MUSIC

Market Uptake Support for Intermediate Bioenergy Carriers

D2.2: Description of IBC Market Potential

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EXECUTIVE SUMMARY

MUSIC aims to improve logistics and trade of biomass and intermediate bioenergy carriers (IBCs). Furthermore, MUSIC targets to inform, engage, train and support consortium partners as well as (industrial, regional and other) stakeholders on this topic. The object of the present document is to evaluate the market potential for said IBCs based on qualitative data from interview experts and estimations. The qualitative, interview-based data shows that European policy and its national implementation play a crucial role for the market uptake in order to provide security for investors, plant operators and consumers of IBCs alike. The quantitative, calculation-based estimation weighs average sizes for torrefaction and (fast) pyrolysis against the needs of a certain sector or the targets defined in the Renewable Energy Directive (REDII). In the case of torrefaction, the estimation shows that torrefied biomass can contribute well to achieving the targets set out by the steel industry to substitute coking coal as transformation input in blast furnaces. In the case of pyrolysis, the overall share towards the REDII targets is quite marginal, but in combination with other biofuel production technologies, fast pyrolysis is an important pillar to cover the overall share. Hence, IBCs are expected to contribute significantly in specific sectors (e.g. maritime fuels or steelmaking industry) or in national contexts.

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Abbreviations

CS	Case study
Dx.x	Deliverable
EC	European Commission
EGD	European Green Deal
EU	European Union
EU-27	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden
EU-28	EU-27 and United Kingdom
EU ETS	Emission Trading Scheme
FEC	Final Energy Consumption
FP7	European Union 7th Framework Programme for Research
GHG	Greenhouse gases
H2020	Horizon 2020: European Union 8th Framework Programme for Research and Innovation
IBC	Intermediate bioenergy carrier
ktoe	kilo tonnes oil equivalent
NECP	National Energy and Climate Plan
RED	Renewable Energy Directive
TJ	Terra joule
TRL	Technology readiness level
Tx.x	Task
WP	Work Package

1 Introduction

"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 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, 2020)

This deliverable aims to provide an overview of the market potential up to 2030 and beyond of IBC technologies. Given the low technology readiness level (TRL) of microbial oil compared to torrefaction and pyrolysis, this analysis focuses on torrefaction and (fast and slow) pyrolysis technologies as laid out in the grant agreement[1].

1.1 Approach for Determining the Market Potential of IBCs

In order to analyse the market potential of IBCs, a twofold approach was selected during the proposal stages of the project: (1) forward casting and (2) backward casting. The forward casting approach is based on the status quo of IBCs today and extrapolations based on that while the backward casting approach considers energy and climate plans for 2030 and determines how IBCs should develop based on that. However, it became apparent that the forward casting approach needed modification as the database for the forward casting proved to be insufficient.

1.1.1 Survey on Status Quo of IBCs

Initially, the **forward casting approach** was based on an extrapolation of the current IBC plants based on a determined growth rate over the past years. In autumn 2019 a MUSIC internal survey was conducted to collect information on existing IBC plants using torrefaction or pyrolysis technology. This survey[2] should have served as baseline for the forward casting of the IBC market potential; however, the survey has 52 entries, many of which are incomplete and hence do not allow further processing. Out of the 52 entries, only 17 plants are currently operational; however, over half of these plants are at pilot or demonstration scale. 46% of these entries have no information on the status of operation. Furthermore, 20 of the entries refer to torrefied biomass, nine to pyrolysis, and one to microbial oil. This leaves 31% of the entries with no information on technology. Based on the low number of entries overall and especially the inconsistency in data availability, it was not possible to extrapolate how the IBC market will develop based on survey data alone.

[1] The low TRL was also confirmed indirectly in the interviews (see Chapter 2) as none of the interviewees explicitly considered microbial oil in his/her responses while it was not excluded in the interviews themes/questions.
[2] The data was predominately provided by MUSIC partners IBTC/Bioenergy Europe, BTG and CERTH.

1.1.2 Final Approach to Determining the Market Potential

During the proposal stage, only the **backward casting approach** was supposed to be based on expert interviews in combination with relevant literature (policy documents, scientific and non-scientific literature). However, the difficulties in the forward casting approach extended these methods of data collection to both, forward and backward casting. In addition to the qualitative interview-based analysis (see Chapter 2), a quantitative, calculation-based **estimation** of the market potential is presented in Chapter 3. This estimation is based on EU data and scenarios (Eurostat, 2020a, 2020c; European Commission, 2016), assumptions made by and information provided by the MUSIC partners who have key expertise on pyrolysis and torrefaction and hence were able to share some insights how the markets might develop. As a result of this, no distinction between forward and backward casting is made in the presentation of the results. However, during the discussion, forward and backward casting are differentiated based on the results of primary data collection and secondary data.

