Research for the Benefit of SMEs	

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Table of Contents

Publishable Executive Summary I
1 Introduction 1
2 Objectives 1
3 Methodology 1
3.1 Questionnaire-based survey 2
3.2 In-depth consultations and on-site visits 3
3.3 Literature research 3
3.4 Study of socio-economic aspects 4
4 Results 4
4.1 What we learned from industry 4
4.1.1 What the questionnaires revealed 4
4.1.2 Socio-economic aspects 8
4.1.3 Feedback from the in-depth consultations and visits to industry 9
4.2 Overview of commercial pre-treatment equipment and coating systems for wood 13
4.2.1 Methods of treatment 14
4.3 Key findings from the literature 17
4.3.1 Literature review on wood destructible fungi 17
4.4 Literature review on plasma treatment for wood protection 21
4.4.1 Analysis of the State-of-the-art 22
4.5 The most relevant patents 30
4.5.1 Conclusion of patent search 35
5 DURAWOOD System Specifications Report 37
5.1 Definition of the wood sample analysis before and after the treatment 38
5.2 Definition of trials to be carried out at laboratory and at industrial scale 39
5.3 Individual component specifications 40
5.3.1 Cost sensitivity for a wood coating machine 40
5.3.2 DURAWOOD functional subsystems 41
5.4 Design and assembly of plasma source for trials at laboratory scale (power supply, electrodes, gas inlet system) 43
5.5 Design and assembly of a plasma source for industrial trials 45
5.5.1 Subsystem Specifications of the DURAWOOD prototype 46
5.6 Safety considerations for the operation the system in the wood industry 48

6 Overall conclusions 53
7 Literature 56
Annex I- Questionnaire for wood products manufacturer 61
Annex II- Questionnaire for plasma equipment manufacturers 66
Annex III- Cover letter for questionnaire survey 71
Annex III- On-site visits semi-structured questionnaire 72

Publishable Executive Summary

This report outlines the work carried out as part of an EC funded project called DURAWOOD - Development of a solvent - free coating process for wooden facades. A bottom-up approach was employed by consulting with industry stakeholders and research was carried out in order to obtain a clear understanding of the technological needs and specifications of European wood manufacturers *(furniture manufacturers, building wooden materials manufacturers, etc*) and other relevant stakeholders. The results of this consultation will be used to support the R&D effort and to ensure that the proposed specifications for the DURAWOOD system are in line with industry needs and expectations.

A questionnaire-based survey was carried out among wood manufacturers, pre-treatment equipment manufacturers from Europe and outside the EU, in order to achieve an understanding of their needs, existing equipment used, and their level of investment in new technologies, etc. In addition the questionnaire highlighted the socio-economic issues that would be important to take into account during the development work, as well as serving to identify likely dissemination activities and the potential uptake possibilities of the project.

Over 400 questionnaires were sent out. In parallel with this, a series of on-site visits and consultations were also conducted with selected companies related to the wood sector. A comprehensive literature review was also carried out, as well as a review of the most common coating systems to coat wooden products and a patent review of the novel technology to protect wooden materials against weathering and decay fungi.

A response rate of 10% was achieved from the survey mainly from European wood manufacturers, as well as, plasma equipment manufacturers and 7 on-site visits were conducted in order to supplement the feedback from the questionnaires and provide more quality feedback. Key findings reveal that the main limitation related to the use of water-borne coatings is its poor ability to protect the wood against fungi, which confirms the need for a system such as DURAWOOD to enhance the wood protection properties of water-borne coatings. From the responses achieved, it can be concluded that the DURAWOOD system, as it is initially defined in this project, will meet the basic requirements of wood manufacturers and will meet with a clear technical need in the sector. Most of the respondents claimed that they would invest in this novel technology if its cost would return dividends in terms of economic benefits. Moreover, from a series of on-site visits made to wood processing companies, the need to provide improved systems to maintain the characteristics of the wood was again manifested. In conclusion the results of the research confirm and clarify the interest of the wood industry in extending the durability of treated wooden materials.

The literature research reveals the possibility for the use of plasma technology to protect wooden materials against fungi and weathering, thereby improving the performance of the water-borne coatings. The patent review shows that a clear interest exists to improve the current technologies to coat and extend the durability of the wood exposed to outdoor conditions. The advantages and disadvantages of alternative technologies have been discussed, as well as the state-of-the-art of plasma dielectrical barrier discharge technology to improve the performance of water-borne coatings for wood. The future research in the framework of the DURAWOOD project will be based on and guided by

these results in order to ensure that the future system will be useful and relevant for its uptake in wood industry.

1 Introduction

The aim of the DURAWOOD project is to develop a new industrial process, based on the application of plasma DBD to improve the coating adhesion of wood and decrease the wettability of the surface in order to make it waterproof.

Work Package 1- *Stakeholder Targeting and Needs Definition*, aims to ensure a bottom-up approach and industry driven thrust to this research and development.

The initial objective is to gain a deeper understanding of the requirements and needs of European wood manufacturers in terms of currently used wood preservation methods, existing technology and management systems, usability and ergonomic requirements, price sensitivity for the different wood products, etc.

It is vital to establish an understanding of the existing knowledge and capability levels of operators, to analyse price sensitivity and the quality aspirations of end-users of pretreatment equipment, as well as to gain an understanding of the impact of existing and upcoming norms and legislation pertaining to wood coatings, and finally to identify the key socio-economic factors that could have an impact on the future use and uptake of the project results.

2 Objectives

Given the above mentioned objectives of WP 1 objectives stated above, analysis and conclusions will be drawn from the respective data and results. Amongst other details this report compiles and discusses the following information:

- Existing coating systems
- Limitations and short failings of existing technologies
- Price Sensitivity
- Existing and upcoming norms and legislation pertaining to the use of wood coatings
- Socio-economic aspects

3 Methodology

In order to achieve the objectives of this work package, a comprehensive methodology was followed. First of all, a questionnaire-based survey was implemented. In addition, consultation sessions or in-depth interviews and on-site visits were conducted with a selected group of industry stakeholders, wood manufacturing companies, as well as plasma equipment manufacturer, paint and varnish manufacturers. Furthermore, an extensive literature, patent and socio-economic review was carried out.

3.1 Questionnaire-based survey

The European-wide survey centred on carrying out a **questionnaire-based survey**. Questionnaires for wood and plasma equipment manufacturers were drawn up. The overall aims of the surveys were used as the starting point for discussions on how to prepare the questionnaire and what types of questions needed to be included. Following the project Kick Off meeting an initial draft of this questionnaire was circulated among the consortium so that all partners could contribute their suggestions, opinions and input into its design, and to eventually arrive at a consensus as to the final content of these questionnaires. Also data from European Wood Associations was taken into account.

During the design of the questionnaire it was agreed to keep it as concise as possible, and to avoid open-ended questions in as much as possible, as well as questions which proved cumbersome or time-consuming to complete. In order to facilitate the interpretation of results, questions, where possible, were kept closed ended. Opportunity to provide additional comments was also woven into the questionnaires in order to afford respondents with the opportunity to share their comments, suggestions and wider input with us.

Copies of the final questionnaires have been included in Annex I and II of this report.

In terms of the deployment of the questionnaires, it was decided that on-line versions would prove to be the most efficient means of distributing them and to this end a highly effective on-line surveying tool was employed called SURVEY MONKEY (www.surveymonkey.com).

Survey Monkey is a powerful and simple-to-use online survey tool, where surveys can be readily built and customised to meet with specific needs. By creating a professional account, results can then be collected and analysed using various criteria. This secure tool offers confidentiality of the results. The tool also enables professional users to generate reports directly on the website and makes them available for download in an easy-to-use format (.doc, .xls, .pdf), greatly facilitating the process of collecting responses as accurately and efficiently as possible.

Questionnaires in the English, Slovak and Spanish language were uploaded onto the SURVEY MONKEY tool and are readily accessible from the following links:

- **Questionnaires for wood product manufacturers (furniture manufacturers, manufacturers of wooden structures for buildings, wooden packaging materials manufacturers)**
  - www.surveymonkey.com/s/wood_products_manufacturers
    (English version)
  - www.surveymonkey.com/s/fabricantes_de_productos_de_madera
    (Spanish version).
  - www.surveymonkey.com/s/DURAWOOD_DotaznIk_spracovateov_dreva_SK
    (Slovak version).

- **Questionnaires for plasma equipment manufacturers**
  - www.surveymonkey.com/s/wood_products_manufacturers

In addition, links to the questionnaires were embedded in the **DURAWOOD Website,** which has been further promoted by links via the partner web-sites and initial press releases.

A concise and informative cover letter (Annex II) was then drawn up that would serve to briefly inform potential respondents about the DURAWOOD project and its envisaged benefits, to highlight the importance of their contributions and feedback as well as to provide them with a link to the questionnaires and the project website. This cover letter and link were sent to over 400 in Europe and globally.

It is important to mention that the results of the questionnaires are confidential and to this end no company names will be mentioned in this report.

3.2 In-depth consultations and on-site visits

In addition to the survey, the work to be carried out as part of this bottom-up research also includes the planning and realization of on-site visits with wood manufacturers, pre-treatment equipment manufacturers, paint and varnish manufacturers. This is important in order to become familiar with the industrial setting and needs of companies in the area wood coating systems. A semi-structured questionnaire or guide of questions was also prepared to assist in structuring the in-depth consultations with the wood furniture manufacturers in as much as possible in order to heighten the usability of the feedback (Annex III).

In total 7 on site visits were made to different sectors related to the wood and wood coatings industry. 4 of them were made to paint and varnish manufacturers, formwork manufacturers, manufacturers of wood elements for building and a plasma treatment equipment manufacturer in Spain. In total 3 on-site visits were made to a consulting company who deal with producers of lacquers and wood finishes. A visit was also made to a company that specialises in the restoration of antique furniture and old wooden buildings, as well as to a Slovakian manufacturer of outdoor wooden furniture.

These on-site visits involved an introduction to some information *(non-confidential)* about DURAWOOD so that the company could familiarise themselves with the project and its objectives. The results of these visits were evaluated in order to get a clear picture of the present technological situation of the wood industry, which will be discussed in detail in the section on the Results and Conclusions.

Again, it is important to note that the results of the on-site visits and interviews are confidential and to this end no company names will be referred to in this report.

3.3 Literature research

In order to complement the findings of the questionnaire based survey among industry as well as the in-depth consultations and on-site visits, an extensive literature research was also carried out. On the one hand, scientific papers on the application of plasma

treatment for wood coating and the effect of fungi on wood facades were reviewed. On the other hand, a thorough patent review was carried out, in order to obtain knowledge of any existing plasma pre-treatments for wood coating systems.

3.4 Study of socio-economic aspects

A comprehensive socio-economic analysis was carried out, the results of which will represent the platform upon which the dissemination, training and exploitation actions will be built. The aim was to identify key socio- economic factors that need to be taken into account, such as user friendliness, acceptance by the target industry, modularity, cost, etc. These factors will also influence on the most appropriate marketing approach. To this end, a series of socio-economic questions have been included in the survey questionnaires in order to carry out of an assessment of the expected socio-economic impact of the knowledge and technology generated, as well as analysis of the factors that would influence their exploitation (e.g. standardisation, ethical and regulatory aspects, etc.).

The results of the socio-economic study will enable the identification of barriers (both real and perceived), threats, opportunities and will help the consortium to roadmap required training and dissemination approaches and dissemination material content and argumentation.

4 Results

In this section we will outline the key findings that emerged from the questionnaire-based survey, the company visits and in-depth consultations, as well as the literature, patent and internet reviews. The most significant and relevant findings are presented and discussed.

First of all, we will discuss the feedback and key results received from the questionnaires, as well as the in-depth consultations and on-site visits. We will also highlight the socio-economic issues revealed. We will then provide an overview of the main equipment currently in use among the sector. We will finally report on the key findings from the literature and patent reviews.

4.1 What we learned from industry

4.1.1 What the questionnaires revealed

Questionnaire-based survey among wooden material manufacturers

The survey among wood manufacturers was answered by 40 companies from Spain (25% of responses) and Slovakia (20%), Malta (10 %), France (7.5%) and Belgium (5%). The remainder of the responses (30%) came from; Denmark, France, Finland, Ireland, Netherlands, Norway, Portugal, Romania, Slovenia, United Kingdom and the United States. The majority of companies that answered the survey were from European countries (see figure 1).

The bulk of respondents were from the SME sector whereby 80% of them have less than 50 employees and 12% have more than 250 employees.

These companies were drawn from various sectors of the wood industry: 32.5% are manufacturers of wooden structures for buildings: facades, doors, doorframes etc., 15% were furniture manufacturers and 5% were wooden packaging materials manufacturers, 11% were from other activities such as wood panels and furniture components. Finally, 6% of respondents were wood experts.

