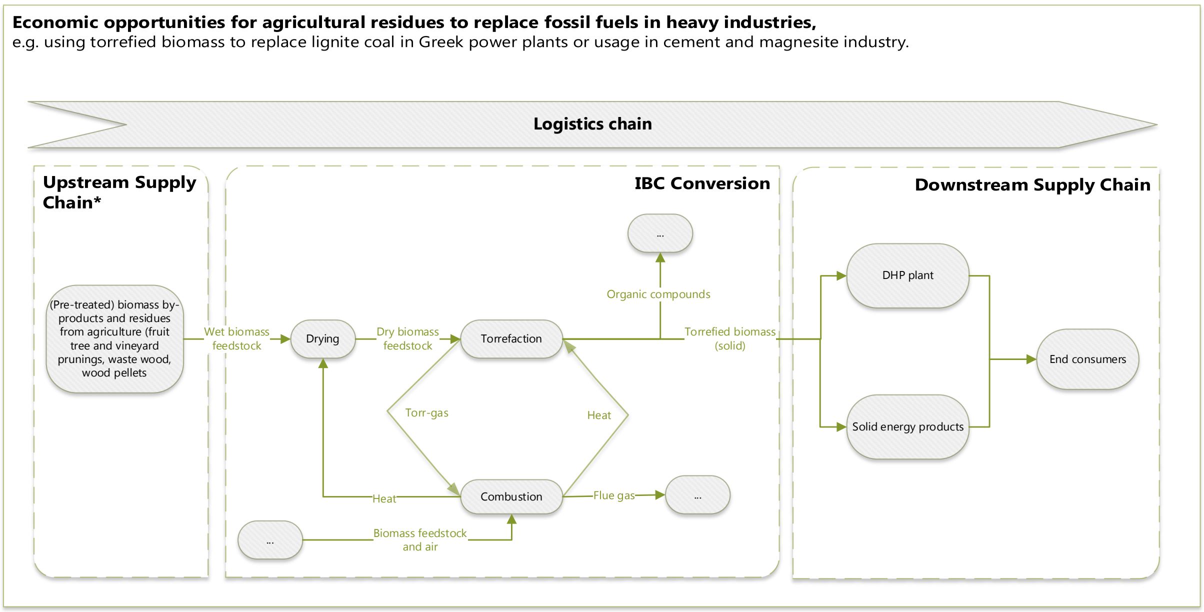

Figure 3. Potential supply chain of converting agricultural residues to torrefied biomass to replace lignite coal in district heat and power plants and in heavy industries.

4.2 Macro-environment of "The Case Study Greece" - PESTEL+I

Table 5. Macro-environmental factors affecting the potential value chain of the case study Greece (H-Hindrance, E-Enabler)

PESTEL category/code	Greece
Political (P)	Lignite phase out (2028) will lead to socio-economic changes, which might push torrefaction into a winning position to replace a part of lignite (E) National energy and climate plan includes biomass logistics (E) Current political situation and gas shortage will extend exploration of lignite mines at least until 2028 (H) Greek government prioritises wind and solar as renewables and use of biomass at first for material applications (H)
Economic (E)	Funding (e.g. public funds, EU funds) available for infrastructure for public companies but also the private sector and also for the transformation to renewable fuels / for a decarbonised economy (E) Farmer and owner associations as gateway to smaller farms -> initiation of collaborations for feedstock collection, storage and transport (E) High competition for woody feedstocks, pellet industry demands large biomass feedstocks (H) Large amounts of torrefied biomass not available, currently no production capacities in Greece (H)
Social (S)	IBC technology and sustainability criteria not known in Greek population and politics (H) Small scale farms have limited capacities to introduce/support alternative and new schemes (collection residues, install storage, adapt cropping procedures) (H) Difficult economic situation of rural farms and companies prevents investment in new technologies and processes (H)
Technological (T)	Permeability, grindability enables industrial applications (replace lignite) (E) Torrefaction improves biomass feedstock quality (homogenisation) and leads to improved handling for several applications (e.g. in district heating) (E) Scattered small farms, collection of residues and storage difficult to organise (H) High qualitative fluctuations (H)
Ecological (E)	Catastrophic droughts reduce available of (woody) biomass (H) Forest management not well organised. (H) Use of (low-cost) woody residues and farming residues (olive kernel, production residues/wastes etc) for heating. (E) Increasing use of residues from forestry could lead to better forest management and hence could contribute to reduction of forest fires (E) Cascading use applications (depending on quality and added value (E)
Legal (L)	From 2023, ban on burning of agricultural residues (E) European legislation REDII not yet fully implemented in Greece (H) Therefor little political and financial incentive to produce IBC from residues (H)
Infrastructural (I)	Small and scattered farms make collection of biomass residues difficult (H) Waste collection and machinery infrastructures can be explored for biomass residues collection (E) Online trading platforms can trigger efficient distribution and handling of biomass residues (E) Strong agricultural area Thessaly is connected through infrastructure (E) High potential of biomass residues availability in the agricultural sector (straw) (E)

