CHAPLIN: *Collaboration in aspHalt APplications with LIgniN in the NetherLands*

This project focus on Programmalijn: Thermochemische- en Chemisch katalytische conversietechnologie

Locatie(s) waar het project uitgevoerd wordt:

- Activities of WFBR will be executed at: Bornse Weilanden 9, Wageningen, The Netherlands.
- The activities of the partner TNO will be executed at: MEC-lab, Bakemastraat 97k, Delft, The Netherlands.
- The activities of Avantium will be executed at DAWN Pilot Bio-refinery (chemiepark Delfzijl), Oosterhorn 4, 9936 HD Delfzijl, The Netherlands.
- The activities of the University of Utrecht will be executed at Princetonlaan 8a, 3584CB Utrecht, The Netherlands.
- AKC: Olivier van Noortweg 10, 5928 LX Venlo, The Netherlands.
- The activities if H4A will be executed at ZVAC (Zeeuws Vlaamse Asfalt Centrale), Wervenweg 10, 4551 MC Sas van Gent, The Netherlands.
- The activities of NTP will be performed at De Koppeling 18, 6986 CS, Angerlo, The Netherlands.
- The activities of Latexfalt will be executed at Hoogewaard 183, 2396 AP Koudekerk aan den Rijn, The Netherlands
- The activities of Dura Vermeer will be executed at: Central Laboratory and Asphalt Mixing Plant APE, both at Eemweg 82, 3755 LD Eemnes, The Netherlands.
- The activities of the BioBased delta will be executed at Auvergnedijk 2, 4612 PZ, Bergen op Zoom, The Netherlands.
- Demonstration roads are planned in Bergen op Zoom and in Wageningen. Exact locations will be defined during the execution of the project. Both municipalities are located in The Netherlands.

0. Public summary

Motivation

The Netherlands is producing and maintaining high quality roads. To maintain this road network, asphalt and its asphalt binder quality (bitumen) should keep its high performance level and should meet strong environmental criteria. In that respect bitumen as residue of an oil refinery is of fossil origin and this by-product is facing decreasing production volumes, due to the closure of bitumen producing refineries and variable qualities as a higher share of light products is extracted from the bitumen fraction. Also the insecure situation in the Gulf region will have a strong impact on the availability and fluctuation of prices of oil and bitumen. To address these recent changes in bitumen quality and to prepare for the future, there is a need for renewable binder suited for asphalt applications. Lignin, a binder in lignocellulosic biomass, and extracted in high volumes as a by-product of pulp and cellulosic ethanol production, may serve as bio-based alternative to bitumen. Lignin has been researched for some years, but detailed analyses on its production, binder behavior, outdoor performance in the user phase, recycling options, techno-economic and life cycle assessment is limited.

Project aim

The aim of this project **CHAPLIN** is to evaluate lignin, which is produced in The Netherlands, in asphalt applications and monitor current and novel test roads of selected lignins.
CHAPLIN will generate data on the availability of locally and Internationally sourced lignins and study its suitability as binder in hot mixed asphalt. The partners in CHAPLIN cover the full value chain including lignin production, processing of lignin in asphalt, test road construction, and integral knowledge of lignin, bitumen and asphalt. This combination of partners will ensure project success and assure short-time market deployment as soon as competitive business cases are developed.
The program line of TKI-BBEG 'Thermochemical and Catalytic conversion technologies' has the potential to contribute substantially to the goal of CO_2 reduction. The use of biomass in large scale industrial applications, such as asphalt, do support such an effort. CHAPLIN perfectly suits this goal since its using lignin as a partial binder in asphalt and this application creates a carbon sink for decades and the used lignin will not be burned as is the case today. This offers sustainable solutions for the future.

Planned activities
CHAPLIN is structured in work packages headed by different work package leaders. In WP1 the lignin availability and sourcing in the Netherlands and outside will be assessed. In WP2 the blending and modification of lignin and bitumen is tested on lab scale. Suitable lignins will be tested in asphalt construction on lab scale and detailed analyses of the binder including aging will be performed in WP3. Selected lignins will be tested in the lignin asphalt production at larger scale (pug mill) and the overall process will be monitored on health & safety aspects, processing and recycling in WP4. Construction and monitoring of test sections will be performed in the municipalities participating in CHAPLIN in WP5.The technical performance of lignin asphalt will be supported by a full techno-economic and LCA assessment. CHAPLIN will generate a road map how to come to full implementation of lignin based asphalt in the future infra world.

Results
CHAPLIN will deliver results on the technical, including recycling, economic and environmental performance of lignin based asphalt from existing demonstration roads and novel demonstration roads. The influence of the Dutch climate (e.g. UV radiation, water/dryness cycles, and frost-dew cycles) on the top layers of demonstration roads, in which several types of lignin have been used, will be monitored by a sufficient monitoring plan. This project will deliver the feasibility results in a well written report.
Next to that, **CHAPLIN** will generate knowledge on the use of lignins, which are produced in the Netherlands, in this asphalt application.
Performance results over a longer monitoring period will be essential to validate the use of lignin in the asphalt binder to continue the full scale upscaling towards commercial application of lignin based asphalt in the near future. After finalising this project the monitoring will be continued within the larger **OVERALL CHAPLIN** program. Results of **CHAPLIN** will form the basis for implementation of lignin as a binder for asphalt application at the asphalt mills in the Netherlands and other countries.

1. Deelnemers en derden

1.1 Overzicht van deelnemers

No	Naam deelnemer	Short name	Type organisatie	Rol in project
Co	Wageningen Food & Biobased Research	WFBR	Research organisation	Coordinator and WP leader; market survey of technical lignins; characterisation and modification of lignin sources
P1	Biobased Delta	BBD	Non profit foundation	WP leader and lignin supplier
P2	University Utrecht	UU	Research organisation	TEA and LCA
P3	Asfalt Kennis centrum	AKC	SME (klein bedrijf)	Asphalt and H&S tests
P4	TNO	TNO	Research organisation	Assessing modified lignin blend performance; assessing lignin-asphalt performance.
P5	H4A	H4A	SME (midden bedrijf)	Production and monitoring of lignin-based asphalt
P6	NTP	NTP	SME (midden bedrijf)	Production and monitoring of lignin-based asphalt
P7	Dura Vermeer	DURA	Large industry	Developing, testing and producing lignin asphalt applications; construction of test sections.
P8	Latexfalt	LTX	SME (midden bedrijf)	Blending and testing of lignin-bitumen blends
P9	Vertoro	VERTORO	SME (Klein bedrijf)	Market survey of technical lignins; analysis and conversion of selected technical lignins to char; supplier of lignin fraction
P10	Avantium Chemicals BV	AVT	SME (midden bedrijf)	Production of Dawn lignin
	Linked stakeholders			

S1	Bergen op Zoom	BoZ	Government	Advisory board
S2	Wageningen	Wag	Government	Advisory board
S3	Provincie Noord Brabant	PNB	Government	Advisory board
S4	Provincie Zeeland	PZL	Government	Advisory board
S5	Provincie Gelderland	PGld	Government	Advisory board
S6	Provincie Zuid Holland	PZH	Government	Advisory Board

The partners (large industries, SME's, RTO's) in **Chaplin** cover the full value chain from university to contract research organisations to small to medium enterprises and large companies (see figure 1) The chain includes the production of lignin, processing of lignin in asphalt, road construction, and integral knowledge of lignin, bitumen and asphalt. This combination of partners will ensure success of the execution of this project and will assure short-time market deployment as soon as competitive business cases are developed.

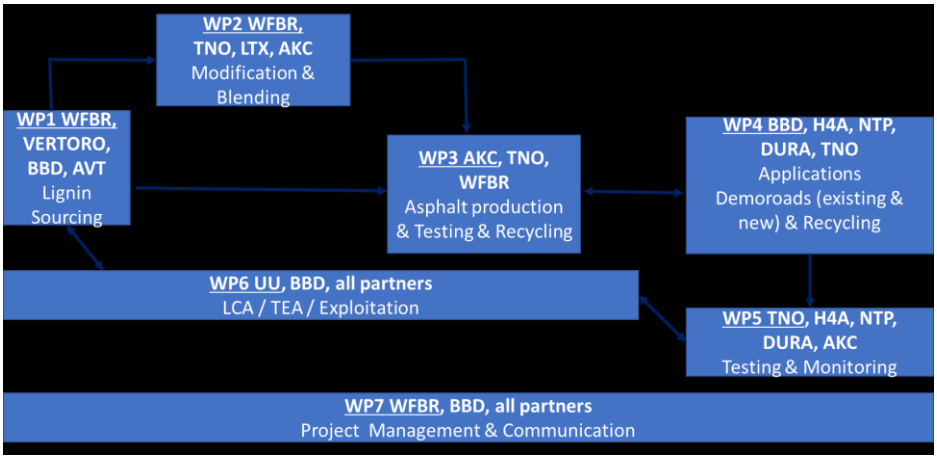

Figure 1: Block scheme showing the full lignin to asphalt chain and work packages involved

1.2 Beschrijving per deelnemer en essentiële uitbestedingsrelaties

Coordinator: WFBR
Benefit for partner joining the project: WFBR develops processes using lignin as a raw starting material for bio-based products and energy. WFBR will use this project to further develop its lignin based asphalt technology. Already quite some types of lignin's have been evaluated by WFBR. Now there is an opportunity in **CHAPLIN** for the Dutch lignin producers to join this technology which will benefit the Dutch bio-based market. Also for the end users of the lignin based asphalt technology there is an opportunity since Dutch lignin will benefit the costs for producing and applying bio-based asphalt. By using lignin the overall carbon footprint will be dramatically reduced.
Benefit for consortium of partner involved: Apart from technology developer, WFBR is also an internationally recognised RTO with a large experience in both setting-up and coordinating large multi-stakeholder R&D-projects and the deployment of full sustainable biomass-to-products value chains. WFBR has ample experience with the development of lignin based asphalt in the Netherlands together with stakeholders. On its campus a demonstration cycling path is present.
Specific project contribution: WFBR will coordinate this **CHAPLIN** project, and further will be involved in a number of WP's. Main focus will be the evaluation of the lignin products coming from the two producers in the project and translate the properties to applicability in asphalt.
Partner 1.: BioBased Delta
Benefit for partner joining the project: BBD is an alliance of Dutch provinces, businesses and knowledge centres in the delta region of North Brabant, Zeeland and South Holland. Together, we are pioneering and stimulating a sustainable bio-based economy. We support initiatives to use biomass as a raw material in the chemical, construction and packaging industries. We are applying natural residual flows from agriculture, forestry and horticulture to reduce our reliance on fossil raw