This wide range of SME respondents from diverse European countries, coupled with the data of their varied sizes and activity will facilitate the consortium in ascertaining the different points of view among the players in the wood industry. Armed with this wide reaching information, the consortium is in an advantageous position to make informed decisions based upon the data gathered when defining the specifications of the DURAWOOD project.

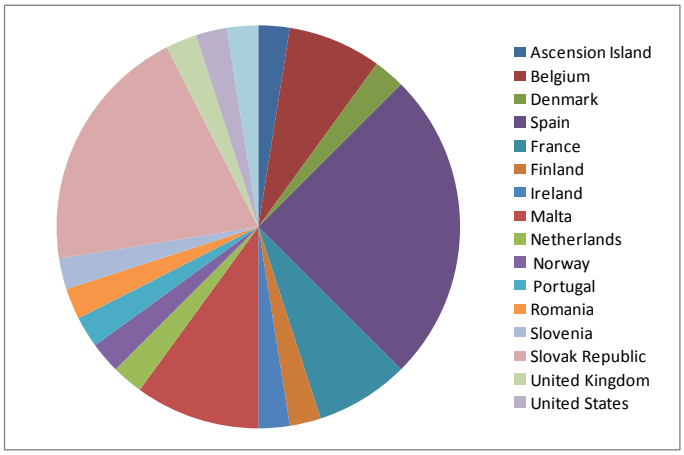


Figure 1. Country of origin of the respondents of the survey among wood manufacturer

The wood species most referred to by respondents was European Spruce (*Picea Abies*), with 58% of responses, followed by Scots Pine (46%), European Larch (42%), Sessile Oak (42%), European Ash or Common Ash (29%) and European Beech (25%). Furthermore, the respondents indicated use of other species of wood, such as tropical woods, Maple, American Oaks, Yellow Poplar, Ash, Merbau, Lodgepole pine, Douglas fir, chestnut and walnut. The species most selected by the respondents correlates well with the draft list of the species suggested by STUBA. To this end, the wood species that will be used to study the plasma treatment of wood will include the European Sprice and Sessile Oak and European Larch samples.

Figure 2 below shows the wood species selected by respondents:

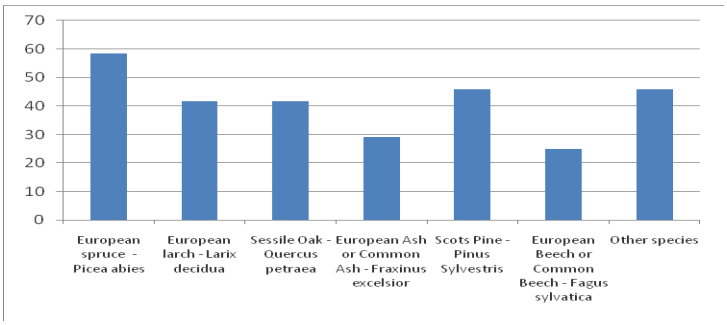


Figure 2. Wood species selected by the respondents.

78% of respondents stated that the application of coatings is carried out in their manufacturing process. According to 62.5% of replies the main rationale in applying this coating is to extend the durability and lifespan of wood for outdoor conditions. While, respondents had a variety of reasons for applying coatings, the main reasons can be summarised as follows: 50% of respondents cited waterproofing of wood as a reason, 50% cited enhancement of aesthetic appearance of wood (gloss…), and almost 44% said the protection of wood against fungi or mould. Other reasons cited were to modify the colour of wood (almost 19%) and to improve the mechanical properties of the wood (12,5%). This confirms the importance of wood coatings for maintaining wood condition and appearance.

In terms of aspects of current coating solutions that could be improved, 60% of respondents cited the extension of the durability of wood for outdoor conditions and the protection of wood against fungi or mould as areas for improvement. The third feature which respondents felt needed to be improved was the waterproofing of wood (33%) These responses confirm the relevance of the project objectives to bridge the gap and industrial need in the wood sector, as these three reasons above are in direct correlation with the features that the DURAWOOD system has identified and wants to improve.

The minimum durability of wood that would be acceptable, was cited in the range of 5 to 8 years by 50% of the respondents, whereas 36% of respondents said that 10 years or more would be the minimum. However, the general prerequisite stated by the respondents, is a minimum durability of between 5 and 8 years, which equates with the durability established in the preliminary specifications of the DURAWOOD system.

While 70% of respondents claimed to use water-borne coating products, 67% of them found that materials treated with water-borne coatings were more susceptible to attack by fungi. A third of respondents stated that water-borne coatings offer lower resistance to water (waterproofing) of the wood in comparison with solvent borne coatings and the same percentage pointed out the fact that more layers of water borne coatings need to be applied to obtain the same performance as solvent based coatings, which is time consuming and costly. None of the respondents felt the performance of water-borne coatings to be comparable to that of solvent borne coatings. The system that will be developed within the framework of this project will investigate how to enhance the protective action of water-borne coatings against fungi, mould and decay, as well as to improve its resistance to water.

Concerning the coating application process respondents indicated different ranges in terms of the time lapse between the processing of the wood and its eventual coating. 26% of respondents stated that there was no specific time frame and that generally the

coating is applied just before the wood product is distributed. In the case of 20% of respondents the timeframe would need to be less than 2 days between the processing of the wood and its eventual coating. 13.3% said that the timeframe ideally should be between 2 and 10 days. Finally, 6.7% of respondents stated that the coating is applied during the wood manufacturing process. The same percentage of respondents (6.7%) stated that the timeframe should be between 10-20 and 20-30 days. These results reveal a high variability in timeframes, most probably due to the type of process each industry uses, however in the majority of cases amongst the surveyed companies, the application of coatings to wood is carried out just prior to distribution. In view of these results, the DURAWOOD system should cover all the possible ranges in keeping with the capacity of the plasma technology.

In terms of how long the coating process lasts, for 40% of respondents, the complete coating process takes between 30 to 60 seconds per square meter, and 30% of respondents said it lasts between 1 to 5 minutes per square meter. 20% claimed it takes a few seconds and the remaining 10% of respondents said that 10 to 30 seconds per square meter is the time needed for completing the coating process. These results showed that for the most of the respondents (70%), this process will last between 30 seconds and 5 minutes per square meter. This could be a good starting point to begin the definition of the specifications for DURAWOOD system.

Surprisingly, almost 74% of respondents did not know which fungi are the most problematic for wooden materials. Amongst those respondents who claimed to know, 21% identified *Serpula lacrymans* as the most problematic wood decaying fungi, followed by *Trametes versicolor* and *Coniophora puteana* (with 16% respectively). From these responses, there is a clear knowledge gap among wood manufacturers about which are the most problematic fungi The results however did show that apart from this they are aware that fungi are one of the foremost problems in terms of wood durability in outdoor conditions. The laboratory work which will be conducted to study the propagation of fungi in treated wood samples will include, among others, the top three fungi selected in the questionnaires.

The questionnaire incorporated a number of questions which considered the technical characteristics desired for the new DURAWOOD system. For 83% of respondents it would be acceptable to have a coating pre-treatment stage in their facilities. The few companies who would not find it acceptable said it would be due to an increase in costs that this stage could represent. According to 47% of respondents, this pre-treatment stage should be done on-line, but for 35% it would also be acceptable if it is done off-line.

Wood manufacturers were then invited to rank the importance of the characteristics that they would value in an on-line wood coating system. Low purchasing costs and competitive maintenance pricing were the most important considerations cited by 46%. Other noteworthy aspects that manufacturers would like to see in this novel system include it being easy to install and use and its ability to reduce the damage from fungi, mould whilst improving the waterproofing of wood. All of these desired features have been taken in account into the requirements that prototype should meet.

Although the response rate has been low, around 10%, the questionnaire has afforded a good understanding of what the general specifications for the DURAWOOD system should be. Based on these responses, the DURAWOOD system, as it was defined

initially in this project, will fulfill the fundamental requirements of wood manufacturers and this will in turn meet with a clear technical need in this sector.

Questionnaire-based survey among plasma equipment manufacturers

The survey addressed to plasma equipment manufacturers was answered by 11 companies, (around 10% of response rate) one third of which were from Spain, one third from Germany and almost 17% from France and the United Kingdom.

60% of the companies who answered produce vacuum plasma and plasma equipment. 40% produce open-air plasma equipment and 20% manufacture corona equipment. 20% of responses came from companies that produce ion or plasma sources.

All respondents produce equipment for various coating applications such as polymerization, thin film coatings for photovoltaic systems and to hydrophobize the surface.

According to 60% of the responses, following the plasma pre-treatment stage the coatings applied by their customers are typically paints, varnishes, lacquers, adhesives, polymers, and inks among others. The range of industrial sectors where their technology is applied is wide-ranging. from the automotive sector, the packaging sector, medical applications, electrical and microelectronics industries, photovoltaic systems etc. However, the wood sector was not mentioned by plasma equipment manufacturers.

Plasma equipment manufacturers were then asked to rank the importance of the characteristics that they believed their customers would value in a novel wood coating system. All respondents cited an efficient pre-treatment phase as being a very important feature, followed by speed, the stability of the pre-treatment phase, low consumable costs and the fact that it is an on-line system. It is important to highlight that contrary to the most important specifications selected by the wood manufacturers, for plasma manufacturers the most important characteristic is the efficiency of the pre-treatment phase. As experts in this area, this implies that in the field of plasma technology, the determination of this parameter is of significance.

4.1.2 Socio-economic aspects

The questionnaires also included a number of questions that would enable us to gain an insight into key socio-economic aspects which could have a major impact on the future exploitability of the technology in the marketplace. The aim was to get an insight into the willingness of wooden materials and plasma equipment manufacturers to invest in new technology and improvements, to indentify the key motivators for such investments, their willingness to invest in a technology such as the proposed DURAWOOD system, the level of investment they might be willing to consider, the expected impact and desired specifications for such a technology and their familiarity and perceptions about plasma technology. The key findings are discussed below.

Questionnaire for wooden materials manufacturers

According to 36% of responses, the foremost motivation to invest in an innovative technology such as DURAWOOD would be environmental and social responsibility

considerations. 27% of respondents said that the motivation would be to gain a competitive and marketing edge. Finally, market and consumer pressure to increase the performance of outdoor wood coatings and to provide an effective alternative to solvent-borne coatings would represent a motivation to invest for 18% of respondents respectively. According to these results, it could be concluded that a need exists in the market to provide sufficient wood protection against fungi attack.

54.5% of respondents indicated that they would be prepared to invest €30,000 in the technology in the event that it would have a marked improvement on coating performance, and if the system was properly costed to show the economic return and benefits of the investment. In general respondents believed that is too early to calculate or determine whether the price of the equipment is acceptable to them.

Questionnaire for plasma equipment manufacturers

The results of this survey revealed that the application of plasma treatment for the pre-treatment of wood derivatives is not an unknown technology to them. 60% of respondents said that they are aware of attempts to develop wood coating systems in the past. These responses indicate that a clear motivation exists.

Concerning the price that they felt their customers would be willing to pay for wood pre-treatment equipment, 50% of respondents estimated this to be in the range of €20,000-€40,000. This correlates well with the general price range that was envisaged for the DURAWOOD system.

4.1.3 Feedback from the in-depth consultations and visits to industry

Spanish formwork systems producer for civil and residential works

An on-site visit was made to a company that produces formwork systems for civil and residential works to establish their requirements in terms of wood durability and preservation. This plant produces around 350,000 modules per year.

By and large the modules are hired out for use in different civil works and settings. One of this company's goals is to extend the durability of the mechanical properties of the modules as much as possible. Currently, their products have an average lifespan of 20 applications.

Only 20% of the modules are coated to protect the wood panels from the damaging effects of humidity. Should their product get wet it becomes warped and is therefore unusable in a civil engineering setting. For this particular company the life span and durability of the wood are not based solely on the quality of the coating but more so on the mechanical strength of their product. Its needs are based more on having a product with high dimensional and structural stability, which offers good weather resistance. To apply the coating they merely immerse the panel in the coating product.

Although DURAWOOD touches on some aspects of this company's industrial needs, not all can be addressed by the system. In any case, the company found the project interesting.

German Plasma Equipment Manufacturer (offices in Spain)

This global German company has focused its activities on the development of an atmospheric-pressure plasma process. They have experience in the field of tailored surface-treatment solutions needed to apply coatings to different surfaces. As a result of the use of their patented plasma technology, the surface energies of plastics, metals or glass are increased considerably, leading to surfaces that are more receptive to coating, applying print or adhesive bonding.