1.2 Methods of Data Collection

In order to collect data to determine the market potential of IBCs, several methods and sources were chosen:

- Interviews with (industry) experts
- Outcomes from other MUSIC deliverables, especially D2.3 (EU and national regulatory framework: present and future developments) (Buffi *et al.*, 2020)
- Outcomes from other MUSIC tasks, especially Task 3.8
- Policy documents (such as directives, regulations, strategies and action plans)
- European Statistical Data (e.g. from Eurostat)
- Industry papers, e.g. company reports and strategies
- Scientific publications

As interviews were used as a mean of primary data collection, interviewee selection was crucial. The interviewees were established through network sampling (Merriam 2009); the MUSIC partners provided suggestions of key participants based on their relevance to the MUSIC project, their understanding and knowledge of IBCs and European (bio-)energy legislation as well as their national implementation. Overall, 13 in-depth interviews were carried out with experts from (bio-)energy policy, technology and networking organisations. These interviews were open-end and semi-structured (Merriam, 2014) and based on a set of questions which guided the conversation. The themes on which the questions were based are listed in Chapter 2.1. The data was analysed with the qualitative analysis software NVivo (QSR International Pty Ltd., 2018).

In addition to the interviews, internal online workshops were carried out as part of the work in WP3 (see Deliverable 3.6). Although not initially intended to serve as data for this deliverable, the insights from the workshops provided valuable information on IBC market potential. Through using this data, the consulted pool of experts was extended to include the workshop participants, resulting in collated opinions of 35 experts. Finally, the results were discussed among the DBFZ MUSIC team as well as reflected upon with two senior members of staff at DBFZ.

The results in the following chapters are hence based on the analysis of the interview data (audio files, extensive set of notes), the outcomes of the online workshops and consideration of relevant scientific and non-scientific literature[3].

1.3 Discussion of the Term “Intermediate Bioenergy Carriers”

Through the nature of the initial market uptake support call issued by the EU as well as other official EU documentation, the term “intermediate bioenergy carriers” is an integral part of this project. However, we are aware that this terminology is EU specific and does not reflect terminology in other industries or sectors as well as scientific literature. Hence, the terms “densified biomass” as well as “thermally treated biomass” were used for online and literature searches as well[4]. The technology specific terms “pyrolysis”, “torrefaction” and “microbial oil” were also applied in search engines. This difference in terminology was also recognised in the different interviews and reflected upon. It might be meaningful to further explore this subject on terminology in WP3 (and WP7) to tailor documents and publications to the needs of the different stakeholder groups. One interviewee also raised the point that “intermediate” can not only be understood as “a step in the value chain prior to final conversion and use” but also as a component of time. In this interviewee’s opinion, the term “intermediate” could be a synonym for “interim”, indicating that IBCs are only a short-to medium term solution on the pathway to a carbon-neutral bio-economy. However, in EC terminology, in that case the term “drop-in fuels” is used. In conclusion, how the terminology IBC is or can be understood by different stakeholders should always be considered prior to engaging with them in order to avoid confusion and misunderstanding.

2 Results and Insights from the Primary Data

This chapter describes the insights from the analysis of the primary data. Firstly, an overview of the interview outcomes is presented; in a second step, the data from the interviews was compared to the outcomes of the three online workshops. Finally, the data collected through both was discussed and reflected upon with senior staff at DBFZ to establish gaps and core points.

2.1 Views of Industry Experts on IBC Market Potential

The interviews with industry experts were focused around the following themes in order to later enable forward and backward casting of IBC market potential:

(1) **The role of IBCs in the European/national energy mix, today and in 2030;**
(2) **Measuring the impact of IBCs as part of the RED II, given their “intermediate” nature;**

[3] The consulted literature is included in the reference list at the end of this document.
[4] “Densified biomass” also includes standard pellets, briquettes etc. which are not within the MUSIC scope. However, using this search term yielded richer results and non-IBC results were excluded later on.

(3) What measures (e.g. incentives) need to be put in place now, for IBCs to have a significant impact later on?

2.1.1 The Role of IBCs in the European/National Energy Mix

When talking about this first theme, it became apparent that the focus of the interviews was set on one IBC technology which interviewees either had the most experience with or which they thought to be most relevant to their national context.

With regard to torrefaction, the following aspects were mentioned by several interviewees: Torrefied biomass is brought to market in several forms or shapes, such as powder, pellets, briquettes or granulate. This allows for a broad variety of applications and hence torrefied biomass can be used in different sectors and industries. However, application of torrefied biomass as a substitute for or co-firing fuel to fossil solid fuels such as coke, coal or lignite seems to be common. One interviewee highlighted that torrefied biomass is included in an existing standard for solid bioenergy carriers (ISO TS 17225-8[5]).

Furthermore, especially with regard to pyrolysis oil, the interviewees agree that the term "intermediate bioenergy carrier" is misleading as it suggests a primary focus on energetic applications. Instead, the energetic use of pyrolysis oil is seen as an interim solution until material use (e.g. through upgrading in bio-refineries) for bio-based products becomes the preferred usage pathway. The interviewees agree that products derived from pyrolysis can become a crucial element of the bio-economy. Actually, one interviewee described that the first commercial use of pyrolysis oil was indeed material use in Canada where aromas/sugars from wood pyrolysis were used to replicate barbeque flavour (Burdock and Fenaroli, 2010). A recent statement by advisors to the Dutch government support this development, as they claim that certain energetic use of biomass (e.g. direct combustion) should be phased out in favour of material use for bio-based products (Flach, 2020; Social-Economische Raad, 2020; Strengers and Elzenga, 2020), however, the Dutch government is yet to take any formal action.

