Deliverable report

Deliverable Data		
Deliverable number	D4.1 & D4.2	
Dissemination level	LignoCOST members	
Deliverable name	Bitumen binders for road application	
Work package	WG4	
Lead WP/Deliverable beneficiary	Per Tomani, RISE/whole consortium	
Deliverable status		
Submitted (Author(s))	05/04/2023	Richard Gosselink, Ted Slaghek
Verified (WP leader)	14/04/2023	Per Tomani
Approved (Coordinator)	17/04/2023	R.J.A. Gosselink

Contents

1 Preface

The main objective of LignoCOST is to jointly establish a network in which relevant information packages are produced with a focus on sustainable lignin production and valorisation at industrial level (https://LignoCOST.eu/). The LignoCOST action has been structured in 5 working groups (WG) of which WG4 is dedicated to investigating value chains of selected lignin-based products. This deliverable reports the findings concerning the value chain of bituminous binders for asphalt application in which lignin is already used at demonstration scale (TRL6-7) to partly replace bitumen up to 50%.

The objective of this task is to evaluate the commercialisation potential of lignin-based asphalt binders for road pavements:

- Current state of art – Opportunities and barriers from market and technical point of view
- Value chains – Required processing steps & stakeholders

Task force leader: Richard Gosselink (WFBR)
Task force members: Ted Slaghek (WFBR), Minna Yamamoto (St1), Julia Geist (Essity), Hanne Wikberg (Fortum)

2 Evaluation criteria for commercialisation potential

Market potential:

- Drivers for lignin use
- Current commercial production and actors / state of the art
- Market volumes, product segments, bitumen price

Technical requirements & potential challenges for commercialisation

- Lignin requirements – Applicability of different lignin types
- Technical product requirements / specifications
- Key technical challenges for commercialisation
- Upgrading technologies to improve lignin quality for asphalt binder application

Environmental impacts
Legislation, regulations, certifications
Barriers for commercialisation
Value chains: processing steps, key actors & potential gaps
Final conclusions: SWOT for commercialisation potential

3 Drivers for lignin use

- **Sustainable biobased and safe alternative to bitumen**
    - Significantly reduced carbon footprint (long term storage of biogenic carbon in road)
    - Reduced demand of fossil resources
    - Diminishing production of bitumen by oil refineries and lengthening of supply chains
- **Cost competitiveness**
    - Equal or lower cost raw material compared to bitumen
    - Price not fluctuating according to oil price
- **Legislation – limited information available**
    - In some countries the environmental impact is one selection criteria among the price and technical performance in Public Procurements
    - Regulations for biobased asphalt are not in place yet
- **Improved pavement quality – limited data available**

4 Current commercial production and actors / state of the art

Due to its binder, UV stability, hydrophobicity, aromaticity, anti-microbial properties lignin exhibits relevant functionality to act as a binder for asphalt application. An asphalt binder binds together stone aggregates, sand and additives to prepare a durable road construction. Up to 6wt% of binder is used in different asphalt mixtures. Most applied technology is based on hot asphalt production.

Research and demo projects have been conducted in the last 10 years. The Netherlands is frontrunner in the development of lignin-based asphalt. Currently, >30 demonstration roads have been paved with different types of technical lignins. 1 road fully paved with 3 layers of lignin-based asphalt (incl. Reclaimed Asphalt Pavement RAP). Other countries followed: Finland (3), Sweden (2), Canada (5), UK (1), Estonia (1), Spain (1).

The asphalt binder consists of up to 50% technical lignin in 50% bitumen. Two technologies are applied: 1) direct mixing in asphalt pug mill (TRL 6) 2) blending technology (TRL 3-4). For both technologies patent applications have been filed and in some countries these patents have been granted. Several lignin types have been tested in demonstration scale like: Kraft softwood lignin, hydrolysis straw lignin, acid hydrolysis wood lignin, soda straw/grass lignin, soda miscanthus lignin.

There is huge interest from road owners due to:
1) sustainability (reduction in carbon footprint)
2) secure binder raw material for the future
3) additional functionality

5 Market volumes, product segments, and product price

5.1 Market volume bitumen

The overall bitumen market accounts for 90 Mtonnes per annum world-wide. The paving grade bitumen market in Europe is around 11 Mtonnes (2022). Most of the bituminous products are used in 85% road construction; 10% in roofing; 5% others (a.o. carpet tile backings). The price range of bitumen is fluctuating between 300-500 EURO/ton, following the crude oil price, and in May 2022 abound 500 US$ or 500 EURO/ton (see Figure 1).