This company produces apparatus that are being applied in two main sectors: namely the automotive and packaging sector. Their devices are able to treat various different materials such as metals, plastics and paper. Regarding wood products, they have on-going research projects studying the applicability of their technology, but they have so far not obtained any publishable results.

According to this company atmospheric plasma is normally used "in-line". They stressed that its cost is highly dependent on the power source needed to produce plasma using air at atmospheric pressure. The atmospheric plasma device is composed of a chamber in which the plasma generating reaction takes place. The energy needed for this reaction is about 5 kW per chamber which comes from a power source operating at 230 to 400 V.

Concerning the parameters that have an effect on the surface activation, they stressed the strong relationship between the distance of the device and the surface as well as the activation of the surface. This relationship is influenced, on the one hand, by the conductivity of materials and, on the other hand, by the application rate (meters/minute rate (m/min)). For conducting material, the gap between the surface and the device is smaller than for non-conducting material in order to achieve the same effect on the surface. The company carries out tests to determine the distance between the device and the surface with respect to the application rate required by the customer and the surface activation that is needed.

Another relevant parameter is the weather conditions that can facilitate or hinder the activation and the duration of the effect of the plasma on the surface. They said that the coating stage is carried out just after the surface activation to reduce the impact of this parameter.

From their experience the wood energy surface is around 38 to 40 dynes and when a water-based coating needs to be applied the surface needs to be activated until 72 dynes.

Spanish manufacturer of wooden structures for buildings

This company manufactures wooden floors and facades that need to withstand outdoor conditions. The wood species mainly used by this company are "Pine Flanders", with a medium density *(700 kg/m3),* and a large range of different tropical woods with a high density *(1000 kg/m3).*

Its manufacturing process consists of cutting and shaping wood in standard profiles, *(generally these are 100, 120 and 150 mm).* Then the non-tropical wood is treated against fungi. Tropical wood doesn't need to be treated due to its high density which prevents colonization of wood by fungi.

At the final stage and before the packaging of the product, the process finishes with the coating application against UV radiation. The company itself has just started to apply

this coating which is water based. After the application they dry the coating using hot air.

With regard to the treatment against fungi for their non-tropical woods, they use the vacuum technology, also known as "vacuum-dip". This technique applies a high vacuum to blocks of wood in a vacuum oven with the aim of opening the pores of the wood which allows the anti - fungicides to deeply penetrate the wood. In terms of the level of protection gained by this technique it is categorized in 5 levels. Level 3 is the standard measure, whereby the wood is protected against bad weather conditions, but not against continuous immersion in water. Level 4 *(applied Vallfusta)* allows the immersion of wood in fresh water, and level 5 is the protection of wood in saline water.

Generally the vacuum treatment is subcontracted to specialized companies. This is also the case for most wood manufacturing SMEs, since vacuum equipment is very expensive (over 120.000 €).

The company explained that there is a clear need in wood manufacturing to extend the durability of the photosensitive coating applied to wood, and for a more cost effective technology for protecting wood against fungi to current technology, which can represent some 30% of the cost of wood. This company has been in contact with some paint and coatings manufacturers with a view to increasing the durability of the coatings applied to wood.

The company emphasized the need to find a solution to stabilize the properties of wood as time progresses. It is well-known that wood is not a stable material as it reacts with other outdoor elements and is affected by environmental conditions such as temperature and humidity.

Spanish paints and varnish manufacturer

An on-site visit was made to one of world's largest global paints and coatings companies. Among their paints and coatings products, they produce a wide range of coatings for different applications such as marine coatings, decorative coatings, and car refinishes.

The company has made a huge investment to ensure that they meet the requirements of the European Directive for Solvents in Paints and Vehicle Refinishing Products (Directive 2004/42/EC) by reducing the volatile organic content of their products. The company pointed out the significant reduction of solvent content required by this regulation.

Regarding the performance of water borne coatings, they said that more layers need to be applied in the case of these coatings with less solvent content to achieve the same performance as a solvent based coating. In terms of the durability of wood, a 10 year renovation-free warranty for wood facades would be satisfactory. According to this paint manufacturer it is not possible to ensure a 25 year guarantee as claimed by some of the other coating manufacturers.

With respect to the durability of wood, apart from the type of coating used, there are other mitigating factors that could have an influence, such as the type of wood used, the pre-treatment of wood before the coating application, and the environmental conditions.

Slovak Consultancy Company

An on-site visit was made to a small Slovak consultancy company with 10 employees that specializes in helping producers of lacquers and finishes, as well as furniture companies to solve their technology problems. It has been involved in the development of water borne coating systems, UV paints and in recent years focused on the use of nanoparticles in these products.

In view of the Paints directive, they are now highly active in water borne systems, as they predict a huge increased in their use on the market.

Concerning performance, they say that problems are specific from one kind of wood to another. With softwood common problem include unevenness of the wood surface caused by for instance ingrown branches, moisture nests or by resin channels. In terms of durability of wood and performance of coatings, they suggest extending durability of wood for outdoor conditions, to enhance the waterproofing of wood, enhance aesthetics of wood (gloss…), modify the colour of wood, protect wood against fungi or mould and finally improve the mechanical properties of the wood. Better durability is demanded mostly by customers buying transparent lacquers. Transparent films are susceptible to loss of aesthetic appearance. They expect that minimum performance requirements from the DURAWOOD system will significantly increase resistance of wood to fungi and decay, and will significantly increase its water resistance, will require easy maintenance, be of low cost, will improve efficiency of water borne coatings on the wood, will improve mechanical properties of water borne coatings, and will extend the aesthetic appearance of coated wood

Slovak furniture and wooden building restoration company

An on-site visit was made to a Slovak company that restores antique furniture, old wooden buildings, and that produces atypical interiors. It is small company of about 12 people. They use paints and coatings, as well as fungicides, in their everyday activities.

The Paint Directive (2004/42/EC) will impact them significantly because they will have to eliminate solvent borne lacquers and paints.

They are often dealing with problems such as loss of visual quality, blackness, greyness of coated wood. Recently they started using waterborne systems containing nanoparticles and have no complaints on its performance so far, as they feel that if it is applied properly it won't cause problems, however this could indeed be an observation that is based on them having only recently stated using water-borne coatings. However, they did say that any exposed spots will age faster.

Concerning the durability of coated wood, for their needs a system that offers a minimum of 5 years restoration-free service is acceptable, however ideally it should last far longer 10-20 years, similar to the durability offered by woods treated with oils and waxes. If possible, the best could be permanent/lifelong durability, as customers do not want to deal with repetitive treatments and maintenance.

Slovak producer of exterior wood products

An on-site visit was made to small Slovak company that produces exterior wood products, mainly garden furniture – different garden and patio furniture, small garden buildings, timber, outhouses etc. All products are being sold to Germany, so they are dealing with high quality products.

The Paint Directive (2004/42/EC) will impact them significantly because they will have to eliminate solvent borne lacquers and paints, and exchange them with water borne systems which will have to offer the same durability and visual quality as those mentioned above.

They are dealing with a specific problem, whereby they are trying to get rid of resin rising on the surface of softwood at higher exterior temperatures (above 25°C). For that purpose they are testing chemicals which should decrease the rate of resin rising.

Concerning the durability of coated wood, they feel a restoration-free period of minimum 3-5 years would be acceptable. They feel market pressure to extend durability of their products. They prefer to use known and well-established items rather than cheaper ones. Quality is paramount, because they are oriented mostly at the export market.

Slovak producer of thermal wood

An on-site visit was made to small Slovak company that produces wood that is thermally modified by microwave heating. Such a modification adds value to a wood and conceals blue stain. Thermally modified wood can be used in a wide range of outdoor applications, such as siding, decking and patio and garden furniture.

Durability of thermally treated wood is much higher than that of the traditional woods.

The motive for this on-site visit was to offer help to solve a specific problem that affects thermally treated wood, whereby such a wood is much more difficult to paint or apply coating on it. Thermal treatment changes the properties of the material being treated. Plasma treatment has potential for activation of such wood and subsequent coating could be much easier. To this end, the company is very interested in the potential application of the DURAWOOD system on their products.

4.2 Overview of commercial pre-treatment equipment and coating systems for wood

The most **commonly used coating equipment used on wood** are examined providing the DURAWOOD consortium with invaluable information to ensure the design of the DURAWOOD system is as versatile and adaptable as possible.

The different systems to protect the wood can be divided into two broad groups. On the one hand, is the application of different kinds of products or coatings, to protect the wood against weather conditions, UV light and fungi. On the other hand, thermal and/or pressure treatments can aid the impregnation of the coatings applied to enhance their performance.

The type of coating and the system used to apply them depends on the required use for the wood which is coated. The protection afforded by the coating applied will depend upon the quantity retained by the wood, the depth of penetration and the permanence of the coating in the wood *(WAP, 2004)*

The final grade of protection achieved by each coating will be defined by the coating itself, the application system chosen and the species of wood to be treated.

The most common application system for wood coatings or preservatives includes (WAP, 2004):

- Brushing and spreading
- Spraying, deluging and fogging
- Immersion
- Hot and cold steeping in open tanks
- Pressure Impregnation
- Double vacuum

4.2.1 Methods of treatment

The most common methods of wood treatment are discussed below:

Brushing

This is the most common way of applying coatings on-site and is particularly convenient for the general public. The coatings need to be applied on clean and dry wood in flood coats. In the main, these types of coatings are used in less severe ambients where the risk of wood being attacked by fungi is very low.

Spreading

Spreading systems are usually used to apply wood coatings as pastes by hand or mechanical means. Normally spreading is used for the treatment of embedded timbers.

Spraying

This system is most commonly used in situ and also as a pre-treatment of wood, its results are comparable to the brush application. As with the brushing method, if the desired absorption of the coating is not achieved, further applications should be made after the initial treatment has soaked in.

Fogging

This technique consists of dispersing the liquid coating through nozzles after heating the liquid. The coating is dispersed as a “fog” of fine droplets. Usually this treatment is applied to under-floor areas and roof voids.

Deluging

The coating is applied from various types of jets as the wood is passed through a tunnel. This is mainly used in conjunction with organic solvent coatings but could also be used with water borne coatings systems, tar oils and creosote.

Immersion

This method involves immersing the wood into the coating. This system is normally used in the industry to treat large pieces of wood at the same time. The effectiveness of the treatment is related to the time that the wood has been immersed. In light of this, this method could serve for a wide range of hazards of wood, with the time the wood is immerse determining the absorption of the coating.

Hot and cold steeping in open tanks

This method is comprised of two basic steps: step one is to apply heat to the wood in order to reduce the humidity of the timber and step two is cooling the wood with the aid of the coating.

There are several variations of this method depending on whether the wood is heated and cooled in the bath of coating solution or if this is carried out as series of separate steps.

For example, one variation consists of firstly heating the wood to remove the humidity and then the coating is drawn into the wood to allow it to cool. However, the most common method is to heat up the bath and timber together to 180ºC and then allow it to cool down progressively. This method can be speeded up using two baths, one hot and one cold.

This method increases the penetration of the coating into the wood in comparison to brushing or spraying.

Diffusion

The process of diffusion starts early in the wood processing cycle, whereby the wood is immersed in a strong solution just after sawing. The solution is usually a water-borne solvent containing boron salts where wood is treated for a short period of time.

The wood is then cross-piled under cover to limit drying to ensure the coating diffuses uniformly inside the wood. In the event that the coating used is less severe, the diffusion process could be helped by a pressure process.

Pressure and Vacuum Treatments

In the methods explained so far, the absorption of the coating is by capillarity attraction under atmospheric pressure. The absorption of the coating is improved by increasing the gradient pressure between the substrate and the above coating. This treatment allows deeper and quicker penetration of the preservative applied.

This is achieved by applying pressure treatments and vacuum or double vacuum treatments to the wood.

This is the most commonly used pre-treatment of commercial wood products due to the higher degree of protection and high loads of wood treatment it affords. In general this treatment is not carried out by the wood manufacturers themselves due to the specific equipment required, such as treatment cylinders, storage tanks, etc. Pressure treatments require the wood to be loaded into a cylinder where is flooded with the coating and the pressure is then applied. Depending on the pressure/time, the degree of the penetration will be different thereby achieving different levels of use classes (see table 1)

As a general rule, the higher the risk of wood decay, the deeper the wood coating impregnation is needed. In the industry a code has been established for use classes, from 1 to 4. By and large, a greater degree of protection is required as use class increases. Table 1. illustrates the use classes specified in terms of their use:

Table 1. Codes of use of wood (source: http://www.ptgtreatments.co.uk/)

Code	Use
1	Above ground, covered, permanently dry, insect risk
2	Above ground, covered, occasional risk of wetting
3a	Above ground, coated. Exposed to frequent wetting
3b	Above ground, uncoated. Exposed to frequent wetting
4	In contact with ground or fresh water. Permanently exposed to wetting.

