Innovative methods for wood protection

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Contactpersoon

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Samenvatting

De toegenomen toxische druk op het milieu en de menselijke gezondheid versterkt de noodzaak om het effect van stoffen met een negatief effect op het milieu die worden gebruikt om hout te conserveren te verminderen. Biociden zijn “Stoffen of mengsels die een of meer werkzame stoffen bevatten of genereren, en zijn bedoeld om schadelijke of ongewenste organismen, variërend van bacteriën, virussen en insecten tot schimmels of ratten, te vernietigen, af te weren, te neutraliseren of te voorkomen.”[1] De werkzame stof is meestal een chemische stof maar kan ook een natuurlijke olie, plantenextract, of een micro-organisme zijn. Het toenemende gebruik van hout voor duurzaam bouwen is een van de redenen waarom het gebruik van houtbeschermende middelen zou kunnen toenemen.
Het Ministerie van Infrastructuur en Waterstaat heeft Arcadis gevraagd naar de mogelijkheden voor houtbeschermingsmethoden met een lage - of geen - toxiciteit en naar de huidige stand van de markt.
De volgende vijf vragen staan centraal:

1. Welke houtbeschermingsmethoden zijn er en voor welke houtproducten en toepassingen worden ze gebruikt?
2. Welke houtbeschermingsmethoden hebben de meeste kans om milieu- en/of gezondheidsvoordelen te behalen en om de toxische druk van houtbescherming te verminderen?
3. Welke stakeholders zijn betrokken bij de ontwikkeling, productie en toepassing van houtbeschermingsmethoden?
4. Welke factoren stimuleren en belemmeren het op de markt brengen of houden van (deze) zoutbeschermingsmethoden?
5. Wat kunnen beleidsmakers en marktpartijen doen om belemmeringen weg te nemen en kansen te benutten?

Deze vragen worden beantwoord door middel van een literatuuranalyse in de vorm van een literatuur/patentonderzoek om nieuwe houtbeschermingsmethoden te identificeren, een SWOT-analyse om de lage/niet-toxische houtbeschermingsmethoden te groeperen en te beoordelen, een ronde van interviews om de houtbeschermingsmarkt te verkennen, en een hackathon met marktpartijen om kansen te identificeren voor de problemen die in de interviews zijn besproken. De resultaten zijn gekoppeld aan het theoretisch kader. Er worden drie theorieën gebruikt om de validiteit van de resultaten te ondersteunen: de Transitietheorie, het Vijfkrachtenmodel van Porter en Geïntegreerde Plaagdierbestrijding.

Uit het literatuur- en patentonderzoek kwam een lijst naar voren van mogelijke houtbeschermingsmethodieken met beperkte impact op het milieu en gezondheid. Sommige methodieken worden al toegepast (bijvoorbeeld houtmodificatie) en anderen bevinden zich in eerdere stadia van innovatie. De verschillende behandelingsprincipes worden gegroepeerd in acht groepen: chemische modificatie, fysische behandeling (bijvoorbeeld thermische modificatie, waterafstotend maken), chemische impregnatie, impregnatie met natuurlijke stoffen, biologische bestrijding, nanotechnologie, genetische modificatie en genetische selectie. Houtmodificatie, biologische bestrijding en impregnatie met natuurlijke stoffen blijken het meest kansrijk om milieuwinst te behalen. Chemische modificatie kan de levensduur van houtproducten aanzienlijk verbeteren en beschermen tegen de meeste biologische agentia. Stoffen zullen door hun chemische binding nauwelijks uitlogen.

Met biologische bestrijding kunnen niet-toxische biologische agentia worden gebruikt om andere, ongewenste biologische agentia af te schrikken, gebruikmakend van het concurrentievermogen van soorten. Vaak wordt geëxperimenteerd met de schimmel *Trichoderma*. Deze wordt al voor het beschermen van planten toegepast.
Een alternatief dat in de handel verkrijgbaar is, is de technologie waarbij hout met lijnolie als waterafstotende stof geïmpregneerd wordt en de schimmel als natuurlijk pigment voor de bescherming tegen UV dient. Het op een natuurlijke manier waterafstotend maken van hout is een vaak toegepaste methode om hout te beschermen. Behandelingen met organische stoffen dragen bij aan houtbescherming, omdat deze stoffen werkzame ingrediënten kunnen bevatten, en tegelijk biologisch afbreekbaar zijn.

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[1] Wat is een biocide? | College voor de toelating van gewasbeschermingsmiddelen en biociden (ctgb.nl)

In de “VERORDENING (EU) Nr. 528/2012 VAN HET EUROPEES PARLEMENT EN DE RAAD van 22 mei 2012 betreffende het op de markt aanbieden en het gebruik van biociden”, is in Annex 1 een lijst van werkzame stoffen vermeld met een laag risico. Deze zullen bij voorkeur worden toegepast en komen voor een vereenvoudigde toelating van houtbeschermingsmiddelen in aanmerking. Sommige van deze stoffen zijn organische stoffen zoals lijnzaadolie of melkzuur. Maar ook stoffen op Annex 1 van niet-biologische afkomst, zoals ijzersulfaat, zijn in principe geschikt voor de bescherming van hout.

De geïnterviewde stakeholders zijn beschreven in dit rapport. Hiermee worden bedrijven en organisaties bedoeld die betrokken zijn bij de houtbeschermingsindustrie. Dat zijn producenten en verwerkers van klassieke biociden, en producenten van behandelde houtproducten. Producenten van beschermd hout met andere niet-klassieke werkingsprincipes en belangen- en brancheorganisaties werden ook geïnterviewd. Het Ctgb, de Nederlandse autoriteit voor toelating van biociden, en ook het RIVM en het Ministerie van Infrastructuur en Waterstaat als overheidsorganisaties spelen door hun betrokkenheid bij de interactie met de marktpartijen en belangrijke rol als stakeholders.

Uit de interviews zijn de hoofdknelpunten in de houtbeschermingsindustrie naar voren gekomen. Belanghebbenden in de industrie ervaren de regels en voorschriften als het grootste probleem. Het gaat dan vooral om de hoge kosten, langdurige procedures, onzekerheid over de uitkomst en de complexiteit van de procedures. Deze problematiek wordt door het Ctgb herkend. Dit remt innovatie en beperkt de mogelijkheden om tot een sluitende business case voor houtbeschermingsproducten te komen. Uitgaande van het Vijfkrachtenmodel van Porter’s model is de markt voor houtbescherming niet aantrekkelijk. Onderzoeksorganisaties zijn de afgelopen jaren gestopt met investeren in houtonderzoek, waardoor kennis in alle regio's van de industrie uit Nederland sterk verminderd is. Dit zorgt er vervolgens voor dat de ontwikkeling van nieuwe technische oplossingen nog meer wordt belemmerd. Door de kracht van de industrie te bundelen, kan de transitie naar een markt voor houtbescherming met een minder negatieve impact op het milieu een nieuwe fase ingaan. Het ministerie van Infrastructuur en Waterstaat (en andere ministeries) kunnen marktpartijen helpen door bijvoorbeeld duurzame innovaties vaker toe te passen. De druk om het gebruik van houtbeschermingsmiddelen met een hoge toxiciteit te beperken kan een kans zijn om het ontwikkelen van alternatieven te stimuleren. Daarbij is de rol van kennisinstellingen essentieel, waardoor het behouden van de kennis en het doorgeven ervan aan nieuwe generaties even urgent is als het creëren van nieuwe kennis.

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Summary

The increased toxic pressure on the environment and human health reinforces the need to reduce the impact of substances with an adverse effect on the environment used to preserve wood. Biocides are “substances or mixtures that contain or generate one or more active substances, and are intended to destroy, eliminate, or destroy harmful or unwanted organisms, ranging from bacteria, viruses and insects to fungi or rats. to ward off, neutralise or prevent.”
The active ingredient is usually a chemical, but can also be a natural oil, plant extract, or a microorganism.
The increasing use of wood for sustainable building is one of the reasons why the use of wood preservatives could increase.
The Ministry of Infrastructure and Water Management has asked Arcadis about the possibilities for wood protection methods with low - or no - toxicity and about the current state of the market. The following five questions are central:

1. What wood protection methods are there and for which wood products and applications are they used?
2. Which wood protection methods are most likely to achieve environmental and/or health benefits and to reduce the toxic pressure of wood protection?
3. Which stakeholders are involved in the development, production, and application of wood protection methods?
4. Which factors stimulate and hinder the marketing or keeping on the market of (these) wood protection methods?
5. What can policymakers and market parties do to remove obstacles and seize opportunities?

These questions are answered through a literature analysis in the form of a literature/patent search to identify new wood protection methods, a SWOT analysis to group and assess the low/non-toxic wood protection methods, a round of interviews to explore the wood protection market, and a hackathon with market participants to identify opportunities for the issues discussed in the interviews. The results are linked to the theoretical framework. Three theories are used to support the validity of the results: Transition Theory, Porter's Five Forces Model, and Integrated Pest Management.

The literature and patent search resulted in a list of possible wood protection methods with limited impact on the environment and health. Some methodologies are already being applied (e.g. wood modification) and others are in earlier stages of research. The different treatment principles are grouped into eight groups: chemical modification, physical treatment (e.g. thermal modification, water repellency), chemical impregnation, impregnation with natural substances, biological control, nanotechnology, genetic modification, and genetic selection.
Wood modification, biological control and impregnation with natural substances appear to be the most likely to achieve environmental benefits. Chemical modification can significantly improve the life of wood products and protect against most biological agents. Substances will hardly leach because of their chemical bond.

With biological control, non-toxic biological agents can be used to deter other, undesirable biological agents, taking advantage of the competitiveness of species. Experiments are often carried out with the fungus Trichoderma. This is already used to protect plants.
A commercially available solution is the technology in which wood is impregnated with linseed oil as a water-repellent substance and the fungus serves as a natural pigment for UV protection. Making wood water-repellent in a natural way is an often-used method to protect wood. Treatments with organic substances contribute to wood protection because these substances can contain active ingredients, and are biodegradable at the same time.

In the “REGULATION (EU) No 528/2012 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 May 2012 concerning the making available on the market and use of biocidal products”, Annex 1 contains a list of active substances with a low risk. These will preferably be used and qualify for a simplified authorisation of wood preservatives. Some of these active substances are of organic origin such as linseed oil or lactic acid. But active substances on Annex 1 of non-biological origin, such as iron sulphate, are in principle also suitable for the protection of wood.

The interviewed stakeholders are described in this report. This refers to companies and organisations that are involved in the wood protection industry. These are producers and processors of classic biocides and producers of preserved wood products. Producers of protected wood with other non-classical operating principles and interest and industry organisations were also interviewed. As government organisations, the Ctgb, the Dutch authority for the authorization of biocides, as well as the RIVM and the Ministry of Infrastructure and Water Management play an important role as stakeholders through their involvement in the interaction with the market parties.

The main bottlenecks in the wood protection industry emerged from the interviews. Stakeholders in the industry see the rules and regulations as the biggest problem. This mainly concerns the high costs, lengthy procedures, uncertainty about the outcome and the complexity of the procedures. This problem is recognised by the Ctgb. This inhibits innovation and limits the possibilities to arrive at a conclusive business case for wood protection products. Based on Porter's Five Forces model, the market for wood preservation is not attractive. Research organisations have stopped investing in wood research in recent years, as a result of which knowledge in all regions of the industry from the Netherlands has been greatly reduced. This in turn further hinders the development of new technical solutions.
By joining the strength of the industry, the transition to a market for wood protection with a less negative impact on the environment can enter a new phase. The Ministry of Infrastructure and Water Management (and other ministries) can help market parties by, for example, applying sustainable innovations more often. The pressure to limit the use of high-toxicity wood preservatives can be an opportunity to stimulate the development of alternatives. The role of knowledge institutions is essential in this respect, which means that preserving knowledge and passing it on to new generations is just as urgent as creating new knowledge.

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1 Introduction

Wood protection is used to increase the lifespan of wood by improving durability. This process could also be beneficial for the sustainability of wood applications as the treated wood might need less maintenance and replacement. Another benefit is the prolonged sequestration of carbon in the wood, which contributes to mitigation of climate change. However, there is a downside to the way wood is currently treated. Traditional biocides, used to prevent wood degradation by micro-organisms and insects, have a negative impact on the environment, mainly because of the active substances in these products. According to the Biocidal Products Regulation, biocides are "Substances or mixtures that contain or generate one or more active substances, and are intended to destroy, repel, neutralise, or prevent harmful or unwanted organisms ranging from bacteria and fungi to insects or rats. The active substance in a biocide can be a chemical, a natural oil, an extract, or a micro-organism."[2]

In the current era of environmental and safety awareness, there is a clear need to decrease exposure to toxic substances. Toxic substances can pose risks for human health, and the environment when they are misused. The European Union Biocidal Product Regulation has the goal to protect human health and the environment, and under this regulation active substances need to obtain an approval and biocidal products are authorised. The European Union is working towards a situation with safe wood protecting products on the market to limit the risk of exposure to toxic substances as much as possible and where biocides can be used safely. The dilemma that follows is twofold. Biocides are needed for wood protection, but they can have a negative impact on the environment. To reduce the negative impact, alternatives with low(er) toxicity are needed.