materials. Bio-based Delta is strengthened by the goals set in international and national agreements such as the Paris Climate Agreement and the National Raw Materials Agreement in the Netherlands. The bio-based transition is an opportunity that must not be missed. The green economy of the future has enormous commercial potential for businesses in our region. For the businesses and knowledge centres cooperating in Bio-based Delta, the transition is a creative challenge, a chance to work together to develop more sustainable, better and more attractive products.
Benefit for consortium of partner involved: BBD has a large network at the (petro)chemical industry, building industry, governmental organisations and knowledge institutes and has a lot of knowledge and experience in chemical and bio-based processes. BBD is the initiator and program manager of the CHAPLIN program. This program covers a period of about 5 years to stimulate technologies and market on asphalt applications with lignin. This program stimulates technologies and market on asphalt applications with lignin.
Specific project contribution: BBD is leader of WP4 and contributes to lignin sourcing, LCA/TEA/exploitation and communication/dissemination.
Partner 2.: University Utrecht
Benefit for partner joining the project: UU supports the development of the bio-based economy and recognises the need to ramp up the development of sectors that have, apart from biomass, few alternatives to decarbonize including chemicals, aviation, shipping and heavy freight transport. This project covers major scientific issues and opportunities for knowledge development on the role of bio-based materials in the Dutch energy transition, biogenic carbon storage and sustainability performance and will lead to at least 2 scientific journal publications.
Benefit for consortium of partner involved: UU is internationally renowned for its research on the transition towards a sustainable energy and resource system with the bio-based economy as one of its main research focus areas. UU takes a critical role in the sustainability debate of the bio-based economy, but also prefers a solution based rather than a problem based perspective regarding issues including carbon debt, (indirect) land use change, cascading and biomass supply chain performances. UU publishes 10 - 20 BBE related articles per year, participates in IEA Bioenergy Task 40, 45 and other BBE networks, works with national and EU policy makers (e.g. DG ENER/RTD), contributes to international conferences and is involved in multiple H2020/Eranet/EU projects.
Specific project contribution: UU uses a broad portfolio of research approaches and modelling tools including life cycle assessment, techno-economic analyses, linear optimisation tools (e.g. MARKAL), process optimisation tools (e.g. Aspen+), LCA tools (e.g. Simapro), GIS and Integrated assessment models. Within this project, UU will conduct a comprehensive life cycle assessment and tecno-economic analysis to determine the environmental and economic performance of the different lignin based bitumen substitutes in asphalt, identify hotspots in the supply chains and address possible methodological issues.
Partner 3.: Asphalt kennis centrum
Benefit for partner joining the project: Develop knowledge on bio based binders for asphalt application.
Benefit for consortium of partner involved: AKC has broad experience on the development and testing of bio based ingredients for asphalt application such as Lynpave (vegetable oil), lignin and cellulose.
Specific project contribution: Testing and monitoring of asphalt using different lignin-bitumen binders. AKC will contribute to the monitoring of health & safety aspects of the production of lignin based asphalt.
Partner 4.: TNO
Benefit for partner joining the project: TNO has been many years active in the development of bio-based binders. By participating TNO will use this project for further development of bio-based binders for asphalt application. This project will broaden our national network of asphalt-lignin partners for

future collaboration. Especially, the Wageningen University & Research (WUR) is an interesting partner to further extend our joint efforts to develop a bio-based building and infrastructure.
Benefit for consortium of partner involved: TNO is an (inter)nationally recognised RTO with a large experience in assessing (innovative) road construction materials and the deployment of bio-based binders for asphalt application. TNO has ample experience with the development of lignin based binders in the Netherlands together with stakeholders.
Specific project contribution: TNO will assess the performance of modified lignin blends and will assess the performance of lignin-asphalt test sections.
Partner 5.: H4A
Benefit for partner joining the project: Produce asphalt.
Benefit for consortium of partner involved: We can share our knowledge, we have a location to produce and test.
Specific project contribution: Our experience, we ‘ve produced more than 2000 ton asphalt with lignin. H4A will produce the asphalt for a new stretch of road and will be involved in the monitoring and recycling of lignin based asphalt.
Partner 6.: NTP
Benefit for partner joining the project: Asphalt production and learn more about bio-based alternatives for bitumen in road construction.
Benefit for consortium of partner involved: NTP has experience with the production of lignin based asphalt for some demonstration sections.
Specific project contribution: NTP will manufacture the asphalt for a new stretch of road. NTP will contribute to the monitoring of existing and novel demo roads.
Partner 7: Dura Vermeer
Benefit for stakeholder linking to the project: Dura Vermeer is interested in investigating the possibility of lignin in asphalt in order to respond to the demand, both internally and externally, to make asphalt more sustainable. The carbon footprint of our asphalt production is large, a bio-based binder can contribute to decrease the footprint. The bio-based economy is high on the agenda of our public clients because of the desire to prevent depletion of earth’s natural resources, a bio-based binder can respond to this need. Apart from that it is useful to investigate the possibilities of lignin as a (partial) replacement of bitumen or as a specific additive to improve the price / performance ratio of asphalt.
Benefit for consortium of stakeholder linked: Dura Vermeer is one of the largest asphalt producing and laying companies in The Netherlands. With a share of approximately 10-15% of the total market, the impact can be high. Dura Vermeer has its own research department including a laboratory with up to date testing equipment (including DSR). Dura Vermeer develops various types of asphalt for a wide range of applications (including noise reduction, environmentally friendly). Dura Vermeer has its own asphalt mixing plants and road construction equipment.
Specific for the project: Dura Vermeer can test lignin binder and lignin asphalt in their own laboratory. Dura Vermeer can produce lignin asphalt on a large scale and construct test sections in their own asphalt mixing plant.
Partner 8: Latexfalt
Benefit for partner joining the project: Important for Latexfalt is the participation in the project with regard to bitumen formulations and development of these formulations in order to facilitate new durable and sustainable road constructions.
Benefit for consortium of partner involved: next to knowledge of the bitumen and asphalt topic Latexfalt will participate with their infrastructure in order to produce the bitumen formulations, especially focussed on blending of modified lignin in bitumen, and evaluate the properties in final product formulations.
Specific benefit for the project: Latexfalt has a large scale cooperation between multidisciplinary industrial partners to enable sustainable solutions for road constructions.

Partner 9: Vertoro
Benefit for partner joining the project: Vertoro's heavy residual lignin fraction or "char" has yet to find a market application. Bitumen appears to be an answer to this and this project contains all the value chain partners required to explore the viability of the same.
Benefit for consortium of partner involved: Vertoro's solvolysis process converts technical lignins into valuable crude oil. The residual heavy lignin or "char" can therefore be offered to the market at prices below that of technical lignin. The associated technology is now TRL6 (100-1000 kg scale).
Specific benefit for the project: Vertoro is feedstock agnostic and therefore has a large database and list of technical lignin suppliers that can benefit the project.
Partner 10: Avantium
Benefit for partner joining the project: Avantium is developing a breakthrough technology for the conversion of woody biomass into sugar streams and a lignin stream. This Dawn Technology is now scaled up to demonstration scale at the Chemport Europe site in Delfzijl.
Benefit for consortium of partner involved: Avantium will supply test quantities of their Dawn lignin for evaluation and will give input on the viability of the use of lignin in asphalt.
Specific benefit for the project: : Essential part of the value chain.

2. Achtergrond met doelstelling en resultaat (maximaal 2 pagina's)

Bitumen is the residue that remains after distillation of crude oil. This by-product of the crude oil industry is a complex mixture of hydrocarbons that is used in applications such as asphalt and for roof coverage purposes. The bitumen is used as an adhesive and typically about 5% of the asphalt mixtures constitutes of bitumen. For applications on roofs about 50 - 70% of the material is bitumen and the rest is filler and additional polymers such as SBS (Styrene-butadiene-styrene). Over the past few years the quality of bitumen produced by the oil refineries is variable at best and also availability is not always guaranteed. Several plants in Europe have been closed for bitumen production. In 2014, the European bitumen production was ca 11 Mt. The Dutch share of this amount is around 300 kt (see figure 2)[1]. This concerns both industrial paving grade bitumen and industrial bitumen (e.g. for roofing). The paving grade bitumen comprise the greater part of the bitumen consumption (83%). With an increasing demand for crude oil products like petrol, lubricants etc., it becomes profitable for oil companies to further refine the bitumen in such products. This has an effect on the availability of bitumen. In September 2019 the price of unmodified bitumen (without additional polymers) hovers around 400 €/ton (Figure 3). Prices for polymer modified bitumen are slightly higher. The implication for the road constructors and roofing producers (end users) is that an enormous effort needs to be undertaken in order to upgrade the bitumen from the oil refineries to the specifications demanded by the end users. The market is looking for substitutes both for this reason and also from the CO2 emission point of view. When bio-based products are used in this application a carbon sink is achieved and a more sustainable source for binders is developed. The usage of alternative sustainable binders, which can (partly) replace the bitumen, contributes to reduce CO2-emissions and at the same time broadens the availability of binders.

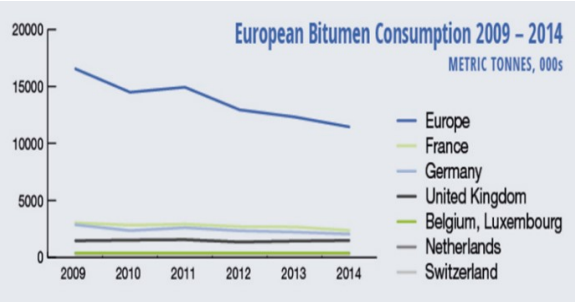

Figure 2: Bitumen consumption in EU and NL[2]

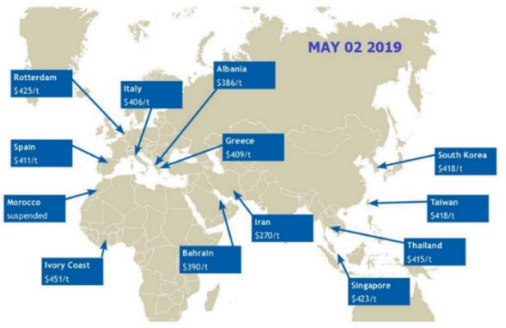

Figure 3. Bitumen prices[3]

[1] Shell venster 02-2016

[2] source: https://www.eurobitume.eu/bitumen/industry/

[3] Source: https://atdmco.com/penetration/bitumen-price.html

In literature several papers have been published on the use of lignin in bitumen application for asphalt purposes. The most recent ones are 1) WO 2015/137813[4] and WO 2019/092278[5]. Both patents describe the use of lignin as partial replacement of the binder in asphalt. Next to these two patents in recent years several papers have emerged describing the use if lignin in asphalt binders as an anti-oxidant (Akusar et al.)[6] , anti-aging (Xu et al., Arafat et al.)[7,8], modifier (Xie et al.)[9]. Also in 2019 a short review has been published by Yue et al.[10] All these scientific papers describe the use of lignin in bitumen from small amounts (0.2% to max 20% by weight). The patents however describe substitution degrees of up to 50%, which is far more significant compared to the search for alternatives for the current bitumen. Also based on the technology, described in the two patents, demonstration roads with a focus on the top layer of roads have been performed or are currently executed. **All the current efforts have been successful up to now what has resulted in a TRL readiness of the technology between 4 and 6. This project proposal describes the research which should lead towards a TRL level of 6/7.** After finishing this project the use of multiple lignin sources as a partial binder in asphalt roads has been evaluated on technical performance during the production and use phase. A detailed TEA and LCA will further support the development of this new asphalt technology towards implementation in the infrastructure as a grown up technology.

* de reden voor het indienen van het project: wat is de urgentie voor de sector?
The urgency for the companies involved **CHAPLIN** resulting in road construction has its origin in the availability of bitumen on the market. These industries are frequently confronted with variable qualities and closing of bitumen producing plants. Also these companies are becoming more and more aware of the carbon footprint related to their industrial activities.
Since a couple of years the industries are looking for bio-based replacements were possible. One of the bio-based polymers that has been explored is lignin. Several pilot studies related to lignin have been performed over the past four years. Up to now the results look promising as indicated by the industry. **The next step in order for the technology to become fully available on the market is a large demonstration of the technology**. Success will ensure the industry that less dependence on bitumen is reached combined with improved properties of the binder for asphalt roads and roofing. The demonstration roads will be monitored on the vital properties including recyclability of the binder, visco-elastic behaviour during application in the environment, LCA study on the carbon foot print, road drag, sound, and rutting. Results up to now are satisfying as indicated by the industries acting the industrial chain. However in order for these technologies to reach full industrial scale application several research questions need to be answered, namely:

1) What is the best approach towards application of lignin in bitumen when mixed in the asphalt mill? Which types of lignin are applicable and what is the availability?
2) How does the lignin based binder behave over the years (user phase) with regard to wear and tear of the top layer of asphalt roads?
3) What will the environmental impact (LCA) with regard to lignin application in bitumen as binder for asphalt road with regard to production of lignin and storage of carbon?
4) What are the emissions into the environment during processing and paving of lignin-based asphalt and during the user phase over a longer period?
5) How long is the life span of lignin based bitumen applied in asphalt?