The vacuum process consists of applying a vacuum inside the wood, which opens the porous surface of the wood allowing a superior and deeper impregnation of coatings.

Commonly the chosen methods when high protection is needed are the ones involving pressure. Although if the wood has small dimension timbers or shorter life, less severe treatments can be acceptable.

If the risk of decay is not too high the wood can be treated by means of periodic retreatment, such as brushing or spraying. In fact, the coatings applied in the pre-treatment phase are normally the solvent borne ones, whereby the most suitable methods for this type of protection are immersion or vacuum.

Apart from the “traditional” systems employed there are other commercial systems currently used to improve and extend the durability of wood. Some of these are completely new products, others are a new combination or variants of the traditional systems. Some new available products which have been introduced are Belmadur® produced by BASF, Accoya ® or PureWood®.

Belmadur® technology uses a specific agent which is an aqueous solution of a crosslinking agent. The air is removed by applying vacuum to ensure that crosslinking agent can reach the innermost cells when the solution is applied under pressure. Then, the wood impregnated is dried at 100°C. This allow to crosslinking molecules to cure by polycondensation, which causes water to be released.

Concerning Accoya® technology this is based on "acetylation" in which the free hydroxyl groups react with acetic anhydride to transform them into acetyl groups. In such a way the free hydroxyls cannot absorb the water according to weather conditions. Therefore the wood increases its stability avoiding swelling, warping and shrinkage.

Finally, the technology developed by PureWood ® consists of applying heat at different temperatures and intervals of time as the moisture modifies the wood. The first stage of this process heats the wood to 100ºC to dry it sufficiently to remove the moisture. Following the heat treatment, heating continues until 250ºC and then the wood is cooled to under controlled conditions. According to the producers, the wood sugars are converted into a natural substance that cannot be digested by insects or support the growth of mold or fungi.

Among these three different commercial products there is no unique all encompassing treatment that would be capable of protecting wood against all decay caused by weathering and fungi, however these systems could be effective in extending the durability of wood. With these methods, it is necessary to treat the wood in some way by thermal, pressure or chemical methods. Thermal and pressure treatments require equipment such as ovens or large cylinders. For that reason wooden material manufacturers cannot apply the treatment during its processing and have to pay to treat the wood *(by outsourcing outside of the company)* using the different commercial techniques available.

The possibility to introduce a pre-stage for wood treatment in the wood manufacturing process could reduce the cost of wood treatment carried out externally, which would being an interesting added-value to DURAWOOD system.

4.3 Key findings from the literature

The literature review has analysed the work done in the field of the application of plasma treatment for wood protection, and in the field of the wood decay fungi. The first part of the work has collected the studies about the fungi and the coating to prevent the colonization of wood by fungi. The second part has focused on the state of the art of the coatings systems applied to coat the wood and the use of the plasma to extend the durability of wood.

4.3.1 Literature review on wood destructible fungi

4.3.1.1 Wood-destructible fungi: an introduction to the field

The primary biotic decomposers of wood are basidiomycete decay fungi, which can attack and degrade both wood in the forest and wood in service (JASALAVICH et al. 2000). As decay progresses the wood becomes discolored and loses strength, weight, and density. Decay and discoloration caused by fungi are major sources of loss in both timber production and wood use, with losses of 15 - 25% marketable wood volume in standing timber and of 10 - 15% in wood products during storage and conversion (JASALAVICH et al. 2000).

The fungi attack the wood structure by degrading cell wall compounds. The two major kinds of fungal decay are white rot and brown rot. White rot fungi degrade the lignin in

the plant cell walls while brown rots preferentially degrade the carbohydrates cellulose and hemicellulose. As a result of such decay, stability of the wood is affected in early stages until the decay is completed leaving white fibrous cellulosic material in case of white rot and brown cubicles of lignin in case of brown rot (NAUMANN et al. 2007). Under certain environmental conditions such as higher levels of humidity and when in contact with soil, wood in service is in danger to be infested by destructive fungi (NAUMANN et al. 2007, SCHMIDT 2006, HUCKFELDT and SCHMIDT 2006).

According to ERLER (2002) the most important and most frequent wood-destructible fungi in the outskirt area are: *Gloeophyllum sepiarium, Gloeophyllum abietinum, Lentinus lepideus, Antrodia vaillantii, Trametes versicolor, Paxillus panuoides*. Other wood-destructible fungi which are less frequent are: *Donkioporia expansa* and *Schizophyllum commune*.

According to SCHMIDT (2006) the common wood decaying Basidiomycetes on wood in outside use are: Gloeophyllum abietinum, Gloeophyllum sepiarium, Gloeophyllum trabeum, Lentinus lepideus, Paxillus panuoides, Schizophyllum commune, Trametes versicolor, Daedalea quercina. Other fungi that occur also on structural timber that is used outdoors in ground contact, like sleepers, poles, posts, fences, bridges and garden furniture are Antrodia vaillantii, Lentinus lepideus, Oligoporus placenta, Serpula himantioides, etc. (SCHMIDT 2006)

The True Dry Rot Fungus Serpula lacrymans is the most common and most dangerous indoor Basidiomycete in central Europe (SCHMIDT 2007) and is involved in 32% of structural damages in Northern and Central Europe (HUCKFELDT and SCHMIDT 2006). The Brown Cellar Fungus Coniophora puteana is beside the true dry rot fungus one of the most important wood decaying fungi in Northern and Central Europe and is involved in approximately 10 to 20% of the structural damages (HUCKFELDT and SCHMIDT 2006).

4.3.1.2 Methods of wood protection

Factors influencing the development of wood preservatives for residential exterior applications are numerous, complex and highly inter-related. Stakeholders in the development include consumers, wood processors, environmental regulators, preservative standard and building code governing bodies, and commercial entities developing the active ingredients and treatment products. The use of treated wood in the residential environment increases the need for a very low risk safety profile for humans, animals and the environment *(Helmer, 2008).* At present all developments of wood preservatives in Europe are preliminary dependant on the European Biocide Directive 98/8/EC. In the future, only active substances and biocidal products assessed and authorized according to the EC directive regulations can be placed on the European market *(Leithoff et al, 2008).*

To reduce the evaluation time of new potential preservatives reliable accelerated methods for laboratory screening are necessary. The state of the art method (European Standard EN 113) needs a prolonged 16 week incubation period. Treated and untreated wood wafers are incubated with different wood-destructible fungi. According to the European Standard EN 113 *(test method for determining the protective effectiveness of wood preservatives against wood destroying basidiomycetes)* the following fungi are defined as test fungi: *Coniophora puteana, Trametes versicolor, Lentinus lepideus, Lentinus cyathiformis, Oligoporus placenta, Gloeophyllum trabeum.*

The resistance to biodeterioration is measured by detection of mass loss of the wood wafers. A new method developed by the Mississippi State University tries to quantify the extent of biodeterioration by measuring the stiffness losses in wood wafers after 4 weeks of fungal exposure. The resistance of untreated and treated radiate pine *(Pinus radiate)* sapwood wafers are tested by incubation with brown rot *(Neolentinus lepideus, Gloeophyllum trabeum and Postia placenta*) and white rot *(Trametes versicolor and Irpex lacteus)* fungi respectively (Przewloka et al, 2008).

4.3.1.3 Decay-influencing factors

The decay and deterioration of softwood and hardwood by fungi are the most common and damaging problems of forest and timber industries worldwide. Although some wood types contain biological substances (for example western redcedar (*Thuja plicata*), Chedgy et al, 2009) that confer resistance against wood decay fungi, most are non-durable and subject to attack by a wide range of fungi (Kumar et al, 2006).

A basis for the prediction of the service life of wood and wood-based products is the exact knowledge of the decay-influencing factors. As key factors for fungal decay the natural material resistance, wood moisture content as well as wood temperature and the relative humidity was found (Brischke et al, 2006).

The environmentally sensitive organic biocides and wood preservatives developed in accordance with the new European Biocide Directive are subject of degradation by non-decay microorganisms themselves. It has been reported that organic biocides are degraded in wood exposed to the full range of microorganisms resulting in the timber becoming susceptible to fungal decay by organisms otherwise controlled by the biocides. This biodetoxification of preservative-treated wood is mediated by a range of Gram negative proteobacteria. For example strains of Pseudomonas have been reported to degrade a number of organic biocides like IPBC (3-iodoprop-2-ynyl N-butylcarbamate, one of the key water-soluble preservatives), chlorothalonil and an oxathiazine derivative (Wallace et al, 2008).

4.3.1.4 Natural durability

For some wood (for example European and Siberian larch (Larix deciduas and Larix sibirica) and western redcedar (*Thuja plicata*)) a natural durability against fungal decay is described in the literature. In the case of larch wood the described natural durability is highly variable ranging from non-durable to durable. The level of durability may be dependent on the content of phenols. The differences in the contents of phenols and the correlated durability may arise from the wide variability between trees, across sites and species, genetic origins and tree age (Sykacek et al, 2006).

In comparative studies leached and un-leached redcedar wood were incubated with fungi as described in EN 113. The leached wood was reduced in the concentration of 5 major extractives (plicatic acid, ß-thujaplicin, y-thujaplicin, ß-thujaplicinol, thujic acid) which could be correlated with fungal growth and decay (Chedgy et al, 2009).

4.3.1.5 New methods / compounds with antifungal activity

Many different methods of wood treatment for improvement of biological durability against fungi based on organic, inorganic compounds or physical methods are described in the literature.

A huge variety of organic compounds with antifungal activity are described. For example cinnamaldehyde and eugenol congeners (Cheng et al, 2008), organosilicons (Vetter et al, 2009, N-alkyl-ß-D-glucosylamines (Muhizi et al, 2008) and dehydroabietic acid derivatives (Savluchinske-Feio et al, 2007) are tested as potent antifungal substances.

Inorganic compounds with wood preservation effects described in the literature are micronized/dispersed copper (Freeman et al 2008), ionic silver (Dorau et al 2004) and water-soluble borates (Baysal et al, 2005). Copper and silver ions have been shown to have potential as a viable, safe and cost-effective wood preservative. The concentration for fungicidal activity is 1.9 µg/L. Treatment of wood with water-soluble borates combines an anti-fungal with a fire-retardant effect. Around 1% w/w boric acid loading was found sufficient for decay resistance against brown- and white-rot fungi.

A physical method described as effective to improve biological durability of wood is the heat treatment of wood at relatively high temperatures in the range of 150 – 280°C. The studies were performed to investigate the effect of heat treatment process optimization on the resistance against fungal attack including basidiomycetes and moulds (Boonstra et al, 2007; Kamdem et al 2002).

4.3.1.6 Representation of wood-destructible fungi in the literature

With respect to the fungi listed in the papers which discuss the effect of substances or methods that serve as wood preservatives most of all (19 papers) only mention the groups of white and brown rot fungi respectively. In the remaining 12 papers the fungi listed in table 2 below are named as test fungi in different frequencies.

Tab. 2: List and frequency of wood-destructible fungi named in the citations of the literature survey.

Species	Quantity of citation
Trametes versicolor	8
Oligoporus placenta	7
Gloeophyllum trabeum	6
Coniophora puteana	4
Tyromyces palustris	2
Acanthophysium lividocaeruleum	1
Heterobasidion annosum	1
Irpex lacteus	1
Laetiporus sulphureus	1
Lentinus lepideus	1
Lenzites betulina	1
Pachnocybe ferruginea	1
Phanerochaete chrysosporium	1
Phellinus sulphurascens	1
Phellinus weirii	1

4.3.1.7 Conclusions

Wood-destructible fungi are an important problem for the timber producing and wood using industries respectively. Decay and other types of damage caused by fungi induce losses of 10 to 15% in wood products during storage and conversion and of 15 to 25% in marketable wood volume in standing timber. Additionally the European Biocide Directive 98/8/EC necessitates the development of new wood preservatives with a very low risk safety profile for humans, animals and the environment. To support this development on the one hand the reasons for the, in some cases observed natural durability of some wood species, such as western redcedar (*Thuja plicata*) are investigated. On the other hand, the decay-influencing factors determined as wood moisture, wood temperature and relative humidity are important subjects of further research. The main focus in the development of new wood preservatives is localized in the area of organic and inorganic substances. Only one physical method based on a high temperature treatment as competition for the DURAWOOD method is described in the literature.

With respect to the fungi listed in the papers the following fungi are named with the highest frequency: *Oligoporus placenta*, *Trametes versicolor*, *Coniophora puteana* and *Gloeophyllum trabeum*. These fungi are also part of the list of the most important wood-destructible fungi determined in task 3.1 of the DURAWOOD project and of the list of test fungi defined in the European Standard EN 113 respectively.