Pyrolysis technology is already proven on commercial scale and several plants are operational or under construction. Pyrolysis oil is an intermediate product which can serve several industries and applications, such as combustion (least effective/basic application), conversion to biofuels or as a basis for chemical products. (BTG Bioliquids B.V., 2020a) All interviewees agree that pyrolysis oil will play a crucial role in (bio-)refineries as it can be used for co-refining with fossil components as well as refining in bio-refineries as this process is simpler and less expensive than extracting sugars for bio-based applications. However, one interviewee raised the issue of competition to palm oil, in particular to palm fatty acid distillate (PFAD) which is currently much cheaper than pyrolysis oil as it is a by-product of palm oil refining.

One interviewee gave the following analogy with nicely describes the market uptake difficulties of IBCs: "Energy carriers are like money, they do not have a value themselves until you allocate a value to them." Hence, according to that quote, the value of IBCs is not generated in that

[5] ISO TS 17225-8: A technical specification intended to cover many products from thermal treatment of biomass. Hence, groups of wood-derived and non-woody biomass are established with up to 3 classes in each group. Each class includes a high and a low subclass so products of thermal treatment processes like steam explosion can considered under this Technical Specification.

intermediate step but instead determined through the value associated with the final product. Hence, in reverse, the higher the value of the final product, the higher the value of the IBC. Additionally, the monetary value associated with decarbonisation needs to be considered, as one interviewee pointed out. Substituting fossil carbon can lead to added monetary value of IBCs / the associated end products as opposed to "just" the energetic or bio-based material use. Furthermore, several interviewees pointed out that the IBC is only as "green" or "clean" as the feedstock. This not only refers to feedstock of sustainable origin, but also indicates the quality of the feedstock. It implies that for high-value adding applications a clean feedstock is required which could come at a premium costs as opposed to low-quality feedstock. However, as subsidies for IBC technologies and associated research and development actions are limited and decreasing, as one interviewee pointed out, there is a need to investigate cheaper feedstock of lower quality. At the moment, torrefaction and pyrolysis technologies run smoothly on clean and homogenous feedstock such as forestry residues or residues from the wood processing industry (e.g. saw dust). However, as all interviewees agree that for pyrolysis, there is a need to further explore the commercial applications to be able to use lower quality and thus cheaper feedstock, such as waste wood or agricultural residues. In the case of torrefaction it was highlighted that technologies already run smoothly on more problematic feedstock than sawdust, i.e. sugar cane bagasse, rice husk or even empty fruit bunches). However, it is important to consider which pre-processing steps are necessary to fulfil the requirements of the final product and whether these pre-processing steps will counteract the original cost advantage of low grade feedstock. Therefore, IBC processes cannot be seen isolated but only in connection with pre-processing steps (e.g. sorting, separating, leaching, screening and milling). Hence, using low value feedstock could decrease the overall cost of IBC technologies and increase market attractiveness.

Overall, all interviewees agree that the role of IBCs will develop as follows: Initially, energetic use in established markets will be preferred. Here, IBCs can be co-fired with fossil energy carriers or substitute them all together. In this context, one interviewee highlighted that power plant operators carry enough financial weight and reliability to commit to long-term contracts which enables the use of IBCs in this context. In the not too distant future (2030 and beyond), the use of IBCs in industrial applications is expected. Projects like the H2020 project TORERO are leading the way in this area. Here, torrefied biomass is applied in industrial processes to primarily replace coke in the blast furnaces for steelmaking and to create industrial heat / process heat. Like power plant operators, a high buying power is associated with the steel industry which enables necessary investments. However, several interviewees mentioned that the current COVID-19 situation and associated difficulties of several global players in the steel making industry (PwC, 2020) could lead to a decrease in investment. On the other hand, energy intensive industries are required to mitigate their fossil energy requirements through renewables based on national and European policy (such as the European Green Deal, see Chapter 2.1.3 and European Commission, 2020a). Furthermore, decarbonisation or carbon-neutrality of these energy intensive industries is desired. However, none of the interviewees dwelt on this subject. Hence, it should be further investigated in the upcoming work in WP3 and WP5 in the context of the case studies.

Besides the role of IBCs in the European or national energy mix, one interviewee described difficulties of the market uptake. According to this interviewee, the crux lies in the funding of new IBC plants. Investors require long-term security which is often measured based on the stability of an industry and their bankability. For example, the bankability of the power sector is typically quite high, as this industry is defined through large corporations which can commit to long-term contracts and have reached a certain (financial) credibility over the years. However, smaller companies which would like to use IBCs for process heat do not have the bankability that is required to secure funding as it is unsure if they will survive the time period which is required for re-financing the initial funding. The interviewee pointed out that this is quite the "chicken and egg situation": without a working reference plant, investors are reluctant to invest but funding for such a reference plant is difficult as investment security is not given.