- Doelstelling

The general objective of **CHAPLIN** is the development of lignin-based asphalt technology to TRL of 6/7 making use of existing demonstration roads and novel demonstration products.
This project is part of a larger program on sustainable solutions for the asphalt binders. The final goal of this program is the introduction of the bio-based polymer lignin in binder applications for asphalt on an commercial scale to enable the production and use of sustainable future asphalt roads.

---

[4] Slaghek, T., van Vliet, D., Giezen, C., Haaksman, I. (2015) Bitumen composition, WO 2015/137813

[5] Landa, P., Gosselink, R.J.A. (2019) Lignin-based bio-asphalt, WO 2019/092278

[6] Akusar et al, Utilization of lignin as an antioxidant in asphalt binder, International Journal of innovative research and technology, 2 (2016) 198 – 207.

[7] Xu G et al., Rheological properties and anti-aging performance of asphalt binder modified with wood lignin, Construction and building materials, 151 (2017) 801 – 808.

[8] Arafat S et al., Sustainable lignin to enhance asphalt binder oxidative aging properties and mix properties, Journal of Cleaner Production, 217 (2019) 456 – 468.

[9] Xie s et al., Lignin as renewable and superior asphalt binder modifier, ACS Sustainable Chem. Eng., 5 (2017) 2817 – 2823.

[10] Yue Y et al., Evaluation of the properties of asphalt mixes modified with diatomite and lignin fiber: a review, Materials, 12 (2019) 400 (doi:10.3390/ma12030400)

The aim of **CHAPLIN** consists of three topics, namely:

1) Evaluation of lignin, which is produced in The Netherlands, in asphalt applications
2) Evaluation of modified lignin
3) Monitoring of the current demonstration roads and novel demonstration roads of selected lignins

Ad 1: Up to now the asphalt technology as described in patent application WO 2019/092278 has been executed with lignin either coming from Scandinavia (Kraft and hydrolysis lignin) or India (Soda lignin). For the Dutch bio-based economy it is beneficial if the lignin can be sourced locally. Currently there are two Dutch companies, Vertoro and Avantium, who are in the process of upscaling their ligno-cellulose based bio-refineries resulting in an interesting lignin side stream which could be suitable for asphalt application. This project will evaluate these lignin side streams, produce asphalt specimens, and potentially apply the asphalt on stretches of roads comparable with the current demonstration roads. The result of this part of **CHAPLIN** is that new lignin side streams are evaluated on their suitability for application in asphalt.
Ad 2: Recent research into the application of chemically modified lignin has led to the discovery that certain chemical modifications lead to improved performance of the lignin/bitumen blends (WO 2015/137813). The implication of this research is that it is feasible to substitute the current produced polymer modified bitumen (PMB), which uses crude oil based polymers such as styrene-butadiene-styrene (SBS) polymers blended in bitumen, can be substituted by lignin based polymers. **CHAPLIN** will continue the detailed evaluation of this technology and evaluate the properties of these modified lignin based PMB in asphalt applications. Especially for asphalt types like porous asphalt (ZOAB) such a technology is very interesting since ZOAB uses PMB.
Ad 3: For the last four years demonstration roads using lignin as part of the binder of asphalt have been constructed. Occasionally these roads are monitored. The aim of this part of **CHAPLIN** is to monitor these demonstration roads on a regular basis and evaluate the life expectancy, emissions, safety and maintenance expectancy of these demonstration roads. Also the recyclability of the lignin/bitumen binder will be taken into account. The result of this part of the project is a further development of the lignin-based asphalt technology and will generate complementary insight of the effect and performance of lignin use as asphalt binder in the Dutch infrastructure. To be able to monitor the whole process of manufacturing, paving and outdoor performance new stretches of roads will be constructed and systematic monitoring will be applied. This has not been performed before.

.

- Resultaat
  - **CHAPLIN** will deliver results on the technical, including recycling, economic and environmental performance of lignin based asphalt from existing demonstration roads and novel demonstration roads. The influence of the Dutch climate (e.g. UV radiation, water/dryness cycles, and frost-dew cycles) on the top layers of demonstration roads, in which several types of lignin have been used, will be monitored by a sufficient monitoring plan. This project will deliver the feasibility results in a well written report.
  - Next to that, **CHAPLIN** will generate knowledge on the use of lignins, which are produced in the Netherlands, in this asphalt application. This added-value outlet of Dutch bio-refinery lignin based residue streams will help the upstream integrated bio-refineries to become more economically (and sustainably) viable supporting their market deployment.
  - Performance results over a longer monitoring period will be essential to validate the use of lignin in the asphalt binder to continue the full scale upscaling towards commercial application of lignin based asphalt in the near future. After finalising this project the monitoring will be continued within the larger **OVERALL CHAPLIN** program.
  - Results of **CHAPLIN** will form the basis for implementation of lignin as a binder for asphalt application at the asphalt mills in the Netherlands and other countries.

3. Projectaanpak en daaraan gekoppeld werkplan (maximaal 3 pagina's)

WP	Short description	Categorie: IO of EO	Performers	Results	Timing

1	Lignin sourcing	**IO**	**WFBR**, VERTORO, AVT, BBD	Overview of lignin sources in the Netherlands and worldwide. Characterised lignins which can be used in asphalt application.	M1-M9
2	Modification & Blending	**IO**	**WFBR**, LTX, TNO	Bitumen blend samples tested at lab scale. Benchmarking against non-modified lignins.	M6-M18
3	Asphalt Production	**IO**	**AKC**, TNO, WFBR	Assessed 6 lignins in binders and in asphalt specimens including recycling, safety and health assessment	M3-M24
4	Asphalt application	**IO/EO**	**BBD**, AKC, H4A, NTP, DURA, TNO	Production of 2 test roads Risk logbook of the project Plan transect testing of the total CHAPLIN program	M12-M18 M1-M24 M22-M24
5	Testing & Monitoring	**IO**	**TNO**, AKC, H4A, NTP, DURA	Monitoring and testing of existing and new demoroads	M3-M24
6	LCA/TEA/ Exploitation	**IO**	**UU**, AKC, BBD	Detailed techno-economic analysis and life cycle analysis	M6-M24
7	PM/ communication	**IO**	**WFBR**, BBD	Smooth execution of the project and useful communication of project results to relevant stakeholders	M1-M24

Work package number	WP1 (IO)		**Lead partner**					WFBR	
Work package title	Lignin sourcing								
Participant number	C	1	2	8					
Participant short name	WFBR	BBD	AVT	Vertoro					
Involvement	XXX	XX	XX	XX					
Start month	M1		**End Month**					M9	

Main objective:

Generate an up-to-date overview of lignin sources which could be used as asphalt binder. Both information on local sources as International lignin sources will be collected.

Specific objectives:

- Objective 1 is to collect information on potential lignin sources from the Netherlands
- Objective 2 is to collect information on potential lignin sources from outside the Netherlands (globally)
- Characterisation of selected lignin sources from the Netherlands and benchmarking against reference lignins (e.g. Kraft).

Description of work

Task 1.1 Overview of lignin sources in NL (M1-M3)

Partners involved in this WP will deliver information on available lignin sources in the Netherlands. Current quantities, purity, available form (solids, liquid), other relevant specifications will be described in a report. Forecasts of available lignin sources in the Netherlands will be made. AVT will give input on acid lignin; BBD on hydrolysis lignin, VERTORO on residual lignin fractions; WFBR will gather and complement this information in a report by using open literature and contact potential lignin producers.

Task 1.2 Overview of lignin sources worldwide (M1-M3)

WFBR and other partners will gather a state-of-the-art overview of the globally sourcing of current and future lignin production including current quantities, purity, available form (solids, liquid), other relevant specifications. WFBR will gather and complement this information in a report by using open literature and contact potential lignin producers.

Task 1.3 Characterisation of selected lignin sources from the Netherlands (M3-M9)

WFBR will characterise the selected lignins from AVT, BBD and VERTORO on its composition, molar mass, thermal properties etc.
Results: Short description of results and relation to other WP's that may use these results. Include go/no-go if applicable This WP will generate a state-of-the-art overview of lignin production in the current and future situation in the Netherlands and worldwide. This information will be used by the partners to describe the future potential of lignin use in asphalt, TEA (WP6), business cases, exploitation etc. This information will also be used to make a proper selection of lignins to be tested in the following WPs.
Deliverables D1.1 Report with overview of lignin sources in the Netherlands (M3) D1.2 Report on the availability of lignin sources globally (M3) D1.3 Report with detailed characteristics of selected lignins used in CHAPLIN (M9)

Work package number	WP2 (IO)		**Lead partner**					WFBR	
Work package title	Modification & Blending								
Participant number	C	3	4	8					
Participant short name	WFBR	AKC	TNO	LTX					
Involvement	XXX	X	XXX	XX					
Start month	M1		**End Month**					M18	

Main objective:
Initial research has shown that modification of lignin has resulted in better properties of lignin as a polymer additive in asphalt binders. The objective of CHAPLIN is to further test and assess the effect of modification of lignin in the binder properties.

Specific objectives:
- Objective 1: Study the effect of chemical modification of lignin on the properties of the asphalt binder blend compared to regular asphalt binder
- Objective 2: Study selected modified lignin/bitumen blends in asphalt test blocks

Description of work

Task 2.1 Lignin modifications (M1-M9)

WFBR will perform modifications (e.g. etherifications) on selected lignins at lab scale (0.5 kg) to tailor the properties to reach polymeric properties in a bituminous binder. These modified lignins will be blended and tested in Task 2.2.

Task 2.2 Characterization of lignin-bitumen blends (M1-M18)

TNO will assess suitability of the lignin-bitumen blends for asphalt application. Blends will be prepared using lignins obtained from different chemical modifications and a combination of blend ratios. Homogeneity of different lignin- bitumen blends will be assessed by using microscopic techniques; i.e. polarized fluorescence microscopy (PFM). Blends will also be benchmarked against references such as neat bitumen (naphtenic or paraphenic).
Potential of the blends to enhance binder properties like flexibility at low temperatures and elasticity at high temperature will be evaluated. These properties will be revealed through rheological assessment using Dynamic Shear Rheometer (DSR). Traditionally polymers are added to bitumen to achieve such functional properties of asphalt binders. A successful incorporation of modified lignin for this application can introduce a renewable alternative to polymers for asphalt binders. In order to chemically fingerprint the binder, the blends will be further characterized using Fourier-transform infrared spectroscopy (FTIR). Compatibility of specific modification of a lignin with bitumen will be evaluated using gel permeation chromatography (GPC) though the mapping of molecular weight distribution. On the basis of binder performance, two blends will be selected for asphalt scale evaluation. LTX will prepare and analyse 2 blends at kg scale and AKC will use the blends to make asphalt concrete for further testing at asphalt scale in WP3.

Task 2.3 Testing of modified lignin-bitumen blend in lab-scale asphalt concrete blocks (M18-M24)
AKC will manufacture asphalt blocks on lab-scale when using selected blended modified lignin-bitumen binders and test the internal strength properties before and after emerging in water. Aging of these blocks will be tested according to International test protocols.