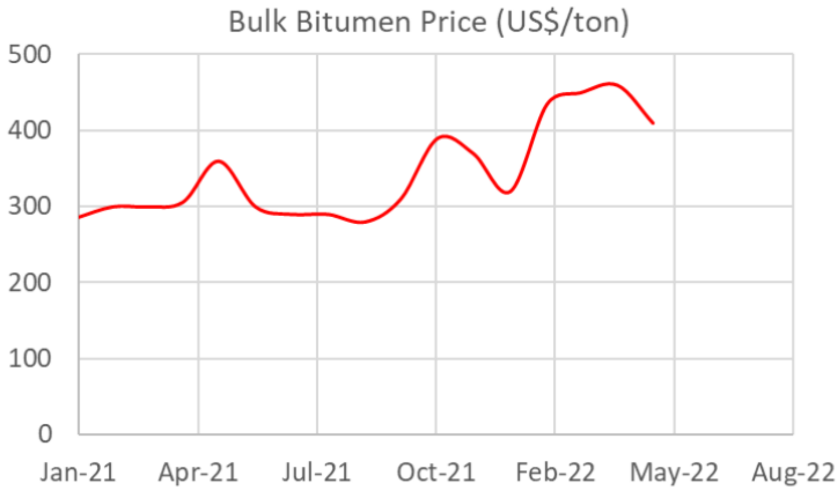


Figure 1. Bulk bitumen price during 2021-2022

In Europe, the bitumen production currently corresponds to demand which is quite stable. The energy transition may lead to decreasing production of bitumen, which is the bottom product of oil refineries. Additionally, the crisis in the Ukraine will have an impact on the bitumen supply from Russia and neighboring countries.
As the current binder technology consist of 50% lignin, which is demonstrated successfully at TRL 6-7, the potential for lignin adaptation to this value chain of bituminous binders is estimated at 45 Mtonnes of technical dried lignin. For two countries the situation is as follows:

Country	Pavement grade bitumen (Mtonnes per year)	Potential lignin based on 50% replacement (Mtonnes per year)
The Netherlands	0.3	0.15
Finland	0.2	0.1

5.2 Product segments

A road pavement can consist of multiple layers like top layer, binder and base layers. Next to that the asphalt product could be different depending on functional requirements, applications, and climate. Up till now most demonstration roads have been paved with in the top layer the innovative lignin-based asphalt. This top layer is not only the most sensitive to climate conditions and wear but can also be visualized during monitoring of the performance during its lifetime. Some demonstration roads in the Netherlands have been paved with lignin binders in combination with reclaimed asphalt pavement (RAP) in the binder and base layers.
In the Netherlands most provincial roads, cycling paths and industrial roads consist of stone mastic asphalt (SMA), while on the highways porous asphalt is applied.

5.3 Product price ranges

In Figure 1 the bitumen average is 500 EURO/ton (2022). The technical lignin prices depend largely on purity, reactivity and production capacity. Based on contact with suppliers and users the average price for a commercially produced Kraft softwood lignin is 700 EURO/ton. It is expected that a hydrolysis lignin, as side stream from cellulosic ethanol production, is valued at 300-500 EURO/ton. Other types of lignins are currently produced at pilot scale and these prices can vary substantially. As this asphalt binder application can be developed by using different types of lignins: Kraft, soda, hydrolysis, organosolv can be used.

Currently Kraft softwood lignin is the base case for application in bitumen as the availability and functionality are within specs for this application. As Kraft lignin is slightly higher valued than bitumen at the moment, the costs of lignin-based asphalt is 10-15% higher compared to conventional asphalt with bitumen (Moretti et al. 2022).

6 Technical requirements & potential challenges for commercialisation

6.1 Lignin requirements – Applicability of different lignin types

Requirements

- Lignin content >60 wt%
- Dry lignin, idealy DM 95%
- Powdered form (average size 200 um)
- Less feedstock dependent: Kraft, soda, hydrolysis, organosolv, acid can be used\
- Lignosulphonates can not be used in this hot asphalt application. Lignosulphonates are used in cold asphalt emulsion technology.