2.1.2 Measuring the Impact of IBCs as Part of the RED II

The second theme focuses on whether IBCs can contribute towards goals of European legislation, especially the Renewable Energy Directive II (RED II) (European Parliament and the Council of the European Union, 2018). Given their intermediate nature, it is not straight forward to count IBCs towards REDII targets as these focus on feedstock and demand side. All interviewees point out that not being directly considered in REDII is an opportunity as well as a hindrance for IBCs and their market uptake. It can be considered an opportunity as this way the application possibilities for IBCs are theoretically endless; however it is also perceived as a hindrance, as not being directly considered for the targets decreases investment in the associated technologies or limits the possibilities for subsidies. One interviewee points out that especially for solid energy carriers (incl. torrefied biomass) the same difficulty applies as they can only be indirectly measured against REDII targets. This implies that solid IBCs need to have some flexibility with regard to their final application to be counted against the most lucrative targets. On the other hand, it is much easier for liquid IBCs (such as pyrolysis oil) to count directly towards REDII targets as a use as advanced fuel in the transport sector is in most cases pre-dictated. However, the REDII does not account for material use of bio-based products, which is contradictory to the anticipated development of IBCs with energetic applications being a short-term solution.

The interviewees, regardless of their national background, agree that the national implementation of the REDII (and EU legislation in general) is key to the success of IBCs and other renewable energy carriers. Especially with regard to the feedstock, national policies can promote the use of residue streams and hence hinder or enable IBCs. This aligns with the earlier observations of one interviewee with regard to the competition to palm oil. If palm oil use is restricted through national policy, the chances for IBC implementation increase. The interviewees highlight that successful lobbying activities can lead to (in-)directly promoting the implementation of IBCs through advanced fuel quotas or feedstock restrictions. In order for the lobbying activities to be successful, the major industries in the national context, e.g. oil refineries in Scandinavia, need to be on the same page. However, as one interviewee observed, there are currently contradictory perspectives from major industry players, mainly related back to their stance on the use of palm oil. Another interviewee indicated that discussion on REDII will be reopened soon and this provides an opportunity to raise awareness of IBCs and their profile with the European Commission even if they still not count directly towards REDII targets. Through this, IBC specific needs in research and development can be highlighted to reduce their costs in the long-term.

Given the context of the REDII and the eligible feedstock as per Annex IX[6] (European Parliament and the Council of the European Union, 2018, L328/204), IBCs are viewed as an opportunity for some of the feedstock options. While currently predominantly using woody residues, IBCs derived from agricultural residues can provide a chance for the final product to be counted towards REDII targets while creating opportunities for agricultural businesses. Especially in Southern Europe, as pointed out by several interviewees, there is a need for improved agricultural practices and better residue management. Using agricultural residues for the creation of IBCs can lead to new revenue streams for farmers while improving the storage and transport worthiness of these residues. However, the upstream supply logistics need to be further developed for this to become a reality.[7] One interviewee indicated that such a development could be promoted through national support schemes for agriculture as technology implementation, market development and legislation should go hand in hand. Furthermore, it was mentioned that if conversion of agricultural residues to IBCs was a viable option advancing cascade uses of raw materials/feedstock, agricultural malpractice (such as burning residues on the fields) could be penalised.

Most interviewees indicated the importance of the National Energy and Climate Plans (NECPs) as they will indicate how the REDII targets as well as other European legislation (e.g. Common Agricultural Policy: European Commission, 2020g) will be implemented nationally. These NECPs serve a time frame from 2021 to 2040 and are crucial for the energy transformation up to 2050. However, in the opinion of several interviewees, the member states are quite “traditional” in the drafting of the NECP and set rather unambitious targets for the use of biomass/bioenergy. Furthermore, one interviewee mentioned that “biofuels are like a hot potato”, nobody really wants to get too deeply involved in this matter, as they are much more complex (with regard to supply/feedstock as well as spectrum of final products) as other renewables, such as solar and wind power. This does make it more difficult to establish sustainable measures and incentives which promote the use of biomass or biofuels in particular.

The interviewees were not in agreement on the role of REDII with regard to investment security. One-half of the interviewees claimed that the REDII is a stable and long-term policy which will stay (nearly) the same for the anticipated life-time of an IBC conversion plant, hence providing investment security. On the other hand, some interviewees argue that the REDII alone does not support IBCs’ uptake, as they are not directly mentioned in the directive. This does allow for other investment opportunities which can be counted towards the targets more directly and hence hinder funding. In addition, some interviewees mentioned that they perceive a certain reluctance from the European Commission to promote biomass in the same way as other renewables are promoted as this apparently goes hand in hand with the discussion on the use

[6] Annex IX lists feedstocks for the production of biogas for transport and advanced biofuels which are eligible for being counted towards shares defined in REDII.

[7] This is one of the challenges further studied in the Greek and Italian case studies where feedstocks for the IBC conversion plants is predominantly sourced from agricultural organisations.

of palm oil. Here, the opinions and lobbying work of non-governmental organisations (NGOs) can have a negative impact on the market potential of IBCs as they hinder their implementation. Several interviewees see the largest potential of IBCs in the sectors, where energy cannot be substituted through electricity (and hence solar or wind power) or hydrogen, such as heavy-duty road transport, aviation and especially the shipping industry[8]. One final aspect with regard to REDII was mentioned by one of the interviewees; the REDII is such a broad framework to "keep every member state happy" which makes the national implementation so different across the member states. This is an advantage, as all member states can draw on their strength and their respective feedstock and residue streams but makes a truly "European perspective" and market for IBCs difficult to achieve.