Results:
Short description of results and relation to other WP's that may use these results. Include go/no-go if applicable

Deliverables
D2.1: production of at least 4 different chemically modified lignins on 0.5 kg scale.
D2.2: production of at least 4 different blends of chemically modified lignins and bitumen on lab scale.
D2.3: production of at least 4 different asphalt varieties using the chemically modified lignin/bitumen blends on lab scale
D2.4: testing of lab scale produced asphalt on strength before and after aging

Work package number	WP3 (IO)		**Lead partner**					AKC	
Work package title	Asphalt production								
Participant number	C	1	3	4	9	10	6	7	
Participant short name	WFBR	BBD	AKC	TNO	VERTORO	AVT			
Involvement	X	X	XXX	XXX	X	X			
Start month	M3		**End Month**					M24	

Main objective: Testing and assessing of selected lignin materials in two different asphalt mixes on labscale. Asphalt mixes (SMA and AC surf mixes will be tested), mix design, recyclability, health & safety, technical performance will be tested on labscale. This research is needed to be able to know the processing conditions for the upscaling of the lignin asphalt technology in WP4.
Specific objectives:

- For the production of asphalt in WP4: Testing and assessing of selected lignin materials in various asphalt mixes and determine the optimal mix design.
- Determine the health and safety aspects (ARBO / H&S) by measuring volatiles etc.
- Study recycling of lignin modified asphalt (RAP) by assessing samples obtained from WP4.
- Process conditions which are relevant for the production of asphalt at mill scale will be determined including storage, transport and paving aspects related to temperature homogeneity, segregation and compaction.

Description of work
Task 3.1 (M3-M24)
Different lignins from the partners in the project will be used for making formulations to produce on labscale porous (ZOAB) and SMA asphalt specimens which will be tested by AKC on: mix design, dosing of lignin in mixer, mix order and determine optimal mixing time and temperature. The ZOAB and SMA asphalt specimens will be tested before and after emerging in water on its mechanical strength. Also modified lignin resulting from WP2 will be tested by AKC in a lignin-bitumen binder system. Unmodified lignin and a modified lignin will be tested in a AC Surf formulation to test its durability by AKC.
Task 3.2 (M3-M15)
In the manufacturing process of making lignin based asphalt test blocks, the emission of components will be monitored by specific adsorption equipment. Test results on health & safety aspects will be used for the upscaling technology in WP4.
Task 3.3 (M6-M24)
Recycling of existing lignin based asphalt will be performed by using samples delivered from WP4. AKC will test the aging, rheology and blend characteristics on extracted binders (in collaboration with TNO).
Task 3.4 (M9-M18)

In this Task the transfer of processing conditions from labscale to mill scale will be evaluated on the following aspects: 1) Storage, transport and stability of lignin asphalt, 2) Production scheme including temperature, cooling down, spreading, densification (ASPARI techniques)
Results: Different novel lignins, from several partners in the project (BBD, AVT, VERTORO) will be tested in asphalt application. Additionally, modified lignin produced in WP2 will be evaluated. Detailed results on their binder behaviour, performance in asphalt and aging will be delivered and compared to a reference Kraft lignin. Results on emissions of volatile will be gained during processing of lignin. These results will be used in WP4 to make the optimal process choices to produce lignin based asphalt at pug mill scale.
Deliverables D3.1 Report on the technical performance of different lignins in asphalt application D3.2 Report on health and safety aspects for the manufacturing of lignin based asphalt D3.3 Document on the recycling aspects and behaviour of lignin based asphalt D3.4 Report on processing conditions to use lignin for the production of asphalt at pug mill scale

Work package number	WP 4 (IO)		**Lead partner**					BBD	
Work package title	Applications								
Participant number	C	1	2	3	4	5	6	7	
Participant short name	WFBR	NTP	H4A	BBD	TNO	Dura Vermeer			
Involvement	X	XXX	XXX	X	X	XXX			
Start month	M3		**End Month**					M24	

Main objective: The main objectives of this work package is to construct new stretches of roads using commercially available lignin in the two municipalities designated (Bergen op Zoom and Wageningen) with the aim of monitoring from production of asphalt, construction of the roads until the end of the project.

Specific objectives:

- Determine types of lignin based bitumen with which these stretches of roads will be constructed
- Tendering designs and prescriptions of road sections to be constructed with lignin based asphalt?
- Monitoring and reporting of the construction, including photos and videos.
- Recycling of current lignin/bitumen asphalt

Description of work

Task 4.1 Determine types of lignin based bitumen (1 month, after the testing at AKC)

Until now several road sections with lignin based asphalt have been constructed. The applied lignins were Soda, Kraft and Hydrolysis lignin. New lignins have become available, like the processes from Vertoro and Avantium. The oldest road sections were constructed in 2015, without monitoring the impact on environment, public health & safety, sustainability, lifetime and costs. Based upon some experiences with these sections, the above mentioned lignins will be tested in WP 2-3 at AKC, in total 6 types: The aim is to choose the best applicable lignins in road sections for testing on a practical scale, based upon chemical and physical tests. The aim is to choose the best applicable lignins in road sections, based upon chemical and physical tests. The road sections will be situated in the municipalities of Bergen op Zoom and Wageningen.

Task 4.2 Risk analyses and monitoring of risks (M1-M24)

Based upon the results of task 4.1 and the experience with the road sections constructed since 2015, we make a risk log book, based upon the RISMAN method for risk management. The RISMAN method is a trusted methodology in the infrastructure industry, but it is used more and more in other industries as well. The RISMAN method contains 4 steps: determine project goal(s), identify risks, determine the critical risks and the last step is to identify mitigation measures. Starting with a risk analysis the risks are identified and monitored all over the project. During the project the risks will frequently be evaluated.

Task 4.3 Monitoring the execution of road sections (4-10 months after tendering)

Based upon plans and prescriptions in the provinces of Zeeland, Zuid-Holland, Noord Brabant and Gelderland together with the road owners some sections will be defined to be constructed with lignin based asphalt. The road sections to be tested will be part of a larger section that needs to be reconstructed due to common maintenance. The larger sections will be tendered according the Dutch law, while the test will be part of it. The planning depends of the agenda of the municipalities. Bergen op Zoom has foreseen a reconstruction works by the end of 2019. For Wageningen the planning still must be defined. In WP5 the plan for monitoring these sections has been worked out.

Task 4.4: Recycling of current lignin/bitumen based asphalt.

H4A will remove the top layer of an existing lignin based asphalt demoroad and use and test this lignin in a recycling process, e.g production of a PR formulation. Samples of old top layer and recycled PR asphalt will be tesed in WP3 by AKC in collaboration with H4A.

Task 4.5 Drafting full OVERALL CHAPLIN road section testing program (M22-24)

The results of testing and monitoring of all WPs and the risk log book will give a view of what we still need to know to get lignin asphalt accepted and implemented. For proceeding the OVERALL CHAPLIN program we will make a roadmap for testing other types of transects and the information we need to have from these tests.

Results:

Technological and financial analyses on the differences in technology and costs with traditional road constructing

Reporting of road section constructions

Overview of risks and measurements to reduce them

Deliverables

D4.1 Evaluation report of the tests on laboratory scale

D4.2 Report covering the evaluation of risks with a risk log book

D4.3 Plan of activities and monitoring plan for road sections to be (re)constructed and tested with lignin based asphalt

D4.4 Evaluation report of the (re)constructed road sections

D4.5 CHAPLIN roadmap for further testing of transects

Work package number	WP5 (IO)		**Lead partner**					TNO	
Work package title	Testing & Monitoring								
Participant number	3	4	5	6	7				
Participant short name	AKC	TNO	H4A	NTP	DURA				
Involvement	XXX	XXX	XX	XX	XXX				
Start month	M3		**End Month**					M24	

Main objective:

WP-5 focuses on assessing durability and monitoring performance of the road test sections. TNO will be the lead partner in this work package and H4A, NTP, AKC, DURA will participate actively by supporting testing at the lignin-bitumen blend, asphalt production levels. For the performance monitoring of lignin based asphalt test sections, the partners will support extraction of asphalt cores and making the test section available for monitoring and inspections.

Specific objectives:

- Assessing performance of materials in relation to durability at both binder and asphalt scale where tests will be performed on extracted asphalt cores both for the new roads constructed and the already existing roads.
- Visual inspection of test sections for possible failure modes: ravelling, cracking, rutting etc.;
- Monitoring performance of the old and new test sections of different surface layers: stone mastic asphalt (SMA), porous asphalt (PA);

• Monitoring emissions and possible health related hazards with respect to lignin sources.
Description of work Task 5.1 Assessing binder performance (M1-M24): TNO will evaluate the durability of the binder and asphalt once applied to the road and structural monitoring of the field performance over time. H4A, NTP, DURA and AKC will provide materials from production batches (i.e. binder and asphalt) for the new road test sections. Besides the sampling of materials after production, asphalt cores from the sections will be taken and the binder will be extracted by H4A, NTP and/or Dura Vermeer for further analyses with regard to ageing. A maximum of 8 samples (combination of asphalt mixtures and moments in time) will be tested by TNO. The binder from the asphalt cores will be extracted and ageing susceptibility of the binder will be evaluated by TNO by rheological and chemical characterization. Rheology of the extracted binder will be assessed and will be compared with the field database of the binders which can indicate on durability of the lignin-bitumen binder compared to regular bitumen binders. Chemical ageing index of lignin -bitumen binder will be assessed by quantifying the change in functional groups using Fourier-transform infrared spectroscopy (FTIR). Gel permeation chromatography (GPC) will be used for measuring compatibility and ageing susceptibility of lignin-bitumen blends over time though mapping of molecular weight distribution. Task 5.2 Assessing asphalt performance (M1-M24): A maximum of 8 samples (combination of asphalt mixtures and moments in time) will be tested by TNO. TNO will assess susceptibility of the road test sections to moisture damage by performing tests on asphalt cores taken at different course of time. Freeze-thaw tests will be performed in extreme temperature cycles to reveal the response of lignin based asphalt in moisture-saturated conditions. At low temperature conditions and also due to ageing, asphalt binder undergoes transition to its glassy state. As a result asphalt roads become susceptible to cracking due to limited flexibility of the binder. To evaluate performance of the road at low temperature conditions, relaxation tests on asphalt cores will be performed. Task 5.3 Visual inspection of current and novel test sections (M1-M24) DURA, H4A, NTP will perform visual inspections of current and novel test road sections every 6 months which will complement the asphalt performance tests of the asphalt cores (see Task 5.2). Task 5.4 Monitoring health and safety aspects (M12-M24): Health and safety related aspects of lignin during handling and lignin based asphalt production will be monitored by H4A/AKC. Air quality and possible inhalation hazards will be evaluated while handling lignin powders or fine particulates. Odour and emissions will be probed in-situ during production of asphalt, transportation and operations. The extent of toxicity from the resulted emissions and its impact on health and safety will be evaluated. From the first phase of evaluation, if required, structured monitoring of possible emissions during service life of new lignin based asphalt sections can be performed.
Results: • Report with results on assessment of lignin based asphalt performance under real life conditions; • Performance monitoring results on old and new road test sections with impact analysis of lignin based asphalt on health and safety etc.
Deliverables D5.1 Report on assessment of lignin based asphalt performance; D5.2 Performance monitoring report on old and new road test sections with impact analysis of lignin based asphalt on health, safety etc.

Work package number	WP6 (IO)	**Lead partner**			UU					
Work package title	LCA / TEA & Exploitation									
Participant number	C	1	2	3	4	5	6	7	8	9	10
Participant short name	WFBR	BBD	UU	AKC	TNO	H4A	NTP	DURA	LTX	VERTORO	AVT

Involvement	x	xx	xxx	x	x	x	x	x	x	x	x
Start month	M6		**End Month**					M24			

Main objective: The main objectives are to determine the environmental and techno-economic performance of asphalt with various lignin additions, and explore the possible deployment after reaching TRL 9 in the Netherlands.

