BIO2MATCH: A TOOL FOR OPTIMISING THE MATCH BETWEEN LIGNOCELLULOSIC BIOMASS AND CONVERSION TECHNOLOGIES

T.M. Lammens[1], M. Vis[1], H. de Groot[2], B. Vanmeulebrouk[2], I. Staritsky[2], B. Elbersen[2],
E. Annevelink[3], W. Elbersen[3], E. Alakangas[4], D. van den Berg[1]
1) BTG Biomass Technology Group B.V., Josink Esweg 34, 7545 PN Enschede, Netherlands; Lammens@btgworld.com
2) WUR Alterra, Droevendaalsesteeg 3, 6708 PB Wageningen, Netherlands
3) Wageningen UR – Food & Biobased Research, Bornse Weilanden 9, 6708 WG Wageningen, The Netherlands
4) VTT Technical Research Center of Finland, Koivurannantie 1, FI-40400 Jyväskylä, Finland

ABSTRACT: This paper describes 'Bio2Match', a biomass and technology matching tool that was developed in the S2Biom EU project. Bio2Match brings together a large collection of data on both biomass properties and technology characteristics, in an interactive way. The tool is built on a database of conversion technologies and a database of biomass properties, and can be used to optimally match biomass feedstocks to conversion technologies, in order to support stakeholders in the bio-based economy with an optimised exploitation of existing biomass resources across borders. In this paper both databases will be described, as well as the methodology used by the tool to match biomass to technologies, and the way that Bio2Match works in practice.
Keywords: bio-based economy; circular economy; database; lignocellulosic sources; conversion technology; policies

1 INTRODUCTION

One of the main challenges for the development of a bio-based economy in Europe is to optimise the resource efficient use of biomass through all bio-based value chains at a European level. Different regions supply different types of biomass, which have different characteristics. At the same time, these different regions also have different demands for products, which can be produced with different technologies. The S2Biom project addresses this complexity, with the provision of tools and databases to support an optimised exploitation of existing biomass resources across borders. The activities in this EU FP7 project cover the whole value chain from primary lignocellulosic biomass to end-use products and from logistics and pretreatment to conversion technologies, in order to support the development of strategies for the best ways to realise a bio-based economy [1].

In this paper the S2Biom biomass and technology matching tool 'Bio2Match' is presented. It is an openly accessible online tool that is based on a method developed to match the available lignocellulosic biomass resources to the most suitable conversion technologies, taking into account the value pyramid of end use applications (materials, chemicals, fuels, energy). Each conversion technology has specific biomass input requirements (e.g. cellulose and lignin content, ash and moisture content, particle size, density, etc.), while the composition and characteristics of biomass at roadside varies widely. Some biomass types can be used in many different technology options, while others are hard to process or will need extensive pre-treatment.

First the two main databases underlying the tool will be described, namely the conversion technologies and the biomass characteristics databases, that were constructed during the S2Biom project and for which data were supplied by the various partners [2]. Then the methodology of the matching tool will be described, followed by a detailed description of the matching tool itself: what are the functionalities, how does it work, and what information can be drawn from it.

2 CONVERSION TECHNOLOGIES DATABASE

Biomass conversion technologies form the essential link between a variety of lignocellulosic biomass sources and a variety of final products. An overview was prepared of conversion technologies that are potentially relevant for the production of energy and materials in the period up till 2030 [3]. Based on this overview, a selection was made of conversion technologies that are relevant today, and that are expected to contribute significantly to renewable energy and the bio-based economy in 2020 and 2030. This selection was divided into three main classes:

- Thermal conversion technologies (T)
- (Bio-)Chemical conversion technologies (BC)
- Anaerobic digestion (AD)

2.1 Database structure

In order to structure the database, each class was then further subdivided into main categories, subcategories and individual process names. An example of this is for thermal conversion technologies: one category (level 1) is 'direct combustion of solid biomass', with subcategory (level 2) 'Fluidized bed combustion for CHP', and process name (level 3) 'Circulating Fluidized Bed direct combustion'. Another subcategory (level 2) is then 'Fixed bed combustion for heat', with for example the process name (level 3) 'Grate boiler with straw for heat'.