6.2 Technical product requirements / specifications

The Netherlands requirements

- Bitumen quality used is often 70/100 or 40/60
- Lifetime of a top layer is 12-15 years

Technical product requirements / specifications (Netherlands):

- Stable binder properties
- For porous (PA) and stone mastic asphalt (SMA):
    - Indirect tensile strength ratio (ITSR %) of minimum 80% after emerging under water test
- For AC surf mixture: Stiffness and resistance to fatigue (4-points bending test)
    - Stiffness: 3600 – 11,000 Mpa
    - Fatigue resistance: 100 - 130
    - Track formation (Fc Max): 0.2 - 4.0
- Careful assessment and documentation of technical performance with new materials

Finland requirements

- Quality requirements of new asphalt layers and mixtures/materials specified in detail in Finnish Asphalt specification (www.pank.fi)
    - Resistance to abrasion by studded tyres
    - Resistance to permanent deformation
    - Water sensitivity, roughness, skid resistance, air void content
    - Composition (VC, VFB, binder content and grading) etc.
- Short paving interval on main roads (~5 years)
- Softer bitumens used in Finland than in central Europe, enabling the use of hot-in-place recycling
    - All materials need to be recyclable
    - Typical range of recycled asphalt 20-75% and recycled asphalt used in more than 70% of paving sites
- More info: Finnish Transport Infrastructure Agency

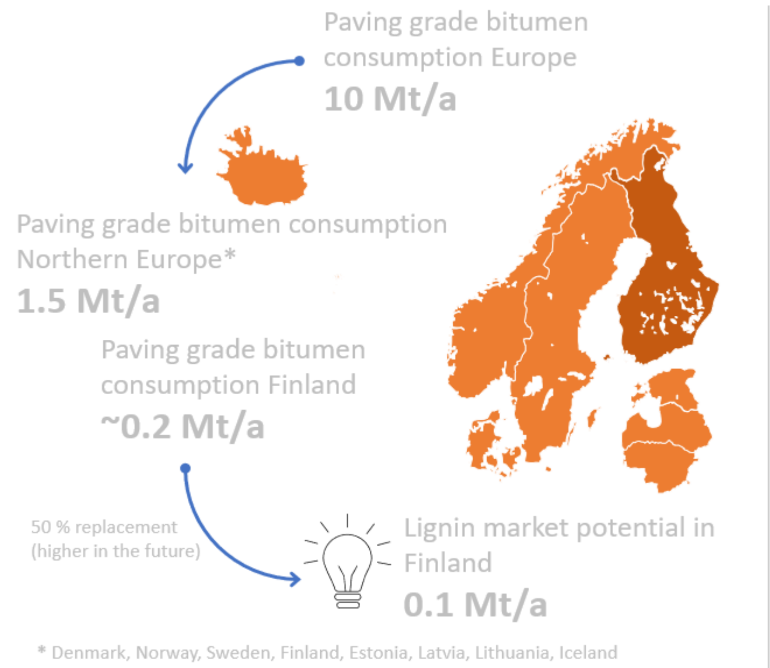


Figure 2. Finland paving grade bitumen demand and lignin market potential

6.3 Key technical challenges for commercialisation

For commercialization of lignin-based asphalt, some key technical challenges have to be solved. These are:

- Feed of powdered lignin into asphalt pug mill / blender. In the Netherlands this has been solved by using a either melting bags with lignin or feeding the lignin via a mobile silo.
- Proper blending
- Process temperature
- Continuity of feed and supply
- Varying requirements for asphalt in different geographical areas, requiring intensive R&D
- Long-term follow-up of demonstration roads to ensure pavement durability
    - The same quality and the same durability as provided by primary materials required
    - Long-term monitoring of road quality is needed

6.4 Upgrading technologies to improve lignin quality for road pavement

For the asphalt technology in which 50% of bitumen can be replaced by lignin, no upgrading technology is needed to fulfil its functionality as binder in road pavement. However, modification of lignin via etherification could increase the functionality of lignin closer to the bitumen properties. This has been studied by Nahar et al. 2022. The rheological behavior of modified lignin-bitumen binders is more similar to bitumen 70/100 grade.

7 Environmental impacts

Lignin contains biogenic carbon which is stored during the growth of the lignocellulosic feedstock. Using lignin as partial substitute for bitumen, not only substitutes a fossil resources but additionally facilitates the long-term storage of biogenic carbon in a road (including recycling). This will ultimately lead to a substantial CO_2 emission saving via this application. This was calculated for Kraft lignin subsituting 50% of bitumen in road pavement and led to 35%-70% lower CO_2 emission per ton of asphalt (Moretti et al. 2022). Further findings are:

- The production of lignin can have a large impact on the overall LCA, in particular when natural gas is avoided by using biomass side streams for energy make up at the pulping mill.
- Additional energy savings in pavement production with lower processing temperature can be applied. Normally asphalt is produced at 180°C; lignin-based asphalt is produced at 140°C.
- Emissions in pavement processing are limited due to the lower processing temperature and the more biobased asphalt binder mix.