2.1.3 Measures (Potentially) Supporting the Uptake of IBCs

With regard to other incentives and measures to support the development of IBCs and their market uptake, the interviewees agree that technology is not the problem. In their opinion, pyrolysis as well as torrefaction are conversion technologies which have been commercially proven and now need a supportive legislative framework to be implemented more broadly. The hope of several interviewees is that the European Green Deal (EGD[9]) will help with that implementation.

The EGD does not only consider energy but aims to support the achieving of climate as well as carbon targets. While energy is one aspect of this, it also considers different industries and agriculture. This provides a more holistic approach and opens up opportunities for IBCs to be used in bio-based materials, the circular economy and an overall sustainable bio-economy. It provides a long-term strategic vision of carbon neutrality by 2050 and shows different scenarios how the European economy could be decarbonised. With this central focus on decarbonisation, many industries which were less relevant or less called to action through previous legislation, now have been provided with a framework to take action. As mentioned earlier, all interviewees again refer to the application of (solid) IBCs in the energy intensive industries, such as steelmaking or magnesium or calcium plants. Here, IBCs can replace fossil energy carriers and overall help to decarbonise the industry. Also, bio-based applications of e.g. pyrolysis oil receive recognition in the EGD as it considers all aspects of the bio-economy and not only energetic applications. However, a downside of the EGD, as mentioned by nearly all interviewees, is that it does not provide any details on carbon and climate mitigation strategies for certain industries but just lays out a framework in broad terms.

Especially in the context of Greece, an EU member state which is currently driven by de-lignification of the energy sector, the interviewees highlight that the use of IBCs could help with that transition. Not only agricultural practices as well as income for farmers could be improved, also land previously used for lignite mining can be utilised for the growth of feedstock for IBC applications, such as short rotation coppice (e.g. poplar). One interviewee highlights that this way

[8] The shipping industry and its role in the market uptake of IBCs is studied in detail in the Sweden/Finland case study, where pyrolysis oil from Scandinavia is considered for upgrading to maritime biofuel in the Netherlands.
[9] See Buffi *et al.* (2020), Deliverable D2.3 (Chapter 2.1) for more information

of cultivating abandoned land combined with mobile torrefaction could add value to the regional bio-economy and to the lives of the rural population. Additionally, if grown on degraded land, this could be accounted for in GHG emissions calculations according to REDII; high GHG emission saving would have a positive impact on the market value of the IBC and the associated biofuel.

Another funding mechanism mentioned by several interviewees is the Innovation Fund (European Commission, 2020d). This fund provides funding for innovative low-carbon technologies and processes in energy intensive industries, carbon capture and utilisation (CCU), construction and operation of carbon capture and storage (CCS) as well as innovative renewable energy generation and energy storage. However, the interviewees had mixed feelings about this funding scheme, as the previous NER300programme (European Commission, 2020e) was perceived as unsuccessful.

2.1.4 Overview of Workshop Results Relevant to IBC Market Potential

The views of the expert interviewees were confirmed in the three workshops[10] on the macro-environment of IBCs (Pfeiffer *et al.*, 2020). REDII and EGD were mentioned as the central elements of shaping the (bio-)economy and (bio-)energy utilisation in the next years and decades. All workshops participants agree that national implementation of these EU documents is key for successful (regional) market uptake of their respective IBC of study. One element that became clear in the workshops was a wish for more clarity regarding the upstream supply chain, e.g. with regard to the Common Agricultural Policy or EU legislation on waste wood and residues while the expert interviewees focused more on the demand side/ downstream supply chain. In summary, the workshops complemented the data from the interviews and did not raise any contradictory aspects.

2.2 Reflection on the Results

After the expert interviews, the results were reflected upon by the DBFZ MUSIC team as well as in separate conversations with two senior members of staff. Overall, these feedback and reflective sessions did confirm the interview data as well as the workshop outcomes but brought up some aspects which were previously not mentioned or only hinted at. While REDII and European Green Deal were broadly discussed during the expert interviews and in the workshops, the EU Emission Trading Scheme (EU ETS) (European Commission, 2020c) and Effort Sharing Regulation (European Commission, 2020b) were only hinted at or mentioned in the context of other funding schemes and incentive programmes (e.g. the EU ETS provides funding for the Innovation Fund). This difference in perception of importance of EU directives and regulations is assumed to be connected to the main area of study and expertise of the interviewees and conversation partners. Furthermore, the impact emission trading and especially carbon-dioxide pricing have on the market uptake of IBCs was hardly commented on by the interview-

[10] The workshop concept is presented in Deliverable D3.6 (public, engagement workshop format(s) and content); direct workshop results will be published in Deliverable D3.7 (public, reports on regional engagement workshops). D3.6 can be found here: https://cordis.europa.eu/project/id/857806/results

ees although it is expected to be an important driver. Hence, this needs to be further investigated in the regional context of the case studies. While most of the expert interviewees work closely with one specific intermediate on a daily basis their view on relevant policy was much more narrow that the understanding of others who take a more systemic approach or consider the (bio-)economy as a whole. Nevertheless, this issue is not further investigated as part of this deliverable as insufficient data from the expert interviewees is available for further analysis. However, the importance of these policies are recognised and their content is covered in deliverable D2.3. Furthermore, they will be considered in the regional specific analyses in WP3, WP5 and the case studies.