The categories (level 1) that were distinguished in the database are the following (preceded by their class):

T. Direct combustion of solid biomass
T. Gasification technologies
T. Syngas platform
T. Fast pyrolysis
T. Torrefaction
T. Treatment in subcritical water
BC. Techniques from pulp and paper industry
BC. Chemical pretreatment
BC. Biochemical hydrolysis and fermentation
BC. Biochemical ethanol and bio-based products
AD. Anaerobic digestion

In May 2016 the conversion technologies database contained about fifty technology entries. All the individual entries can be accessed in the database that is accessible in the S2Biom toolbox through the S2Biom website [1].

2.2 Technology criteria and characteristics

For each technology, a set of criteria was defined that need to be met by the biomass in order for it to be processed by that specific technology. For matching the technology criteria with biomass characteristics, the three main classes received different sets of specifications. Thermal conversion technologies have criteria for corrosion, ash agglomeration (fouling), ash content, and NOx emissions. Chemical and biochemical processes have criteria on the lignin, (hemi-)cellulose and ash content. Anaerobic digestion has criteria for digestibility and biogas yield. These will be described in more detail in the tool methodology section 4.

The database also contains general information on each technology, such as a description and a technology readiness level, as well as specific technology parameters such as conversion efficiency, product output investment costs, labour requirement, etc. An overview of the most important criteria is given below. This list is not exhaustive, but is meant to give a brief overview of what can be found in the database.

General information:
- Name and subcategories
- Description of main operating principle
- Level of commercial application
- Current Technology Readiness level
- References

Technology parameters:
- Type and capacity of outputs (typical values)
- Conversion efficiencies
- Number of typical full load hours per year
- Typical lifetime of equipment
- Non-biomass inputs (e.g. natural gas, chemicals)
- Investment costs
- Labour requirement for typical installation (fte)

Biomass input specifications:
- Common biomass input for the technology
- Max. moisture content (% as received)
- Min. bulk density (kg/m^3, as received)
- Max. ash content (wt-%, dry)
- Min. ash deformation temperature (°C)
- Max. nitrogen content (wt%, dry)
- Max. chlorine content (wt%, dry)
- Max. lignin content (g/kg dry)
- Min. cellulose content (g/kg dry)
- Min. hemicellulose content (g/kg dry)
- Min. biogas yield (m^3 gas/ton dry biomass)

2.3 Products of the technologies in the database

The bio-based products that are covered by the conversion technology database were aligned with the ten 'product-market combinations' (PMC's) of lignocellulosic bio-based products that are expected to contribute the most to the market demand in 2020 and 2030 in the EU. These were defined in another part of the project (Table I) [4].

Table I: The PMC's and their contribution (defined in petajoules) to EU28 in 2020 and 2030

Product	Market	PJ-2020	PJ-2030
Heat	Heating	3242	4740
Electricity	Power market	743	1040
Biofuels	Transport fuel	112	629
C5-6 sugars	Polymers, chemicals, etc.	8	23
Biomethane	Grid, transport	64	188
Aromatics	(Petro-)chemical industry	9	26
Methanol	Transport, chem. industry	3	13
Hydrogen	Transport, chem. industry	2	19
Ethylene	Transport, chem. industry	0	23