To minimize the time for efficiency test and evaluation of new wood preservatives the development of less time consuming methods is required. The state of the art method EN 113 needs a 16 week incubation time for the efficiency test of new wood preservatives. A new method in the actual state of development is based on the measurement of mass loss correlated with loss of stiffness. On this field the development of a new quick PCR-based method for the detection of infiltration of untreated and treated wood by fungi would be of high interest.

4.4 Literature review on plasma treatment for wood protection

STUBA has performed an extensive literature review of publications related to the DURAWOOD project. From the last 30 months, about 60 references in the literature research related to project were found and evaluated.

Classical wood treatment methods are plagued with many drawbacks, such as energy inefficiency (thermal methods), harmful to the environment (chemical methods), etc. In recent years, public concern about the environment has lead to the creation of regulatory programs to reduce air pollution increasing the pressure on wood manufacturers to reduce harmful emissions derived from chemical treatments (VOC) and thermal treatments (CO_2). The wood industry has thus been forced to source out renewable resources and environmentally friendly chemical methods for wood protection and the following offers a summary of the current State-of-the-art in terms of the related research that has been carried out to date.

A main trend in the wood industry is increased bonding of wood products as a result of the use of more engineered wood products. For a bond to form, the adhesive must intimately encounter most of the wood substrate surface. Wetting is an important issue in the adhesive bond formation (Charles R, Frihart R, 2004), since most wood adhesives are water-based. Wood has a relatively polar surface that allows the general use of water-borne adhesives; however some woods are harder to wet. This is a particular

problem for a wood surface, which was exposed to a high temperature drying (Sernek M, Kamke FA, Glasser WG, 2004). In these cases a chemical treatment of the wood surface, which promotes wettability or provides new bonding sites, should improve adhesive bond performance.

Plasmas sustained at atmospheric pressure are commonly used to improve the wetting and adhesion properties of polymer materials, and have been tested also for the wood surface treatment (Sakata I, Morita M et al, 1993), (Podgorski L, Chevet B et al , 2000), (Rehn P, Wolkenhauer A et al , 2000), (Bente M, Avramidis G et al , 2004), (Mertens M, Wolkenhauer A, Viol W, 2006).

Although also low-pressure plasma processes have been studied for this purpose (Mahlberg R, Niemi HEM et al , 1999), (Blantocas GQ, Ramos HJ, Wada M , 2006) atmospheric pressure processes are more attractive for wood industry applications because of their lower cost, higher throughput, and ability to operate in-line without vacuum systems. Atmospheric pressure plasma systems are typically based on volume Dielectric Barrier Discharge (DBD) arrangement, where the treated material is placed between the discharge electrodes (Sakata I, Morita M et al, 1993), Podgorski L, Chevet B et al , 2000) or the material itself works as one electrode (Rehn P, Wolkenhauer A et al , 2000). However, this arrangement is problematic for the treatment of thick pieces of wooden material (several centimetres), where excessive high voltage is needed, thus raising some serious workplace safety issues. In addition, the wood piece being the part of discharge electrical circuit results in considerable resistive power losses that deteriorate the economy for such treatment.

The problem of resistive power loss can be addressed by employing a rare gas plasmajet generator (Bente M, Avramidis G et al , 2004) or laser ablation method (Mertens M, Wolkenhauer A, Viol W, 2006), either of which represents rather ‘expensive’ solutions. A more practical approach, which we are offering in this article, is to use a planar DBD plasma source, such as the Diffuse Coplanar Surface Barrier Discharge (DCSBD) (Simor M, Rahel J et al , 2002). Due to the planar geometry of discharge electrode, the electrical current and discharge plasma is confined into the approximately 0.3 mm thick layer above the DCSBD electrode. The resistive power loss in the bulk of wood material is therefore negligible. In addition, the small thickness of DCSBD plasma layer results in high plasma volume power density comparing to the volume DBD. High volume power density is desirable in order to enhance the concentrations of generated reactive species.

4.4.1 Analysis of the State-of-the-art

4.4.1.1 Pre-treatments

Chemical pre-treatment: Wood modification with an N-methylol compound (DMDHEU) (Yanjun et al. 2006) was shown to improve several wood properties, such as its resistance to fungi causing decay and staining, its dimensional stability and its slightly increased equilibrium moisture content. Outdoor exposure of uncoated mDMDHEU-treated wood revealed lower weight losses and less cracking than did the untreated specimens. Studies on the outdoor exposure of coated mDMDHEU treated and untreated specimens are still in progress. Preliminary results after an 18 month exposure period to natural weathering reveal enhanced adhesion and less formation of check sand cracks on the coated mDMDHEU-treated surfaces. However, microscope

observations revealed that while the solvent-borne alkyd finish was able to penetrate into the first layers of the wood cells, water-borne acrylic finishes only spread over the wood surface.

Biological pre-treatments: A new approach is based on the biotechnological preconditioning of the wood surface by appropriate micro-organisms prior to application of the paint in order to achieve superior absorption and penetration depth of preservatives. The structure of the research effort being carried out in this field is based on a repeated test series and enables a dynamic improvement of the coating systems. Thus these studies should provide a basis for improvement and development of durable coating systems for wooden claddings with low fungicide content. This research is being carried out by the EMPA (Wood department, section wood protection/microbiology).

4.4.1.2 Materials

Wide range of different materials can be treated with DCSBD plasma. Most of articles so far were dealing with treatment of **thin films**. (Eichler M. et al. 2008) worked with dielectric barrier discharges at atmospheric pressure, silicon wafers were treated for low-temperature direct wafer bonding with annealing lower temperatures with the objective of packaging in microsystems. Interesting results were found for plasmas from nitrous oxide and synthetic air (80% N_2+20% O_2). Synthetic air plasma treatment reached the highest bond energy and was chosen because of its low price and easy handling.

DCSBD plasma was in the last period used for surface activation of **non-wovens**. (Černák M. et al., 2007) used DCSBD plasma for activation of thermally bonded polypropylene nonwovens. They developed a treater equipped with a fabric rolling system for continuous fabric modification treatments which can handle webs fabric width up to 21 cm (size of A4 sheet). They used DCSBD plasma source generating active plasma exposure layer of 21 x 9.5 cm at power up to 500 W. A video of this system is available on http://gimmel.ip.fmph.uniba.sk/treaters/ . Their results show that once treated, the plasma-activated PP nonwovens may not be stable. There are often changes in the wettability and surface chemistry as a function of the storage time after treatment (J.R. Roth 2001). This behaviour, called sometimes 'hydrophobic recovery', is believed to be caused by gradual reorientation of the surface chain segments and depletion of polar groups when the surface is exposed to the air or to other nonpolar media. They also found that that the 17 gsm PP nonwovens treated for 0.8 s at the maximum plasma source power of 500 W were hydrophilic with the strike-trough time less than 5 s even after 6 months storage in ambient air, and that no washing out effect was observed on the plasma treated samples. The treatment parameters correspond to surprisingly low energy consumption of approximately 1 kWh per 1 kg of the treated fabric. Most relevant articles were dedicated to activate surface of paper and different species of wood. Samples of Norway spruce (Gindl, Sinn et al. 2001) with a cross-section of 8-10 mm and a length of 70 mm were stored in a climate chamber at a temperature of 20°C and a relative humidity of 65% until they had reached an equilibrium state at a moisture content of 12%. They were used for comparison of different methods assignment of surface free energy by measurement the contact angle. Samples of European spruce (Tiňo et al. 2008) were used for evaluation of intake capability of LCM surface by adsorption dyeding method and its utilization for

evaluation of changes in surface polarity cause by DCBD low-energy plasma. (Pykönen, M., et al 2008) used atmospheric plasma and corona plasma treatment to study ageing effect of paper substrates. (Pykönena, M., et al 2009) used different types of plasma to treat pigment –coated surface-sized papers at laboratory scale. plasma activation increased surface wettability and oxygen/carbon (O/C) ratio. The changes seemed to occur especially in respect to high molecular weight dispersion chemicals of both pigment and latex particles. When compared to corona treatment, pilot scale argon plasma provided higher polarity on the surface and smaller O/C ratio on the reverse side on the paper. (Jimenez, A.,B. et al. 2008) reported on the effect of atmospheric air pressure plasma (AAPP) treatment on the mechanical properties and interfacial behaviour of different lignocellulosic fibres to cellulose–acetate–butyrate (CAB). The heat generated during the plasma treatment causes dehydratation of the fibres and the etching effect of plasma degrades their macrofibril structure. (Vander Wielen, L.C. and Ragauskas, A.J. 2006) studied effect of dielectric barrier discharge treatment of cellulosic fibers (test sheets). The wet-tensile and wet-stiffness of the paper increased with extended dielectric-barrier discharge treatment. Cold-plasma treatment of bleached kraft pulps was accompanied with only minor changes in surface chemistry and yet these changes provided substantial and beneficial changes in physical properties.

4.4.1.3 Methods for evaluation of plasma treatment

For evaluation of plasma treatment can we used various methods and their combinations. ATR-FTIR analysis revealed the presence of a macromolecular structure, based on Si-C and Si-O-Si bonds in the wood surface (Denes et al. 1999). It was demonstrated that relative short treatment times are enough for efficient surface modification. Atomic Force Microscopy (AFM) can be used to study the changes in film surface feature (Huang, et al. 2009a, Lee et al. 2009) or indicate the progressive growth of the plasma "polymer" (Denes et al. 1999, Eichler, Michel et al. 2008).

FTIR analysis confirmed the formation of additional polar functional groups on the wood surface due to the plasma treatment (Odrášková, Ráhel' et al. 2007) or can be used to monitor the development of degradation products (Stark, et al 2004).

X-ray photoelectron spectroscopy (XPS) can be used in assessing ageing effect in atmospheric plasma activation of paper substrates (Pykönen, Sundqvist et al 2008, Pykönena, Silvaania et al 2009) or chemical composition of emergent film can be analyzed (Huang, et al. 2009a, Lee et al. 2009) or it can be used to verify the occurrence of surface oxidation (Stark, et al 2004)

Surface free energy of wood using contact angle measurements can be calculated by Zisman method (Gindl, Sinn et al. 2001).

The photoemission plasma species in the continuous cyclone atmospheric pressure plasma was identified by optical emission spectroscopy (OES) (Huang, et al. 2009a).

Adsorption dyeding method can used to evaluation of changes in surface polarity cause by DCBD low-energy plasma (Tiňo et al. 2008)

4.4.1.4 Conditions of the treatment

- Atmosphere

Depending on what gas is used different results can be achieved. The gas used in the treatment must be suitable for this one, may be O2, He, N2, CO2, Ar synthetic air… and it must be as homogeneous as possible.

SiO2-like thin films for example were deposited by a remote-type, atmospheric pressure plasma enhanced chemical vapor deposition (AP-PECVD) using a pin-to-plate-type, dielectric barrier discharge with gas mixtures containing hexamethyldisilazane (HMDS)/O2/He/Ar. (Kim et al., 2009) and it was seen that increasing HMDS flow rate in the gas mixture increased the deposition rate but more impurities such as Si–(CH3)x were introduced in the deposited film due to the incomplete decomposition of HMDS and the surface roughness was also increased.

It was proven too that when the O2 flow rate was increased at a constant HMDS flow rate, the deposition rate was maximized at 600 sccm. Furthermore, the lowest Si–$(CH3)_3$ and Si–(CH3)x, and the smoothest surface were obtained near the 600 sccm.

Mixes like O2 and N2 can be used also although some times for some parameters they work better alone. It was noted that for example for 100 °C annealing temperature, pure oxygen and nitrogen plasmas, respectively, showed lower bond energies than the plasma treatment with mixtures of N_2 and O_2 with which bond energies of 2.2 J/m^2 can be achieved (M. Eichler, 2008). Also was found that for plasmas from nitrous oxide and synthetic air (80% N_2+20% O_2), synthetic air plasma treatment reached the highest bond energy and was chosen because of its low price and easy handling.

- Time of application

Time of application will be the time during which the sample will be attached by the plasma and during which that one will suffer some kind of change.