4.3 Strategies and Recommendations for "The Case Study Greece" – SWOT/TOWS Matrix

Table 6. SWOT/TOWS Matrix for "The Case Study Greece"

INTERNAL FACTORS / EXTERNAL FACTORS	**S (Internal Strength) – enablers:**	**W (Internal Weakness) – hindrances:**
	S1: Create jobs and additional income of farmers or engage former workers from the lignite industry **S2:** Torrefied biomass is considered to be an effective partial substitute of lignite **S3:** Use of cheap or free of-cost residues and wastes as feedstock **S4**: Energy density of torrefied biomass (15-18,7 GJ/m3) approx. 2x higher then raw biomass (wood pellets: 7,5-10,4 GJ/m3) and in the same range as coal (18,4-23,8 GJ/m3) **S5**: Permeability, grindability enables industrial applications (replace coke) **S6**: High biomass residues availability in the agricultural sector (straw) **S7**: Strong agricultural area Thessaly which is connected through infrastructure	**W1**: Economic viability of the whole system not clear (CAPEX, OPEX, cost-benefit) **W2**: Missing skilled labor and infrastructure (storage, collection and processing), which needs to be built by skilled labor (+I). **W3**: Currently no pilot plant or production plant in Western Macedonia **W4**: Available mobilizable biomass not sufficient for large scale energy applications **W5**: Financial and time constraints often don´t allow technological development/investments as many small farmers can´t afford expensive new machines and extra labor efforts **W6**: Fluctuations in quality and quantity of residual biomass delivery
O (External Opportunities) – enablers: **O1**: Biomass is preferred for material use in policy. **O2**: Promotion of RE synergies, including biomass (possibly co-firing with lignite) **O3**: De-lignification (lignite phase-out) of Greece by 2028 (now postponed to 2035?). Lignite phase out will lead to socio-economic changes, which, push torrefaction into a winning position (supply to CHPs) **O4**: From 2023 ban on burning of agricultural residues **O5**: National energy and climate plan includes biomass logistics **O6**: Funding (e.g. public funds, EU funds) available for infrastructure for public companies but also the private sector and also for the transformation to renewable fuels / for a decarbonized economy **O7**: Farmer and owner associations as gateway to smaller farms **O8**: Cascading use applications (depending on quality and added value	**Strategy 1:** Replace part of lignite by torrefied biomass produced from unused biomass waste (previously burned biomass) and mixed wastes in CHPs and industrial applications **Strategy 2:** Available equipment/machinery must be shared across organisations -> organisation by new intermediate logistics companies which engages former labour from lignite mines -> mining company should be also engaged or should invest/transition of industry to renewables **Strategy 3:** Also, material applications (cascading use depending on quality) of higher quality torrefied biomass should be considered as carbon source e.g. in H2 related technologies and other applications (fertilizer production, cement addition, steel). Support carbon sequestration as a business model for the industry and rural farmers. **Strategy 4:** Establish association of owners from agriculture, forest, other, waste handlers and industry (energy, mining) and municipalities **Strategy 5**: Create incubator to support small innovative start-ups for renewables and regional resources and energy supply -> involvement of population	**Strategy 6:** Analyse economic and ecologic viability of the proposed system on different scales, in different regional context. Construct real pilot plants for torrefaction in Greece. **Strategy 7:** Create Investment fond by regional industry, owner associations and municipality -> Push policy for implementation, implement education program for retraining of farmers, mining workers, … **Strategy 8:** Increase efficiency of torrefaction also for difficult biomass waste feedstocks and mixed waste (SRF, RDF) as feed