Specific objectives:

- Determine the full environmental impacts by carrying out a comprehensive life cycle assessment for production and end-of-life phase including GHG emissions and at least 10 other impact categories
- Carry out a techno-economic assessment, comparing the production costs of lignin-based asphalt with 100% bitumen based reference, assess potential for cost reductions and – linked to the first objective – determine the possibility for a premium for lignin-based asphalt
- Determine the market potential for lignin-based asphalt until 2030 and actions needed to full commercial implementation

Description of work

Task 6.1 (M6-M24): Preliminary studies have shown that the production of lignin-based asphalt may offer lower GHG emissions compared to a 100% bitumen based alternative (Khandelwal, 2019). Also, the long-term carbon storage may yield significant climate benefits. However, little is known about the other environmental impacts lignin-based asphalt production, including emissions during the production phase, also depending on the specific feedstock source, isolation pathway and potential modification. Also the possibilities to recycle lignin-based asphalt after the use phase and related environmental impacts and benefits are unknown. Task 6.1 aims to fill this knowledge gap as far as possible by collecting data from work packages 1-3 for the production phase and 4 and 5 for the use and the end-of life phase . Special attention will also be given to displacement effects when (kraft) lignin is diverted from current uses as fuel in e.g. pulp mills. For the production of lignin, foreground data on production processes, energy flows and emission for will be obtained from the lignin producers within the consortium (Avantium, Vertoro, Biobased Delta), and for Kraft lignin based on literature and interviews. Data for the modification of lignin, blending, application of asphalt on the road and data on the recyclability (/other end of life options) will be obtained from Wps1-5. Depending on the data availability, the impact categories selected for this LCA will cover the most relevant environmental issues of asphalt. A pre-selection of impact categories is based on a recent LCA for different asphalt mixes in the Netherlands (TNO and EcoChain 2018) and include: climate change, fossil resource depletion, human toxicity, marine and freshwater ecotoxicity and acidification. The use of bitumen, diesel in transport and machinery for road construction and process heat and electricity in asphalt production are important contributors to GHG emissions (climate change), consumption of crude oil and natural gas (fossil resource depletion. Eutrophication and acidification impacts are currently mainly caused by NOx emissions from fossil fuel combustion. SOx emissions could become more relevant as a result of sulphur in lignin sources and increased sulphur levels in bitumen. Refineries could potentially shift sulphur from marine fuels to other outputs as a result of increasingly strict limits to sulphur levels in marine fuels set by the International Maritime Organization (IMO). Emissions of Non Methane Volatile Organic Compounds (NMVOC), including benzene and formaldehyde, from asphalt production, transport and during road construction are important contributors to human toxicity and smog formation. A final selection will be made in the first phase of the research project. Midpoint indicators will be used to evaluate the environmental impact. Given the limited scope of this project and the expected limited impacts, possible scope 3 effects will not be investigated.

Task 6.2 (M6-M24) explorative techno-economic assessment. The competitiveness of lignin-based asphalt with traditional asphalt is a key aspect for the success and deployment. The main lignin types and production pathways included in Wps1-3 will be screened in an explorative techno-economic assessment, in which the range of cost of lignin, possible modification, blending and application on the road will be assessed and compared to the 100% fossil-based alternative, including scenarios for the development of lignin-and bitumen

prices. Special attention will be given to the possibility to claim GHG benefits (based on Task 6.1) and related advantages for public procurement under the CO_2 performance ladder scheme.

Task 6.3 (M6-M24): preliminary roadmap for deployment

Based on global/European lignin availability, further development from TRL 6 to 9, anticipated scale up possibilities, and the anticipated demand for asphalt in the Netherlands (and beyond), a preliminary roadmap will be developed indicating how fast and for which specific applications lignin-based asphalt may be deployed, including a quantification of the associated biogenic carbon sequestration and GHG benefits until 2030, based on the results of Task 6.1.

All tasks will be carried out primarily by UU, with input from AKC and BBD and other partners, mainly to provide input data and links with WPs 1-5.

Results

Expected results will first and foremost include a better understanding and quantification of the environmental benefits and impacts of lignin-based asphalt. This will clearly go beyond a "carbon footprint only" assessment, but, given the limited time and budget for actual measurements with different types of lignin, we foresee a limited number of impact categories (e.g. 5). The focus will mainly be on the production phase, and to the extent possible on the end-of life options. In addition, the explorative techno-economic assessment will explore under which circumstances lignin-based asphalt may be able to compete with bitumen-based asphalt. Last but not least, the preliminary roadmap will provide an indication for the potential for roll-out in the Netherlands the potential contribution to the Dutch GHG emission reduction targets.

Deliverables

- D6.1 Quantitative environmental life cycle assessment of production and End-of-life phase for a limited number of impact categories and comparison with fossil alternative (M21)
- D6.2 Explorative techno-economic assessment of different lignin and asphalt production routes (M21)
- D6.3 Preliminary roadmap for deployment in the Netherland until 2030 including the potential contribution to the Dutch GHG emission reduction targets (M24)

The main deliverables will be these three reports. In addition, UU aims to publish one or two articles in international, peer-reviewed open-access scientific journals, likely as part of a PhD thesis of a junior researcher.

Work package number	WP7 (IO)		**Lead partner**					WFBR			
Work package title	Project Management & Communication										
Participant number	C	1	2	3	4	5	6	7	8	9	10
Participant short name	WFBR	BBD	UU	AKC	TNO	H4A	NTP	Dura Vermeer	LTX	Vertoro	AVT
Involvement	XXX	Xx	X	X	X	X	X	X	X	X	X
Start month	M1		**End Month**					M24			

Main specific objective:

- To execute the scientific and content management of the project
- To organise both the external project communication and internal/external dissemination of project results
- To create a plan for the exploitation of the **CHAPLIN** technology. Since already two patent application have been filed new results will be evaluated for additional patent filing.

The MT hours specified are those necessary for management relating to the content. Administrative hours are not separately declared but are part of the overhead costs. Communication and dissemination activities are

integral part of the project. However, because they are not eligible within TKI BBE these costs made by WFBR are fully kept outside of the project budget.

Description of work (incl. methods/techniques and role partners)

Task 7.1. Project Management Activities (M1-M24)

Partners (Task leader underlined) WFBR and all.

Activities:

- Organising a kick off meeting: one full day will be organised by WFBR in Wageningen within two weeks are signing of the project contract
- Monitoring the progress of the project: every 6 month a meeting will be organised at the premises of one of the partners. In total including the kick-off meeting 5 meetings will be organised on M5, M6.M12, M18, M23.
- Half year and year progress reports will be prepared and send to RVO by WFBR with input of all the partners (M7, M13, M19).
- Annual report: this report will be send to RVO in M13. The final draft report will be send to RVO in M23 (Nov 2021). After remarks from RVO a final report will be finalised no longer than 13 weeks after ending of the project. Also the financial report and the final grant fixation request will be send to RVO within 13 weeks after the end of the project by WFBR with input of all the partners.
- For the consortium members a dedicated teamsite will be organised and hosted by WFBR.

The results of all Tasks will be reported by brief notes; each work package will result in a report (intro, sum of notes, discussion/conclusions). The Annual and Final Report will consist of an intro, sum of work package reports and a discussion/conclusions.

Task 7.2. Communication Activities (M1-M24)

WFBR will make a communication note at the start of the project about the scope and deliverables of the CHAPLIN-NL project which will be sent to relevant stakeholders. The final results of the project will be communicated via a communication leaflet.

Task7.3 Dissemination Activities (M1-M24)

Partners (Task leader underlined): WFBR with input all partners

Activities:

- Final project report will be send to RVI in M24 (December 2021) of within 13 weeks after the project is finished.
- Major project results will be submitted for an oral lecture at a suitable international congress/symposium.
- Contributions to the TKI-BBEG events in 2020 and 2021. During the progress of the project these contributions will be defined.
- A national stakeholder workshop **CHAPLIN** will be organised in the Q4 of 2021.

Task 7.4: Exploitation of **CHAPLIN** results M12-M24)

Partners: WFBR and all other partners

An **CHAPLIN** technology exploitation plan will be prepared by BBD taking the already filed patent applications into account. If there is an opportunity new patent applications will be filed during the course of the project.

Results:

Reports for the customer (RVO/TKI BBEG), project communication materials, dissemination activities, and the results of the exploitation of the **CHAPLIN** technology will be reported together with the follow-up activities.

Deliverables

D7.1: Annual report (M12)
D7.2: Final report ultimately 13 weeks after finishing project.
D7.3: Project leaflet at project start and by the end of the project
D7.4: TKI/BBEG Event contributions
D7.5: Conference Paper/Poster
D7.6: National stakeholder workshop
D7.7: Exploitation **CHAPLIN** results

4. Duurzaamheid en maatschappelijke relevantie (maximaal 2 pagina's)

Project connection to Programme Lines TKI BBEG
Efficient and sustainable use of biomass for the production of bio-based products (food/feed ingredients, chemicals, materials) and bioenergy (fuels, power heat) via bio-cascading and bio-refinery processes is at the core of the "Strategic Biomass Vision towards 2030" of the Dutch government (2015), and also clearly addressed by the Dutch Sustainable Biomass Commission (2015). Based on this identification, the Dutch government has developed the R&D Agenda Bio-based Economy 2015 – 2027 "B4B" (2015). The basis for this agenda is that it was clearly recognised that the emergence of the Bio-based Economy not only will be (part of) the answer to various environmental threats, but also will contribute to the growth of the Dutch Economy. One of the programme lines Thermochemical and Catalytic conversion technologies has the potential to contribute to the goal of reduction of CO_2 so urgently needed. The use of Biomass in large scale industrial applications, such as the infra, do support such an effort. **CHAPLIN** perfectly suits this goal since the aim of this project is to use lignin as a partial binder in asphalt and this application creates a carbon sink for a number of decades and the used lignin will not be burned off as is the case today. This offers sustainable solutions for the future.

- Geef aan waarom in het project sprake is van cascaderend gebruik van biomassa en, of een hoogwaardiger gebruik van biomassa

Lignin is one of the organic side streams that is created during the bio-refinery treatment of ligno-cellulosic biomass. Two companies involved in this project (BBD, AVT) work on the creation of lignin as a side stream using ligno-cellulose as starting raw material for the development of sugar derived building blocks for polymer synthesis (e.g. lactic acid and furandicarboxylic acid respectively). VERTORO, the third company in this consortium works on the valorisation of residual lignin side streams towards lignin crude oil. The crude lignin oil is a feedstock for chemicals, materials and fuel. The remaining residual lignin fraction could be an excellent source for asphalt applications. In both cases ligno-cellulosic biomass is treated in a cascading sequence generating products with a higher added value than the caloric value (burning).

- Geef aan hoe het project bijdraagt aan de verduurzaming van de Nederlandse Energiehuishouding

CHAPLIN directly contributes to the Dutch Climate Agreement (The Hague (NL), July 2018) with the overall goal of 49% GHG-emission reduction (48.7 Mt CO_{2eq}) in 2030 (compared to 1990) by generating applications for lignin which will create a carbon sink and as such reduces the emission of CO_2 when compared to the current outlet for lignin which is burning. **CHAPLIN** develops alternatives for the crude oil based bitumen as binder in asphalt. By bridging the proposed asphalt application for lignin on the longer term the development of sustainable biomass supply chains such as lignin in The Netherlands can be developed in parallel to necessary technology developments. Therefore full market implementation of the lignin based binder technology can take place directly when the technologies are ready to be implemented.

- Voor projecten die niet hoofdzakelijk gericht zijn op energietoepassingen, moet u kunnen aantonen dat er sprake is van een significante vervanging van fossiele grondstoffen zoals aardgas, aardolie en steenkool.

The current use of virgin bitumen in The Netherlands is around 300.000 tons per year (12.6 PJ per year) of which most is used asphalt production. In Europe the number of virgin bitumen use is around 12.5 million tons The current technology aims at 50% replacement of the use of virgin bitumen with lignin.

- Maak een kwantitatieve berekening waarbij u op projectniveau aangeeft welke reductie in CO_2 emissies (ton CO_2/jaar) in Nederland kan worden bereikt.