The Dutch Ministry of Infrastructure and Water Management is interested in alternative technologies with low toxicity to protect wood against microbial and insect degradation. This includes biocides with low toxicity but also biocide-free technologies. In line with Integrated Pest Management, the functionality of alternative technologies is crucial. The Ministry aims to get insights in what can be done to overcome barriers and stimulate new developments to get to new, innovative, low-toxicity methods for wood protection. The objective of this research is therefore to find a way to overcome this dilemma.

[2] Definition as presented by the Dutch Ctgb. What is a biocidal product? | Board for the Authorisation of Plant Protection Products and Biocides (ctgb.nl)

1.1 Research questions

This research report will answer the following central questions:

1. Which wood protection methods are available and for which wood products and applications are they used?
2. Which wood protection methods are most likely to achieve environmental and/or health benefits and to reduce the toxic pressure of wood protection?
3. Which stakeholders are involved in the development, production, and application of wood protection methods?
4. Which factors stimulate and hinder the marketing and keeping on the market of (these) wood protection methods?
5. What can policy makers and market parties do to remove obstacles and seize opportunities?

1.2 Definition and readers guide

In this report the reader will gain insights on the abovementioned questions. This report uses the terms *wood protection* and wood preservation. The difference between these terms is worth explaining because it sets the discourse for the entire research. While wood preservation refers to the impregnation of wood with biocides to prolong the lifespan of wood, wood protection3 is used in a broader sense. Wood protection also refers to technologies (treatments) that increase the durability of wood but does not only rely on the principle of toxicity. Wood protection is considered as the umbrella term that also includes wood preservation.
The report starts with the methodology, which encompasses the theoretical and analytical framework, the methods, and the research plan. The results of this research are presented in four chapters. First, the available alternative technologies for wood protection are presented and the most promising alternatives are selected. Second, stakeholders in the market are characterised and the barriers and opportunities for innovation in the wood protection industry are identified. After this, there is a chapter on barriers and opportunities for the market. The research report ends with a conclusion for the Ministry in which options to stimulate the transition towards non-toxic options in the wood protection market are presented. Appendix 1 provides the overview of possible wood protection technologies. Appendix 2 shows the interview questions.

[3] IRG Wood Protection (irg-wp.com)

2 Research Methodology

2.1 Theoretical framework

The research leans on two theories to support the methodology and it uses an abductive approach to gain insights on the results. The Transition Theory is important as it relates to the wider (macro) system of changing to a new way of working. In the case of wood protection: towards a way of wood protection with minimal toxic impact for the environment. Porter's '5 forces theory' gives a model of the way businesses operate and the way new businesses could enter the market. This is especially relevant on a micro-level.

2.1.1 Transition theory

Professor in societal transitions Jan Rotmans of Maastricht University has been one of the founding authors of the theory of Transition Management. Transition theory describes change in complex (societal) systems. For the purpose of this research, the wood protection industry, its customers and its stakeholders are seen as such a system. Transition management is based on key notions of complex systems theory, such as variation and selection, emergence, coevolution, and self-organisation. It involves a cyclical process of phases at various scale levels: stimulating niche development at the micro level, finding new attractors at the macro level by developing a sustainability vision, creating diversity by setting out experiments, and selecting successful experiments that can be scaled up. This is known as the multi-level perspective, which is also applied in this research.

Any transition will typically appear as an S-curve: a long, initial pre-development phase, followed by a tipping phase which consists of a take-off of the transition, and a subsequent breakthrough. After this the transition stabilises and becomes the new norm. The transition is visualized in Figure 1.

Transition management relies on systems thinking. Like other complex systems, the wood protection industry and its stakeholders are a socio-technological system. Technology cannot be seen separately from society as technology is always used in the social sphere. In a transition, technology changes, but social changes need to happen to adopt technological changes.

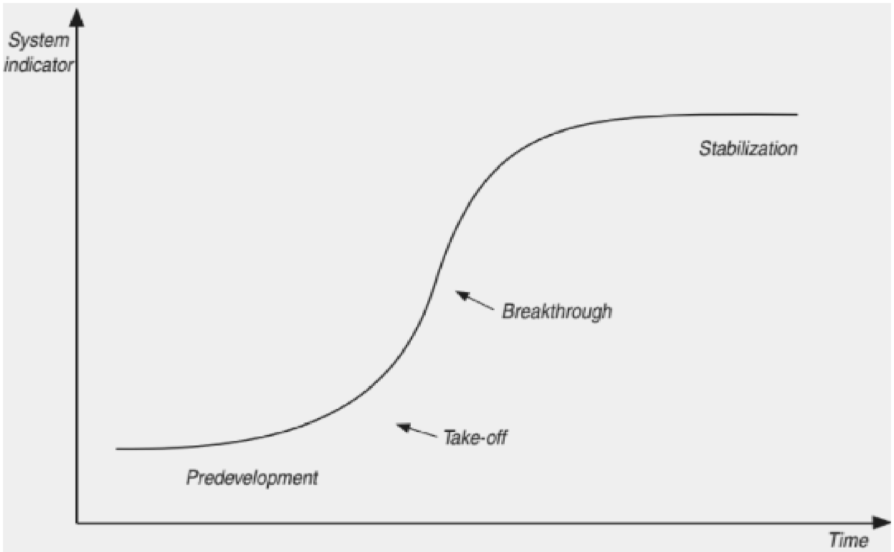

Figure 1 – Phases of socio technical change[4]

Transitions are never predictable and will occur in different patterns. There are four main transition pathways: *Transformation pathway,* in which there are niche innovations (micro level) that cannot disrupt the landscape developments (macro level) but can cause a change in the sociotechnical regime (meso level). The *de-alignment and re-alignment pathway* destabilises landscape developments, and stakeholders do not trust the regime anymore, which can cause de-alignment. Eventually the regime will stabilise, and one niche innovation will become dominant. The *technological substitution pathway* occurs when there is a sudden shock in the landscape developments, which gives room for niche innovations to take over. This pathway is typified by a fast breakthrough phase if the niche innovations are mature enough. The *reconfiguration pathway* describes a changing environment caused by multiple, independent niche innovations which cannot change the regime independently, but as a series of multiple innovations it is possible to eventually change the landscape.

[4] Temporal paths for technology transition and innovation. Source Rotmans

The Transformation pathway is characterised in Figure 2.

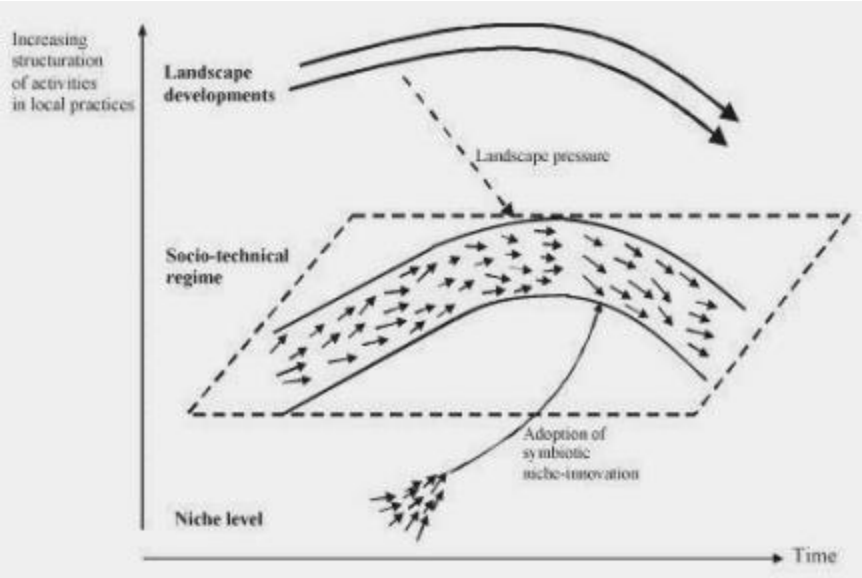

Figure 2 – Transformation pathway of socio-technological change[5]

2.1.2 Porter's Five Forces

This model[6] by Michael E. Porter was created in 1979. It aims to help understand and assess the competitiveness of an industry. The level of competitiveness identifies the attractiveness of entering this market by describing the 5 forces that are relevant to the market. Attractive markets have few competitors or there might be a gap in the market that a business can target with strategic positioning.
Emphasising the importance of identifying imperfect markets offering more profitable opportunities, the model provides useful information to direct a business' strategic approach and marketing. If the business is an existing firm and want to a better understanding of the current market, they can analyse their current position and plan their future direction by aligning it with their strengths and addressing their weaknesses. If it is a new business, or it is entering a new industry, they can highlight how they are most likely to succeed. Applying 'systems thinking', the Porter model simplifies several complicated microeconomic theories into five components that impact a market's long-term profitability:

- The bargaining power of the buyers
- The threat of new entrants
- Competitive rivalry
- Threat of substitution
- Supplier power

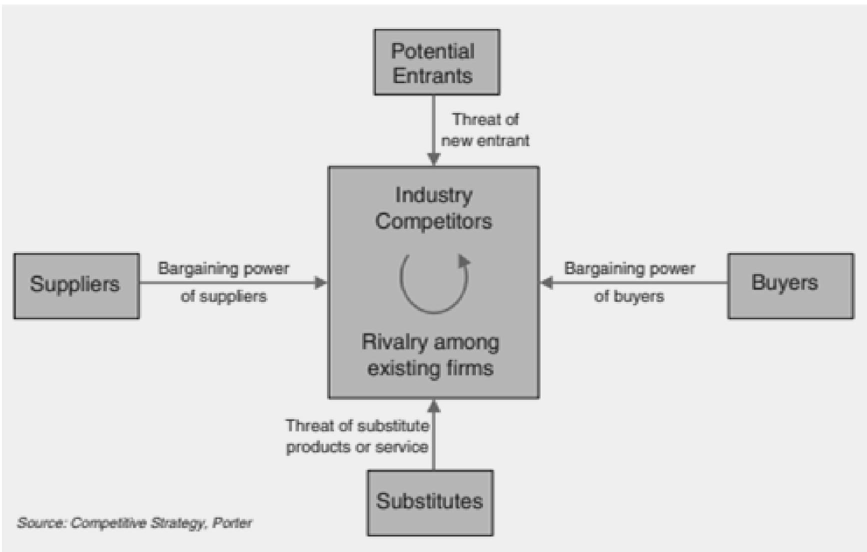

Figure 3 - Porter's Five forces

[5] Circular Economy in the Textile Industry (wur.nl)
[6] Porter's Five Forces: The Ultimate Guide - SM Insight (strategicmanagementinsight.com)

Competitive rivalry is the central box of the model, a function of the other four forces. The importance of negotiating power and bargaining arrangements is identified, this focus on external factors is more prominent than in other market analysis theories.
An attractive industry with high profits will have one or more of the following characteristics: high barriers to enter; weak suppliers bargaining power; weak buyers bargaining power; few substitute products or services; low competition.
An unattractive industry with low profits will have one or more of the following characteristics: low barriers to enter; strong suppliers bargaining power; strong buyers bargaining power; many substitute products or services; intense competition.

Buyer Power
In certain marketplaces, buyers have more power and can apply pressure on companies to lower prices. If competition is high and the customer has many choices, they have a higher power. Buyers can also join to have a stronger influence on changing the behaviour of a firm. For example, for ethical reasons consumers might boycott a brand.

The Threat of New Entrants
What is the likelihood of new entries in the market? If an industry is perceived as attractive, increased competition is highly likely. If too many new entrants enter that market, its potential profitability will decline. If a marketplace has few but immensely powerful players in it, they will try and make it as difficult as possible for new companies to enter that market. Other barriers to entering that market also need to be considered. Entry barriers include government policies, patents and technology.

Competitive Rivalry
The current competition within the marketplace is obviously an important consideration. Understanding competitive rivalry uncovers how many competitors there are and how much they spend on marketing, what competitive advantages they have (if any), the level of continuous innovation and any differences in quality between players.

Threat of Substitution
Customers might be able to choose to substitute a product or service with another. Not to a competitor’s product from the same market—but instead, switching product categories altogether. For example, a person might stop purchasing fast food and instead purchase pre-made frozen healthy meals. The more substitute items there are, the more likely customers are to be drawn to an alternative product.

Supplier Power
Firms must research and consider different alternatives for supply in the market. Raw materials for example can vary a great deal in terms of price and quality. Having the right supplier is critical. How much power does that supplier have? How many competitors do they have? Will their price be consistent or are they likely to increase it? The fewer suppliers there are, the more power they have. The cost of switching suppliers and the ease of distribution is also a consideration.

2.1.3 Integrated Pest Management

The concept of Integrated Pest Management[7] (IPM) is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. The UN’s Food and Agriculture Organisation (FAO) defines IPM as *“the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms[8].”* IPM programs use the latest, comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment.

[7] Integrated Pest Management (IPM) Principles | US EPA
[8] Plant Production and Protection Division: Integrated Pest Management (fao.org)

Although IPM is primarily used in agricultural settings, it can also be applied to wood protection. IPM takes advantage of all appropriate pest management options including, but not limited to, the judicious use of pesticides. In contrast, organic agricultural production applies many of the same concepts as IPM but limits the use of pesticides to those that are produced from natural sources, as opposed to synthetic chemicals.
IPM is not a single pest control method but, rather, a series of pest management evaluations, decisions and controls. In practicing IPM, producers who are aware of the potential for pest infestation follow a four-tiered approach. The four steps include:

Set Action Thresholds
Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not always mean control is needed. The level at which pests will become an economic threat is critical to guide future pest control decisions.