T (External Threat) – hindrances: **T1**: The strategy for RE in Greece focusses on wind and solar energies (offshore wind and solar PV), while biomass has still a marginal role. **T2**: Biomass waste from straw, olive pruning and … is used already in the food and wood industries for heating **T3**: Using ICC for energy depends on national legislation and more specifically on the current (slow) implementation of the RED II directive in Greece **T4**: Economies of scale not existent? Continuously available mobilizable volumes of biomass residues too low? **T5**: District heating plants partially run by municipalities (private vs. public purchasing) **T6**: Political instability in Europe leads to heavily fluctuating and rising biomass feedstock and material costs resulting in unstable market price developments. Low willingness to invest. **T7**: Farms and agricultural enterprises are small and scattered	**Strategy 9:** Use synergies with other renewables technologies (H_2, solar, carbon capture, recycling, …) to implement torrefaction **Strategy 10:** Push acceleration of REDII implementation in national legislation and standards **Strategy 11:** Increasingly advocate for sustainable advanced bioeconomy applications at different political levels (e.g. local resources use etc.)	**Strategy 12:** Show and analyze economic viability in a real implementation case and include economic value of ecosystem function and services as well as societal benefit -> reduction of external resources imports, reduction of emissions, increase efficiency of residues use, increase independence from external resources **Strategy 13:** Organize Large scale campaign (in synergy with other renewables initiatives) and support investment and support/subsidize uptake of concept by farmers (collection infrastructure, create storage and pretreatment facilities on former unused or partially abandoned industrial buildings)

5 The Case Study International:

"Torrefaction for steel production"

5.1 Introduction "The Case Study International"

During the Case Study International the steel producer ArcelorMittal (AM) analysed in collaboration with other project partners the potential to expand the use of torrefied biomass to replace a significant portion of fossil fuel (coal coke) used in its blast furnace (Figure 4). Beyond waste wood a number of hybrid feedstocks that are partially biogenic may be used, including SRF (Solid Recovered Fuel) and RDF (Refuse Derived Fuel). The advanced case study investigated a value chain broadening the range of biomass feedstocks to be torrefied at AM's Ghent facility (Torero plant (https://www.torero.eu/)). The strategic case study investigated the logistics and feasibility of torrefied material made from a range of different woody biomass (waste wood) and hybrid (SRF, RDF) feedstocks for use at other AM steel mills in Europe (Table 7 and 8, D5.5, Reumerman et al. 2022).