Different times have been tested in some experiments and, although the result does not depend only on this but on the combination of all the used parameters, it has been possible to see that at least as regards the wettability the longer the treatment time the higher the wettability since the contact angles found by measurements of contact angle between a drop on the wood and the wood itself are lower (Laurence Podgorski, 2000)**Error! Bookmark not defined.**. Denes et al (1999) investigated the use of cold plasma treatment carried out under pressure (50 mTorr) using Hexamethyldisiloxane gas. The trials resulted in the deposition of a hydrophobic film (high contact angle values, 130º) on the surface. It was demonstrated that relative short treatment times are enough for efficient surface modification. (Podgorski et al 2000) studied how to change the wettability of the wood by plasma treatments with the purpose of improving the durability of coatings. The treatment time was 5 min, the pressure 0.08 mbar, and the distance from the samples to the plasma source 44 cm. An important decrease in the contact angle was observed due to the plasma treatment: wood was oxidized like synthetic polymers. (Rehn et al 2003)**Error! Bookmark not defined.** studied how a wooden surface could be modified by dielectric barrier discharges. He says, that due to the short treatment time of approximately 1 s the plasma process is economical. (Pykönen et al 2008) observed, that the changes in the surface chemistry depended on treatment time and composition of the substrate surface. (Korachi et al 2009) studied the biocidal effect of atmospheric plasma. Optimal killing parameters such as time, temperature and AC and DC high voltage power levels were tested for different bacteria in water. Treatment times of plasma from

10 to 120 minutes were used and evaluated after 24,48 and 72 hours. (Huang et al 2009a) studied the influences of plasma conditions such as treatment time, plasma power, nozzle distance, and gas flow rate on the PET surface properties. The influences of plasma conditions such as treatment time, plasma power, nozzle distance, and gas flow rate on the PET surface properties were studied. There were used treatment times from 0 up to 600 seconds. It was found that such cyclonic atmospheric pressure plasma is very effective in PET surface modification, the reduced water contact angle was observed from 74° to less than 37° with only 10s plasma treatment. (Lee et al 2009) investigated through the analysis of contact angle and calculation of work of adhesion, the change of surface properties related to the plasma power, treatment time, and flow rate of O_2 gas before and after plasma treatment.

- Power

(Merlin et al 1999) conducted initial experiments consisting in determining plasma and corona discharge treatment parameters (type of gas, treatment duration, power, etc.) leading to better surface characteristics of wood before and after thermal treatment. Plasma and corona treatments were effective to improve the wettability of wood but no improvements in the coating adhesion were observed. Results showed that even using a higher voltage (15kV), corona discharge is less efficient than plasma to improve wood wettability. (Podgorski et al 2000) studied how to change the wettability of the wood by plasma treatments with the purpose of improving the durability of coatings. To check the influence of the treatment power Oxygen plasma was applied to wood with a power from 400 to 1200 W. The treatment time was 5 min, the pressure 0.08 mbar, and the distance from the samples to the plasma source 44 cm. An important decrease in the contact angle was observed due to the plasma treatment: wood was oxidized like synthetic polymers. Values were close for the different treatment power.

Korachi et al (2009) developed a low cost plasma system that works at atmospheric pressure and operates with either DC ((12 and 20 kV) or AC (12 kV low frequency -1 kHz) high voltage power supplies with a purpose of sterilization. This system was tested for its biocidal effect on a wide range of micro-organisms in water. (Kim et al., 2009) carried on a study which consisted on depositing SiOx thin films with gas mixtures composed of hexamethyldisilazane (HMDS)/O2/He (2 slm)/Ar (600 sccm) using an atmospheric pressure plasma enhanced chemical vapor deposition (AP-PECVD) system with remote-type dielectric barrier discharge (DBD) source and 5 kV 25 kHz AC power. Especially, to generate high-density plasma at low breakdown voltages, a pin-to-plate-type DBD consisting of a multi-pin power electrode instead of a planar power electrode was used. (Yuji et al 2008) used a microwave (2.45 GHz) power supply was to excite the plasma. The vibrational and rotational temperatures in the plasma were measured at approximately 0.18 eV and 0.22 eV.

- Distance

(Podgorski et al 2000) studied how to change the wettability of the wood by plasma treatments with the purpose of improving the durability of coatings. To check the influence of the treatment power Oxygen plasma was applied to wood with a power from 400 to 1200 W. The treatment time was 5 min, the pressure 0.08 mbar, and the distance from the samples to the plasma source 44 cm. Studying the distance from the samples to the plasma source they saw how the wettability decreased as the distance between samples and the plasma source increased.

The kinetics of wood surfaces polarity changes during the plasma treatment in the air atmosphere was measured in dependence on distance between the wood surface and plasma electrode surface (d_{p-w}) which was in the range from 0 -1,17 mm. In distances 0-0,35 was found effect of hydrophilization, while in distances 0,35-1,04mm was found effect of hydrophobization. This finding is important, because it shows, that it is possible to change polarity of the spruce wood surface without chemicals, simply by setting the different mutual distance of the DCSBD plasma electrode and wood surface (Tiňo et al. 2008).

- Pressure

There is an important difference between the low pressure processes and the atmospheric pressure processes. Due to the known limitation in low-pressure processes, limitation about space, cost of a vacuum system. Some studies like Y.S. Kim's one as other had to be focused on the development of non-thermal plasma sources operating at atmospheric pressure. (Rehn P, Wolkenhauer A et al 2003, Kim, Lee et al. 2009, Eichler, Michel et al. 2008). Most of relevant articles are connected with atmospheric plasma, it means plasma operating under normal laboratory air pressure.

- Temperature

The temperature has been also one of the main points in the process. Getting a low temperature of process became a concern since high temperatures could damage the sample or some properties of the sample surface. The plasma pre-treatment of wood surfaces with a dielectric barrier discharge under atmospheric pressure and under an average process gas temperature of 35°C increases the fracture strength of glued robinia wood by 28% (Rehn P, Wolkenhauer A et al 2003). SiO_2-like thin films were deposited at a low temperature (<50 °C) (Kim, Lee et al. 2009). Using dielectric barrier discharges at atmospheric pressure, silicon wafers have been treated for low temperature direct wafer bonding with annealing temperatures down to 100 °C (Eichler, Michel et al. 2008). Polyethylene terephthalate (PET) films are modified by cyclonic atmospheric pressure plasma. The experimentally measured gas phase temperature was around 30 °C to 90 °C (Huang, et al. 2009a). Atmospheric pressure plasma can be worked at <75 °C (Kim, Gweon et al. 2009) or room temperature (Lee et al.2009, Liang, Li, et al. 2010) The experimentally measured gas phase temperature was around 30°C–85°C (Huang et al. 2009b).

4.4.1.5 Effects

- Hydrophobization effect

This effect consists of getting the surface of the sample waterproof, avoiding the water to go into and this way avoiding the wood to change the shape as well as the appearance of some fungus. Some studies have been dealing with it. Some ideas like depositing SiO_x thin films with gas mixtures on the sample surface have became success (Y.S. Kim et al., 2009). Also some tests were performed to deposit thin films (based on ethylene or

fluorine) by plasma or corona treatments. This kind of deposits could be considered either on bare wood or on coated wood with a low stain, that is to say, a stain whose sensitivity against water would be solved because of this kind of films (Laurence Podgorski , 2000). (Tiňo et al. 2008) found relation of surface polarity on distance between the surface of electrode and surface of treated wood sample. Simply by changing the distance it is possible to change surface polarity of treated surface.

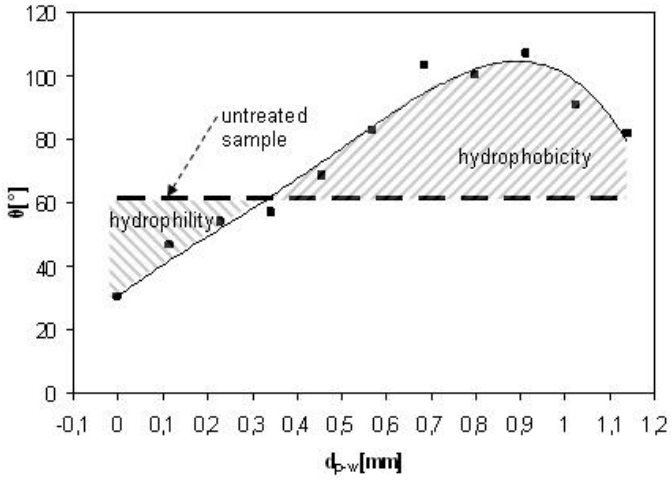


Fig. 3 Dependance of contact angle (θ) on distance between surface of spruce wood and surface of plasma electrode(d_{p-w}). Area of hydrophilic impact of plasma in distances up to 0.35mm from surface of electrode and area of hydrophobic impact of plasma treatment in distances more 0.35mm from surface of plasma electrode are shown.

(Podgorski et al 2000) studied how to change the wettability of the wood by plasma treatments with the purpose of improving the durability of coatings. Checking what gases were better for improvement of wetting, they found that ammonia leaded to an increase in contact angles, it means that ammonia is able hydrophobize surface. They were also working with decreasing the wettability so that the surface becomes waterproof. Some tests were performed to deposit thin films (based on ethylene or fluorine) by plasma or corona treatments. This kind of deposits could be considered either on bare wood or on coated wood with a low stain, that is to say, a stain whose sensitivity against water would be solved because of this kind of films.

- Hydrophilization effect

(Podgorski et al 2000) studied how to change the wettability of the wood by plasma treatments with the purpose of improving the durability of coatings. Checking what gases were better for improvement of wetting. They found that oxygen, nitrogen, carbon dioxide gave good results with decreasing of contact angle. Surface treatments were convenient either to improve wettability and therefore coating adhesion or to decrease wettability in order to provide an extra protection. Their experiment consisted on selecting treatment parameters (type of gas, treatment duration, power) leading to better surface characteristics of wood, before and after thermal treatments.

To check the influence of the treatment power Oxygen plasma was applied to wood with a power from 400 to 1200 W. The treatment time was 5 min, the pressure 0.08 mbar, and the distance from the samples to the plasma source 44 cm. After treatment, samples were placed in an air conditioned room (20°C and 65% of relative humidity) and sheltered from light. Contact angles were measured 15 d after the treatments. An important decrease in the contact angle was observed due to the plasma treatment: wood was oxidised like synthetic polymers. Values were close for the different treatment power. (Odrášková, Ráhel' et al. 2007) studied the advantages of a new method of plasma activation based in a diffuse coplanar surface plasma. In the experiment Radial cuts of Pedunculate oak (*Quercus robur L.*) heartwood was activated by Diffuse Coplanar Surface Barrier Discharge (DCSBD) plasma. The plasma treatment resulted in a considerable increase of free surface energy and in the substantial reduction of 50 µl water droplet uptake time. By using the sessile droplet technique, they identified a significant increase of polar component of surface free energy after the treatment. Polar part of surface free energy is associated with the presence of acid/base forces (electron donor–acceptor bonds). The presence of acid/base functional groups on wood surface was consequently confirmed by infrared spectroscopy and by the shift of wood surface pH level to a more acidic value. (Rehn P, Wolkenhauer A et al , 2003) proved that the plasma pre-treatment of wood surfaces with a dielectric barrier discharge under atmospheric pressure and under an average process gas temperature of 35 ºC increases the fracture strength of glued robinia wood by 28%. The uptake time of a water droplet can be greatly shortened and the wetted area can be substantially increased by a plasma treatment.

- Biocidal effect

The plasma treatment has been tested for getting the sample free from unwanted microorgamismes. When the plasma is applied, ozone molecules are created because the impacts between the electrons and oxygen molecules, being these responsible for the sterilization.

This system was tested for its biocidal effect on a wide range of micro-organisms in water. Optimal killing parameters such as time, temperature and AC and DC high voltage power levels were tested for bacteria (Korachi et al., 2009)

4.4.1.6 Conclusions

Classical wood treatment methods are plagued with many drawbacks, such as energy inefficiency (thermal methods), harmful to the environment (chemical methods), etc. In recent years, public concern about the environment has lead to the creation of regulatory programs to reduce air pollution increasing the pressure on wood manufacturers to reduce harmful emissions derived from chemical treatments (VOC) and thermal treatments (CO2).

Different points of view on this topic were taken into count. First it was possibility of pretreatment. It was published, that are known methods for chemical and bilogical pretreatment. Chemical pretreatment serves to improve several wood properties, such as its resistance to fungi causing decay and staining, its dimensional stability and its slightly increased equilibrium moisture content.

It has been found, that plasma is suitable to change properties of various materials from thin films, through non-woven materials, glass, metals up to paper and wooden materials. One of main results says that cold-plasma treatment of lignocellulosic fibres

was accompanied with only minor changes in surface chemistry and yet these changes provided substantial and beneficial changes in physical properties.

Conditions of plasma treatment plays crucial role on final properties of treated materials. Atmosphere, time of application, power, distance, pressure and temperature were examined. It was found that result of the treatment does not depend only on one parameter but mostly on the combination of all the used parameters.