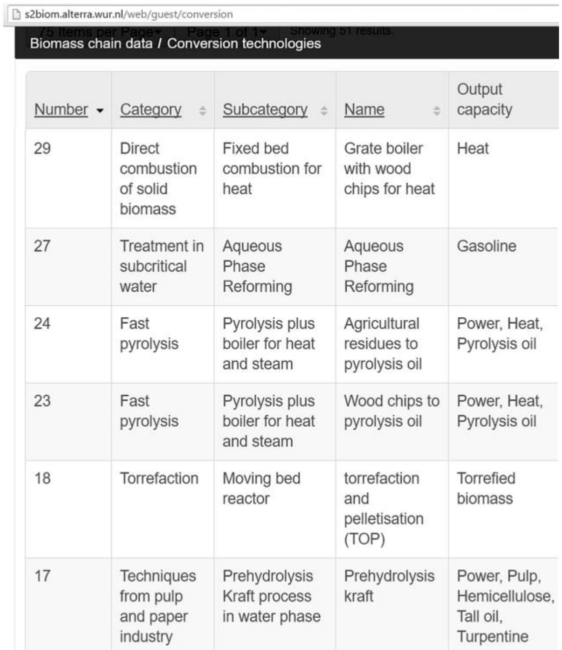
The conversion technology database covers the production of heat and electricity extensively, because these technologies are currently the furthest developed and widely available. The production of advanced biofuels is covered by a number of technologies, such as through biochemical production of cellulosic ethanol as well as through the production of drop-in fuels with pyrolysis or gasification. Biomethane was covered by incorporating production technologies through anaerobic digestion and gasification. For methanol a production route through gasification was incorporated. For three PMCs, namely BTX (aromatics), hydrogen, and ethylene, no data could be obtained of a sufficient quality to include the technologies in the database.

With regards to the production of bio-based products through the sugar platform, it was decided only to include the product ethanol in the database, through the combination of the separate entries for pretreatment and enzymatic hydrolysis (producing C5/C6 sugars) with fermentation (converting the sugars into ethanol). This was done for the same reason as mentioned above: only for ethanol sufficiently reliable data could be obtained. As it can be expected that at a later stage processes will become commercial that can convert the C5/C6 sugars to other products as well, ethanol represents the future bio-based products that are currently only made from sugar or starch crops, such as for example lactic acid.

A similar matter is the case for fast pyrolysis. The general concept of fast pyrolysis is to produce pyrolysis oil close to the location of the biomass. The pyrolysis oil can be transported much more efficiently than the raw biomass, and will often be further processed at another location. Further processing then means the production of for example pyrolysis oil diesel (a drop-in biofuel), but could also mean the direct combustion of pyrolysis oil in a district heating or power plant. So a range of bio-based products can be made from pyrolysis oil. In the database a couple of separate entries were combined into new ones, in order to provide examples of value chains from biomass to a final product via fast pyrolysis. These examples were not meant to cover all the possibilities regarding the production of bio-based products from biomass through the fast pyrolysis process.

2.4 Database presentation

The database can be accessed online, where it looks as shown in Figure 1. By clicking on a certain conversion technology, you can access the details of that technology and obtain all the information that was mentioned in section 2.2.



s2biom.alterra.wur.nl/web/guest/conversion

Biomass chain data / Conversion technologies

Number	Category	Subcategory	Name	Output capacity
29	Direct combustion of solid biomass	Fixed bed combustion for heat	Grate boiler with wood chips for heat	Heat
27	Treatment in subcritical water	Aqueous Phase Reforming	Aqueous Phase Reforming	Gasoline
24	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Agricultural residues to pyrolysis oil	Power, Heat, Pyrolysis oil
23	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Wood chips to pyrolysis oil	Power, Heat, Pyrolysis oil
18	Torrefaction	Moving bed reactor	torrefaction and pelletisation (TOP)	Torrefied biomass
17	Techniques from pulp and paper industry	Prehydrolysis Kraft process in water phase	Prehydrolysis kraft	Power, Pulp, Hemicellulose, Tall oil, Turpentine

Figure 1: Excerpt of the database contents page

3 BIOMASS CHARACTERISTICS DATABASE

The biomass characteristics database, which can be accessed through Bio2Match as will be described in section 5, contains property data of about fifty different lignocellulosic biomass types that are available in Europe. Similar to the conversion technologies database, these types were divided into different categories, in the areas of forestry, agriculture, and other land use, as well as industry and consumer waste. The structure will be further described below. Besides the characteristics of the various types of biomass that were gathered for the matching tool, also local availability and cost-supply data were gathered, in a different part of the S2Biom project. These data are also available through openly accessible online tools, on the S2Biom webpage.