3 Estimation of IBC Market Potential

In order to quantify how the market(s) for IBCs might develop, the estimation of IBC market potential is based on three pillars: (1) demand from an exemplary sector/application, (2) technological roll-out and (3) feedstock availability. For pillar (1) and (2) it is differentiated between pyrolysis oil from fast pyrolysis and torrefied biomass. The selected exemplary sectors/applications are the upgrading and use as a transport fuel in the case of pyrolysis oil and the application of torrefied biomass in blast furnaces. The rationale for these selections are given in the respective sub-chapters 3.1 and 3.2. For pillar (3), no comprehensive calculation on EU level was possible. However, for regional or national analyses this pillar should not be neglected, as type of feedstock, its spatial distribution and availability do play a crucial role for the uptake of IBC technologies. Regional biomass availability is considered in more detail in the four case studies (see WP5) and in other EU H2020 projects such as HyFlexFuel[11] and CAFIPLA[12]. Data on feedstock availability and potentials from the FP7 project S2Biom (Dees *et al.*, 2017) was considered, however, as data is only available in tonnes not energy content and a meaningful (technology and feedstock specific) conversion from this weight-based unit to an energy unit could not be achieved within the scope of this deliverable. Hence, the further estimations are based on pillar (1) and (2). As baseline for all calculations, Eurostat data for EU-27 is selected (Eurostat, 2020a)[13]. For future development, the EU Reference Scenario 2016 is referred to (European Commission, 2016)[14], using EU-28 data and subtracting the country data for the United Kingdom. Additionally, data on existing and planned torrefaction and pyrolysis plants as well as fuel/material characteristics were derived from deliverable D2.1 (PowerPoint presentation on lessons learned from earlier projects)[15] from the MUSIC project (Vos *et al.*, 2020), provided by the respective project partners (van der Stricht, 2020; BTG Bioliquids B.V., 2020b) or extracted

[11] https://www.hyflexfuel.eu/; https://cordis.europa.eu/project/id/764734/results (D 1.3 Report on regional feedstock potentials and preference regions for HTL projects)

[12] http://www.cafipla.eu/; as part of CAFIPLA an interactive online atlas for selected biomasses in the European Union will be developed. This online atlas will be available by May 2023.

[13] The associated Excel-file is available for download here: Eurostat Energy Balances. EU-27 historical data is selected as the estimations on market potential only consider EU-27 as the United Kingdom is leaving the EU.

[14] The associated Excel-file is available for download here: Excel sheets with EU and EU country results

[15] Available on CORDIS: https://cordis.europa.eu/project/id/857806/results

from the survey (see Chapter 1.1.1). The calculations and respective tables are included in the following subchapters or in the Annex.

3.1 Pyrolysis – Contribution to the Share of Advance Biofuels

In order to calculate the market potential for (fast) pyrolysis oil, the application of pyrolysis oil as a transport fuel was selected. There are two reasons for choosing this application: Advanced biofuels can be counted towards REDII targets and the application as a (maritime) transport fuel is studied in CS Sweden/Finland. Hence, good reference data is available to compare potential pyrolysis oil production against the share of advanced biofuels in the final energy consumption (reference year 2018) and final energy demand (future prognosis) in the transport sector. The results are presented in Table 1. They show that a rapid market growth of pyrolysis plants is required to cover the entire share of advanced biofuels in 2030. However, several technologies are currently being explored to cover that share, hence it can be assumed that only a part of the share needs to be covered through advanced fuels from pyrolysis oil (ETIP-B-SABS 2, 2020; European Commission, 2018; SETIS, 2020). Furthermore, pyrolysis oil could be used for higher-value (material) applications (Muggen, 2020).

Table 1: Backward Casting of Pyrolysis Market Potential

		2018: Final Energy Consumption Transport Sector EU-27, Future: Energy Demand Transport Sector EU-27	share of advanced biofuels acc. to REDII	share of advanced biofuels acc. to REDII	share of advanced biofuels acc. to REDII	No. of necessary EMPYRO-sized plants to cover this share based on min. capacity	No. of necessary EMPYRO-sized plants to cover this share based on max. capacity
	Unit	ktoe	%	ktoe	TJ		
	Source	EuroStat (2018) / EU Reference Scenario (2016)	REDII (halved, based on double-counting)				
Year	2018	286,778	0.1	287	12,007	50	35
	2020	304,173	0.1	304	12,735	53	37
	2025	299,934	0.5	1,500	62,788	262	182
	2030	297,952	1.75	5,214	218,306	910	633

(a) European Parliament and the Council of the European Union, 2018

(b) For EMPYRO and pyrolysis oil properties/characteristics, see Annex for further details

Hence, together with MUSIC partners BTG and BTG-BTL, three possible growth scenarios for EMPYRO-sized pyrolysis plants were developed:

Table 2: Scenarios for Pyrolysis Market Development

Base scenario	Just 3 EMPYRO-sized pyrolysis plants operational (Hengelo, Netherlands; Lieksa, Finland and Gavle, Sweden) (designed for transport fuel production)
Low-growth scenario	For each year between 2024 and 2030 a single (1) extra plant is built. By end of 2025: 5 operational plants, by the end of 2030: 10 operational plants
High-growth scenario	For each year between 2024 and 2030 five (5) extra plants are built. By end of 2025: 10 operational plants, by the end of 2030: 38 operational plants

These three scenarios result in the following forward casting potentials (Table 3).

