Deliverable report

D2.3 Review paper on opportunities identified for lignin valorization processes and opportunities to increase Technology Readiness Levels

Deliverable Data		
Deliverable number	D2.3	
Dissemination level	lignocost	
Deliverable name	Review paper on opportunities identified for lignin valorization processes and opportunities to increase Technology Readiness Levels	
Work package	WG 2	
Lead WP/Deliverable beneficiary	Pieter Bruijnincx	
Deliverable status		
Submitted (Author(s))	20/04/2023	Pieter Bruijnincx; Various LignoCOST members, including from WG2, have contributed to the IEA report that serves as this deliverable.
Verified (WP leader)	21/04/2023	Pieter Bruijnincx
Approved (Coordinator)	24/04/2023	Richard Gosselink

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Working Group 2

1 Introduction and Approach –

Building on task 2.1 on establishing a lignin specific technology readiness level scheme for lignin valorization processes (see deliverable 2.1) and task 2.2 on reviewing the full field of lignin production and lignin valorization routes, the synthesis of these efforts was envisaged in task 2.3 which is concerned with reviewing the state of the art in the field of lignin production and conversion, with the aim to identify opportunities for further technology development, in particular how the various (nascent) technologies could be (better) connected to various value chains (as also studied in WG3), and the aim to identify hurdles for further development, i.e. for processes to move up the technology readiness level scale. As with task 2.2/deliverable 2.2 this task/deliverable topically covered both existing and novel lignin production and conversion technologies, i.e. technologies concerned with the 'upstream' part of biorefining (separating biomass into its constituent components and generating the lignin) and the 'downstream' part of biorefining (further conversion and valorization of isolated technical lignins). The exercise was technology agnostic and thus would extend to all up- and downstream examples. In addition, a major recent development in lignin valorization, i.e. the so-call lignin strategies, combines up- and downstream conversion in a one-step process, liberating the lignin and rapidly converting it away to a more stable end product. As the field has (re)exploded in the past 10 years or so, the numbers of pretreatment (upstream) technologies, the number of downstream conversion technologies and the number of examples of lignin-first strategies has also exploded; this is not only the case in terms of the technology/conversion method used, but also in terms of the feedstock and process operations involved in the lignin valorization efforts. As noted task 2.2/deliverable 2.2, a comprehensive review or perspective was deemed unfeasible also given the many contributions to the open literature that are already available on more aspects of lignin valorization. Indeed, as of March 2023 >4500 original review papers are available in the public domain that cover the field of lignin valorization (scopus search), to many of which LignoCOST (and WG2 members have contributed). A nice, impactful example of this is the lignin-first review written by WG2 member Koranyi et al. on lignin-first methodology (*Molecules* 2020, *25*(12), 2815; https://doi.org/10.3390/molecules25122815). Given that the field is largely saturated with peer-reviewed review and perspective papers, we opted for another way to deliver on this task.

In 2020 the chair of the action was approached with the request to collaborate with task 42 of the IEA Bioenergy on issuing a joint report on lignin valorization. The scope and aims of this report largely coincided with the scope and aims of deliverable 3; the report has been published in October 2021 (see https://www.ieabioenergy.com/blog/publications/sustainable-lignin-valorization/) and the appendix. It is a joint publication, accrediting the LignoCOST action and with contributions from various LignoCOST associated authors and is presented here as deliverable 2.3 of WG2 (figure 1).

Figure 1. Front cover and title page of the IEA Bioenergy Task 42/LignoCOST joint report on sustainable lignin valorization. The full document is attached as appendix 1.

2 Conclusions and outlook

The field of lignin valorization is rapidly evolving and bustling with opportunities, but serious hurdles also remain to be taken. Here the conclusions from the IEA Bioenergy Task 42/LignoCOST joint report are integrally reproduced:

Conclusions

Lignin-derived chemicals such as phenols for the production of adhesives and resins have rapidly increased in the last 5-10 years. Additional applications close to the market include asphalts and additives for concretes (i.e., polyurethanes),

The major part of the developed applications uses lignin as a macromolecular stream. Kraft lignin and lignosulfonates are the most abundant technical lignins already tested for several applications.

In the short term, the production of lignin-derived SAFs could have a chance to be rapidly integrated in existing oil refinery infrastructures to produce drop-in fuels, especially for the aviation and marine sectors.

- The volume of Kraft and lignosulfonates could decrease in the future due to the reduction in printed paper and the increasing trend in the use of recycled paper. In contrast, technologies for biorefineries are expected to reach higher TRLs and to be more widely available in the market. This could increase the volume of technical lignins through biorefinery applications.
- In addition to phenols, fine chemicals from lignin with huge potential include aldehydes and BTX.
- The use of innovative and light materials with improved mechanical and technical properties will progressively involve wide sectors in the future. In this regard, lignin-derived carbon fibres could have an important market share. In the long term, the main application could be the progressive replacement of steel with carbon fibre. At the same time, lignin could be used as a coke replacement in the iron and steel industry.

Research in the short term must include a higher exploitation of the most abundant technical lignins, namely kraft and lignosulphonates, mainly for the production of macromolecules (i.e. adhesives, resins, carbon fibers).

Research in the medium to long term must include:

- the development of novel value added applications (i.e. nanoparticles, smart materials);
- the development of novel biorefinery layouts yielding high purity lignins and to prove their scalability;
- integrated techno-economic and environmental assessments

Finally, a deep knowledge of the lignin structure is a key element to tailor the lignin chemistry and to achieve streams with standardized properties.

3 Appendix

Appendix 1: Joint report 'Sustainable Lignin Valorization' IEA Bioenergy task 42/LignoCOST by S. Mastrolitti, E. Borsella, A. Giuliano, M.T. Petrone, I. De Bari, R. Gosselink, G. van Erven, E. Annevelink, K.S. Triantafyllidis, H. Stichnothe (2021, 195 pp.)