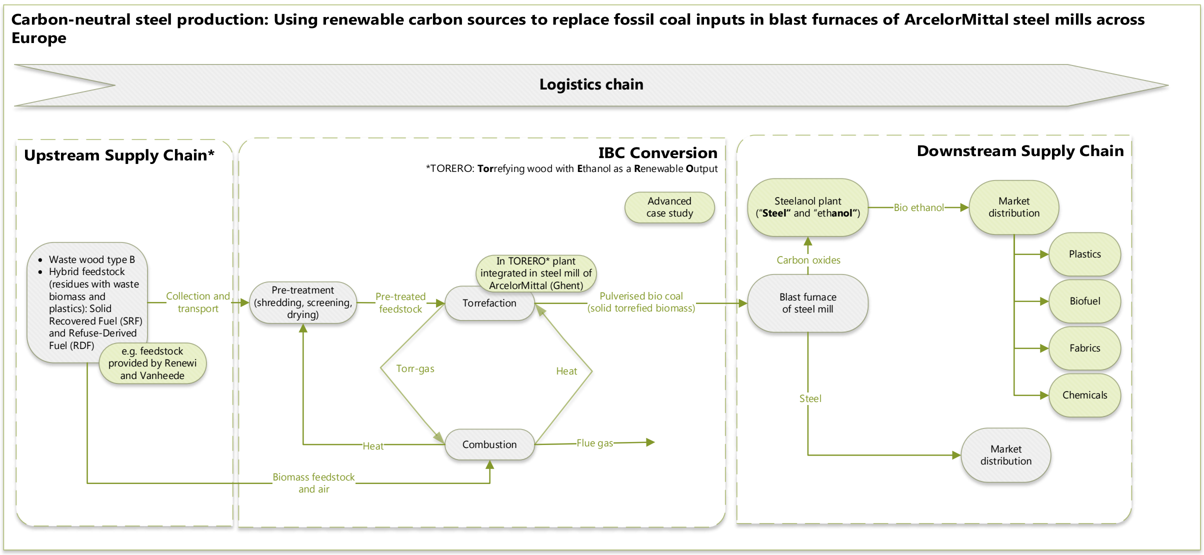

Figure 4. Potential supply chain of converting waste wood and hybrid feedstocks (residues with waste biomass and plastics: Solid Recovered Fuel (SRF) and Refuse-Derived Fuel (RDF)) to torrefied biomass to replace fossil coal coke in steel mills.

5.2 Macro-environment of "The Case Study International" – PESTEL+I

Table 7. Macro-environmental factors affecting the potential value chain of "The Case Study International" (H-Hindrance, E-Enabler)

PESTEL category/code	International
Political (P)	EU sustainability policy limits exploitation of forest residues (H) Change of actual regulations (recycling vs. ignition) in discussion (E) LCA is key for a sustainable application of biomass in steel mills (E)
Economic (E)	Sourcing of cheap biomass feedstock will become difficult because of demand of other higher value industries and related products (chemical industry/biorefinery) (H) Prices of woody residues and waste will increase which could make it uneconomical to use woody feedstocks for energetic applications (H)
Social (S)	Contribution to net-zero steel production will lead to better public acceptance of the steel industry (E) Low acceptance of energetic use of wood (H) Campaigning against bioenergy wood use (H)
Technological (T)	Part of coal coke can be replaced in blast furnaces (E) Specifically adapted torrefied biomass for steelmaking required (high permeability and hardness) (H) Possible application of torrefied biomass as a carbon source in steel material (E) Possible application of torrefaction derived syngas in new steel making processes (DRI-EAF) as reducing gas (E)
Ecological (E)	Exploration of woody residues and mixed wastes for feedstock instead of pellets made from round/stem wood (E) Use of waste wood from catastrophic events, support of forest management may increase biodiversity in some regional settings (E) Exclude wood pellets originating from illegal and unsustainable logging/suppliers (H)
Legal (L)	No uniformity in declaration of waste wood in national legislation(s) across Europe (H) Prevent use of pellets and torrified biomass made of stem wood (H)
Infrastructural (I)	Hybrid waste feedstocks (RDF, SRF) could be available in large amounts in proximity of steel mills (E) Regional feedstock availability not sufficient/economy of scale not in place, long-distance shipping of biomass feedstocks/torrefied biomass to steel mill required (H)

5.3 Strategies and Recommendations for "The Case Study International" – SWOT/TOWS Matrix

Table 8. SWOT/TOWS Matrix for "The Case Study International"