3.1 Database structure

The biomass characteristics database was set-up with four levels. The first level was mentioned above, the level two subcategories are the following:

- Primary forestry production
- Primary forestry residues
- Primary production of lignocellulosic crops
- Agricultural residues
- Grassland
- Other land use
- Secondary residues from wood industries
- Secondary residues from industry using agricultural products
- Biodegradable municipal waste
- Post-consumer wood

The third and fourth level define the biomass to a more specific type. For example: 1. Forestry; 1.1 Primary forestry production; 1.1.1 Stemwood from final fellings; 1.1.1.1 Stemwood from final fellings from broadleaf trees. Another example would be: 4. Industrial residues; 4.1 Secondary residues from wood industries; 4.1.3 Secondary residues from pulp and paper industry; 4.1.3.1 Bark residues from pulp and paper industry; etcetera.

3.2 Biomass properties

In order to be able to match the different types of biomass to the conversion technologies as described above, a number of properties were gathered for each biomass type. Because biomass properties depend to a large extend on circumstances, it is not feasible to define exact values per type of biomass. A classification system was set up for the properties, dividing the biomass in four classes (ranges) per property, with class 1 as the 'most desirable' class (e.g. low ash content, high biogas yield, etc.), and class 4 as the 'least desirable' class. The exact ranges per property for each class are depicted in Table II. The rationale behind these properties is further described in section 4.1.

Table II: Biomass properties and their classification

Property	*Unit*	Classification			
		1	2	3	4
Chlorine content	*wt-% d.m.*	<0.02	0.02-0.1	0.1-0.4	>0.4
Ash deformation temperature	*ºC*	>1200	1000-1200	800-1000	<800
Ash content	*wt-% d.m.*	<1	1-3	3-10	>10
Nitrogen content	*wt-% d.m.*	<0.3	0.3-1	1-2.5	>2.5
Carbohydrates	*wt-% d.m.*	>65	50-65	30-50	<30
Lignin content	*wt-% d.m.*	<10	10-25	25-35	>35
Biogas yield	*m^3/ton a.r.*	>300	150-300	50-150	<50
Digestate has an application		Yes			No

4 MATCHING METHODOLOGY

The fundamental biomass characteristics that determine the value or risks for a certain type of conversion system were identified, to be able to match different biomass types to different conversion technologies.

Figure 2 shows a simplified classification concept. It shows that each feedstock type has qualities that are relevant for different types of conversion processes. Some of these (physical) characteristics can easily be modified (at some cost) by a basic treatment such as drying or chipping, while other characteristics are more 'fundamental', in the sense that they cannot easily be modified, for example the lignin content. Only these fundamental characteristics will be taken into account for the matching tool, while the physical characteristics (notably moisture content and bulk density) will be taken into account as a cost factor rather than a showstopper.

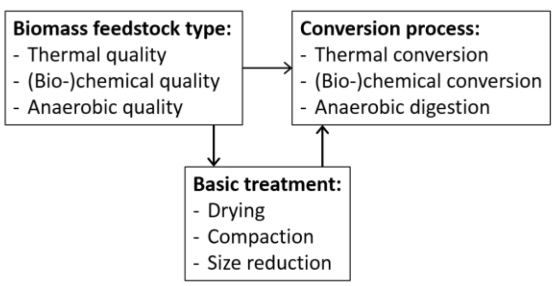


Figure 2: Simplified classification concept

4.1 Properties and their classification

For a thermal conversion system, the main feedstock-related challenges are related to corrosion, slagging & fouling, higher heating value, and NO_x emissions. The chlorine content, ash deformation temperature, ash content, and nitrogen content were taken as the most important indicators for these potential issues. A high ash content has a number of drawbacks: i) it does not contribute to energy production; ii) it may increase wear of the machinery; iii) it will generally cost money to discard ash; iv) stoves are generally designed to a limited ash amount. The nitrogen content is not so relevant for operation of the thermal conversion technology itself. But emission reduction measures make a conversion technology more expensive, and less economical to apply on a small scale (below 1 MWth). Therefore the nitrogen content is indeed relevant to take into account, especially for smaller conversion systems.