Monitor and Identify Pests
Not all insects, weeds, and other living organisms require control. Many organisms are innocuous, and some are even beneficial. IPM programs work to monitor for pests and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds. This monitoring and identification removes the possibility that pesticides will be used when they are not really needed or that the wrong kind of pesticide will be used.

Prevention
As a first line of pest control, IPM programs work to manage the crop, lawn, or indoor space to prevent pests from becoming a threat. In an agricultural crop, this may mean using cultural methods, such as rotating between different crops, selecting pest-resistant varieties, and planting pest-free rootstock. These control methods can be very effective and cost-efficient and present little to no risk to people or the environment. For wood protection, this could be more complex, but not impossible.

Control
Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programs then evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identifications, and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

2.2 Analytical framework

With the theories presented in the theoretical framework, patterns in the market, opportunities and best practices were identified. An analytical framework is created to make sense of the indicators that are used to assess the different wood protection methods. This is done by means of a SWOT analysis. This SWOT analysis is used to gain insights in the strengths, weaknesses, opportunities, and threats of the groups of wood protection methods. Relevant technical-, market- and sustainability aspects were systematically covered per wood protection method based on the summarised actual state of the art. In this report it is not possible to cover and explain the detailed scientific (toxicity) background of the different wood protection methods. The qualitative scoring of each of the technical elements in the SWOT was done by consultation of experts from the field of wood protection and according to expert judgement of the research team. The sustainability rating of the wood protection categories is mainly based on the principles used in Integrated Pest Management as the leading theory. The theory of Porter's Five Forces was of minor importance when rating the alternative wood protection technology. The summarised (analysis) results are presented in Chapter 3.2., more details can be found in Appendix 1 of this report. The Technological Readiness Levels (TRL) presented in Chapter 3.2 are estimated based on expert judgement. It must be considered that TRL only describes the technological status of innovations, not the legislative status.

2.3 Data Acquisition

Data acquisition for this research was performed with three different methods: a literature/patent search, stakeholder interviews, and a hackathon.

2.3.1 Literature/Patent Search with Artificial Intelligence

An AI tool was used to gain insight in all possible methods available for wood protection. Based on the relevant search terms given by the expert team, the tool uses artificial intelligence to search in scientific literature and patents in the English language to find all wood protection methods. The AI tool searches for a clearly defined function (protection against degradation) and an object (wood or other natural fibers). The search includes many synonyms. The results were subsequently grouped in categories (see Appendix 1).

2.3.2 Stakeholder interviews

The stakeholder interviews are meant to gain insights in the market of wood protection and preservation. Interviewees were asked about their role in the market, their expertise and/or products, but also about barriers they encounter in the market. The interviews are conducted in a semi structured way. Questions about the abovementioned topics were prepared, but interviewees were also free to express their opinion about other matters and follow-up questions were asked about the most interesting results of the interviews. In the table below, the interview participants are summed up.

Name	Role in the market	Date
Janssen PMP	Production of chemicals	March 2022
Foreco	Supplier wood protection technologies	March 2022
Centrum Hout	Wood users' expertise centre	March 2022
SHR	Research and testing centre	March 2022
Accsys Groep	Supplier wood protection technologies	March 2022
Xylotrade	Supplier wood protection technologies	March 2022
Zwarthout	Supplier wood protection technologies	March 2022
Ctgb	Evaluation of biocides	March 2022
Woodchem	Supplier wood preservation technologies	March 2022

Table 1 – Interview participants

The interview questions are presented in Appendix 2.

2.3.3 Hackathon

The hackathon aims to bring market stakeholders together to find solutions for previously identified barriers in a high-pressure environment. The term was first used in the IT industry, where it was meant to solve problems and develop innovations in small groups, in multiple rounds. Because of the time pressure, participants are forced to think quickly and use their creativity to come up with solutions. Once the solutions are clear, there is a deep dive into one of the solutions to further think it through.
The hackathon took place in June 2022. The topics that were discussed followed from the insights gained in the interviews held with stakeholders. The stakeholders in the interviews were also invited for the hackathon. A total of 13 participants were present during the hackathon, including a representative of the Ministry of Infrastructure and Water Management, the project team, and hackathon leader. Participants were divided in groups of four to discuss one of the topics: technical barriers, barriers in rules and regulations, business case, or knowledge development. After the first round of brainstorming, the results were shared with the entire group of participants and discussed further. For the deep dive, the participants were assigned to different groups and topics to ensure a new discussion would emerge. At the end of the hackathon, another plenary discussion took place to share the results with other participants.

2.4 Research Plan

The research was carried out in two stages. In stage 1, an artificial intelligence tool was used to inquire information about potential wood protection methods. These methods were then grouped and used as a basis for the SWOT analysis. In stage 2, the market for wood protection was researched by means of stakeholder interviews and a hackathon. A schematic representation of the research plan can be seen in Figure 4.

In the first three steps of the project (the Patent search, the interviews and the SWOT model) the first two questions of the research where investigated:

1. Which wood protection methods are available and for which wood products and applications are they used?
2. Which wood protection methods are most likely to achieve environmental and/or health benefits and to reduce the toxic pressure of wood protection

The next three questions were investigated with the interviews and the Hackathon which was performed in the second phase:

3. Which stakeholders are involved in the development, production and application of wood protection methods?
4. Which factors stimulate and hinder the marketing and keeping the on the market of (these) wood protection methods?
5. What can policy makers and market parties do to remove obstacles and seize opportunities?

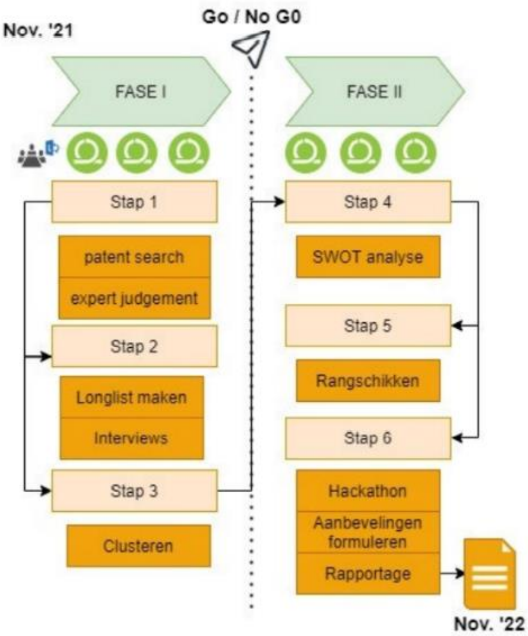

Figure 4 - Project planning

3 Methods and applications for wood protection

3.1 Background

This chapter provides an overview of common knowledge on wood degradation and wood protection and is composed of expert knowledge from both the interviews and the research team. Wood is a natural product and therefore, it is also susceptible to natural causes of degradation. Degradation can be caused by weather influences, such as water, UV light, and exposure to extremely high/low temperatures. Living organisms can also cause decay of wood.
Brown rot, white rot and soft rot are caused by fungi affecting the cell wall of the wood[9]. Furthermore, insects such as several species of beetles, worms or wood wasps can cause damage to the wood. Lastly, bacteria living in anaerobic conditions can cause decay in water applications where wood is fully submerged[10]. Termites are a risk for wood degradation in more southern Europe climatic regions. However, with accelerating climate change and the species migrating north, it is possible that termites will enter the Netherlands as well in the future.
Wood protection aims to prevent such biological degradation. This might be achieved by several different methods. Toxicity can kill organisms. Other principles are to make the wood inedible for organisms, or to increase the water resistance of wood.
Wood protection and preservation methods have been used for many centuries, as human development is closely connected with the use of wood. In the ancient Egyptian culture, methods like bitumen and garlic boiled in vinegar were already used to preserve wood and protect it against organisms. More modern technologies for wood preservation emerged in the 1700s, when mercuric chloride and copper sulfate were first recommended. In the 1800's zinc chloride, coal-tar creosote and copper naphthenate were first used and in the 1900's most of the wood preservatives that are currently used (or have been blacklisted) were invented, like copper chromate arsenate (CCA). The impact of CCA-treated wood on the environment and human an animal health was not known when it was first patented in 1938. Arsenic is a human carcinogen, and it also causes nervous system damage and birth defect. Although CCA is banned in the EU, it is still widely used in other parts of the world (over 60.000 t/year)[11].
The need for wood protection methods with less toxicity is evident. There are several alternative possibilities for wood preservation. Some technologies are more mature than others. The field of application of wood protection methods is classified by using the Use Classes from the EN 335:2013. These Use Classes (UC) are introduced in Table 2.
The expected conditions of the final wood product are central in these classes and therefore the classes are wood species independent.

[9] Hout_Houtaantastingen_deel1_dec2013.pdf (houtinfo.nl)
[10] Hout_Houtaantastingen_deel2_dec2013.pdf (houtinfo.nl)
[11] Present Status and Future Strategies for Wood Preservation Industry. Dhiman & Dutt: Chap-11.pmd (researchgate.net)

Use class	Description	Service conditions	Typical usage	Risk of leaching
UC1	UC1 wood products are used in interior construction, such as studs, joists, roof trusses, furniture and millwork. The preservatives are intended to protect against termites. These products are typically preserved with borates and may be ordered in higher borate retentions for areas where the Formosan termite is present.	Above ground, interior construction, dry. Protected from weather and interior sources of water such as leaking plumbing, condensate, pools and spans.	Interior construction.	None
UC2	Products in UC2 are used where there is potential moisture exposure and there is a need for protection against decay fungi as well as termites. Products available include lumber, millwork, glu-lams, flooring and furring strips.	Above ground, interior construction, damp.	Interior conditions where the moisture content occasionally exceeds 20%.	Low
UC3A	Products in UC3A may be exposed to the full effects of the weather but are in vertical exterior walls or other types of construction that allow water to quickly drain from the surface.	Above ground, exterior, protected, coated and rapid water run-off.	Coated millwork, siding and trim.	High
UC3B	Materials in UC3B are used where they are exposed to all weather cycles including intermittent wetting, but with sufficient air circulation so wood can readily dry. See UC4A for sawn components that may be physically above ground but that are required to be treated for ground contact. This includes sawn components that are difficult to replace and critical to the structure, or that may be exposed to ground contact type hazards due to climate, artificial or natural processes or construction.	Exterior construction, above ground, uncoated or poor water run-off. Excludes above ground applications with ground contact type hazards.	Decking, railings, joists and beams for decks and freshwater docks, fence pickets, uncoated millwork.	High
UC4A	Products treated under UC4A are those used (1) contact with the ground, fresh water, or other situations favourable to deterioration; (2) used above ground but are difficult to maintain, repair or replace and are critical to the performance and safety of the entire system/construction; or (3) used above ground but may end up in ground contact or are subject to hazards comparable to ground contact due to climate, artificial or natural processes or construction.	Ground contact or freshwater contact, Ground Contact or Fresh Water. Includes above ground applications with ground contact type hazards or that are critical or hard to replace.	Sawn fence, deck and guardrail posts, structural lumber, joists and beams for decks and freshwater docks, timbers.	Very high
UC4B	Wood in the UC4B category is typically used in contact with the ground in severe environments, in climates with high potential for deterioration and in critically important components.	Ground contact or freshwater contact, heavy duty, critically important components.	Permanent wood foundations, building poles, horticulture posts, utility poles, decking, above tidal piers and docks, and in areas with high potential for fungal decay.	Very high

Use class	Description	Service conditions	Typical usage	Risk of leaching
UC4C	Wood treated to UC4C can be found where there is extremely high potential for deterioration, with considerable exposure to moisture such as in rivers or lakes.	Ground contact or freshwater contact, extreme duty, extremely critical components.	Land or freshwater pilings, foundation pilings and utility poles in areas with a severe potential for fungal decay.	Very high
UC5	Wood treated to UC5 is preserved for the most demanding conditions such as salt water immersion where it may be exposed to marine borers and other salt water organisms. Unlike the other Use Categories, the subcategories are based on the location where the product will be used, reflecting the specific threats posed.	Salt and brackish water and adjacent mud zones; continuous marine salt water exposure.	Marine pilings, bulkheads, bracing.	Very high

Table 2 – Use classes of wood according to the EN 335:2013[12]

In general, a first step in the process of wood protection is often the (kiln) drying of wood. Wood with a moisture content lower than 21% is theoretically no longer subjected to rot. If it remains below that moisture content there is no fungal decay possible. Wood protection can be done by different ways of treatment.[13]. Solvents or emulsions can be sprayed on, or applied by shortly soaking, (double) vacuum pressure process in an autoclave, or coverage by hand. Mineral salts in a water solution can be applied by long soaking, vacuum pressure or changing pressure in an autoclave, or diffusion. These kinds of treatments are normally applied after machining the wood to the final profile.

Figure 5 - Wood preservation in an autoclave[13]

3.2 Alternatives to wood preservation methods

The results of the literature/patent research with technologies to protect wood has been divided into eight groups. The division is based on similarity of the mode of action; however, this classification is not all-encompassing. The eight groups are introduced and explained below, while examples of concrete treatments are provided in Appendix 1. The results are organised following the SWOT terminology and are based on expert consultation and some literature.

3.2.1 Chemical modification (TRL 8-10)

Chemical modification of wood is described as a reaction between wood cell wall components (cellulose, hemicellulose and lignin) and a covalently bonding chemical reagent, resulting in the formation of a stable chemical bond. This modification of the cell walls protects the wood against water, decay, and thermal degradations. This can be achieved with a few chemical reagents, such as acetic anhydride, carboxylic acids, isocyanates or even biopolymers (furan) made from agricultural waste.