The amount of replacement of virgin bitumen by lignin in The Netherlands is estimated around 150.000 tons per year. For every ton lignin used as binder in asphalt 2.3 tons of CO_2 is sequestered since lignin contains between 64 and 66% carbon. Therefore the estimated amount of CO_2 sequestered is 150.000 tons x 2.3 = 345.000 tons CO_2 per year.

- Bereken het herhalingspotentieel van het project per jaar in Nederland:

A 50% replacement of virgin bitumen with lignin results in an estimated reduction of non-renewable energy consumption with 6.3 PJ per year from the avoided use of bitumen. During production, the required temperature of the asphalt mix can be reduced from 170-180 ^{o}C to approximately 130 ^{o}C if lignin is used. This could reduce natural gas consumption with 22% and reduces natural gas consumption with 0.5 PJ per year resulting in a total net saving of 6.8 PJ per year.
Cradle-to-factory-gate GHG emissions of regular ZOAB are estimated at 72 kg CO_2-eq/t ZOAB. A 50% replacement of virgin bitumen with lignin, GHG emissions are reduced with 11 – 26% for Kraft lignin or bio-refinery lignin respectively (Khandelwal 2019). The total development of new roads and maintenance of existing roads requires about 8.0 Mt asphalt per year in the Netherlands. Depending on the type of lignin used, the estimated cradle-to-factory gate GHG savings are estimated at 0.06 – 0.15 Mt CO_2 eq. per year if 50% of bitumen are replaced with lignin. During end-of-life, part of the bitumen are released through incineration as CO_2 to the atmosphere. If we assume a net balance between virgin bitumen supply and release during end-of-life of 12.6 PJ per year, GHG savings would increase to 0.76 – 0.85 Mt CO_2 eq. per year (emission factor bitumen: 80.7 kg/GJ). Potentially, additional savings can be achieved during the use phase if lignin binders increase the life-time of asphalt or if it reduces rolling resistance.

- Geef aan welk deel van het potentieel naar verwachting binnen een termijn van minimaal 5 jaar (na implementatie van het project) wordt benut.

For H4A 5% of the total production of asphalt is established during 2019 based on the current activities on lignin based asphalt. For the coming 5 years the share of lignin based asphalt can grow to 15- 20 %, which means for H4A a production of 20 kton. The amount equals about 20% reduction in CO_2. In the Dutch market 10% substitution of the asphalt market seems possible in 2030 which is about 800 kton.

For Vertoro:

Year	Amount of bitumen replaced by Vertoro “char”	New direct jobs created by Vertoro
2020	1-5 tons	2-3
2025	1-5 kton	10-15
2030	1-5 Mton	25-30

- Onderbouw de maatschappelijke relevantie van het project.

The Netherlands has good quality roads and this should be secured for the future. For Vertoro see table above (column Jobs).

- Beschrijf verdere eventuele ecologische effecten voor de onderneming of de maatschappij, sociale aspecten en mogelijke negatieve gevolgen op het gebied van duurzaamheid

Among the compounds identified in bitumen and its emissions, some have been listed as carcinogenic by the International Agency for Research on Cancer (IARC) and/or listed as carcinogenic, mutagenic, toxic to reproduction (CMR) and/or hazardous by the European Union.
Lignin, by contrast, is consumed by most people on a daily basis. It is a non-digestible compound made of phenols (aromatic alcohols) and other molecules[11]. It is not a carbohydrate, but is considered an insoluble fiber. It is found in the cell walls of vascular plants and in seeds. Lignin is not digested in the small bowel and is poorly fermented by normal colonic bacteria. It is insoluble in water, but it absorbs water and thus gives bulk to the stool. Foods high in lignin include flaxseed, root vegetables (carrots, parsley, horseradish), wheat bran, edible seeds (in berries, tomatoes), vegetables with edible stems (cabbage, broccoli), green beans, peas, peaches, apples, Brazil nuts[12].
According to the EU, products produced from feedstock listed in Annex IX in the EU Renewable Fuel Directive, like lignin, can contribute to low carbon emissions, thereby stimulating the decarbonisation of the Union transport sector in a cost-effective manner, and improving inter alia energy diversification in the transport sector while promoting innovation, growth and jobs in the Union economy and reducing reliance on energy imports.

[11] National Research Council. (1989). *Diet and health: implications for reducing chronic disease risk*. National Academies Press.
[12] Gropper, S. S., & Smith, J. L. (2012). *Advanced nutrition and human metabolism*. Cengage Learning.

5. Slaagkans in de Nederlandse markt en maatschappij (maximaal 3 pagina's)

Businesscase producent/techniekontwikkelaar/ontwikkelaar product of dienst
Beschrijf voor beoogde nieuwe producten / diensten:

A. Beschrijving van de markt
Road owners, such as municipalities and provinces, who are investing in sustainable road solutions are the target group of this topic. The developed technologies is applicable in current installations where asphalt is produced. Some add on modifications are necessary to feed lignin into the current installations (pug mills). For the participating asphalt companies the target groups are the main source of income. with regard to the opportunities outside The Netherlands (EU and outside EU) the technologies, when successfully applicable, will create great opportunities.
Traditions shows that when applicable in The Netherlands other European countries usually follow. since in the European Union bio-based alternatives are gaining momentum this lignin application for road construction is getting increasing attention.
For the lignin producers Avantium and Vertoro there target group for business of their lignin side streams is broader than asphalt. However if applicable asphalt application as described in this proposal for their lignin side streams will be very important for their operation of the bio-refineries.

- Wat is de marktomvang?

The annual production of asphalt in The Netherlands is around 8 million tons. These activities are mainly focussed on complete maintenance of the road about (2/3) or replacement of the top layer (about 1/3). With regard to the top layer replacement roughly the division between SMA and AC Surf is around 70:30. It is expected that close to 40% can be replaced by the lignin/bitumen technology which would add up to over to 42.000 tons of lignin. If lignin would also be applicable in ZOAB than another 8.000 can be added to this volume (total 50.000 tons of lignin). There is lot of interest for the asphalt industry to work on sustainable solutions. Both recycling and the use of bio-based binders are important developments. For introduction of lignin based asphalt the environmental impact is a strong driver together with a potential longer life time of the road.
Global figures of the use of bitumen alone, amount to USD 76.91 Billion in 2018, with a forecast Market Growth (CAGR) of 4.7%[13].

- Wat zijn de huidige marktontwikkelingen c.q. trends?

The demand for bio-based and circular products for asphalt production is increasing. already municipalities and governments on province level are asking in their tenders for at 30% bio-based materials with regard to road construction. Also if the road constructor meets these requirements a premium can be obtained. This incentive does increase the necessity for bio-based technologies in the construction sector. The current technologies, described in this proposal, do meet these requirements.

- Wie zijn de belangrijkste spelers op de markt en welke positie nemen ze in?

The bitumen market is divided as paving, oxidized bitumen, cutback, polymer modified bitumen, bitumen emulsion, and others. The paving bitumen accounts for the largest market share of 33.21% in 2018 due to accelerated road maintenance and construction ventures all over the world, especially in the APAC. The product also has got enlarged applications in the building of greenhouse floors, bicycle paths, running tracks, railway beds, and runways, among others. Major global players for the production of bitumen include, Indian Oil Corporation, Chevron Texaco Corporation, China Petroleum and Chemical Corporation, Total, British Petroleum, JX Nippon Oil & Energy Corporation, Villas Austria, Royal Dutch Shell, Marathon Oil Corporation, Petroleos Mexicanos, NuStar Energy, Nynas, Exxon Mobil, Bouygues, Imperial Oil.
With regard to road constructors the market is not as global as for crude oil companies. For the Dutch situation the participating road constructors the market is both regional and country wide. Both type of contractors are participating in this project which guarantees that when successful the technoligy will be used country wide. Also it creates opportunities outside The Netherlands for further introduction.

- Maak een concurrentie analyse en maak een overzicht van de concurrentievoordelen.

Currently there are no direct competitors identified who are able to substitute 50% of the bitumen. There are some initiatives such as the plastic road but the describes technologies in this proposal are the only ones describing 50% reduction. See below for Table comprising companies and institutes

[13] https://www.reportsanddata.com/report-detail/bitumen-market

active in the field of blending lignin with bitumen. The Vertoro approach differs from all processes below in the sense that not technical but lignin derived char is used. Char is the Vertoro process is that part of technical that does not dissolve in polar organic solvents following a mild solvolysis reaction. The part of lignin is high in molecular and comprises no volatiles. As such, it is believed to be more attractive for the foreseen road applications, the surfaces of which can get really hot in summer, thereby creating potentially hazardous fumes.

Company / Institute	**Patent #**
ITERCHIMICA S R L [IT]	TW201922900
INBICON AS [DK]	US2018346658
STICHTING WAGENINGEN RES [NL] ASFALT KENNIS CENTRUM B V [NL]	WO2019092278
GRAFTECH INT HOLDINGS INC [US]	US2018282166
TNO [NL]	WO2015137813

Also due to the increasing demand for innovation with regard to bio-based solutions in asphalt the tenders are more and more focussed on this topic and less to price competition. The climate targets of the customers are more and more leading when a construction project is approved.

- De positie van de deelnemers op deze markt voor en na het project (o.a. marktaandeel).

For the participating road constructors the position in the Dutch asphalt market will become more prominent since they will acquire more and more tenders by municipalities and provinces due to the implementation of the lignin based binder technology as described in this proposal.
The lignin producers, who are participating in this project proposal, will gain more momentum for their bio-refineries since the value of their lignins will increase when compared to the current value which is linked to the caloric value. it is estimated that when successful implementation in the asphalt binder the price of their lignin will increase for=m around 100 €/ton to about 400 € /ton which is the current value of bitumen.

<u>B. Strategie</u>

- Op welk gedeelte van de markt wilt u zich in het bijzonder gaan richten?

The road constructors will aim for their current clients as described above. especially municipalities and forestry owners are the most predominant clients who have interest in the sustainable solutions. for the lignin producers their focus will be on the road constructors which they regard as their future clients. The short term focus will be on road constructors in The Netherlands and on the long term the scope might be broadened to EU countries close to The Netherlands.

- Welke bedrijven gaan geld verdienen met de resultaten uit dit project? En hoe?

It is expected that especially contractors and road owners will benefit from this new technology since the technology will allow for less maintenance during the life time of the road. Reduction is maintenance is actual money maker. Also since it is feasible to produce asphalt with a binder that consists of 50% bio-based materials there will be an increasing demand for this type of asphalt which can be sold with a premium.
For the lignin producers they will be able to sell their lignin at higher prices than the current caloric value of their lignin as described above (100 € versus 400 €/ton). This higher value automatically implies the increase in value for the bio-refinery operations.

- Wat wilt u binnen nu en 5 jaar bereiken?

The road constructors aim to achieve a fully automated system for handling lignin in the asphalt mill. The automation will facilitate a smooth processing of lignin in the asphalt mill and at the same time reduce cost for the production of asphalt. In the first 5 years depending on the geographical area up to 10% of top layers will be substituted by this technology. Later next to top layers also the other layers of which a road consists will contain lignin as well.
Vertoro aims at showing market traction, which is very important for the investors of Vertoro since such a market traction will allow Vertoro to move towards 1 kton per annum scale demo plant; most likely to be built in Geleen. This could be operational by 2021 (Vertoro). the scale demo will be the first stepping stone towards large scale production.
A similar route is available for Avantium for their bio-refinery in Delfzijl. The Dawn Technology process is currently being tested in the Pilot biorefinery in Delfzijl with a maximum capacity of generating 7 tons of lignin per year. Avantium is aiming for commercial scale up towards a flagship plant with a

capacity of producing 50.000 ton of lignin per year in the next 5 years. In the base case scenario, this lignin will be burned for its energy value (~1.5 €/kg), the price of which is heavily reliant on the presence of SDE subsidy for burning biomass in a coal fired power plant. Using the lignin instead to replace bitumen in asphalt at a price of 4 €/kg would result in an additional revenue of 125 million euro's a year (2.5 €/kg * 50.000 ton) which would significantly increase the economic viability of the Dawn Technology. This project will contribute to the business case by demonstrating the suitability of the lignin in asphalt applications, this will help ensure a market for lignin during the further scaling up of the Dawn Technology in the Netherlands.