INTERNAL FACTORS / EXTERNAL FACTORS	**S (Internal Strength) – enablers:** **S1**: Production of 2nd generation fuels due to using residues and wastes instead of primary biomass (RED II Annex IX) **S2**: Torrefaction technology does not have that high requirements on feedstock/is flexible regarding the use of different feedstock, respectively mixed wastes (e.g. RDF and SRF) à W5 **S3**: Homogenisation of diverse and bulky biomass wastes through torrefaction (W3) → improvement of logistics processes and storage, increased energy density **S4**: Utilisation of syngas for ethanol provision for chemistry (STEELANOL plant concept) **S5**: Optimum ratio of permeability and hardness of torrefied biomass is crucial in steel making **S6**: Torrefaction can handle waste wood type B and C, utlilisation of large waste wood feedstock pool and integration in circular economy **S7**: Torrefaction technologies have in general at TRL 7 **S8**: Reduced CO_2 emissions in blast furnace operation up to 3.5% (if 10% of fossil coke is replaced by torrefied biomass)	**W (Internal Weakness) –hindrances:** **W1**: ArcelorMittal has no waste management permit **W2**: ArcelorMittal has no long-term contracts/offtake agreement with feedstock providers (no long-term feedstock security due to uncertain development of political framework) **W3**: Specific applications in steelmaking require high quality torrefied biomass (and also quality feedstock, quality problems with SRF and RDF due to heterogeneous waste mixture) **W4**: Torrefaction technology integrated in steel making is not mature yet (currently only 2 % of coke can be replaced) 10 % target **W5**: Pelletising of torrefied biomass requires one further/additional process step (further energy use, …); Simplicity of processes is reduced/complexity is increased (many process steps) **W6**: Small-scale torrefaction cannot supply large demand, upscaling is not at commercial level; only few companies have successfully scaled up (by modular set-up of torrefaction units); minimum torrefaction plant capacity > 50,000 t/a (input) to be economically viable **W7**: Waste collection and storage capacities not sufficient in waste management companies
O (External Opportunities) – enablers: **O1**: Increasing amounts of demolition waste (caused by natural disasters) **O2**: Time pressure on industry, market is changing (e.g. caused by Fit for 55 Package, ETS, EGD, Mission Possible report of ETC); Demand for carbon-neutral steel on the market (amount?), e.g. due to mission possible report of ETC; Demand for renewables/carbon in chemistry; All sectors are looking into alternative resources for their products, boom of bio-products à interest in torrefied biomass is increasing, possible increase of market capacity **O3**: Currently unused amounts of feedstock (e.g. waste wood type B and C) on the market **O4**: Change of actual regulations (recycling vs. ignition) – in discussion; LCA is key; Is Torero actually recycling of waste? Or is it just ignition? **O5**: No renewable feedstock alternatives established for blast furnaces in steel production (e.g. green hydrogen-based electricity for electric arc furnace – EAF – in development)	**Strategy 1:** Carbon oxide as by-product in TORERO process can be used in follow-up processes (e.g. chemistry, STEELANOL plant, hydrogen production), utilisation of synergies of several innovative technologies **Strategy 2:** Use of currently unused feedstock (waste wood type B and C) **Strategy 3:** Integrate TORERO in existing processes: Austrian small steel companies (e.g. Fürst) already have included renewables and innovative technologies ("Flagship Projects": Guss Ink (Austria); Vernamo (Finland); MUSIC) **Strategy 4:** High demand for torrefied biomass (esp. in energy-intensive-industries), further promotion of torrefied biomass as an intermediate solution with a comparably high TRL (because hydrogen-based steel not yet mature) **Strategy 5:** European roll out through adaptation of existing plants (CO_2 reduction through TORERO) **Strategy 6:** Foreign market may provide better environment for torrefaction application in steel industry (with higher	**Strategy 9:** Establishment of long-term agreements (contracting) between ArcelorMittal and feedstock suppliers could be pushed by Fit-for-55 package **Strategy 10:** Specific usage pathways depending on feedstock need to be defined, Ladder of Lansink should be included in the new Belgian legislation from 2025 **Strategy 11:** Adaptation/Improvement of torrefaction process enables use of waste wood type C (at minimum emissions) **Strategy 12:** Get in contact with companies that are equally experienced in integrating innovative (e.g. Guss Ink, Vernamo, projects of Thyssen Krupp, projects of Feralpi) **Strategy 13:** Use ambitious net-zero target to establish an independent innovation investment platform (similar to bioenergy catalysts), involve regional municipalities **Strategy 14:** Further collaboration activities with potential feedstock providers, e.g.: project with Vanheede regarding testing and estimation of unused materials (SRF/RDF) amounts; testing of more and