Strengths

Chemically modified wood has a rather long lifespan expectation (around 20-50 years), it has good functionality for a wide variety of damages to the wood, and it is currently available in the market. There is a low risk of leaching in the application.

[12] Arcadis, edited from: Wood Preservative Use Categories (preservedwood.org)

[13] VHN - Doe meer met hout... :: Wat is verduurzaming van hout

Weaknesses
Even though it is a more and more used method for wood protection, it is relatively expensive to produce. It might also be sensitive to fire; the wood can show signs of discoloration. Besides, only a few wood species are suitable for most chemical modification processes.

Opportunities
The market for chemical modification is growing because of a growing demand for wood products with a low toxicity.

Threats
The production of chemical modification methods is technically complex and can only be done in a few places in the Netherlands. The (lack of) knowledge of consumers might pose a threat for the use of chemically modified woods by consumers, as misuse could lead to health or environmental problems.

3.2.2 Physical treatment (thermal modification) (TRL 8-10)

Physical treatment relies on the principle to reduce the influence of water/moisture in wood by reducing the attractiveness of wood for water. The most common version of physical treatment is thermal modification.
This technique uses heat, usually at temperatures between 160 °C and 240 °C. As a result, the molecular structure of the wood is degraded, and especially the number of hydroxyl groups in the wood will substantially decrease. Other ways of physical treatment might be water repellent treatments (hydrophobation), for example with (natural) oils or other bulking treatments. These treatments are discussed in 3.2.4.

Strengths
Thermal modification causes the wood to absorb less water, improves dimension stability and makes the wood less susceptible to microorganisms. It has a lifespan of around 15 to 25 years when not in ground contact. The production process is simpler than that of chemical modification, which makes it cheaper as well.

Weaknesses
Toxic residue from the production process can occur, and the production process requires a lot of energy for heating. Thermally modified wood becomes brittle, so it is not suitable for construction purposes. It has a distinct scent and the modified wood is more susceptible to some wood defects like checks and broken knots (in case of softwoods).

Opportunities
It is rather well available on the market. It might be applied on both softwoods and (tropical) hardwoods. It is the most sold type of modified wood and the toxicity in the product itself is very low.

Threats
The market for thermal modification has a high level of competition, which makes it less attractive to new entries. There is rivalry among existing firms. Technical knowledge is needed to apply the wood correctly. Bad wood qualities will result in bad products after modification, however thermal modification is sometimes considered as a treatment that turns B and C grades into an A grade.

3.2.3 Chemical impregnation (TRL 9-10)

The impregnation of wood with chemicals is typically done with vacuum pressure in an autoclave. Usually synthetic biocides, such as copper based substances or Iodopropynyl butylcarbamate (IPBC) are used for chemical impregnation.

Strengths
The lifespan of chemically impregnated wood varies from 10 to 30 years or more, depending on the environment (moisture, temperatures and the microorganisms) and the application of the wood. The substances and processes are relatively well controllable, the production process is relatively cheap, and application requires only a small amount of active substance in most cases.

Weaknesses
There is a risk of leaching when chemically impregnated wood is used in ground contact and water contact applications. Also, during the end of service life there is still a risk of leaching, and reuse in a circular economy is hindered by the impregnated chemicals. Wood waste treated with toxic biocides has to be incinerated in special plants.

Opportunities
Chemically impregnated products with the highest toxicity have already been taken out of the market. If the production process and application is done following the right procedures, there is a low risk of toxic effects on the environment. A beneficial aspect of chemical impregnation is that it is possible to make a very specific, dedicated substance for one purpose. The market has little competition, there are different parties that are able to impregnate wood and demand could rise if climate change causes more degradation by insects or micro-organisms.

Threats
Chemical impregnation has a partly negative image due to the toxicity. It seems likely that fungicides are not sufficiently effective to function as pesticides. If there are no better alternatives, chemical impregnation will be used as an effective treatment for biobased materials.

3.2.4 Impregnation with natural substances (TRL 2-9)

Impregnation with natural substances relies on the same principles as chemical impregnation. The difference is that the chemicals used for this method originate from natural sources. However, this does not necessarily mean that they are not harmful to human health or the environment. Impregnation with natural substances can be done with for example linseed oil, several polyphenols, and flavonoids.

Strengths
The production process can be simple, but depends on the substance used. There are naturally occurring toxic substances, which work as a natural biocide. Treatments with natural substances can be done in some cases with small amounts of substances, depending on the effectiveness.

Weaknesses
Not all techniques are ready to be marketed yet, so there might be little supply for some substances. Not all properties of biological substances are known yet, they might be expensive and might not always be available. The lifespan of wood products impregnated with natural substances can have more variation than in the case chemical impregnation.

Opportunities
The source of the substance can be an important factor for its sustainability and environmental profile.

Threats
Admission on the market as a wood protecting agent is difficult because of restrictive legislation and economical aspects, making the attractiveness of the market low. When there is a disparity between the perceived toxicity and the actual toxicity, users might end up in dangerous situations.

3.2.5 Biological control (TRL 3-4)

Biological control refers to the use of organisms or products of organisms to withhold harmful organisms from wood products. A competitive fungus such as Trichoderma can be used to deter decay fungi. Lactic acid bacteria are also used to outcompete other species. Pheromones can be used to lure away (predominantly male) insects.

Strengths
Biological control can be used against fungi and insects. Products for biological control are cheap and easy to produce, they are not toxic.

Weaknesses
Pheromones are mainly useful in forestry, when timber is drying. The lifespan of biological control products is unknown, it can be difficult to implement, and it is not effective for all kinds of degradation. Pheromones are still in an experimental phase and are not 100% effective.

Opportunities
It can be used for a very specific treatment of wood and climate change might cause more demand for these specific treatments.

Threats
It is unsure whether the environment is disturbed when a high concentration is used. The application requires specific, technical knowledge and there is a risk for the environment when pheromones are not used correctly.

3.2.6 Nanotechnology (TRL 3-4)

Nanotechnology is an established technique. For wood protection its functionality is similar to that of water repellent surface treatments. Nanomaterials have at least one primary dimension of less than 100 nanometers. Nanomaterials for wood protection could be nanometals (copper, silver) or photocatalytic nanoparticles which are mainly used in coatings.

Strengths
Nanotechnology could have a hydrophobic effect on the wood. It is often applicable on wood, and it is mostly a surface treatment, not an impregnation. The fact that it does not always work on the principle of toxicity has benefits.

Weaknesses
Higher amounts might be needed for an adequate effect and there are possible harmful side effects because of the small (nano) scale; however, this effect is yet not known. The use of nano products seems rather expensive. The application process could be harmful to humans, though not necessarily toxic. The product is not easily biodegradable.

Opportunities
Even though it is a relatively new technique, the market exists.

Threats
There are several nano products available in the timber sector, but few in the wood protection industry. It has a dubious image due to the scale of compounds used.

3.2.7 Genetic modification (TRL 2-3)

This technique could provide biocide-free durable wood in the future. Genetic modification is a technique that can alter DNA in living organisms in order to grow desired characteristics. This could mean to extract DNA from tree species that are naturally resistant to rot, and using it to modify other, less durable tree species. This method can be considered as wood protection before the tree is harvested. In the agricultural sector, this principle has been applied before.

Strengths
In theory, genetic modification has many possibilities for wood protection. Products can be made in a very specific way, tailor-made for the demand and without toxicity.

Weaknesses
The effects of genetic modification could be reversible, and many features are still unknown.

Opportunities
It could create long lasting, biocide free wood which, as an additional benefit, possibly could also sequester more carbon.

Threats
Genetic modification is a long-term investment, and a lot of research and development still needs to be done. Possibly, genetic modification could cause a disruption in the biological balance, and negative (side) effects are hard to predict. The attractiveness of the market is very low. Genetic modification is regulated and is not allowed unless it is certified. Preparing a positive business case is almost impossible because of the long growing time of trees.

3.2.8 Genetic selection (TRL 2-3)

Genetic selection has been used in plant breeding for a long time. By crossing two sub-species of a plant, a new sub-species can be created. The technique is used to combine beneficial characteristics of two different sub-species. For wood protection, this could mean crossing tree species with preferable wood properties with sub-species that do not have these properties. This method can also be considered as wood protection method.

Strengths
Genetic selection might result in wood that can achieve a longer lifespan. It might be possible to grow products specific for the demand.

Weaknesses
This method is barely applied in the wood industry because of the long time needed to grow trees.

Opportunities
Just like genetic modification, it could create long lasting, biocide free wood which possibly could also sequester more carbon.

Threats
The attractiveness of the market is very low. The long timescale in forestry makes it nearly impossible to create a positive business case. It could lead to less genetic variation in forests, causing them to be more susceptible to plagues.

3.3 Most promising alternatives

As seen in the SWOT analysis there are multiple low/less/non-toxic wood protection products on the market. Based on the TRL criterium, methods with a high TRL are more likely to achieve environmental and/or health benefits in the short term due to the lower risks in marketing and progress in technical development. Nevertheless, there are developments with a lower TRL, but they have a lot of potential if further developed. Therefore, the methods are grouped in methods already available on the market and methods with potential and the requirement of further development support.
In line with IPM, which states that the least harmful pest control methods should be used first, a list of most promising methods has been composed. From the results of the SWOT analysis and estimated TRL, the following alternatives are thought most likely to achieve environmental and/or health benefits as they are less toxic than the currently used wood preservation methods. The toxicity of these alternatives is not studied in detail since this does not fit within the scope of this research. It must be noted that even in the case of already available technologies, new developments, optimisation and up-scaling are still ongoing.

3.3.1 Currently available technologies

Physical treatment (thermal modification)
Heat treated lumber is frequently applied and sold by numerous companies. Its main purpose is to repel moisture in wood. This is achieved by heating the wood. The production costs have been low. It is not known yet what the effect of higher energy costs will have on this method.

Chemical wood modification
This wood protection method is already available and is generally known for its low negative environmental impact in the use phase. The chances of leaching are also low. It has the potential to be a good substitute for the current wood preservation methods because of its targeted application, long lifespan, and excellent preservative properties although the price might be a limiting factor.
Known alternatives are acetylation/esterification, furfurylation, resin modification, polymerisation, iodination and DMDHEU (dimethylol dihydroxy ethylene urea) modification.

3.3.2 Technologies under development

Biological control
Biological control could become a very good alternative to the current wood preservation methods. It is a relatively cheap alternative, although most of these products need authorisation as a biocide. Biological control has an adequate effect on a wide variety of applications mainly in the field of plant protection, where it is already widely used. However, this effect is often short lived, while it should be long lasting for wood protection. Further research should prove the effect on wood. The toxicity is relatively low; however, it could lead to a disruption of biodiversity when it is used, and ‘good’ insects are also repelled.
Known alternatives are pheromones, lactic acid bacteria, biocontrol with various biological agents, and *Trichoderma*.

Impregnation with natural substances
The development of impregnation with natural substances is still in an early stage for some compounds but could become a promising alternative in the future. Impregnation with natural substances could still have harmful effects. It can be highly targeted, small doses could be very effective and the natural substance could be biodegradable, preventing accumulation of the active substance in the natural environment.
A few examples of alternatives with low toxicity are wood and plant extractives, different natural oil, essential oils, wood vinegar, terpenes, tannins, flavonoids, cinnamic compounds, allyl isothiocyanate (AITC), caffeine, chitosan and propolis/bee glue. Commercially available wood products impregnated with natural substances are frequently based on natural oils. This is also the principle of the concept which is working with linseed oil and the fungus *Aureobasidium* as a pigment to protect the oil from degradation and therefore increasing the service life.

4 Stakeholders and legislation

4.1 Market overview

The market size for wood protection in the Netherlands has declined over time. In the past, shipbuilding, the need for railways and saline aquatic applications were large drivers for the wood protection market, but these applications have been substituted by other materials or even the IT industry. In the present day, a few examples of the market for protected wood products are wood for garden applications and the construction industry.

The suppliers of the wood protection market can be divided into producers of chemicals, application resellers, and smaller innovative wood treatment companies. They are represented by the trade association for wood preservation in the Netherlands. The overview of stakeholders below is by no means complete. This is a selection of companies and organisations in the Netherlands known by the research group, but there may be others that are missing from this list. The producers of chemicals are in most cases large companies, while wood preservatives are often a small niche market for them. These companies produce chemicals but also do research & development into new biocides. Chemicals from these organisations are used by companies selling their own wood preservatives (B2B). There are also numerous wood traders importing preserved wood from other European countries. They are not involved in the preservation process, but only act as resellers of preserved wood products.

Innovative wood protection methods more frequently originate from smaller and medium size enterprises. Among other products, these companies produce various protected wood products, such as a chemically modified wood products, wood with charred surfaces, linseed treated products, and copper treated timber. For an overview of Dutch companies, please be referred to the member list of the VHN.[14]
There are some trade- and knowledge organisations in the Netherlands related to wood and biobased products. Several Universities and other research institutes such as TNO, TU Delft and Wageningen University & Research used to be active in wood protection, but their interest has declined in the past years but would probably like to build up more knowledge due to the increasing application of wood. Universities of Applied Sciences such as van Hall Larenstein and Saxion maintain and try to create additional knowledge about wood.