A (bio-)chemical conversion system was defined here as the pre-treatment of lignocellulosic biomass, followed by conversion of the polysaccharides into products like fuels or chemicals, but also as including processes from the pulp and paper industry. There are many fundamental characteristics that influence the potential success of (bio) chemical conversion of lignocellulose into fuels and chemicals. For our suitability approach we used the three most basic indicators: lignin content, carbohydrate (cellulose + hemicellulose) content, and ash content.

In an aerobic digestion conversion system a large part of the cost is determined by the size of the reactor. It is important that the yield per reactor volume per year is high enough. Therefore the methane yield per ton (or m^3) of substrate is very relevant. The cost of the disposal of the digestate is also relevant, therefore the potential applicability of the digestate (e.g. as fertilizer) was also taken into account.

The classification of the fundamental biomass properties is shown in Table II. For each technology, the minimum requirements were defined per property, in terms of which is the minimum class that can still be handled by that technology. Some processes will be able to handle only the highest quality (class 1) biomass, while others may be able to handle lower quality (e.g. class 3 or 4) biomass as well. This classification system should help to determine what type of conversion systems are needed to effectively utilise the available biomass types in Europe under competitive conditions.

Biomass has physical properties as well, besides the types of fundamental properties that were described before. One can think of moisture content, particle size, bulk density, etc. These properties vary widely, and often depend on the method of harvesting with the end-use application already in mind. The physical properties that were taken into account for the matching tool are moisture content and bulk density. These are properties for which at roadside reliable data or estimates were available, and which are quite important for the various conversion technologies, especially thermal conversion, given that the moisture content has a high impact on the lower heating value of a feedstock. For the physical properties threshold values rather than a classification system were used.

4.2 Matching methodology

The methodology for the matching tool was defined on the basis of the classification system described above, with fundamental characteristics (which cannot easily be modified) and physical characteristics (which can easily be modified). The matching procedure for each biomass and each technology is schematically shown in Figure 3. Depending on which type of technology is chosen (thermal, (bio-)chemical, anaerobic fermentation), the relevant fundamental properties of the biomass are first compared with the fundamental technology criteria (step 1). When each biomass property class has a lower or equal number than the technology criteria for those properties, there is a fundamental match, and the tool subsequently investigates the physical properties (step 2). When the values for the main physical properties also match, the tool generates the answer "there is a match", indicated by a green traffic light symbol. When there is a fundamental match but no physical match, the tool generates the answer "there is a match, if the biomass receives basic treatment", indicated by a yellow exclamation mark. When there is no fundamental match, the tool does not proceed to step 2, but generates the answer "there is no match", indicated by a red traffic light symbol. The way this tool looks in practice and how a user can work with it are described in section 5.