Table 3: Forward Casting of Pyrolysis Market Potential

		scenario	No. of EMPYRO-sized pyrolysis plants	capacity min.	capacity max.	share of advanced biofuels acc. to REDII	prognosed pyrolysis capacity against REDII share (min. capacity)	prognosed pyrolysis capacity against REDII share (max. capacity)
	Unit		-	TJ/a	TJ/a	TJ	%	%
Year	2025	base	3	720	1,035	62,788	1.15	1.65
		low growth	5	1,200	1,725	62,788	1.91	2.75
		high growth	13	3,120	4,485	62,788	4.97	7.14
	2030	base	3	720	1,035	218,306	0.33	0.47
		low growth	10	2,400	3,450	218,306	1.10	1.58
		high growth	38	9,120	13,110	218,306	4.18	6.01

Considering these three scenarios, it becomes clear that pyrolysis capacity can be rapidly increased to over 13,000 TJ by 2030 if the high-growth scenario becomes a reality; however, the contribution towards REDII targets is still modest with a maximum of 6.01% by 2030 in the high-growth scenario. Nevertheless, in specific (regional business) cases, pyrolysis oil can make a significant contribution to national targets or targets in specific sectors (e.g. maritime fuels). This is further explored in the respective case study (CS Sweden/Finland).

3.2 Torrefaction – Transformation Input in Blast Furnaces

In order to calculate the market potential for torrefaction, the application of torrefied biomass in blast furnaces was selected as this is studied in CS International within the MUSIC project and good reference data is available. However, torrefied biomass can be applied in other sectors to substitute fossil energy carriers such as lignite to generate heat (which is studied in CS Greece). However, with the commitment of the steelmaking industry to reach carbon neutrality by 2050 (Energy Transitions Commission, 2018), funding opportunities for the coal and steel industry (European Commission, 2020f) and the framework of the EGD, this analysis can provide valuable insights into this selected demand driven perspective.

In 2018, the entire transformation input into blast furnaces in the EU-27 was of fossil origin and amounted to 30,271.5 ktoe (Eurostat, 2020a, 2020b). Considering that the transformation input over the past decade remained relatively stable (e.g. 2013: 29,825.1 ktoe; 2008: 33,956.6

ktoe), no rapid decrease over the next years/decade is expected. Therefore, a continuous need of 30,000 ktoe was used as baseline for future prognosis. However, it is expected, based on the commitments from the steelmaking industry that the share of bioenergy, in particular torrefied biomass, will increase. Hence, a steady increase of the share of torrefied biomass as input in blast furnaces is considered. Additionally, an average capacity of 200,000 tonnes torrefied biomass per year and plant was considered to determine the necessary number of torrefaction plants (Vos *et al.*, 2020). The results of these estimations are presented in Table 4.

Table 4: Backward Casting of Torrefaction Market Potential

	Transformation input (blast furnaces)	share of torrefied biomass	share of torrefied biomass	share of torrefied biomass	No. of necessary average sized plants (min. higher heating value)	No. of necessary average sized plants (max. higher heating value)
Unit	ktoe	%	ktoe	TJ		
2018	30,271	0	-	-	-	-
increased share of torrefied biomass	30,000	5	1,500	62,802	16	11
	30,000	10	3,000	125,604	31	22
	30,000	25	7,500	314,010	79	56
	30,000	50	15,000	628,020	157	111
	30,000	100	30,000	1,256,040	314	223

(a) Eurostat, 2020a

(b) van der Stricht, 2020 & Vos et al., 2020 for torrefaction properties/characteristics, see Annex for further details

This estimation clearly shows, that a significant amount of torrefaction plants is necessary to supply the suggested shares of torrefied biomass for application in blast furnaces. However, the entire transformation input could be covered with 314 average-sized torrefaction plants. To consider, whether these targets can be achieved, a forward casting estimation was carried out (see Table 6). Based on (Batidzirai *et al.*, 2013; Cremers *et al.*, 2015) a more rapid development opposed to pyrolysis oil can be expected (see Table 5).

Table 5: Scenarios for Torrefaction Market Development

Base scenario	Three (3) average-sized torrefaction plants producing torrefied biomass for the application in blast furnaces
Low-growth scenario	For each year between 2024 and 2030 a two (2) extra plants are built. By end of 2025: 7 operational plants, by the end of 2030: 17 operational plants
High-growth scenario	For each year between 2024 and 2030 five (5) extra plants are built. By the end of 2025: 13 operational plants, by end of 2030: By end of 2030: 38 operational plants

Considering these three scenarios, it becomes clear that torrefaction capacity for application in blast furnaces can be rapidly increased to over 200,000 TJ by 2030 if the high-growth scenario becomes a reality; and nearly 50% of the total transformation input could be covered with that capacity (minimum heating value). Additionally, torrefaction is not the only technology currently explored for this purpose. Biochar and pyrogas from slow pyrolysis[16] as well as hydrogen solutions can contribute to the transformation input (Energy Transitions Commission, 2018). Therefore, on EU level as well as in specific (regional business) cases, torrefaction as input material in blast furnaces can make a significant contribution to national targets or targets in specific sectors (e.g. industry: steel and iron production). This is further explored in the respective case study (CS International). Furthermore, torrefaction can provide resources for other processes, e.g. to replace lignite in district heating plants. This case is further explored in CS Greece.