Parties involved in regulations are the Ministry of Infrastructure and Water Management, the RIVM (National Institute for Health and the Environment) and the Ctgb (College voor de toelating gewasbeschermingsmiddelen en biociden; Board for the authorisation of plant protection products and biocides). Other ministries might also be (partly) involved in regulations.

Consumers of wood protection products or protected wood could be other companies (B2B) or private users (B2C). The wood protection market has been an unattractive one for a long time, according to Porter's Five Forces model. As previously stated, the market size has declined over time. There is also a fair amount of rivalry between competitors on the market, not in the least because of the threat of substitution with other materials. In the transition to a wood protection market with low/no toxicity methods, wood protection companies feel the threat of substation by innovative new alternatives as well.

4.2 Regulatory frameworks

The European and therefore the Dutch market for wood protection is foremost regulated by European law. The most important regulations are the Biocidal Products Regulation (BPR, Regulation (EU) 528/2012)[15] with its Annex I and the REACH regulation (EC 1907/2006). REACH stands for Registration, Evaluation, Authorisation and Restriction of Chemicals. It entered into force on the 1st of June 2007. It was adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry.

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[14] VHN - Doe meer met hout... :: VHN Ledenlijst
[15] BPR Legislation - ECHA (europa.eu)

It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. REACH applies to all chemical substances, not only those used in industrial settings (but exceptions exist)[16].

The BPR came into effect on the 1st of September 2013. Before the BPR, there was the Biocidal Products Directive 98/8/EC. This directive did not have a direct legal effect and was implemented through national laws, like the Dutch law “Wet gewasbeschermingsmiddelen en biociden (Wgb)”. The BPR is in effect in the entire European Union and its goal is to protect human health and the environment against harmful effects of biocides through a harmonised set of rules that apply to all member states. It states that it is only allowed to own, apply or sell products with a biocidal function or claim if the product has been authorised on the Dutch or European market.

The European Chemicals Agency (short: ECHA) registers all active substances, biocidal products and suppliers. The agency also harbors all information about the BPR. Biocidal products must be registered with ECHA. However, the agency does not provide the assessment for authorisation itself. Assessment of new biocidal products and reevaluation of biocides already available in member states is carried out by the Competent Authorities of EU member states.

The Ctgb[17] is the Dutch Competent Authority for the authorisation of biocides. The organisation evaluates active substances and biocidal products. Applicants have to deliver their own data for risk assessment before the start of the assessment procedure. Only biocidal product of which the active substance it is based on is approved can be evaluated for admission on the market. The assessment is done for four categories: human health (toxicology), environmental safety (ecotoxicity), efficacy, and physical-chemical properties. For the assessment, the BPR defined 22 product types (PT) which are divided into 4 main categories (Disinfectants, Preservatives, Pesticides, Other biocides). For wood protection, PT8 (wood preservatives) is the dedicated product type.

Whether or not a biocidal product can be authorised depends on more factors than just toxicity. The products also have to have a clearly defined use for which their efficacy is demonstrated. When a biocidal product is authorised, it is admitted on the market for a period of 5, 10 or 15 years. After this period, it needs to be reassessed according to the regulations which then apply. Admission in other EU countries is also possible. Biocidal products that do not meet the requirements for authorisation but can be used without risk or are vital for society are given the label “Exclusion substance“. These active substances are not allowed in principle, but can be used under strict conditions when there is no other alternative available. Another, slightly milder category is “Candidates for substitution”.

These are active substances that are given permission for a shorter period (or no approval). In the approval process, research is done on whether there are other, less harmful alternatives with the same functionality. There is also a simplified authorisation procedure for products with active substances which have been registered in Annex I of the BPR[18]. These are substances which are deemed relatively safe (lesser risk) for use (such as linseed oil or lactic acid). The simplified authorisation procedure takes less time than the regular authorisation procedure.

[16] Understanding REACH - ECHA (europa.eu)

[17] Home | College voor de toelating van gewasbeschermingsmiddelen en biociden (ctgb.nl)

[18] Wijziging bijlage I - ECHA (europa.eu)

5 Identified barriers and opportunities

5.1 Key issues

From the answers given by the interview participants, representing several stakeholders in different fields of wood protection, four important topics were identified to be relevant for hindering and stimulating innovation in the wood protection industry. The aim was not to interview as many stakeholders as possible, but to get a qualified overview of different segments within the wood protection industry. The four identified topics are:

1. Regulations
2. Knowledge development
3. Business case
4. Technical feasibility

These topics have been discussed in the hackathon, where possible solutions were developed. The outcome of the discussions with the participants has been set out below. The key issues mentioned during the interviews and the hackathon are also listed here.

5.1.1 Regulations

Stakeholders experience the regulations for chemicals and wood preservatives as a large barrier for innovation. More precisely, the procedures for authorisation of new products and the renewal of the authorisation of existing products are carried out by the Ctgb, which experiences a lot of pressure because of a large quantity of requests for product authorisation and for (re-)evaluation of substances. The organisation currently cannot cope with the amount of work that needs to be done, which is the reason for delays in evaluation- and authorisation procedures.

The current time frame for an approval of an active substance is long. Approval for a substance plus the product authorisation based on a new, not-Annex I substance is around 6 to 8 years. In extraordinary cases, the total processing time could be 12 to 14 years. According to several stakeholders, including Ctgb, these procedures are costly (around €200.000 to €400.000 euros + several millions for toxicity data and other studies). Although all data for the risk assessment should be delivered before the start of the procedure, there is no absolute guarantee for the active substance to be approved or the biocidal product to be authorised. For small companies it is almost impossible to pay the application fees and wait for the results of the procedure and as a result, they would rather bypass the Ctgb altogether.

The goal of these rules and regulations is to guarantee the efficacy of the biocidal product and the protection of human health and environment. Wood preservatives are available to consumers as well. If these are used according to the instructions, they are deemed safe; but misuse cannot be prevented, potentially causing harm to human health and the environment. This could be solved by only letting certified professionals work with wood preservatives, in a protected environment.

Another opportunity to make the procedures faster is to divide the amount of work among member states more equally with the help of ECHA and the European Commission. The Netherlands, as a country with a relatively small logging industry and wood protection industry, still gets a fair number of applications for wood preservatives, while countries like Germany and Scandinavian countries might be able to better assess these applications. Currently Ctgb has a waiting list for dossiers because of time constraints and their workload, but they cannot refuse Annex 1 applications and requests under transitional law. The Ctgb could also help applicants by organizing more face-to-face communication during the authorisation procedure.

5.1.2 Knowledge development

Scientific knowledge about wood protection is disappearing from the Netherlands, and the organisation of this knowledge is scattered. Universities and large research organisations like TNO have mostly stopped investing in research and there are no educational programs for wood in the Netherlands. As a result, there are no new innovations, and it is increasingly difficult to find skilled construction workers who know how to work with wood. The knowledge hub for wood protection is in countries where there is a large logging industry like in Germany, Austria, Slovenia and in Scandinavia, where there still are professors and studies for wood sciences.

Preservation of knowledge is a relevant topic if the Netherlands wants to play a role in the acceleration of biobased building. A lack of sufficient knowledge and skills for timber constructions could lead to faulty design or inadequate applications, which in turn could lead to early degradation of wood in constructions, with large costs and risks for society. This could be avoided by improved knowledge. Furthermore, the possibilities to avoid biocides can be improved by following certain rules and guidelines which help to protect the wood without chemical treatments.

A potential solution is the introduction of the concept of integral wood protection which brings together the existing regulations as well as the technical demands to protect wood from degradation with a minimum of substances with a negative impact on the environment (see also chapter 6.3). This is in line with the thought of IPM. To improve the knowledge base, which in the end can substantially contribute to the reduction of biocides, a knowledge center (larger than the existing Centrum Hout) for biobased building or a chair in wood construction/protection/applications could be established. Wood protection can be taken along with the more modern, and popular sciences, for example Biobased Sciences and Life Sciences. This could shift the supposedly bad and boring perception of wood preservation to that of new innovative technologies. A broad collaboration between the Dutch MBO, HBO and universities could be stimulated and coordinated by the government or the industry to accelerate passing down the knowledge.

The next important thing is to develop knowledge. As suggested in the previous paragraph, a chair group and professor for biobased building could improve knowledge development for wood protection. There is also a need for better alignment between education and market. This could be done by organising better communication between small and medium sized businesses, and universities and other educational institutes. For example, educational curriculums could be based on what the market needs. Furthermore, creative spaces such as a makerspace or a field lab experiment could boost innovations in wood protection. Lastly, structure and financing are important issues. With more collaboration between stakeholders, there is a stronger lobby for more governmental intervention for a level playing field to compete with traditional building materials like steel and concrete.

5.1.3 Business case

The market for wood protection products is relatively small in the Netherlands and marketing new products is difficult and costly. Entrepreneurship in the wood protection industry is seen as challenging by the interviewees.
Strict regulations, high costs of market admission and a too little added value are the main reasons for this. In the past decades after World War II, large markets like shipbuilding, railroads and mining have disappeared. This is also due to the fact that wood preservation has obtained a bad image because of the toxicity of the active substances. Currently, protected wood is mostly sold for garden applications and construction. The market demand for protected wood suitable for construction is expected to increase due to the trend of biobased building, for example (prefab) timber construction. Not only for wooden frame structures (CLT), but also for facades and indoor applications. As regulations become stricter, there are less biocides that meet the criteria on the market. With the existing regulations it is evident that the variety of available wood preservatives will decrease in the coming decades, but this is not necessarily unfavourable for biobased building.

With the existing regulations most innovations come from small and medium size businesses, because large corporations do not want to risk losses due to large investments if their products are not authorised. Therefore, the small and medium sized businesses are the ones that could benefit most from government intervention. These interventions could be Kickstarter subsidies or warranty funds, support in financing patent applications in the starting phase or subsidies for certificates and a Life Cycle Analysis. One example of a financial incentive already in place is the WBSO of the Dutch RVO (Netherlands Enterprise Agency). The government could also stimulate businesses by using their innovative products more often, for example by asking for protected wood with less toxicity in bids for projects, by organising change events or a Small Business Innovation Research.

Recycling of copper treated wood was also suggested as an opportunity to develop a business case in a circular economy for the wood protection industry. Copper can be extracted from the protected wood products and used again in the same or another application. However, this business case is not deemed feasible yet, because recycling companies do not focus on extracting substances from the bulk waste. This could also be stimulated by government intervention. Circular business cases could receive benefits if their circularity is proven to be beneficial to society and resources can be safe[19]. Often there are large costs associated with the processing of treated wood.

[19] Hout | Recycling Nederland

5.1.4 Technical feasibility

Not all wood protection methods are fit for all purposes or environmental conditions, and some work better than others. Needless to say, interior wood which is kept dry needs no protection against fungi. Wood used in seawater is exposed to strong degradation factors and requires adequate treatments. Although a lot of research had taken place in the last 100 years, the technical possibilities for new wood protection methods have not all been explored yet. This is a challenge lying ahead, as the answers are still unknown. However, there are promising alternatives for wood preservation as discussed in Chapter 3. In Table 3, several of these alternative solutions for traditional wood preservation have been assessed for their suitability in the main Use Classes (for Use Classes, see Table 2).

Use class	Chemical modification	Thermal modification	Copper + add. Treatment	Bio-finish	Copper treatment	Competitive fungi	Plant extract & oils	Genetic Selection	Glue containing plywood	Watering wood	Water repellent treated wood (surface treatments)
1	✓	✓	✓	?	✓	X	?	✓?	✓?	✓	✓?
2	✓	✓	✓	?	✓	X	?	✓?	✓?	✓	✓?
3	✓	✓	✓?	✓	✓	X	?	?	?	✓?	✓
4	✓	X	✓?	X?	✓	✓	?	?	?	?	✓?
5	X	X	X?	X	X	X	?	?	?	?	X

Table 3 – Suitability of protected wood per use class. ✓= suitable; X = not suitable; ? = unknown; ✓? = probably suitable; X? = probably not suitable

As seen in table 3, there are good alternatives for Use Classes 1, 2 and 3 and to a lesser extent Use Class 4. Accoya and copper treatment, which have been on the market for longer and have proved their efficacy, seem to have the broadest field of application. Also, thermal modification is a good alternative as long as it is not used in constructions. The efficacy of plant extracts & oils are still unknown, and more research is necessary to determine this. As a result of the severe conditions of marine applications (UC5), only toxic preservatives (like CCA) have been used, which are not easily replaced by low or not toxic alternatives. The use of some certified tropical hardwoods is used as an adequate alternative.

5.2 Synthesis

Naturally, all topics that have been discussed in the previous sub chapter are related and influence each other.
The entire wood protection industry is driven by the external need for protection of wood. As shown in figure 9, two factors limit the wood protection industry: Shrinking demand and strict regulations/costly authorisation procedures. In turn, these factors have created a drive to create wood protection methods that do not fall under the strict regulations and the movement for sustainable building has helped reinforce this need for innovation. Overall, the market for traditional wood preservation is shrinking and the variety of biocides is decreasing too.
The shrinking market and the bad image towards the sometimes-toxic effects of wood protection is one cause of the decline in attention from knowledge institutions. Wood protection knowledge is disappearing, there are few/no new students learning about it and there is little knowledge about building with wood in the workforce. This in turn is affecting innovation, as no new knowledge is created, and no less harmful wood protection methods are invented.