O6: Increased capturing of CO_2 in steel production processes (CCU/CCS technologies can also benefit torrefaction CO_2 neutrality); proportion of advanced biofuel depends on mass balance **O7**: High demand for torrefied biomass in foreign countries/markets (esp. steel production industry in China for instance) **O8**: Price for fossils is very high (approx. 500€/t coke, May 2022 – high fluctuations, but rising trend); price for torrefied biomass: 200-225€/t; geopolitical and energy crises (e.g. Ukrainian-Russian war), many European states are striving for energy import independence **O9**: ISO 17225 (regarding standardisation of torrefied biomass)	feedstock potentials, lower feedstock and labour costs and larger demands due to higher steel production), e.g. emerging countries such as India and African countries for transferability of the concept to other regions **Strategy 7:** Alternative energy source urgently needed for flexible provision of biomass, torrefaction makes it better storable and transportable, higher energy density of torrefied biomass can well contribute to meet demands; torrefied biomass will be part of RE mix/integrated RE system **Strategy 8:** Reduction of overall emissions and environmental damage by re-integrating waste feedstock in industrial processes	more materials while focusing on further development of torrefaction technology allows use of residues and wastes like waste wood type B, enlarging of feedstock portfolio, exploitation of materials with worst quality **Strategy 15:** Need of exact definition of biomass potentials and determination of mobilizable technical biomass potential (exact available amounts), knowledge transfer and use of expertise of biomass experts, applying dashboards and other digital tools for biomass potential calculations (see also T9) **Strategy 16:** Standardisation process must be put forward; companies need to be increasingly integrated into the ISO certification processes
T (External Threat) – hindrances: **T1**: Political uncertainty on European and national level (especially regarding steel making industry, waste utilisation, advanced biofuel classification acc. to RED II); Future use of municipal waste will rather be material instead of energetic use; EU sustainability policy limits exploration of forest residues **T2**: Only little cross-cutting communication and lack of information exchange between industrial sectors; not always willingness to collaborate in industry along the supply chain (waste management companies, torrefaction companies and steelmaking companies) **T3**: No social acceptance of burning forest residues **T4**: Not many competition (torrefaction technology) hinders development of technology, prices increase (regarding torrefaction technology), need diversification of technologies and companies **T5**: High discrepancy between theoretical, technical and mobilizable potential of all considered feedstock types; Limited biogenic feedstock resources in Belgium; Only approximate biomass potential estimations in place, no consideration of feedstock competition (e.g. particle board industry is huge in Flanders, recycling industry, chemical industry); sourcing of cheap feedstock Is threatened by existing and future demand of other industries, prices will increase **T6**: Insufficient waste separation process at waste treatment site (depending on technology), resulting inhomogeneity of waste as input for torrefaction **T7**: Current value chains in steel industry and waste industry will not change that fast because adaption of processes is related with huge expenditures (conservative industry is not willing to invest in R&D) **T8**: Permit to utilise dangerous waste is missing **T9**: High fluctuations in material, feedstock and energy carrier costs	**Strategy 17:** Demonstration, correct communication and transparency of overall supply chain, especially feedstock sourcing process (using waste and residues, no use of logging/stem wood, no damage of biodiversity) **Strategy 18:** Uniform legislation on waste wood categorisation and permit to use dangerous waste (e.g. waste wood type C) across EU countries should facilitate re-integration of large volumes of waste feedstock in circular economy; associations and lobbyists need to consult policy makers and promote advantages of a uniform legislation because this will guide investment willingness **Strategy 19:** As the potential of torrefied biomass to replace all fossils in steel production is limited, in the short-term, syngas from torrefaction can be used for additional applications as well (CCS/CCU, DRI-EAF)	**Strategy 20:** Promotion of interindustrial projects, increasing communication between different industries (waste handlers, chemical industry, steel industry) in order to expand the feedstock portfolio; cross-sectoral interests (Eurofer, Cefic, Cemtec) **Strategy 21:** ArcelorMittal should apply for waste handling permit in order to become more flexible and to decrease dependency on feedstock supplier; long-term agreements with municipalities to source their waste feedstock; ArcelorMittal becomes shareholder in regional utility companies (PPP – public private partnerships) **Strategy 22:** Establishment of a social-innovation spin-off network to increase public acceptance, transparency of activities and positive overall public image **Strategy 23:** Waste management company should improve the separation processes of waste (mechanical and chemical), specifically pretreatment process in relation to torrefaction process