- Welke niet-technologische aspecten spelen in de productieketen een rol? Hoe gaat u daarmee om?

The logistics and delivery of lignin in bulk quantities need to be sorted out. Preferably lignin should be supplies via large trucks. During the course of this project this non-technological aspect will be addressed together with safe processing in the asphalt mill.
The lignin producers will have to adept the wishes of the asphalt producer. Also the economy of scale will be taken into account during the course of this project. These aspects should be studied and improved with value chain partners as is the objective of this project. However the logistic aspects between lignin producers and asphalt producers is not new and will be sorted out.

- Wat is de termijn tot aan de marktintroductie na afloop van het project?

From experience is known that the full scale introduction of a new technology in the Dutch asphalt market is laborious. However since fairly recent especially the lower government organisations such as municipalities and provinces are speeding up technologies which would directly address the bio-based agenda it is expected that with a few years at least 20% (of the expected 50.000 tons of lignin) of the asphalt volume will be covered with the lignin/bitumen technology which would add up to close to 10.000 tons per annum. On the mid-term (about 10 years) it is expected that close to 80% will be covered by the lignin /bitumen technology which would cover 40.000 tons per annum. After this period there will be a steady growth also outside The Netherlands.
The lignin producers expect that in 2020 the first small scale samples from their pilot plant will start producing products for the asphalt market and in 2021 the semi-commercial scale samples from the plant will become available. with increasing demand the economic activities will expand. It is expected within 5 years the first commercial bio-refinery will open its doors.

- Vervolgstappen: Welke vervolgstappen zijn er nog nodig na afloop van het project om tot marktintroductie van de innovatie te komen? Wie gaat daarbij wat doen?

The follow-up after finishing this project is implementation of the developed technology will be the next step towards a full scale production of lignin based asphalt for the Dutch market. Further expansion to other parts of Europe is expected to follow once the results in The Netherlands become available. Already there is interest from Germany and even India.
Vertoro will expand their plant into a large scale production.

- Hoe wordt de verkoopstrategie opgezet? Die moet inzicht geven in de ontwikkeling en marketing van de in het project gebruikte technologieën / concepten / diensten nadat het project is afgerond. Hoe gaat dit project vervolg krijgen?

Especially the road constructors have to play an important role in selling the technology. Introduction to their current clients via standard communication channels such as meetings, seminars, and social media. This communication campaign will result in an increasing demand for the technology described in this proposal.

- Geef de be

The picture 4 b irst approaches towards the application of l

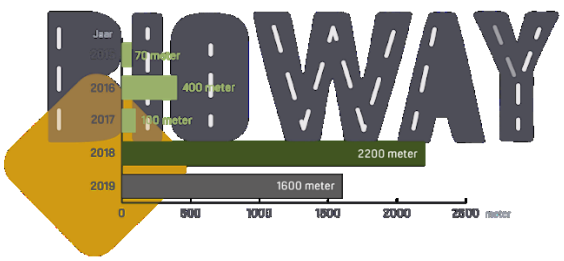

Figure 4. Overview of road sections constructed by with lignin based asphalt by H4A (2015-2019)

C. Financieel

- Wat dient er tot volledige commercialisatie nog te worden geïnvesteerd qua kosten en door wie?

The road constructors will need to invest in equipment such as storage tanks and automated dosing of lignin in the asphalt mill. These costs will be covered by the road constructors via own reserves and or credit from banks. Since the opportunity for implementation of this technology for clients of the road constructors will result in increased revenues it is expected that the investments will have a return of investment in xx years

- Hoe wilt u deze investeringen financieren?

These investments will be covered via credit form the bank and own reserves.

- Vat het economisch perspectief samen in onderstaande tabel per deelnemer.

Businesscase eindgebruiker

Economisch perspectief voor te ontwikkelen product/proces/dienst (AKC)					
Projectkosten	€ 90.000				
Kosten commercialisatie	€ 20.000				
Totaal kosten	€ 110.000				
Jaar	**2021**	**2022**	**2023**	**2024**	**2025**
Verwachte omzet (€)	€ 20.000	€ 25.000	€ 25.000	€ 40.000	€ 45.000
- waarvan export (€)	€ 5.000	€ 10.000	€ 10.000	€ 20.000	€ 20.000
Verwachte brutowinstmarge (€)	€ 2.500	€ 3.000	€ 3.000	€ 4.000	€ 4.000
Verwachte kostenbesparingen (€)	n.v.t. (geen productiebedrijf)				
Netto opbrengsten (€)	€ 2.500	€ 3.000	€ 3.000	€ 4.000	€ 4.000
Netto opbrengsten (€) (cumulatief)	€ 2.500	€ 5.500	€ 8.500	€ 12.500	€ 16.500

Market

H4A has already five years of experience with pilot-projects with the use of lignin as natural binder.
The last years, 2018 and 2019 we produced about 2000tons of this Bioway asphalt.
For the upcoming years we prospect that this amout should rise.

Strategy

We will modify our plant for the production, so we can produce faster and lower the production costs.
We also have to prove the quality of the Bioway asphalt, so we can convince our potential clients.
The upcoming period we have to invest in measuring and monitoring of the asphalt.

Financial

The upcoming 5 years we expect that we can produce an asphalt with lignin as binder for 10% more expensive than traditional asphalt..

Economisch perspectief voor lignine is asfalt (H4A)					
Projectkosten	75.000				
Kosten commercialisatie	25.000				
Totaal kosten	100.000				
Jaar	**2020**	**2021**	**2022**	**2023**	**2024**
Verwachte omzet (€)	200.000	400.000	800.000	1.000.000	1.250.000
- waarvan export (€)	20.000	40.000	80.000	100.000	125.000

Verwachte brutowinstmarge (€)	40.000	80.000	200.000	500.000	100.000
Verwachte kostenbesparingen (€)	40.000	80.000	160.000	200.000	250.000
Netto opbrengsten (€)	2.000	**4.000**	**10.000**	**25.000**	**50.000**
Netto opbrengsten (€) (cumulatief)	**2.000**	**6.000**	**16.000**	**41.000**	**91.000**

Economisch perspectief voor te ontwikkelen product/proces/dienst (NTP)					
Projectkosten	97000				
Kosten commercialisatie	25000				
Totaal kosten	123000				
Jaar	**2020**	**2021**	**2022**	**2023**	**2024**
Verwachte omzet (€)	90.000	180.000	270.000	540.000	1.080.000
- waarvan export (€)	0	0	0	0	0
Verwachte brutowinstmarge (€)	2.000	4.000	6.000	12.000	24.000
Verwachte kostenbesparingen (€)	720	1.440	2.160	4.320	8.640
Netto opbrengsten (€)	2720	2720	2720	8160	16320
Netto opbrengsten (€) (cumulatief)	2720	5440	8160	16320	32640

Market
Dura Vermeer produces approximately 900.000 tonnes of asphalt per year, this means a share of approximately 10-15 % of the total market in The Netherlands. Public clients are demanding more and more sustainable asphalt innovations. Bitumen is used as a binder in asphalt, it originates from the refining of crude oil, for example from the Middle East. There is currently no sustainable, green binder that can be used in road construction.

Strategy
Dura Vermeer participates in this development of a bio-based lignin binder to be able to produce sustainable asphalt. It responds to the needs of clients and possibly leads to cost savings. Dura Vermeer can increase its market share and make more profit on this type of asphalt mixtures. A marketing plan will be set up to inform our clients about the possibilities and the gains to be achieved with this special product.

Financial
Dura Vermeer investigates in the research and development of biobased binders, return of the investment should preferably be within three years after market introduction.

Economisch perspectief voor lignine als bindmiddel in asfalt (DURA)					
Projectkosten	**63.000**				
Kosten commercialisatie	**400.000**				
Totaal kosten	**463.000**				
Jaar	**2020**	**2021**	**2022**	**2023**	**2024**
Verwachte omzet (€)	**50.000.000**	**52.500.000**	**55.000.000**	**57.500.000**	**60.000.000**
- waarvan export (€)	**-**	**-**	**-**	**-**	**-**
Verwachte brutowinstmarge (€)	**1.000.000**	**1.100.000**	**1.300.000**	**1.500.000**	**1.800.000**
Verwachte kostenbesparingen (€)	**1.000.000**	**1.500.000**	**2.000.000**	**2.500.000**	**3.000.000**

Extra werkgelegenheid (fte)	**2**	**5**	**10**	**16**	**25**
Netto opbrengsten (€)	**200.000**	**300.000**	**400.000**	**500.000**	**600.000**
Netto opbrengsten (€) (cumulatief)	**200.000**	**500.000**	**900.000**	**1.400.000**	**2.000.000**

SWOT analyse

- Geef in een SWOT-analyse een totaalbeeld weer van sterkten, zwakten, kansen en bedreigingen.

Main Strengths • Application of technology proven on small demonstration level	**Main Weaknesses** • Recycling of lignin based bitumen not yet proven • LCA needs to be evaluated under real industrial conditions • Life time evaluation of asphalt roads not yet clear
Main Opportunities • Increase demand for lignin for higher economic value in NL BBE • Real market interest from BBE stakeholders willing to invest in the technology • Diversification of the technology to other parts of the world. Increase innovation power NL. Possible licenses world wide	**Main Threads** • Fluctuation of crude oil price • Development of an alternative bio-based concept for asphalt • Acceptation by community/ bad publicity

- Hoe worden de risico's (zwakten en bedreigingen) gemanaged? Denk ook aan de niet-technologische aspecten die bij de marktintroductie van de projectresultaten een rol kunnen spelen (marktacceptatie, kostprijsaspecten, keten/netwerkstructuur, wet- en regelgeving, normering en certificering, kennisbescherming e.d.). Hoe gaat u daarmee om?

Risks and threads are managed by the different consortium partners who will mitigate technological risks by measuring health and safety aspects and take necessary precautions if needed. Results of CHAPLIN will be discussed with the advisory board members to facilitate the use of lignin as asphalt binder in the near future as a main stream binder including acceptance by authorities and road owners.

6. Mate van vernieuwing en versterking van de Nederlandse kennispositie (maximaal 2 pagina's)

- De huidige internationale stand van onderzoek en/of ontwikkeling.

In the search for alternatives for bitumen as asphalt binder several biobased binders were tested in most cases at relatively small substitution level of bitumen. Binders developed from micro-algae[14], vegetable oil streams[15,16], wood derived bio-oil[17,18] led to some improvements in an asphalt binder, but only the vegetable oils were used as rejuvenating agents to compensate for aged bitumen quality decrease. The last alternative biobased material to substitute bitumen is lignin, which is the primary biobased material studied in this work.

[14] Chailleux et.all., Alternative binder from Micro-Algae: Algoroute Project, Conference paper, 2012

[15] Deneuvillers, Christine and Van den Kerkhof, Eric, Innovative vegetal based products in road construction, Introduction of Vegecol © Colas, 2007.

[16] Rahman et.all, Use of waste cooking oil, tire rubber powder and palm oil fuel ash in partial replacement of bitumen, Construction and Building Materials, 2017.

[17] Gao, et.all., Rheological Behavior and Sensitivity of Wood-Derived Bio-Oil Modified Asphalt Binders, MDPI, 2018.

[18] Metwally, et.all., Development of Non-Petroleum Based Binders for Use in Flexible Pavements, InTrans Project Reports 10-2010, IOWA State University, 2010.