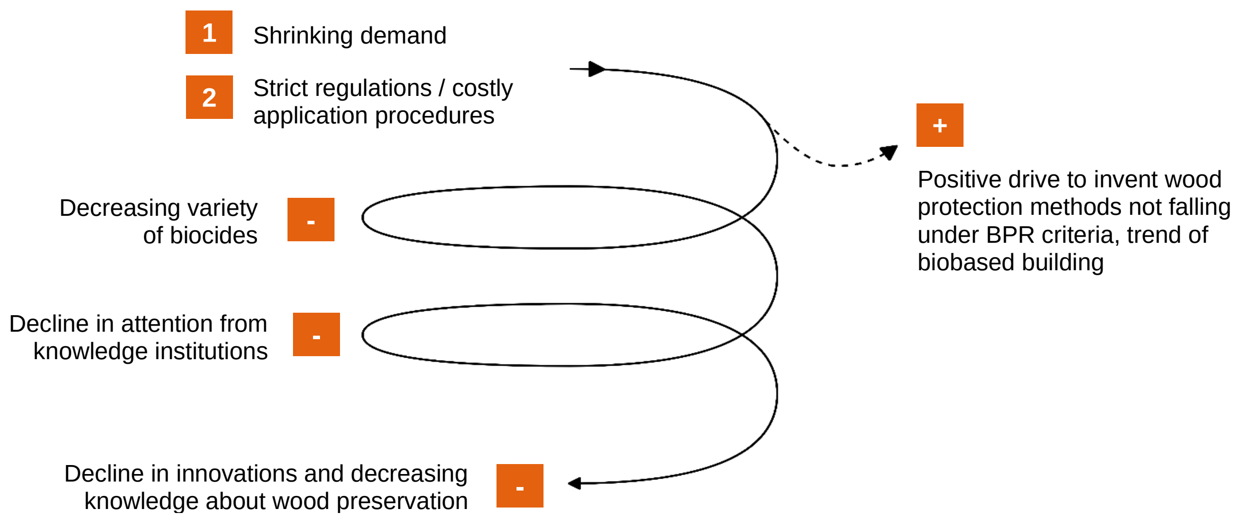

Figure 6 - Limiting factors

When the market is assessed with Porter's Five Forces model, the wood protection industry is perceived as an unattractive market. The threat of new entrants is low, because there is heavy governmental regulation and a shrinking market. Buyers have a moderate to large bargaining power because they can choose between different products. Consumers choose for functionality (*how long will this product last?*), not for substances (*what is this product made of?*) even though that is what sets companies apart (Unique Selling Point) in the wood protection industry. However, it is not unthinkable that consumers might boycott toxic products if the general awareness about sustainability and toxicity increases. This also relates to the threat of substitution. The construction industry is very sensitive to prices, and there are other alternatives for protected wood, like bricks, steel and concrete. There is a lot of rivalry between competitors. Patents are protected within the company and secrecy is deemed important for business processes. Besides, the industry growth is negative, which means that companies have to fight for profits and for their share in the market.

Looking back at the transition theory discussed in chapter 2.1, some conclusions can be made. In the market for wood protection, change is driven by legislation, which is in turn driven by environmental and human health concerns. This is the urgency of the problem and for individual companies, there is external pressure to change. The transition in the wood protection industry has started, but it is still in the pre-development phase, because wood protection without toxicity is not yet accepted as the new norm. At micro level, the transition has taken off. Many companies have started to create more environmentally friendly alternatives for wood preservation, although this is still at niche level. Wood protection companies could use marketing to stimulate the sustainable image of their low/no toxicity products. To prove their claims, they can use Life Cycle Analysis (LCA). As the change in the wood protection industry is still ongoing, it is hard to predict which transition pathway it might follow. In its current state, the change could be best described by the Transformation pathway. In the coming years it can be expected that these alternatives will enter the take-off phase and will disrupt the current socio-technological regime. It is perceived that not one new technology will monopolise, but a combination of new technologies could break through. This could of course be stimulated by governmental intervention which will be discussed in Chapter 6.

5.3 Discussion

This research is a combination of an inventory of facts and the valorisation of knowledge with interviews. The literature and patent research which has been used to create Appendix 1 and has been used as the basis of the SWOT analysis, which has been used to assess the suitability of each group of wood protection methods, together with our experts' opinion. Therefore, it can be concluded that this part of the research is robust.

The interviews were used to assess the market. The robustness of the interview results is defined by how many times a certain topic has been discussed by the interview participants. When something has been mentioned many times it can be seen as robust, and thus true for the whole industry. When something has been mentioned once, it may be a personal sentiment or opinion of the interview participant.

With this method, it was discovered that the perceived problems around the authorisation process are felt by all interview participants, including the Ctgb itself. This includes the complexity, the unpredictability, the costs and the duration of the authorisation process which is why some suppliers tend to avoid the authorisation procedure. It is not said that this is caused by the Ctgb. A lot of the issues related to the authorisation process are caused by the demands from the BPR legislation.

However, some topics that were mentioned less often are the prediction of a reduced variety of wood preservatives, and the probability of more insect species migrating north. These two claims are considered plausible. Stricter regulations will cause less variety in biocides, this is a cause-and-effect relationship. Climate change can cause northward migration of insects, as a warmer climate in the Netherlands can become a new habitat for species like termites. It is unknown how long or how much global warming it takes for these insects to migrate to the Netherland. It might happen in 50 years already[20].

Also, the coupling of this research with the theoretical framework is not a perfect match in all cases. The Transition Theory relies on systems thinking, and therefore it can be used to view the whole industry on its way towards a sustainable future, but it cannot assess the individual, different methods for wood protection. Also, Porter's 5 Forces model is used to assess the relationship between stakeholders and customers, but not between methods. To fill in this gap, the theory of Integrated Pest Management has been used. This theory is applied to the different methods for wood protection and to the principle of Integral Wood Protection which will be introduced in Chapter 6.3, but not to the stakeholders and the market. The different theories used cover different parts of the research report.

[20] Invasive termites in a changing climate: A global perspective - Buczkowski - 2017 - Ecology and Evolution - Wiley Online Library

6 Strategies for stimulating innovation

6.1 Introduction

In this chapter the different actions and opportunities that market parties and policy makers could take are described. In the theoretical framework, the Transition Theory was described. This theory is very much applicable for removing obstacles and seizing opportunities in changing towards a low toxic way of wood protection (including preservation) as it applies systems thinking to make sense of the developments in the wood protection industry.
In our society, we wish to live in a risk-free and clean environment. This creates a dilemma as toxic products are needed to protect wood and protect it from insects and other biological threats. In short, there is a tension between the functionality of quality wood and the negative effects of the means and measures to protect the wood.

6.2 Main Questions

There are several main questions that can be asked to move forward in this dilemma:

What are the main trends in the market?

Wooden constructions sequester carbon and thereby help mitigate climate change, one of the greatest threats the world is facing today. Climate change supports the need to reduce CO_2-emissions by building in a more circular way, for example by using wood. The longer the service life of a wooden product, the longer CO_2 is fixed in buildings, therefore wood protection can contribute to sequestration of CO_2. Due to climate change, biological threats can arise in places that were not a problem before (insects or micro-organisms that were not present at first are now migrating to other parts of Europe), causing the need for more wood protection in buildings or other wooden structures.

Another big trend is the cooperation for legislation by member states in the European Union. On the one side it creates a setting in which current criteria are expanded, and the legislation becomes a moving target. This trend also creates extra workload for authorities in The Netherlands like Ctgb as they can process requests from other EU countries as well.

A third trend is the need to reduce toxic pressure on people and the environment. The awareness about the effect of toxicity on human health and the environment is increasing as the environment is polluted. Health risks could increase because of this. This is a global problem.

What are the problems that arise and the barriers that block innovation?

The barriers for innovation and transition to a low/no toxicity wood protection industry have been identified and clustered in 4 different topics: technical feasibility, business case, legislation, and knowledge development. On the technical side there are limits of what is technically feasible at the moment to reduce the toxic level of active substances and still has a sufficient protecting effect on wood. For the business case, R&D costs exceed the financial capacity of the smaller companies in the market. On the executive side, there is a capacity issue at Ctgb.

This results in long processing times to authorise new (biocidal) products, which in turn has a negative impact on the business case for companies to come up with new innovations. Lastly, there is little knowledge preservation and building in traditional knowledge institutes, which creates problems for timber construction, and creates a dependency on a short number of skilled people. This could lead to mistakes that could have been prevented if there had been more knowledge.

What can be done by market parties and policy makers?

Market parties and policy makers can stimulate the transition to a more sustainable wood protection industry by focusing on knowledge development, stimulating cooperation between stakeholders and focus on reorganising the legislation procedure. These interventions can help to take the niche market of wood protection with low/no toxicity to a broader market. A few suggestions are presented below.

6.2.1 Knowledge development

Circular building with biobased materials is a trend that will create more demand for protected wood products. One way to stimulate the market is to create collaborations between commercial parties, universities, and governmental institutions. Knowledge development could be stimulated by creating knowledge networks or Incubators / technology hubs. These could be located at traditional knowledge institutes like universities, if they have an innovative character.

6.2.2 Collaboration of stakeholders

If collaboration between government institutes like Ctgb and the commercial market could be organised, it would decrease the barriers for new innovations. Policy makers could stimulate the collaboration between parties for example by:

- Organising change labs / events.
- Challenging the market with a Small Business Innovation Research (request for innovations).
- More face-to-face communication during the authorisation procedure to manage expectations.

This could facilitate a breakthrough in the transition process, leading to the widespread adoption of sustainable wood protection technologies.

6.2.3 Reorganise the legislation procedure

One approach to mitigate lengthy authorisation procedures is to share the workload within the EU. A more integral European approach could lead to a better division of workload between European Competent Authorities. At the moment, the Dutch Ctgb is taking up more than its fair share of wood protection dossiers. ECHA and the European Commission play a role in this, as the application for the authorisation procedure starts at the European level. Other countries could take on the Dutch approach of a tariff-based, independent administrative body that can decide how the formation is being expanded. This could cause a better balance between supply and demand of authorisation tasks.

6.3 A new concept - Integral Wood Protection

A supporting approach to avoid or reduce wood preservatives in the Dutch market is the concept of integral wood protection (IWP). This concept, which applies systems thinking, is a combination of European regulations, technical requirements considering wood specific requirements. To some extent, it is described in the German DIN 68800-1:2019 and is mandatory for architects and builders to a certain degree. Essential to this approach is the use of several measures on different parts in the whole chain from forest to application. We present levels, aspects and measures that might belong to the scope of IWP in the Dutch context. The concept does not exist yet in the Netherlands but seems to be a promising approach to reduce or even avoid the use of toxic wood preservatives.
An important part of wood protection starts before the application of wood protection products. If the way wood protection is seen can be changed, it can be approached in a different way. It highlights the importance of preventive wood protection, instead of corrective wood protection. The idea of IWP is to limit the use of toxic wood protection methods by 1) preventing the use of wood preservatives, 2) minimalising the need (thus the degree of) for wood preservatives and 3) if wood preservatives need to be used, use the least toxic preservatives.

To prevent the use of wood preservatives, IWP starts at the source: growing trees. The sustainability of the tree species is important for the application as a wood product, as well as the location of growing, substitution with new trees, availability, and eco-labels like FSC. Robust wood species such as Azobé (tropical hardwood) require little to no wood protection and non-durable species like Radiata Pine need a protection treatment. However, hardwood species grow slowly and therefore cannot generate the same amount of wood in a year as fast-growing, less durable species. Besides that, there is some discussion in Europe related to the extensive use of slow growing tropical wood species. This is the reason why, from a business and sustainability point of view, it is interesting to make fast-growing European tree species more durable.

Subsequently, the processing of wood that has been harvested from a forest is also influential for its durability. Drying the wood faster or slower can have impact on the end product and also the environmental impact of the process (use of machines, electricity, fuel) needs to be considered.

Furthermore, there is no need to use tropical hardwood for all applications only because it is a more durable species. In applications that are not or barely exposed to the weather (interior), the use of less durable wood is not a problem. Therefore, if wood preservatives are applied, there is no need to apply more than necessary for the intended use and lifespan.

Design also plays a role in the durability of wood. A well-designed construction will last longer and puts less strain on the wood. The construction needs to have the right amount of ventilation, and the wood must be protected from humidity. Also, maintenance and wear need to be considered. In a well-designed construction, the affected wood should be easily accessible for maintenance or replacement.