6 Conclusions

6.1 The Nordic CS

FPBO as an intermediate bioenergy carrier made from residues of sustainably managed forests represents a promising regionally available resource for advanced biofuels. The PESTEL+I and SWOT/TOWS analysis showed that some technology challenges in upscaling and ongoing certification and standardisation processes slow down the speed of market uptake. Associations and joint ventures between international stakeholders and industry should further promote forest residues use for advanced biofuel production and communication between different industrial sectors (forestry, fuel, energy and transport). Social acceptance issues can be avoided by acceleration of information campaigns and by following guidelines to use certified feedstocks from sustainable managed forests and by applying life cycle assessment. Technology development should be designed to support synergies with other renewable energy sources (green hydrogen), regional abundance of woody residues/wood and forest industry and most promising and profitable applications e.g. as a feedstock for sustainable aviation fuel.

6.2 CS Italy

The concept of the Italian case study to use agricultural biomass residues and convert them to Microbial Oil for further upgrade to biofuel at first appears as a reasonable approach to replace unsustainable palm oil-based biofuels in ENIs refineries. ENI is committed to phase-out palm oil by 2023 in the frame of EU directives goals of high-ILUC + net zero emissions by 2050, including a feedstock switch in biorefinery production. The economic environment in the Veneto region seems most promising for a first implementation project around the existing biorefinery in Porto Marghera.

A concept for collection, storage and transport of very heterogeneous agricultural biomass residues as feedstocks, however, is not yet put into practice. One problem especially in the south part of Italy are the many small and scattered farms e.g. olive plantations. Even small collaborations between farms could be an issue if it comes to real implementation. Support by agricultural associations could be very helpful for the initiation of innovative hubs and biomass trade centres.

At the moment technological challenges are persistent in the conversion process to MO and further research activities are needed to increase the TRL level and process efficiency. Therefore, market uptake of MO for upgrade to HVO biofuel may require more time and is not foreseen for the near future. Alternatively, there could be other higher value application for the IBC as an intermediate carbon carrier (ICC) in material-based applications.

6.3 CS Greece

Our analysis of a case study to collect residual agricultural biomasses in Greece (Region of Western Macedonia), conversion by torrefaction and further use in district heating and industry

showed several promising pathways for implementation. Stakeholders were interested in the approach but currently no industrial scale torrefaction plant is located in the region. Similar to the case study in Italy the large number of small and scattered farms makes it difficult to implement a concept for collection and storage of residual biomasses which are available in abundance. Associations and contracts between groups of farmers and industry could be a solution. Another hindrance for widespread market uptake of biomass and IBC (torrefaction) based concepts is the almost sole focus of the government on support of wind and solar as renewable energy sources. Biomass applications for energetic use are not prioritised in the Greek government policy.
A first real pilot project in synergy with other renewable project should be implemented to convince investors of the usefulness of the concept in specific economic and regional contexts. The project, along with a large public information campaign and involvement of local start-up companies, could convince local authorities and industry for further upscaling of the technology for market uptake.

6.4 CS International

The application of torrefaction technology in steel making which was investigated in the CS International can contribute to net-zero steel production until new technology pathways (e.g. hydrogen-based steel production, DRI-EAF) are mature. Quality issues of feedstocks for torrefaction may affect produced steel quality and have to be addressed by future research to increase the proportion of torrefied biomass for replacement of coal coke in blast furnaces. Availability of large amounts of biomass and hybrid waste feedstocks may be limited in proximity of large steel mills. In addition, also other industries are increasingly demanding waste feedstocks for their processes in the course of implementation of circular economy concepts.
Further innovative concepts for torrefied biomass in steelmaking such as use as carbon source in steel material or use of syngas in DRI-EAF processes should be explored in the future.
Large scale integration of torrefaction in steel making can only be applied in regions with large enough abundance of woody biomass waste feedstocks. The frequently changing regulatory framework in Europe (REDII, Waste Framework Directive, …) does not always provide investment security for long-term contracts between steel industry and other partners. Standardisation process of torrefied biomass for steel making must be accelerated to enable widespread market uptake.

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