Considering the effects of the plasma treatment it is obvious, that different combination of condition parameters gives different results. Main effects are hydrophilization and hydrophobization. One of most interesting results says, that it is possible to treat surface of wood with the same atmosphere (non-costing air) and to obtain hydrophilization or hydrophobization effect. This depends on gap between electrode and surface of treated material. This finding will be used to design cost-effective Durawood system. Beside all the other findings was also published, that plasma has biocidal effect, mainly in the case, when Oxygen is present in the working atmosphere. When the plasma is applied, ozone molecules are created because the impacts between the electrons and oxygen molecules, being these responsible for the sterilization. This will help to eliminate number of fungi spores on the surface of the wood, which will help to fulfill request to eliminate amount of fungicide needed for protection of such a treated wood.

4.5 The most relevant patents

Following an exhaustive patent search a number of patents which could hold relevance for the DURAWOOD project have been identified and discussed.

As we have seen in the literature review there are many different systems and technologies to protect wood for outdoor sue and extend the durability of wood.

These traditional techniques differ from the DURAWOOD system which uses plasma to activate the wood surface and improve the adhesion of water-based coatings. The present patent review has been focused in new and similar technologies using plasma to coat wood and different materials with the aim of protecting and extending the durability of the coating.

This patent review does not include the inventions related to new formulations of coatings or paints, given that the DURAWOOD project is focused on a new technique that improves the performance of current water based coatings.

Table 3 below provides for each patent the following data: publication number, title, inventor(s), applicant(s), publication date, abstract and additional comments.

In the patent review not many patents have been submitted by large companies. In fact only one of the patents was submitted by a large company located in Finland. Most of the interesting patents returned are recent.

In total, 11 relevant patents relating to techniques to modify surface properties of the substrate have been found and can be classified as follows:

- Inventions that use plasma technology to coat any substrate different from wood (WO2005095007; WO2004101891).
- Inventions that apply plasma to change the surface characteristics of wood (PL355633, WO2006133524; JP5069417; WO/2008/085139).

- Methods for modifying wooden surfaces without using plasma techniques (WO1998DE00953; EP2162238, JP2008238418; JP10080907; JP6170809).

Table 3: results DURAWOOD patent search

Title	Publication number	Publication date	Inventor(s)/Applicant(s)	Abstract	Comment
Method and apparatus for coating a susbstrate using dielectric barrier discharge	WO2005095007	13-10-2005	OSE KLAUS [DE] et al./ VITO [BE] et al.	There is described a method and apparatus for coating a substrate with an inorganic-organic hybrid polymer material. The method concerns generating and maintaining a plasma according to the Dielectric Barrier Discharge (DBD) technique, said method comprising the steps of introducing a sample in the space between two electrodes, generating a plasma discharge between the electrodes and admixing aerosols containing hybrid organic/inorganic cross-linked pre-polymers to the plasma discharge. There is also described an apparatus for generating the plasma and admixing the liquid coating material (precursor solution) in the form of aerosol to the plasma discharge.	The patent only explains the kind of technology used. It is not indicated the substrate to coat, it seems that is more relevant the polymer used to coat the surface.
Method for plasma treating paper and cardboards	WO2004101891	25-11-2004	RICCARDI CLAUDIA [IT] et al./ UNI DEGLI STUDI DI MILANO BICO et al.	The invention relates to a method for working paper, cardboard and the associated fibres. In particular it relates to a method for improving or simply obtaining new surface characteristics. Said method comprises the treatment with cold plasma of the surface of the substrates, after or during suitable and specific degassing.	In this case the objective is to get a new surface characteristics of cellulosic materials water-repellent, oil-repellent or flame-retardant properties or to enhance the hydrophilic and colour and ink adhesion characteristics
Method for modifying wooden surface	EP0991511	12-04-2000-	PANZNER MICHAEL [DE]; et al./ FRAUNHOFER GES FORSCHUNG [DE)	The invention relates to a method for modifying wooden surfaces, especially by removal of layers. According to the invention, the wooden surfaces are modified thermally using high-energy radiation. This modification occurs by means of thermal absorption. During a short period of exposure of an area of the surface of the wood to the high-energy radiation, a thin layer of said wood is heated abruptly, so strongly that most of the volume of wood thus heated vaporizes or is converted into plasma just as abruptly.	The invention remove the layer of wood damaged by the use of the wood material to coat again the wood surface
Method for modifying wooden surfaces by electrical discharges at atmospheric pressures	PL355633	2004-05-04	VIOL WOLFGANG/ VIOL WOLFGANG	The invention relates to a method for modifying a wooden surface An electrode is arranged opposite the wooden surface for modification and an alternating high voltage applied to the electrode, in order to cause a discharge, between the wooden surface and the electrode, under atmospheric pressure. A dielectric layer between the electrode and the wooden surface to be modified is thus generated and the alternating high voltage applied with a frequency greater than 600 Hz	The invention uses a corona discharge produced at atmospheric temperature. The aim of the application is to modify wooden surface to facilitate the adhesion of various coatings of wood as glue or remove the damaged surface layer.

Method for plasma chemical surface modifications –	**WO2006133524**	2006-12-21	DINEFF PETER DONCHEFF et al./ DINEFF PETER et al	The invention relates to a method for plasma chemical surface modifying of materials and items, and specifically for plasma aided impregnation with solutions containing fire retardants to make porous materials. The subject matter of the invention is solved by the method of plasma chemical surface modification of porous materials and workpieces to provide fire spread and ignition resistance consisting in autoclave high pressure impregnation and further drying at room temperature, a characteristic of which is that before the impregnation the surface of the material or the workpiece is submitted to a treatment for a period of 3 to 300 seconds with cold non-equilibrium plasma of glow electrical discharge at atmospheric pressure that burns under voltage of 1 to 3 kV and at a frequency of 50 Hz to 100 kHz.	This invention uses the plasma technology uniquely to aid the impregnation of fire retardant on textile, leather, wood and foamed polymers.
Surface Treatment of thermally modified wood	EP2162238	2010-03-17	PYNNOENEN JANNE/ STORA ENS O OYJ	The invention relates to a method for treating thermally modified wood, to thermally modified wood treated according to the method and the use of resins as the protective agent for thermally modified wood. According to the invention, on the wood there is applied a liquid resin-based protective agent, which is dried and/or hardened, so that there is obtained a transparent protective surface for protecting the wood against the effects of weather. The protective agent can be phenol formaldehyde resin, melamine formaldehyde resin or urea formaldehyde resin, which is applied on the wood as an aqueous solution and dried by means of heat. Resin decreases the absorption of water in the wood and reduces the cracking of wood. Particularly phenol formaldehyde resin also prevents the wood from turning gray in the open air.	The patent is related to an invention to protect the wood using a thermal treatment. The protective agents are resin or urea.
Surface treatment method of wood	JP2008238418	2008-10-09	YASUNAGA SHINYA et al./ TOKUSHIMA KEN et al	To provide a surface cured coating film being a matte surface layer on the surface of wood by a simple method without using solvent type resin coating to finish the surface of wood so as to have natural mild feeling and to realize extremely excellent durability by curing the surface cured coating film to deposit a tough film. The surface treatment method of wood is composed of the coating process for coating the surface of wood with an uncured electron beam curable resin mixed with 5 wt.% or above of an inorganic powder to provide a coating film with a thickness of 10-500 [mu]m and the electron beam irradiation process for irradiating the coating film with an electron beam to cure the electron beam curable resin.	This invention is related to coat the surface of wood by an electron beam radiation
Surface treatment of wood	JP10080907	31-03-1998-	TAKAHASHI HIROSHI; TAKAHASHI KAZUO/ TAKAHASHI HIROSHI; TAKAHASHI KAZUO	The surface of wood is discolored to a sunburnt appearance state and is modified in quality by irradiation with ultraviolet rays without the use of a chemical or a coating material. As a result of this irradiation the wood turns yellow or yellowish brown and consequently, the surface tissue of the wood changes to have such a nature that it is hardly susceptible to an external influence. The surface color of the wood can be arbitrarily adjusted by the intensity of the ultraviolet rays to be emitted and their emission time, so that a finished product, if it is of the identical type, can be uniformly manufactured in the same color regardless of its quantity. Thus it is possible to inhibit the dispersion of an antibacterial active component or an aromatic component such as hinoki thiol contained in the wood on account of a change in the surface itssue and consequently, maintain the essence of the wood for a long time.	In this case the wood is treated by ultraviolet rays.

Surface treatment of wood	JP6170809 (A)	21-06-1994	NIKI MASAO/ DAIKEN TRADE & INDUSTRY	To obtain a wooden decorative material excellent in the surface protective properties of wood and surface appearance. An impregnating soln. containing a liquid reactive substance substantially non-volatile at room temperature and, where necessary, a catalyst thereof is applied to the surface of a wooden base material to be infiltrated in the surface of the base material and, thereafter, the impregnated base material is heated and pressed to react the reactive substance.	Once the coating solution is applied then the treatment is to heat and press the coating film.
Surface Treatment of Wood Material	**JP5069417**	23-03-1993	ISHIKAWA HIROYUKI ; USUI HIROAK/ MATSUSHITA ELECTRIC WORKS LT	To homogenously improve the surface wettability or film close adhesiveness of wood containing moisture more or less over a large area by enabling the plasma treatment to wood without requiring vacuum equipment. Wood whose moisture content is adjusted to a fiber saturated point or less is treated in plasma excited by performing glow discharge under atmospheric pressure or pressure in the vicinity thereof using upper and lower electrodes.	Plasma technology is only used to adjust the moisture content of wood.
Apparatus and method for treatment of wood, wood fibres and wood-based materials	WO/2008/085139	17-07-2008	CERNAK, Mirko; RAHEL, Jozef./ FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS OF COMMENIUS UNIVERSITY [SK/SK]	The present invention relates to an apparatus for surface treatment of wood, wood fibres and wood-based materials using the action of electric plasma. The invention disclosed herein includes at least one electrode system consisting of electrode systems and situated inside of a dielectric body. The electrode systems above which diffuse plasma is generated preferably at atmospheric pressure, are situated on the same side of the surface of wood, wood fibre layer or wood-based materials and are energised by alternating or pulsed electrical voltage applied between them. The invention further relates to a method for surface treatment of wood, wood fibres and wood-based materials, consisting in treating such surfaces with diffuse plasma generated using the apparatus according to the invention, preferably at atmospheric pressure. Such plasma-treated surface is then advantageously coated with a H_2O containing solution, or the surface is exposed to a monomer vapour or that of another organic substance, or is brought into contact with other materials, or is submerged into a liquid.	The patent explain an invention which uses the same technology that DURAWOOD system will use.

4.5.1 Conclusion of patent search

The large number of patents found revealed, have served to confirm the real need to find a technology capable of effectively treating the surface of wooden materials. Most of the inventions aimed at changing the characteristics of the wood surface to improve the performance of the coatings applied. It has to be emphasized that a variety of methods have been used *(thermal treatment, electron beams radiation, ultraviolet radiation*). 5 of the 11 patents reviewed in depth showed new methodologies or techniques that on the one hand improve the adhesion or the performance of the coating applied on the surface and on the other hand treatments that change the characteristics of the wood surface removing the most external layer which is damaged.

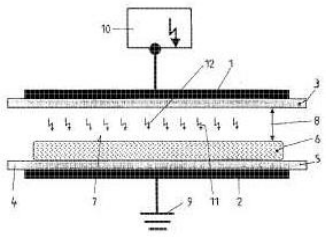
Concerning the rest of the patents that use plasma technology mainly with the aim of changing the surface properties of the substrate, not all the inventions are specifically directed to wood, but to cellulosic materials: textiles, wooden materials, cardboard or associated fibres.

Regarding the objective to apply the plasma technology to the surface, not all the patents about plasma technology claim to extend the durability of wood materials for outdoor purposes. In most cases, the aim of the application is to increase the adhesion of the coating to be applied without specifying the type of coating. Other plasma treatments aimed at increasing the adhesion of fire retardants on the surface or adjusting the moisture content of wood. Among the different patents using plasma technology, is relevant to emphasize and study deeply two of them due to their similarity to the DURAWOOD system: Method for modifying wooden surfaces by electrical discharges at atmospheric pressures (PL355633); Apparatus and method for treatment of wood, wood fibres and wood-based materials (WO/2008/0851390).

The first one, which was approved in 2005, is relevant because the invention has similarities to DURAWOOD in the objective of the treatment that is applied. The invention relates, on one hand, to a system to improve the adhesion of coatings for wood opening the pores between the wood fibres in such a way that coatings such as paints are better anchored. On the other hand, the system could increase the preservation of wood increasing the compaction of wood which will influence the wetting of wood. Other applications of the invention indicated in the patent are: to clean the wood surface by removing the superficial layer, to increase the capacity of the glues applied and bleaching the wood surface.