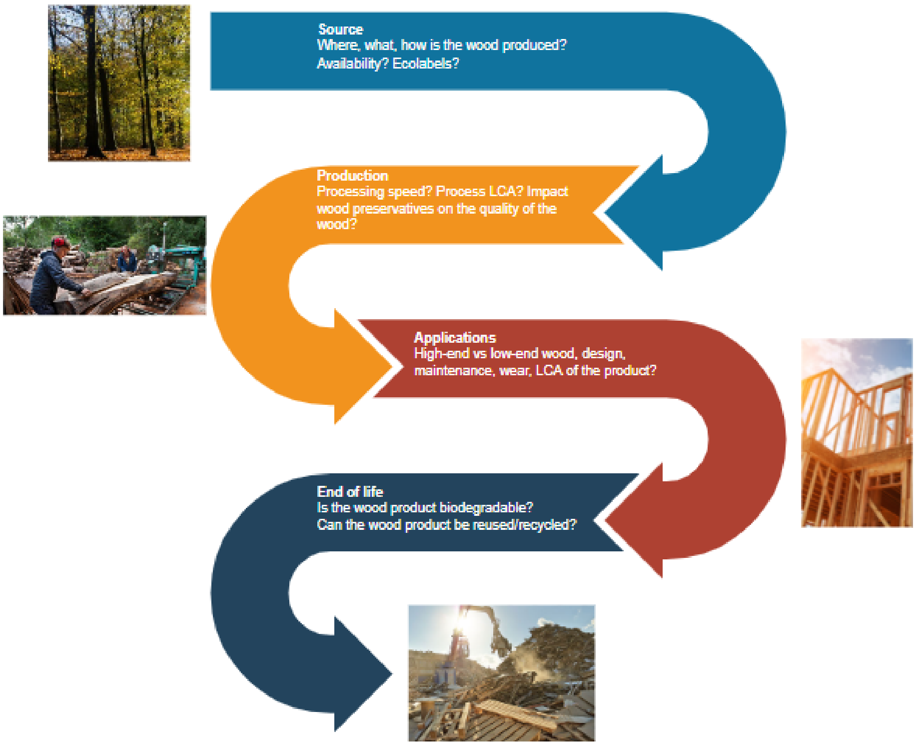

Figure 7 - Integral wood protection

Lastly, the end of service life of wood products is a critical factor in their durability too. The most desired process is the removal of wood preserving substances. However, there are many occasions where this is not possible anymore, and most wood is not ready to be reused in the Netherlands. Wood treated with preservatives is currently seen as chemical waste and therefore the wood must be incinerated. With this process, a lot of resources are lost, so attention should go to the recycling of wood preservatives. Furthermore, chemically treated wood is not allowed to be brought back in the biological cycle (non-biodegradable and toxicity). If wood is treated with biological protection and it is biodegradable under normal circumstances, this would be beneficial for its sustainability although it is difficult to create a working business case.

Appendix 1: List of methods/substances for wood protection

The list presented below is by no means trying to be complete. This list provides and overview of methods and/or substances which are known to work on wood or other organic fibers. Not all methods are commercially available, while others have been on the market for a long time and are considered to be forbidden due to their toxicity.

Cluster	Technology	Functionality	Links
Chemical modification	Resin modification	Thermosetting resin refers to a type of synthetic resin that is cross-linked and cured into insoluble and insoluble substances through a chemical reaction under the action of heat, pressure, or a curing agent. The thermosetting resin is a kind of high molecular weight polymer material, in which molecular chains are cross-linked together to form a rigid three-dimensional network structure. It has excellent characteristics such as high strength, good heat resistance, and good dimensional stability. In lignocellulose, free hydroxyl groups absorb moisture from the atmosphere, causing chemical reactions, forming covalent bonds, and causing wood deformation. This process is reversible. Modifying wood with thermosetting resin is one of the ways to reduce wood expansion and contraction and improve wood dimensional stability. Currently, there are three main types of thermosetting resins used for wood modification: urea–formaldehyde resin (UF), phenolic resin (PF), and melamine–formaldehyde resin (MF).	Link
	DMDHEU (dimethylol dihydroxy ethylene urea) modification	The cross-linking reagent DMDHEU (dimethyloldihydroxyethyleneurea) and its derivatives were used to chemically modify wood. The mode of action is based on DMDHEU cross-linking with the wood compounds and self-polymerisation within the cell wall. The modified material is a polymer composite with the appearance and texture of solid wood. The impregnation causes a permanent bulking of the cell wall and reduces the swelling and shrinkage properties, with the dimensional stability thus considerably increased. In addition, high durability against white, brown and soft rot fungi are obtained. The treatments also enhance the wood's surface hardness and weathering properties.	Link Link
	Polymerization	Here monomers are impregnated into wood or the substrate and (co)polymerisation is used as modification. Durability tests showed that 8% WPG was enough to ensure decay resistance against the tested fungi (improved up to durability class 2), and thus can be used to protect wood used in above ground applications.	Link Link Link
	Plastic treatment	Certain plastics can be used to modify wood. Polystyrene treatments can provide a protection from fungal attack.	Link
	Coniferyl alcohol impregnation	It is known that active peroxidase isozymes exist in mature wood of Norway spruce (Picea abies L. Karst.) and that they remain active for years and are found even in the heartwood (in Scots pine), where all cellular activity has ceased. This peroxidase activity was utilised in the impregnation of wood blocks with a natural monolignol, coniferyl alcohol and hydrogen peroxide. The coniferyl alcohol impregnation experiment resulted in the improved resistance of the wood blocks to fungal decay, while chlorinated anilines were covalently bound into the lignin polymer and they could not be released by mild acid hydrolysis.	Link
	Iodination	In order to assess the efficacy of the wood treatment, a leaching of the iodinated and polymerised wood and two biotests including bacteria, a yeast, blue stain fungi, and wood decay fungi were performed. After laccasecatalyzed oxidation of the phenols, the antimicrobial effect was significantly reduced. In contrast, the enzymatic oxidation	Link

Cluster	Technology	Functionality	Links
		of iodide (I) to iodine (I2) in the presence of wood led to an enhanced resistance of the wood surface against all microorganisms, even after exposure to leaching. The efficiency of the enzymatic wood iodination was comparable to that of a chemical wood preservative, VP 7/260a. The results suggest that the laccase-catalyzed iodination of the wood surface presents an efficient and eco-friendly method for wood protection.	
	Zirconium salts	Disclosed herein is an environmentally friendly wood protecting method against biological deterioration such as fungal, bacterial and insect damage and non- biological wood deterioration such as weathering. The method comprises contacting a wood material with an aqueous solution of a zirconium salts which is followed by a heat treatment step, providing durable protection of wood against biodegradation and improving several other properties of the treated wood. It has surprisingly been found that drying a wood material that has been treated with a water-based composition comprising one or more zirconium salts at high temperatures, will result in wood material with enhanced resistance to biodegradation whilst also exhibiting enhanced mechanical properties of the wood material.	Link
	Acetylation / Esterification	Acetylation is a reaction that introduces an acetyl functional group (acetoxy group, CH3CO) into an organic chemical compound—namely the substitution of the acetyl group for a hydrogen atom.	Link Link
	Furfurylation	Furfurylation is a modification technique that improves many wood properties. The wood is first impregnated with furfuryl alcohol (FA) diluted in a solvent, and afterward the impregnated wood is cured, during which time a FA derived polymer is formed within the wood cell wall and to some extent also within the cell lumina.	Link Link
	Nicotinoid fixation	Starting with an important class of synthetic insecticides which are derived from the natural insecticide nicotine, various new carboxylic acid derivatives of imidacloprid were made accessible. These activated neonicotinoids were utilised for the chemical modification of wood hydroxy groups. In contrast to conventional wood preservation methods in which biocides are only physically bound to the surface for a limited time, the covalent fixation of the preservative guarantees a permanent effect against wood pests, demonstrated in standardised biological tests. Additionally, the environmental interaction caused by non-bound neonicotinoids is significantly reduced, since both, a smaller application rate is required and leaching of the active ingredient is prevented. By minimising the pest infestation, the lifetime of the material increases while preserving the natural appearance of the material.	Link
Physical Treatment	Thermal modification	Heat treated lumber has altered biological and physical properties. The wood is more resistant against basidiomycetes and soft rot fungi and has a lower equilibrium moisture content and fibre saturation point.	Link Link Link
	Carbonisation treatment	Carbonisation is essentially a process for the production of a carbonaceous residue by thermal decomposition.	Link
	Hydrothermal Modification	Hydrothermal treatment refers to a thermochemical process for decomposing carbonaceous materials such as coal and biomass with water in a high temperature and high-pressure condition. This is a method that boosts the dimensional stability and improves the decay resistance of wood with minimal decrements of the strength properties. As an eco-friendly and cost-effective method, the hydrothermal modification of wood is also a promising alternative to conventional chemical techniques for treating wood.	Link

Cluster	Technology	Functionality	Links
	Thermo-Hygro-Mechanical treatment	THM is an eco-friendly method, which relies on the combination of temperature (T), moisture content (MC) and mechanical action. Thermo-hygro-mechanical (THM)-densified wood is more resistant to colonisation and degradation by brown-rot fungi than untreated wood	Link
	Oil heat treatment	Heat treatment in oil (e.g. linseed). The colour of heat-treated wood becomes more uniform and darker, and its dimensional stability (i.e., anti-swelling efficiency) and fungal resistance ae improved by up to 60% and 36%, respectively.	Link
	Pulsed electric field	Pulsed electric fields PEF is a non-thermal, nontoxic method of wood preservation that uses short pulses of electricity for microbial inactivation.	Link
	Impregnation techniques	Vacuum pressure impregnation with protective boron compounds can help again termites.	Link
	Saltwater	Saltwater treatment shows a significant increase of the air-dried density of palm wood samples which increases from 216 to 408 kg/m3 after the wood saltwater immersion. Basic and water saturated densities of Palm wood are also increased by saltwater treatment but way less important than for the air-dried density. This could be explained by the palm fibers densification occurred by the saltwater impregnation into the wood. It is concluded that treated palm wood has better decay resistance for fungi.	Link
Metals and salt-based protection	Cupric ion (in different salts)	Copper ions are often used for their antimicrobial properties. Often in the form of copper sulfates, also as copper nanoparticles.	Link Link
	Silver	Silver has antimicrobial properties, especially nanosilver is commonly research as a more sustainable antimicrobial treatment. It is more common as a nanoparticle.	Link Link
	Chromium / Arsenic	Wood preservatives containing chromated arsenicals include preservatives containing chromium, copper and arsenic. Since the 1940s, wood has been pressure treated with chromated arsenicals to protect wood from rotting due to insect and microbial agent attack and wood-boring marine invertebrates. From the 1970s to the early 2000s, the majority of the wood used in outdoor residential settings was chromated arsenical-treated wood. Effective December 31, 2003, chromated arsenical manufacturers voluntarily cancelled virtually all residential uses of CCA, and wood products treated with CCA are no longer used in most residential settings, including decks and children's playsets. EPA has classified chromated arsenicals as restricted use products, for use only by certified pesticide applicators. It can be used to produce commercial wood poles, posts, shakes, shingles, permanent foundation support beams, pilings, and other wood products permitted by approved labelling. Chromium and arsenic are part of preservatives such as CCB and CCA (together with copper and borate). These are often not environmentally friendly.	Link
	Organotin (IV) complexes	Organotin compounds have been known to possess biological activities and had been used as wood preservatives. Safety and environmental issues limit the use of tributyltin oxide (TBTO) and tributyltin naphthenate (TBTN) wood preservatives to aboveground and industrial applications only.	Link
	Boron based compounds/salts	This method includes boron, as well as boric acids and borates. Particular attention should be paid to leaching of boron species.	Link
	Acid & Peroxy treatment	Acids and peroxides are often used in preservative systems.	Link
Synthetic biocides	Azoles	Azoles are a class of five-membered heterocyclic compounds containing a nitrogen atom and at least one other non-carbon atom (i.e. nitrogen, sulfur, or oxygen) as part of the ring. Important are the conazoles here, which represent a large portion of preservatives used	Link Link

Cluster	Technology	Functionality	Links
		for wood protection. A lot of research is performed on how to make them less toxic.	
	Pyrethroids	A pyrethroid is an organic compound similar to the natural pyrethrins, which are produced by the flowers of pyrethrums. Pyrethroids are used as commercial and household insecticides.	Link
	Triclosan	Triclosan is an antibacterial and antifungal agent present in some consumer products, including toothpaste, soaps, detergents, toys, and surgical cleaning treatments. It is currently not used for wood preservation, but future research might open this possibility.	Link
	Quaternary ammonium salts	Quaternary ammonium salts, also referred to as quaternary ammonium compounds or “quats”, are salts of quaternary ammonium cations combined with a negatively charged anion. They are used as disinfectants, surfactants, fabric softeners, and as antistatic agents.	Link Link
	Carbamates	The carbamates are a group of insecticides that includes such compounds as carbamyl, methomyl, and carbofuran. They are rapidly detoxified and eliminated from animal tissues. Their toxicity is thought to arise from a mechanism somewhat similar to that for the organophosphates.	Link
	Biguanides	Biguanide is the organic compound with the formula $HN(C(NH)NH_2)_2$. It is a colorless solid that dissolves in water to give highly basic solution. These solutions slowly hydrolyse to ammonia and urea.	Link
	Dazomet	Dazomet is a common soil fumigant that acts as a herbicide, fungicide, slimicide, and nematicide.	Link
	Tolueen amides	This method works like DEET. Used as insecticides, especially against biting insects. It is currently not used on wood.	Link
	Amine oxides	This method exhibits low toxicity, high stability in water, low corrosivity to metal substrates (such as steel substrates), excellent penetration and uniform distribution into wood, low odour, waterproofing properties, and high leaching resistance. The wood preservative composition may be applied to the surface of a wood substrate or be applied by pressure treating the wood substrate with the wood preservative composition. Another embodiment is a method of controlling microorganisms, such as fungal decay organisms (generally known as white rot, brown rot, and soft rot fungi) and sapstain organisms, on and/or in a wood substrate, such as fresh cut lumber, comprising applying a biocidally effective amount of the composition of the present invention to the wood substrate.	Link
	Ionic liquids	Ionic liquids effectively protect wood against the action of mold fungi. Ammonium ionic liquids with a nitrite anion are characterised by strong fungitoxic properties, stronger than ammonium nitrates.	Link
	Creosote	Creosote is a category of carbonaceous chemicals formed by the distillation of various tars and pyrolysis of plant-derived material, such as wood or fossil fuel. They are typically used as preservatives or antiseptics. Some creosote types were used historically as a treatment for components of seagoing and outdoor wood structures to prevent rot. The legal status of creosote in the EU is currently unknown. It is preferred not to use this method due to its toxicity.	Link
	(Organo)silicons	Organosilicon compounds are organometallic compounds containing carbon–silicon bonds. Commercially available as OrganoWood.	Link Link
	Dyes	Dyes, both synthetic and organic can have biocidal properties. Especially from the textile industry. Not in the scope of this research.	Link Link
	α-aminoisobutyric acid	Non-toxic amino acid analogue “AIB” α-aminoisobutyric acid. Retardants of fungal spread in wood alpha-Aminoisobutyric acid (AIB) is a nonmetabolised amino acid analogue of alanine, which at low (muM) concentrations acts as a tracer for amino acid movements. At high concentrations (mM), it competitively inhibits membrane transport	Link