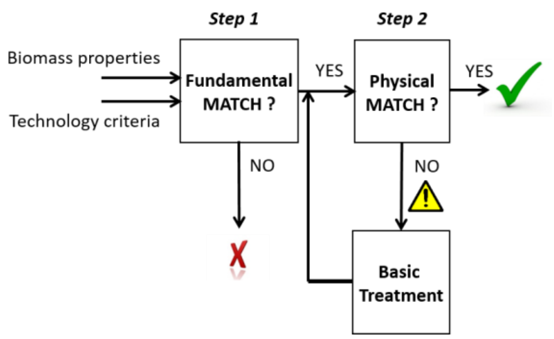


Figure 3. The Bio2Match tool methodology

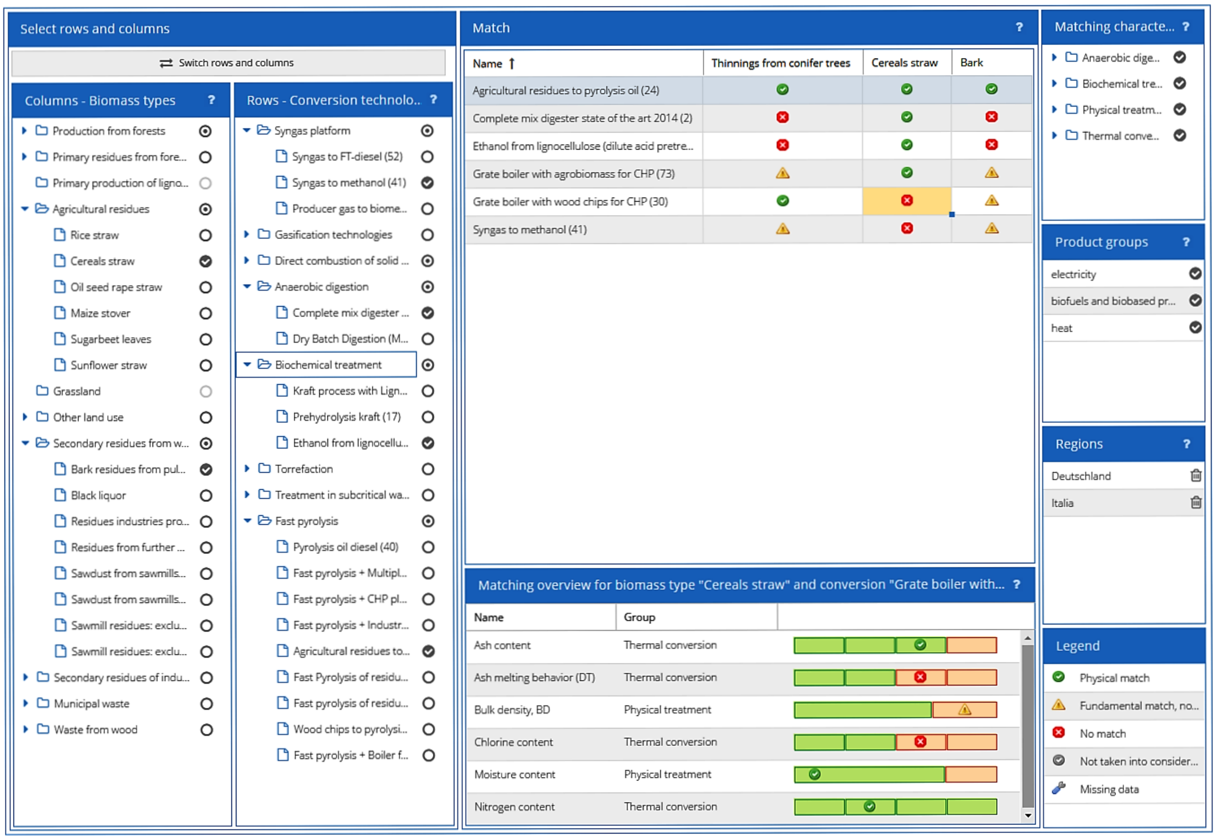


Figure 4. Screenshot of the user-interface of Bio2Match

5 USING BIO2MATCH

The user-interface of Bio2Match is shown in Figure 4. The left two columns are for the selection of biomass types and technologies to match. The user can select any number of biomass types and conversion technologies that he or she is interested in. The central screen then shows which types of biomass match to which conversion technologies, based on the methodology that was described in section 4.2.

The user can then select a single biomass-technology combination to find out why a feedstock does or does not match to a certain conversion technology. The matching classification system is visualized in the screen below the central screen with four blocks per property, in which green blocks represent the biomass quality that the technology can handle. When e.g. only the left block (class 1) is green, that means the technology can handle only feedstock of class 1 quality, when e.g. all four blocks are green the technology can handle all quality classes. The matching symbol (green ok sign or red cross) represents the actual quality of the selected biomass. If the symbol is positioned in a green block there is a match and the label turns green, if it is situated in a red block that means the technology cannot handle that feedstock quality and the label turns red in the case of a fundamental property or yellow in the case of a physical property.