Lignin from biomass has been studied and is known as a potential substitute for part of the bitumen in asphalt and other applications such as resins, carbon fibres, polyurethanes, and composites. The reason to apply lignin as partial substitute for bitumen is its functionality as binder, UV stability properties and it has structural similarities to the aromatic and asphaltene fractions of bitumen, as lignin contains similar unsaturated aromatic rings joined by alkyl chains. Next to that is the potentially large availability of technical lignin of over 70 million tonnes worldwide an important factor[19].
Lignin, especially lignosulfonates, has had over the years numerous applications including cement and in agricultural. With regard to road application lignosulfonates are used as dust control on dirt roads via coating dust particles and subsequent "glue" them together and in cold asphalt emulsion as stabiliser. There are only a few reports on the use of lignin as bitumen replacement and are briefly discussed hereunder. In the patent literature one patent has been filed and published by Polyphalt Inc. (WO 99/42526) on the application of black liquor as partial replacement. Especially the use of surfactants such as DDBSA (dodecylbenzene sulfuric acid) combined with an inorganic acid (sulfuric acid) treatment of the bitumen is claimed. Clearly the use of sulfuric acid is not pursued. Terrel et al.[20] performed research to replace bitumen with kraft lignin in hot asphalt and lignin sulfonates in cold asphalt application. Suitable lignin and lignin sulfonates formulations were prepared from Kraft lignin. None of the binder formulations were suitable alone as a substitute paving binder. However, a 30 % replacement of bitumen appeared feasible with no significant effect on physical properties. Based on limited laboratory experiments it was concluded that asphalt mixtures containing lignin-bitumen binders can be designed to match the structural strength of asphalt mixtures containing conventional materials. The Australian company Ecopave claims it can produce a bitumen species which is derived from natural sources such as tree resins, gum rosins and lignin. Also fractional distillation in combination with hydrogenation is applied whereby the unsaturated double bonds are saturated. These process steps do add to the price of their bitumen and as a result they are not predominantly present in the market. Although they claim that these types of bitumen-like substances can be used up to now there is not a real breakthrough using this technology.
Several references have been published on the use of lignin in bitumen application for hot asphalt application[21]. The most recent ones are 1) WO 2015/137813[22] and WO 2019/092278[23]. Both patents describe the use of lignin as partial replacement of the binder in asphalt up to 50% substitution. Next to these two patents in recent years, several papers have emerged describing the use of lignin in asphalt binders as an anti-oxidant (Akusar et al.)[24], anti-aging (Xu et al. [25], Arafat et al.[26], and modifier (Xie et al.[27]. Also in 2019 a short review has been published by Yue et al.[28]. All these scientific papers describe the use of lignin in bitumen from small amounts (0.2% to max 20%). The patents however describe substitution degrees of up to 50%, which is far more significant in the search for alternatives for the current bituminous asphalt binder. Also based on the technology, described in the two patents, 8 demonstration roads in the Netherlands with a focus on the SMA top layer of roads have been performed or are currently executed.
In the past four years new developments in this area have been published (WO 2015/137813 and WO 2019/092278). These two patents describe new technologies for the use of lignin and chemically modified lignin as partial replacement for bitumen in binders for asphalt applications. Both these technologies have been or are currently in an experimental phase. Several small stretches of top layers of asphalt roads have been produced which bring both technologies to a TRL level of around 6. Besides the Netherlands various European countries are involved in R&D towards lignin applications on industrial scale (e.g. on resins for wood based panels, carbon fibres). Some countries are involved in R&D to study the use of lignin in asphalt applications such as in Denmark (DONG Energy), Spain (Acciona). As far as we know has the Netherlands a front runner position and this project will further strengthen this position.

---

[19] Gosselink, R.J.A. (2011) Lignin as a renewable aromatic resource for the chemical industry, dissertation, ISBN: 978-94-6173-100-5, Wageningen University, The Netherlands

[20] Terrel et al. Evaluation of Wood Lignin as a Substitute or Extender of Asphalt." FHWA Report No. FHWA/RD-80/125, October 1980

[21] Kowalski, et.all., Eco-friendly materials for a new concept of asphalt pavement, Transportation Research Procedia, 2016.

[22] Slaghek, T., van Vliet, D., Giezen, C., Haaksman, I. (2015) Bitumen composition, WO 2015/137813

[23] Landa, P., Gosselink, R.J.A. (2019) Lignin-based bio-asphalt, WO 2019/092278

[24] Akusar et al, Utilization of lignin as an antioxidant in asphalt binder, International Journal of innovative research and technology, 2 (2016) 198 – 207.
[25] Xu G et al., Rheological properties and anti-aging performance of asphalt binder modified with wood lignin, Construction and building materials, 151 (2017) 801 – 808.

[26] Arafat S et al., Sustainable lignin to enhance asphalt binder oxidative aging properties and mix properties, Journal of Cleaner Production, 217 (2019) 456 – 468.

[27] Xie s et al., Lignin as renewable and superior asphalt binder modifier, ACS Sustainable Chem. Eng., 5 (2017) 2817 – 2823.

[28] Yue Y et al., Evaluation of the properties of asphalt mixes modified with diatomite and lignin fiber: a review, Materials, 12 (2019) 400 (doi:10.3390/ma12030400)

- De resultaten van eventueel eerder onderzoek of een haalbaarheidsstudie

In July 2015, the first demonstration road of 70m with a lignin based bitumen binder was realised in Sluiskil in Zeeland. In this top layer soda lignin was used at a 50% substitution degree[29].
In June 2017, the first cycling path of 1000 m length was constructed with 3 different lignins, e.g. kraft, soda and hydrolysis lignin in separate sections in Wageningen at the Wageningen campus[30].

- De alternatieven op de markt beschikbaar of nog in ontwikkeling.

As described in the state-of-the-art, there is not a good alternative on the market for substitution of bitumen as asphalt binder. Lignin as partial replacement of bitumen up to a level of 50% is under development and the current TRL level is about 6. The lignin based asphalt technology is the most advanced technology. To underpin this, up to 10 demonstration roads have been realised during the last four years in the Netherlands with different lignin sources, substitution levels between 30-50% and different lengths (70m – 1000m). The oldest demonstration road of 70m length was paved in 2015 in Zeeland. In all cases the top layer of the roads were constructed with lignin-bitumen binders.
An alternative approach is followed by KWS, a VolkerWessels company, Wavin and Total which are working on the development of plastic roads, also known as the PlasticRoad. The PlasticRoad concept consists of a prefabricated, modular and hollow road structure based on (recycled) plastics. Every component of the PlasticRoad is being designed to make its application completely circular, with the goal of using recycled plastic as much as possible. (Source: https://www.plasticroad.eu/)

- De innovatie van uw project ten opzichte van de internationale stand van techniek/onderzoek.

The following innovation aspects beyond the state-of-the-art are included in this **CHAPLIN** project:

- Structural monitoring of existing and new demonstration roads using lignin in the manufacturing, blending, paving and use phases.
- Testing of novel lignin sources locally produced in the Netherlands by project partners BBD, AVT, VERTORO for their suitability as asphalt binder. Results will be compared to already used lignin sources.
- TEA and LCA of lignin based asphalt including more practical information on lignin production, emissions, performance etc.
- Recycling options with lignin based asphalt

- De (technologische) stap die gemaakt moet worden om het resultaat te bereiken.

Until now we have experienced during about 4 years that lignine based asphalt is technical feasible for some types of lignin in a real demonstration road. However, we do not know:

o Why and how can this be technical feasible?
o What is the lifetime of the road?
o What are benefits for climate, environment, safety, economy and public health?

By testing and monitoring lignin based asphalt from the production phase, construction phase and during the user phase these questions will be addressed and answered to reach the goal of the development of a sustainable road solution.

- Technologische risico's: beschrijf hoe u hiermee omgaat

We start with tests on laboratory scale. The results will give a view of the risks which could occur at scaling up. On the scale of transects we do new tests and monitor them. This will give an overview of the risks in practise. Based on the results obtained we will implement measures and solutions to migitate technological risks.

- Mogelijkheden tot kennisbescherming (Nederland, Europa of wereld).

Knowledge protection will be strengthed by the patents issued by partners (AKC, WFBR, TNO) and the front running position of the Netherlands on this topic. There is high interest from industrial parties in other countries in this lignin based asphalt development and there are multiple changes for export and broadening of knowledge.

- Of en hoe de Nederlandse kennispositie versterkt wordt met dit project.

[29] http://www.innovatievematerialen.nl/index.php/Bioasfalt?id=206,https://www.duurzaamnieuws.nl/proefvlak-met-bio-asfalt-in-zeeland/,

https://www.trouw.nl/nieuws/zeeland-krijgt-primeur-van-groen-asfalt

[30] https://www.deingenieur.nl/artikel/fietspad-van-bio-asfalt

The Netherlands is frontrunner in the development of lignin based asphalt. **CHAPLIN** will contribute to the further development towards commercial implementation and will give the Netherlands a strong leading position on this bio-based topic.

7. Kennisoverdracht en intellectueel eigendom (1 pagina)

Internal knowledge dissemination will be organised via frequent, at least 4, group meetings where the latest results will be discussed and follow up activities planned. Where possible results will be published by e.g. scientific papers, editorials in journals focussed on asphalt bio-based polymers, and via presentations in symposia.
Agreements on IPR within the **CHAPLIN** consortium will be made along the general principles, and be specified in the CA: Foreground will be the property of the Party carrying out the work generating that Foreground ("Own Foreground"). If the work generating particular Foreground is carried out by more than one Party and if their intellectual contributions to such Foreground form an indivisible part thereof, these Parties shall have joint ownership of such Foreground ("Joint Foreground"). The share of ownership of each of the joint owners shall be determined in good faith, taking into account each owner's relative intellectual contribution to the Joint Foreground. The Party owning Foreground – or in the event of Joint Foreground: the joint owners collectively - shall have the exclusive right to file patent applications for such Foreground in their own name(s) and at their own expense. Each Party may transfer ownership of its Own Foreground or license its Own Foreground following the procedures specified below. In the event of Joint Ownership, the joint owners shall appoint a lead owner that is authorized to make legally binding decisions regarding transfer or licensing of the Joint - Foreground on their behalf. The Knowledge Institutes grant to those Industrial Parties active within the same work package as wherein the knowledge is generated and that contribute contribution, a right of first negotiation for a license agreement or transfer agreement with regard to the Knowledge Institute's Own Foreground or Joint Foreground ("Right of First Negotiation"). In case no such industry is interested in a license or transfer agreement, the other industrial parties, not contributing contribution will get a right of first negotiation for a license agreement or transfer agreement. These IPR and other agreements will be laid down in a dedicated Consortium agreement which will be drawn-up, and duly signed after positive evaluation of the current proposal, but before the actual project start.

8. Financiering van het eigen aandeel in de projectkosten

WFBR: Dit project valt binnen de strategische visie van WFBR op ontwikkeling van duurzame oplossingen voor valorisatie van reststromen en het eigen aandeel zal middels strategische middelen worden gefinancierd.
BBD will finance its own contribution by own means.
UU: Dit onderzoek wordt van strategisch interesse gezien. Daarom zal de UU zal het resterende deel in eerste instantie uit eigen middelen financieren.
AKC: 35 k€ will be generated in the normal business model during the project and the spin off period in the near future.
TNO: Het eigen aandeel wordt uit strategische middelen (SMO) van TNO gefinancieerd.
H4A: Eigen aandeel wordt gefinancierd uit eigen middelen.
NTP: Het eigen aandeel wordt uit eigen vermogen gefinancieerd.
Dura Vermeer finances its own share of the costs through the use of own resources and hours of own R&D employees. Given the project size and the duration of the project compared to the turnover of Dura Vermeer, this is not a problem.
LTX: The remainer of the balance will be paid by Latexfalt.
VERTORO: Vertoro heeft hiertoe durfkapitaal beschikbaar.
AVT: Eigen aandeel wordt uit reguliere middelen bekostigd.