Cluster	Technology	Functionality	Links
		and metabolism of protein amino acids and acts as a systemic translocated inhibitor of mycelial extension in fungi. AIB can control mycelial spread of the basidiomycete Serpula lacrymans, the cause of brown rot of wood in buildings.	
Plant-based extracts	Wood extractives	The wood protection against biodeterioration is closely linked to the accumulation of extractives typically in the heartwood. They are often produced by the standing tree as defensive compounds to environmental stresses, conferring natural resistance. However, extractive content is highly variable not only from tree to tree but also within an individual tree.	Link Link Link Link Link
	Plant extract	As an alternative to synthetic preservatives, the use of plant-based, environmentally sustainable preservatives for wood protection has tremendous potential. Often, these are alcohol/ether-based extracts from plants (other tan woods).	Link Link Link
	Essential oils	An essential oil is a concentrated hydrophobic liquid containing volatile (easily evaporated at normal temperatures) chemical compounds from plants. It can help against fungi and termites.	Link Link Link
	Wood vinegar	Wood vinegar is often referred to pyroligneus acid or wood acid. It is a liquid substance produced in precisely controlled pyrolysis of biomass.	Link
	Oil/wax emuslions	Linseed oil, tall oil and waxes are used to make wood water repellent.	Link
Plant extracted compounds	Terpenes	Terpenes are a class of natural products consisting of compounds with the formula $(C_5H_8)_n$. Comprising more than 30,000 compounds, these unsaturated hydrocarbons are produced predominantly by plants, particularly conifers. Terpenes are further classified by the number of carbons: monoterpenes (C_{10}), sesquiterpenes (C_{15}), diterpenes (C_{20}), etc.	Link Link
	Tannins	Tannins also have antimicrobial properties. They are also used for complexation.	Link Link
	Flavonoids	Flavonoids are a diverse group of phytonutrients (plant chemicals) found in almost all fruits and vegetables. Along with carotenoids, they are responsible for the vivid colours in fruits and vegetables. Flavoinoids show higher decay resistance to brown rot fungi, but lower resistance to mold fungi.	Link Link
	Cinnamic compounds	Cinnamic compounds like cinnamaldehyde, cinnamates, cinnamic acids. They can be found in spent coffee.	Link Link
	Allyl isothiocyanate (AITC	Allyl isothiocyanate (AITC), a mustard oil-based natural biocide, has been encapsulated into the cavity of b-cyclodextrin (bCD) and the as-prepared bCD-AITC complex was applied in the strand-based composite manufacturing process to produce a natural-preservative-treated engineered wood panel. This has shown to be an effective and environmentally friendly method is demonstrated to substantially improve the durability of a strand-based wood composite product by incorporating a natural wood preservative system. to produce a natural-preservative-treated engineered wood panel.	Link
	Azadirachtin	Azadirachtin, a chemical compound belonging to the limonoid group, is a secondary metabolite present in neem tree seeds.	Link
	Caffeine	Alkaloids like caffeine are well-known compounds of natural origin, economically suitable and commercial available, which could facilitate their future use for wood protection. Mold and decay resistance of wood treated caffeine is probably related to fact that caffeine has been shown to inhibit chitinases activity, which results in inhibition of fungal growth. Caffeine can also be used to improve the durability of wood, making it sequester more carbon.	Link
	Propolis & beeswax	The eco-friendly wood preservative propolis or bee glue is a resinous mixture that honeybees produce by mixing saliva and beeswax with	Link Link

Cluster	Technology	Functionality	Links
Other Natural biocidal ingredients		exudate gathered from tree buds, sap flows, or other botanical sources.	Link
	Chitosan	Chitosan is a linear polysaccharide composed of randomly distributed β-(1→4)-linked D-glucosamine (deacetylated unit) and N-acetyl-D-glucosamine (acetylated unit). It is made by treating the chitin shells of shrimp and other crustaceans with an alkaline substance, such as sodium hydroxide. Also used to aid fixating other biocides.	Link Link
	Antimicrobial peptides	The protection of natural fibrous materials can be achieved by applying many different chemical and natural biochemical components such as newly discovered antimicrobial peptides.	Link
Side-stream/waste-based biocides	Pyrolysis oil	Pyrolysis oil, sometimes also known as bio-crude or bio-oil, is a synthetic fuel under investigation as substitute for petroleum. It is obtained by heating dried biomass without oxygen in a reactor at a temperature of about 500 °C with subsequent cooling. Pyrolysis oil is a kind of tar and normally contains levels of oxygen too high to be considered a pure hydrocarbon.	Link Link Link
	Kraft black liquor	In industrial chemistry, black liquor is the by-product from the kraft process when digesting pulpwood into paper pulp removing lignin, hemicelluloses and other extractives from the wood to free the cellulose fibers. It can be used to improve durability of the wood against biological agents.	Link
	Soy-based formulations	Okara, soy pulp, or tofu dregs is a pulp consisting of insoluble parts of the soybean that remain after pureed soybeans are filtered in the production of soy milk and tofu. Used together with copper and boron biocides.	Link Link
	Glycerol esters	Glycerol esters are valuable by-products of agroindustry. They have a significant antimicrobial effect. They are commonly used in the food industry as antimicrobial agents. They could be used as well to protect bio-based materials from microbial colonisation. It would be an eco-friendly alternative, consistent with human health, to the classic ways of protecting bio-based materials against microorganisms.	Link
	Whey-Based Stain	Non-toxic stain is made from whey -- a byproduct of cheesemaking It protects wood from water, mildew, and UV damage. It is food-, people-, and pet-safe -- use on raised beds, decks, fencing and furniture.	Link
Biological control	Trichoderma (extract)	Trichoderma is a genus of fungi in the family Hypocreaceae that is present in all soils, where they are the most prevalent culturable fungi. They are one of the most commonly used biocontrol organisms.	Link Link
	Biocontrol	Biological wood protection by antagonistic microbes alone or in combination with (bio)chemicals, is one of the most promising ways for the environmentally sound wood protection. The most effective biocontrol antagonists belong to genera Trichoderma, Gliocladium, Bacillus, Pseudomonas and Streptomyces. They compete for an ecological niche by consuming available nutrients as well as by secreting a spectrum of biochemicals effective against various fungal pathogens. The biochemicals include cell wall-degrading enzymes, siderophores, chelating iron and a wide variety of volatile and non-volatile antibiotics.	Link
	Lactic acid bacteria	The efficacy of chilli juice and/or chilli (capsicum) extract oleoresins as antisapstain agents, paired with Lactobacillus casei was evaluated against two common wood-discolouring fungi, Sphaeropsis sapinea and Leptographium procerum. Both the chilli juice and the capsicum oleoresin showed moderate antifungal activity. No growth of the test fungi was observed on plates amended with 50% chilli juice after 3 weeks of incubation. The synergy between chilli and L. casei was	Link

Cluster	Technology	Functionality	Links
		apparent; the combination chilli/ L. casei treatment system afforded much better inhibition than chilli or L. casei alone.	
	Pheromones	Semiochemicals, or pheromones can be used as pesticides for some insects.	Link Link
Nanotechnology	Nanometals (Copper, Silver)	Metal nanoparticles such as copper, gold, and silver are widely used due to their good and stable impregnation effect.	Link Link Link
	Zinc nanoparticles	Zinc oxide and borate nanoparticles are often used because of their biocidal properties.	Link Link
	Photocatalytic nanoparticles	Photocatalytic activity is a commonly investigated function of semiconductor nanoparticles. One of the most studied forms of photocatalyst nanoparticles is titanium dioxide (TiO_2). TiO_2 nanoparticles have a broad spectrum of activity, including against both Gram-negative and Gram-positive bacteria. They are also applied in self-cleaning systems.	Link Link
	Boron nanoparticles	Nanoparticles containing a boron group or ion. It can be used against termites.	Link
	Nano-silica	Nano-silica can be added to wood to make it more stable and can aid in fixation of other biocides.	Link
	Polymeric nanocarriers	The polymer nanocarrier is a submicron carrier delivery system in the nanoscale and microscopic category, that is, nanoparticles are used as carriers to conduct or transport certain substances through physical encapsulation or chemical bond connection. At present, nanocarrier technology is widely used in the field of medicine. In the wood preservative industry, compared with nanometal impregnation and coating treatment, there are fewer related research literature studies on this technology but can be expected in the future.	Link
Impregnation mediums, enhancers and fixing agents* * These components are mainly used to improve the function of other biocides, in impregnation, fixation or other ways. They mostly do not have biocidal effects themselves.	Cyclodextrin complexation	Cyclodextrins are a family of cyclic oligosaccharides, consisting of a macrocyclic ring of glucose subunits joined by α-1,4 glycosidic bonds. Cyclodextrins are produced from starch by enzymatic conversion. They are used in food, pharmaceutical, drug delivery, and chemical industries, as well as agriculture and environmental engineering. Especially used for volatile, easily degraded compounds.	Link Link
	Tannin-based formulations	Tannins are natural preservative agents found in many plant tissues, but their low toxicity prevents their use as wood preservative on their own. However, they can fix biocides because of their excellent chelating properties. Co-impregnation in a two-step treatment of three biocides, copper, zinc and boron, with tannins is studied. Biocide leaching resistance and treated wood resistance to decay by rots and blue stains are determined. Good retention of copper (II) ions is achieved by first impregnating wood with a commercial chestnut tannin. The treated wood meets the European standard for protection against rots. No protection against blue-stains was obtained as boron retention was not achieved.	Link Link Link
	Emulsion gels	Commercial bio-based emulsion gels formulations containing insecticides and fungicides help to enhance penetration of the active agents. The suitable combinations of solvents and surfactants used in the bio-based formulations enabled rapid wood penetration and high yields retention.	Link
	(Vegetable) oil	Vegetable oils and tall oils can hydrophobise wood, and protect biocides, such as borons, from leaching in water.	Link Link
	Resins	Resins, such as rosin can be used to fix biocides.	Link
	Propyl gallate	Propyl gallate, or propyl 3,4,5-trihydroxybenzoate is an ester formed by the condensation of gallic acid and propanol. Since 1948, this antioxidant has been added to foods containing oils and fats to prevent oxidation. As a food additive, it is used under the E number E310.	Link

Cluster	Technology	Functionality	Links
	Polyvinyl alcohol (PVA)	Poly is a water-soluble synthetic polymer. It has the idealised formula $[CH_2CH]_n$. It is used in papermaking, textile warp sizing, as a thickener and emulsion stabiliser in PVAc adhesive formulations, in a variety of coatings, and 3D printing. It is colourless and odourless.	Link
	Fatty acid-based formulations	Fatty acids can be used to aid formulation. The most common is oleate.	Link Link
	Complexing agent	A method for protecting wood against decay and similar degradation reactions caused by wood decay fungi and similar microorganisms which cause wood decay, comprising treating wood with a wood preservative solution containing at least one complexing agent selected from the group consisting of cyclic sodium polyphosphates, linear sodium polyphosphates, aminocarboxylates, hydroxycarboxylates, organophosphates and siderophores, wherein said complexing agent binds at least a portion of those metals naturally occurring in wood which are essential to the growth of such microorganisms that cause wood decay	Link

Appendix 2: Stakeholder interview protocol

Interviews experts and producers

1. Products

a) What is/are your expertise/activities?
b) Which wood preservation methods do you use and for which application? How did the selection process for a wood preservative go?
c) Does environmental impact count in that choice?
d) What do you understand by toxic pressure from wood protection methods
e) Does your company have an active greening policy in the wood protection process? If so, what exactly does that mean? If not, why?
f) How do you contribute to reducing the toxic pressure of wood preservation products
g) What properties must wood preservation methods have in order to be considered environmentally friendly? What is the most important of these?

2. Barriers

a) What obstacles exist in the marketing of new, environmentally friendly alternatives for wood preservation? Think of:
   - financial
   - laws and regulations
   - technical
   - market
   - other
b) What is the biggest obstacle?
c) How could the Ministry of Infrastructure and Water Management help to remove obstacles?

3. Opportunities

a) What are the most important developments in the wood preservation market in your view?
b) What opportunities or incentives are there for the marketing of less toxic wood protection methods
c) Which opportunity or incentive has the highest priority?
d) How could the Ministry of Infrastructure and Water Management help to create and increase opportunities for less toxic wood protection methods?

Colophon

INNOVATIVE METHODS FOR WOOD PRESERVATION

CLIENT
Ministry of Infrastructure and Water Management

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