This way the user can quickly identify which biomass property is responsible when a biomass and technology do not match. In the example of a grate boiler that is designed for the combustion of wood chips, cereal straw does not match as a feedstock, as depicted in Figure 4. It can be seen that the chlorine content and the ash melting temperature are responsible for the fact that there is no match.

Another outcome could be the case of a match, in which a user may find that a certain biomass type is of such high quality that it would be less than optimal to use it for a certain technology, because another biomass type of lower quality could also be converted by that same technology. Such findings may help to optimise the use of biomass in a region.

A feature of the tool is that the user can select which properties need to be taken into account for the matching. If an expert user finds that for his specific case (be it technology or feedstock) a certain property is not important, he or she can unselect that specific characteristic in the screen to the top right, after which the tool recalculates which technologies match to which types of biomass without that property being taken into account.

Another feature is a product filter, which is situated in the small screen on the middle right side of the interface. Here the user can select which types of products he or she is interested in. For example only heat or electricity, or in fuels or bio-based products. This filter then automatically selects only the technologies that are able to produce those specific products.

The last feature is a regions filter. This is a part of the tool that is linked to another tool on the S2Biom website, which is a biomass supply database [1]. This database contains availability data of all the biomass categories that are in the Bio2Match tool as well. The user can select a certain region and then link to Bio2Match, which then automatically filters the biomass types that are relevant for that specific region. The region on which this selection applies is then mentioned in the other small screen on the right side.

The tool and the conversion technology database that was described in section 2 are linked. For all the technologies in the matching tool the user can find more specific data in the database. So when a user identified an interesting technology for his or her case, he or she can easily look up that same technology in the database to find more detailed information on for example technology readiness level, investment costs, labour requirements, etc.

6 CONCLUSION

With Bio2Match we aim to provide support for the development of strategies for the best ways to realise a bio-based economy in Europe. The tool is intended to be user-friendly to biomass and/or technology experts, but specifically also to other stakeholders in the bio-based economy, such as for example policy makers or entrepreneurs. Bio2Match brings together a large collection of data on both biomass properties and technology characteristics, in an interactive way. It should be able to help you as a stakeholder in the bio-based economy to gain insight in bio-based value chains, and we hope that you enjoy using this tool.

7 REFERENCES

[1] http://www.s2biom.eu (2016).

[2] The partners who supplied data on either biomass or conversion technology characteristics were: BTG Biomass Technology Group, VTT Technical Research Center of Finland, Wageningen University & Research Centre - Food & Biobased Research, Energy Centre of the Netherlands, University of Freiburg, SYNCOM GmbH, European Forestry Institute, Centre of Research for Energy Resources and Consumption Natural Resources Division, University of Bologna - Department of Agricultural Sciences.

[3] M. Vis, R. te Raa, D. van den Berg, H. Knoef, E. Alakangas, J. Karki, A. Uslu, P. Harmsen, W. Elbersen, S2Biom Deliverable D2.1, A method for standardized biomass characterization and minimal biomass quality requirement for each biomass conversion technology (2015).

[4] H. Mozaffarian, M. Londo, M. Pantaleo, C. Kraan, S2Biom Deliverable D7.2, Market analysis for lignocellulosic biomass as feedstock for bioenergy, biobased chemicals & materials in Europe - A quantitative estimate of biomass demand in 2020 and 2030 (2015)

8 ACKNOWLEDGEMENTS

- We would like to thank the EU commission for financially supporting this research under the 7th EU Framework Programme.
- The authors would like to thank all S2Biom partners for their input and fruitful discussions, and specifically Matthias Dees from the University of Freiburg for his inputs regarding forestry products.

9 LOGO SPACE