Table 6: Forward Casting of Torrefaction Market Potential

		scenario	No. of average-sized torrefaction plants (200,000 t/a)	capacity (min. higher heating value)	capacity (max. higher heating value)	share of torrefied biomass (25%)	Capacity of average no. of plants against share of torrefied biomass (25%) (min. higher heating value)	Capacity of average no. of plants against share of torrefied biomass (25%) (max. higher heating value)
	Unit		-	TJ/a	TJ/a	TJ	%	%
		base	3	12,000	16,920	314,010	3.82	5.39
		low-growth	7	28,000	39,480	314,010	8.92	12.57
Year	2025	high-growth	13	52,000	73,320	314,010	16.56	23.35
		base	3	12,000	16,920	314,010	3.82	5.39
		low-growth	17	68,000	95,880	314,010	21.66	30.53
	2030	high-growth	38	152,000	214,320	314,010	48.41	68.25

4 Discussion of IBC Market Potential

As data collection did not directly distinguish between forward and backward casting, this chapter attempts to divide the different opinions and suggestions into the following two questions:

(1) What could happen based on the status quo?
(2) What should happen based on EU Goals?

4.1 Forward Casting: What Could Happen Based on the Status Quo?

With regard to the question of what could happen based on the current status quo, the following aspects become apparent: First of all, the expert interviews show and confirm that IBCs are currently a niche market with few areas of application that happen mainly in the energy context. Based on current legislation, such as REDII, IBCs are rather complex and do not dictate an end use which makes it difficult to relate them directly to a certain target. This might hinder funding and further market implementation.

[16] This is considered in CS Italy.

As one of the interviewees nicely summarised, more reference projects (such as EMPYRO[17] and TORERO[18]) need to be established to support market uptake. These pioneer projects consist of a mix of the following: a bold investor, some subsidies, local value creation and an end consumer who would not be harmed if the project fails. Through only covering a (small) percentage of total demand, risk is mitigated and reference projects can be developed further until they can cover the full demand. This goes together with co-combustion and co-refining options in energy heavy industries and refineries. How exactly the status quo can be used to increase market implementation of IBCs is addressed in the different case studies.

4.2 Backward Casting: What Should Happen Based on EU Goals?

With regard to EU goals in 2030 and beyond, much more needs to happen right now to meet those targets. The estimations in Chapter 3 show that IBCs will be able to contribute to the overall amount of renewable energies needed to fulfil EU and global energy and GHG emission targets. However, the significance of the IBC contribution depends on the selected regional settings or the sector application, which will be further studied in the MUSIC case studies. In order for these regional businesses cases to be successful, a pro-IBC environment needs to be established. Furthermore, the proposed approach of IBCs first substituting fossil energy carriers, then increased application in energy heavy industries and later bio-based products needs to be sped up to significantly contribute to the targets. The European Green Deal is perceived by the interviewees as a good starting point to trigger market uptake and further investment. However, quick and adequate translation into national policy is crucial for this to become a success.

5 Conclusions

Through expert interviews and estimations of IBC market potential, a holistic perspective of current and future developments, especially with regard to EU legislation, was provided. The experts agree that much more needs to be done, especially on national level to support the market uptake of IBC technologies. This is also confirmed through the calculations and estimations. The considerations from this deliverable will influence the work in WP3 in order to determine the market potential in each of the case study regions for the technologies and industries considered. Furthermore, as highlighted in Chapter 1.3, the terminology should be carefully considered in WP3 (and WP7) to tailor documents and publications to the needs of the different stakeholder groups.

[17] https://www.btg-btl.com/en/company/projects/empyro

[18] http://www.torero.eu/, https://cordis.europa.eu/project/id/745810

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Annex: Properties and Characteristics of Pyrolysis Oil and Torrefied Biomass

Table 7: Pyrolysis/EMPYRO - properties and characteristics

	density		1,170.00	kg/m³
	higher heating value	min	16.00	MJ/l
		max	23.00	MJ/l
one EMPYRO-sized plant	capacity EMPYRO in PO[19]		20,000,000	l/a
	capacity EMPYRO	min	374,400,000	MJ/a
			374	TJ/a
		max	538,200,000	MJ/a
			538	TJ/a
	efficiency conversion PO to fuel[20]		0.75	-
	capacity final fuel	min	300	TJ/a
		max	431	TJ/a

Table 8: Torrefaction - properties and characteristics

higher heating value (HHV)	min	20.00	MJ/kg
	max	28.20	MJ/kg
capacity average torrefaction plant in torrefied biomass		200,000	t/a
		200,000,000	kg/a
capacity average torrefaction plant	min	4,000,000,000	MJ/a
		4,000	TJ/a
	max	5,640,000,000	MJ/a
		5,640	TJ/a

[19] PO = pyrolysis oil
[20] This value was agreed on in conversations with MUSIC partner BTG-BTL.