8 Barriers for lignin-based asphalt binder commercialisation

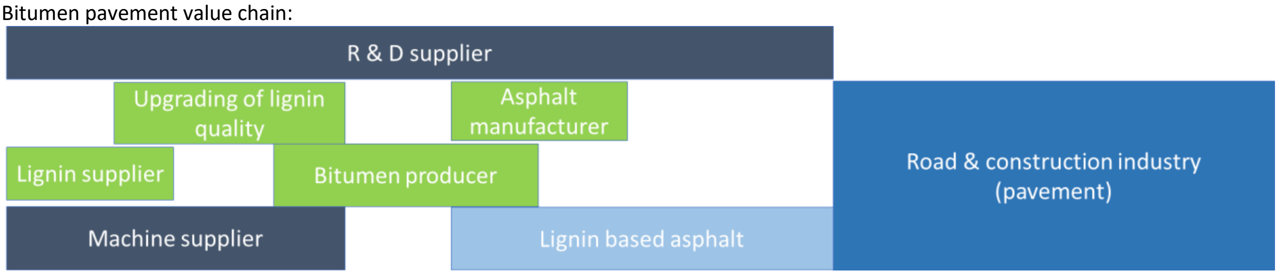
Legislation, regulations, certifications are still in its infancy.

In The Netherlands there is an increase in demand from road owners in tenders to apply for a minimum of 30% biobased in asphalt related to the binder. Now it is still in relation to demonstration roads.
For some lignin-based asphalt mixes a CE certification is available in The Netherlands.
Some other barriers are:

- Large scale availability of lignin for competitive production costs
    - Lignin supply and market still developing, with few producers. There is not a real lignin marketplace yet.
    - Uncertainties for security of supply
- Certification needed with input of LCA data
- Competition with other added value applications (PF resins, carbon fibres, ...)
- Pulp mills must decide to invest in lignin extraction / production units, which needs a high capital investment.
- Capital intensive biorefinery investments associated with high risks
    - Few commercial technologies available

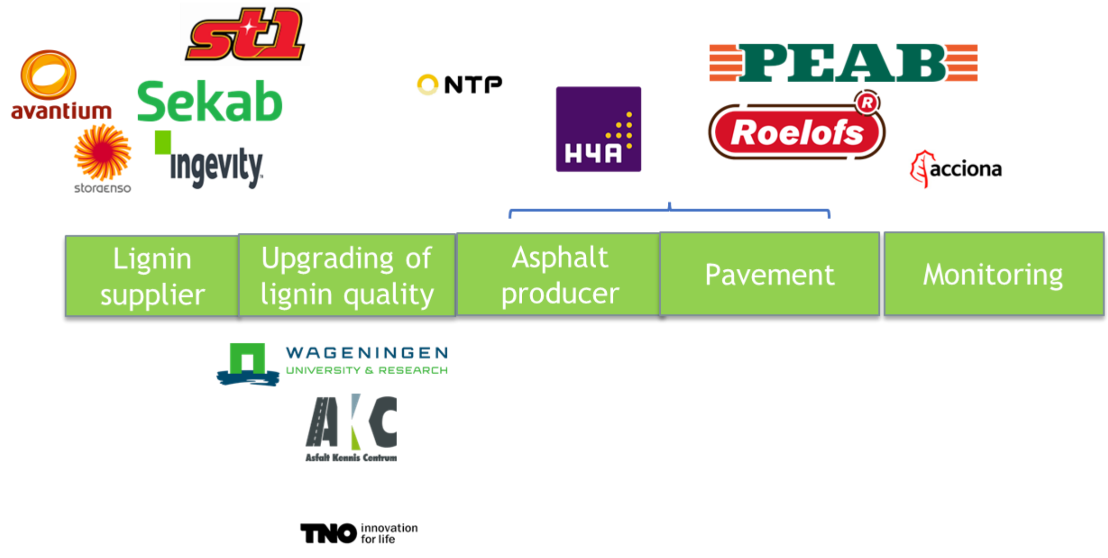
9 Value chains: processing steps, key actors & potential gaps

Bitumen pavement value chain:



10 Value chain stakeholders

Example of simplified value chain with potential Stakeholders which are representatives in different European countries:



11 Final conclusions

As conclusions, a detailed strengths-weaknesses-opportunities-threats analyses (SWOT) has been made for the commercialisation potential of lignin-based asphalt binders:

Strengths • Drop-in biobased substitute for fossil bitumen • No investments needed in asphalt mill, only investment in lignin extraction needed at pulp mill (anyway needed for any lignin valorization route) • Clear perspective of cost competitiveness once more lignin becomes available • Significant substitution rates up to 50% • Environmental benefits and market value through greener solution • Less volatile pricing compared to bitumen	**Weaknessess** • Not cost-competitive yet because of low lignin supply • More monitoring data needed on performance, LCA, recyclability • Due to long road lifetime, it is difficult to predict performance throughout the entire lifetime (often essential to participate in large public tenders) • Each lignin quality needs to be demonstrated (varying lignocellulose raw materials and processes affect the quality) • Each geographical location has different requirements and requires demo roads
Opportunities • Development of a 100% biobased binder • Application in all road layers • An easy baseline application ensuring a basic revenue stream for lignin for any new or existing biorefinery wishing to invest in lignin extraction, to be combined with higher value application later on • Application with relatively high TRL, being close to commercialization • Closure of oil refineries producing bitumen • Change of transport due to electrification and other fuels (hydrogen) lead to less demand of fossil fuels	**Threats** • Little policy support to apply low-carbon/biobased materials (e.g. Compared to energy applications) • Low availability of lignin because of limited availability of commercial applications for lignin (chicken-egg problem) • Failures may

12 Company interviews

As a last activity of the value chain investigation, company (lignin producers, asphalt manufacturers, road owners, governmental organisations) interviews were done

- to understand the full commercialisation potential for lignin-based asphalt binders for road pavement
- to understand the technical challenges & barriers for commercialisation

Next to individual interviews a virtual workshop was organized by LignoCity, RISE, WFBR on 20 February 2023. About 70 stakeholders attending the workshop and gave valuable feedback on this application.

The program of the workshop was as follows starting with state-of-the-art presentations from various countries and in the second part an interactive workshop with feedback from participants on questions related to the commercialization of this application:

Program
13.00 Introduction workshop, announcement speakers and objectives (Richard Gosselink, chair LignoCOST)
13.15 Heikki Lotti, Stora Enso (SE), Lignin production and use in asphalt applications in Europe
13.35 Karl Peebo, Fibenol and Karli Kontson, TalTech (EE), Lignin production and use in asphalt application in Estonia
13.55 Ralph Venema, Asphalt Knowledge Centre (AKC, NL), Status biobased asphalt in The Netherlands
14.15 Biobreak
14.25 Mats Wendel, PEAB (SE), Lignin based asphalt in the Nordic countries
14.45 Natacha Mongeau, FPInnovations (CA), Lignin based asphalt trials and achievements in Canada
15.05 Martin Junginger, Utrecht University (NL), LCA and TEA of lignin based asphalt, experiences from The Netherlands
15.25 Biobreak
15.35 Start interactive workshop and introduction (Per Tomani, RISE)
In this session, questions will be displayed by a service tool (e.g. Mentimeter) to the audience and asked for feedback. A discussion will follow after each menti question, depending on the outcome of each question.

The first part of the workshop with presentations from key actors resulted in a good overview of ongoing initiatives, property requirements and some aspects on sustainability related to the applications. The delivery of sustainability is clear with the opportunity to reduce life cycle climate change impacts substantially (between 30% and 75%) with lignin in asphalt. However, currently, lignin-based asphalt is not cost competitive but the MKI scores are (in most cases) lower (i.e. better!) compared to conventional asphalts. However, it does not make up for the higher cost of lignin-based asphalt over its life cycle. Finally lignin-based asphalt has slightly higher circularity than bitumen-based asphalt.

The second part of the workshop was executed by using www.menti.com which made it possible for all workshop participants to answer some questions we prepared in advance. You can find all Q&A:s in appendix 1 (separate file).

13 Literature

Moretti, C., Corona, B., Hoefnagels, R., van Veen, M., Vural-Gürsel, I., Strating, T., Gosselink, R., Junginger, M. (2022) Kraft lignin as a bio-based ingredient for Dutch asphalts: An attributional LCA. Science of the Total Environment, 806, 150316. DOI: 10.1016/j.scitotenv.2021.150316

Moretti, C., Hoefnagels, R., van Veen, M., Corona, B., Obydenkova, S., Russel, S., Vural-Gürsel, I., Jongerius, A., Junginger, M., Using lignin from local biorefineries for asphalts: LCA case study for the Netherlands. Journal of Cleaner Production, of Cleaner Production, 343 (2022) 131063 https://doi.org/10.1016/j.jclepro.2022.131063

Sayeda Nowrozon Nahar, Ted M. Slaghek, Dave van Vliet, Ingrid K. Haaksman, Richard J.A. Gosselink, Mutual compatibility aspects and rheological assessment of (modified) lignin-bitumen blends as potential binders for asphalt Road Materials and Pavement Design 2022, https://doi.org/10.1080/14680629.2022.2146602