The system is composed of an electrode placed over the wood surface where a high voltage is applied to the electrode to produce a discharge at atmospheric pressure. The piece of wood is moved by means of belt conveyor.

Figure 4 shows a diagram of the system related to this patent. According to the patent, the plasma technology is corona discharge treatment, which is the main difference with the DURAWOOD system.

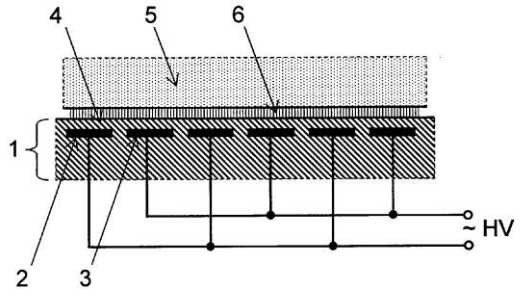


1. Electrode
2. Counter
3. Dielectric layer
4. Conveyor
5. Dielectric material
6. Wooden pieces
7. Wood surface
8. Distance
9. Earth
10. High voltage power supply
11. Discharge
12. Plasma

Figure 4. Diagram of patent PL355633

In relation to patent WO/2008/0851390, this consists of an invention to treat the surface of wood with a plasma layer generated on the surface of a dielectric body, which is separating conductive electrodes situated inside of the dielectric body. In that way the electrodes surfaces are not in contact with the plasma.

The plasma is generated in any working gas, preferably the working gas not containing helium and containing molecules of N2, O2, H2O, CO2, or monomer vapours. The plasma is generated at gas pressures ranging from 1 kPa to 1000 kPa, but preferably at atmospheric pressure. The DURAWOOD system will use the same electrode described in this patent, but the DURAWOOD system will incorporate the other parts needed to work in an industrial environment that this patent doesn't claim.



1 - electrode system
2 - system of electrically conductive electrodes
3 - system of electrically conductive electrodes –
4 dielectric body –
5wood, wood fibre layer, or wood-based material
6. electric plasma layer –
7. auxiliary electrode structure

Figure 5. Schematic cross sectional view WO/2008/0851390

In the light of the search performed here, it appears that the work being undertaken in the DURAWOOD project is not infringing on any protected area. The use of plasma to activate or modify surface is used widely in the industry. However, for the wood industry, the use of this technique is relatively new compared to the use of traditional techniques *(thermal and pressure treatments)* to treat wooden materials.

The section 5 of this deliverable “DURAWOOD System Specifications Report” is not provided in the publically available report.

6 Overall conclusions

The work documented in this report is part of the bottom-up research carried out in Work Package 1 of the DURAWOOD work plan- *WP1-Stakeholder Targeting and Industrial Specifications*.

The future research in the framework of the DURAWOOD project will be based on these results. In addition, the results of the laboratory scale trials will provide important background to supplement the findings of the European-wide survey, the in-depth consultations, on-site visits and the study on socio-economic aspects, and in this way feed the necessary inputs into the design and building of the precompetitive prototype that can then be validated and demonstrated in industry. Moreover, the results of this bottom up research will also feed into future dissemination and communication efforts, as a greater understanding of the needs and motivations of the target group has been obtained.

The main conclusions from the research work documented in this report can be summarised as follows:

- A clear need has been identified in the industry to improve the performance of water-borne coatings, in terms of enhancing wood protection against fungi attack and waterproofing.
- The envisage performance of the DURAWOOD system meets with the requirements of wood industry, in terms of the durability that will be offered by the DURAWOOD treatment, as well as the improved performance of water-borne coatings system against fungi. In addition, findings from the industry questionnaire-based survey and the industry consultations, have revealed a willingness to invest in such a system in view of tangible benefits and economic returns. To this end, it is necessary to carry out work during the project in order to quantify the estimated cost of the final system in the marketplace, establish and quantify the benefits that will be derived by the use of the system (which will give us the "Unique Selling Points" of the system) and to finally provide a calculation of a "return on investment" for end-users.
- From the on-site visits and in-depth consultations it has been further reinforced that wood manufacturers are not satisfied with current wood coating technology, which could be improved to extend the durability of wood.
- The number of patents reviewed, along with an analysis of new technologies/products that have appeared in the marketplace in recent years, have confirmed a big interest in the market to improve current coating systems for protecting wood against weathering and fungi. However, to date none of the currently available solutions will offer the technological innovations or performance of DURAWOOD.

It is important to stress that the literature and patents will be constantly reviewed throughout the project, in order to ensure that our research and development work continues to build on the state-of-the-art, as well as to keep abreast of intellectual property issues, to ensure that the results of our project can be properly protected and exploited. Further consultations with industry will also be carried out in order to ensure

that the results of this research are closely linked with industry needs, expectations and specifications, along all the levels of the development work.

Finally, a **SWOT analysis** has been carried out (See table 9 below) on the basis of the key findings and conclusions of this research. This analysis will assist us in identifying the main Strengths, Weakness, Opportunities and Threats of the proposed research. Such an analysis will provide us with invaluable information that can guide us during the remainder of the project, both in terms of the research and development work and its direction, as well as during the design and implementation of dissemination and exploitation activities to promote the future uptake of the results.

Table 9. SWOT analysis of DURAWOOD project

Strengths	**Weaknesses**
DURAWOOD will improve the performance of water-borne coatings, in terms of resistance to fungi and water-proofing, thereby tapping into a real market need DURAWOOD will be capable of providing durability of wood that is in line with the general market expectations, and the reports from laboratory trials and testing that will be carried out over the course of the project will provide evidence to support this, which will greatly assist in making claims The envisaged price of the DURAWOOD system can be tolerated in the market according to the findings of our research, this is be further strengthened by plans to provide some analysis of the potential return on investment over the course of the project. The market requires a tangible return on investment, and the ability of to quantify required investment and trade these against derived economic benefits from the use of the system will facilitate uptake The proposed DURAWOOD system will enable treatment to be carried out in-line and in the processors facilities, and this will be welcomed by the industry.	The DURAWOOD system will be validated only for the wood species and fungi selected in the project, however, in the future further research work can be carried out to validate its effectiveness for other species of wood and fungi. The system will need to be calibrated before its installation, in keeping with the effect desired by the wood manufacturer. It will be critical that this calibration stage is as simple as possible to avoid this posing a major weakness.
Opportunities	**Threats**
A clear need exists to improve the performance of water-borne coating systems against fungi and water. Currently available technology does not allow wood manufacturers to treat the wood against fungi in their facilities. Current technologies for protecting wood against fungi are based on thermal or pressure treatments, which require cylinder ovens and other expensive equipment. Currently the pre-treatment of wood against fungi	Wood industry is unfamiliar with plasma technology The size of the wood panels to be treated will determine the size of the plasma reactors. This will define the final cost of the system. Significant effort is being invested by industry players in order to develop improved coating systems, so DURAWOOD will require a swift route to market to ensure it stays in the lead

and protecting the wood from weathering are largely carried out by specialized companies. There are no available and efficient on-line wood coating techniques for wood manufacturing processes.	

7 Literature

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Annex I- Questionnaire for wood products manufacturer

1. Please select your country from the dropdown list
2. Please indicate your company's sector of activity (multiple answers are possible):
   - □ *Furniture Manufacturer*
   - □ *Manufacturer of wood structures for buildings: facades, doors, doorframes etc…*
   - □ *Wooden packaging materials manufacturer: box, pallets…*
   - □ *I am not involved in the wood industry or its supply chain, but I have expertise in this field.*
   - □ *Our company is not involved in wood market. (Then finish questionnaire, and this should pop up then: Thank you for your time- you do not need to complete the rest of the questionnaire).*
   - □ *Other(s), please state*

     _____

3. Please select your company's size from the dropdown list
   Insert size ranges in dropdown list
   - □ *≤10 employees*
   - □ *11-50*
   - □ *51-100*
   - □ *101-150*
   - □ *151-200*
   - □ *201-249*
   - □ *≥ 250*

4. Quantity of wooden product produced per month (m^3/year?)

   □

5. What kinds of wood species do you normally use? (multiple answers are possible)

   - □ Norway spruce - Picea abies
   - □ European larch - Larix deciduas
   - □ Sessile Oak - Quercus petraea
   - □ European Ash or Common Ash
   - □ Scots Pine - Pinus Silvestris

- □ Beech Copper - Fagus silvatica
- □ Other species, please state_____

6. Do you apply coatings to the wood?

- □ *Yes*
- □ *No,* please state why _____ (If no, go to question 7)

6.a.) if yes, what is the objective of the wood coating you apply? (multiple answers are possible)

- □ *Extending the durability of wood for outdoor conditions*
- □ *Waterproofing of wood*
- □ *Enhancement of aesthetic appearance of wood (gloss…)*
- □ *Modify the colour of the wood*
- □ *Protect the wood against fungi or mould*
- □ *Improve the mechanical properties of the wood*
- □ *Other reason(s),* please state_____

6.b.) if yes, What aspects of your current coating systems do you think could be improved? (multiple answers are possible)

- □ *Extending the durability of wood for outdoor conditions*
- □ *Waterproofing of wood*
- □ *Enhancement of aesthetic appearance of wood (gloss…)*
- □ *Modify the colour of wood*
- □ *Protect wood against fungi or mould*
- □ *Improve the mechanical properties of the wood*
- □ *Other reason(s),* please state_____

6.c.) If yes (6), what kind of coatings do you use? (multiple answers are possible)

- □ *Solvent borne coating system*
- □ *Water borne coating system*
- □ *Other coating(s),* please state_____

Any answer from 6.b.!

6.d). In your opinion which of the following statements are correct in relation to the performance of water borne coatings for wood? (multiple answers are possible)

- □ Wooden materials treated with water borne coatings are more susceptible to discolouring and damage by mould and blue stain fungi.
- □ Water borne coatings are less durable than solvent borne coatings.
- □ Water borne coatings offer lower resistance to water (waterproofing) of the wood in comparison with solvent borne coatings.
- □ The performance of water borne coatings is similar to that of solvent borne coatings.
- □ We need to apply more layers of water borne coatings to obtain the same performance of solvent based coatings, which is time and cost consuming
- □ Other (s), please state _____

7. In your opinion, which of the following wood decaying fungi is problematic for wooden facades, structures or packaging materials? (multiple answers are possible).
   - □ *Trametes versicolor*
   - □ *Lentinus lepideus*
   - □ *Schizophyllum commune*
   - □ *Donkioporia expansa*
   - □ *Gloeophyllum abietinum*
   - □ *Gloeophyllum trabeum*
   - □ *Coniophora puteana*
   - □ *Antrodia vaillantii*
   - □ *Antrodia serialis*
   - □ *Serpula himantioides*
   - □ *Serpula lacrymans*
   - □ *Oligoporus placenta*
   - □ *Paxillus panuoides*
   - □ *Other(s), please state:*_____ _____ _____
   - □ *I don't know*

8. What is the timeframe between the processing of the wood and its coating? (multiple answers are possible)

- □ *The coating is applied during the wood manufacturing process*
- □ *Less than 2 days*
- □ *Between 2 and 10 days*
- □ *Between 10 and 20 days*
- □ *Between 20 days and 30 days*
- □ *More than 1 month.*
- □ *No specific timeframe- the coating is applied just before wood distribution.*
- □ *Other treatment procedure*, please state_____

9. If it is applied during the wood manufacturing process, how much time does the complete coating process involve?

- □ *a few seconds*
- □ *10 to 30 seconds*
- □ *30 to 60 seconds*
- □ *1 to 5 minutes*
- □ *More than 5 minutes*

10. Would a wood coating pre-treatment stage be possible/acceptable in your facilities?

- □ Yes, if the pre-treatment is carried out on-line during the manufacturing process.
- □ Yes, even if the pre-treatment is done off-line.
  Other, please state_____

- □ No. Please state why:_____

11. What would be the minimum durability you would require from a wood coating system?

- □ Less than 5 years
- □ 5-8 years
- □ 8-10 years
- □ More than 10 years
- □ Of no significance to our application

12. Would your company value access to a novel plasma-based wood coating system to improve the performance of water borne coatings?
    - □ Yes, if it (please rank) *(very important, important, quite important, not so important, not important at all)* :
        - ✓ Reduces damage from fungi and moulds in woods.
        - ✓ Waterproofs the wood
        - ✓ Is easy to install and use
        - ✓ Extends the durability of the wood coating
        - ✓ Low cost to purchase and maintain
        - ✓ Swift to apply
        - ✓ Improves the mechanical properties of the wood
        - ✓ Other (s), please state:

          _____
          _____
          _____

    - □ No. Please indicate why:_____
    - □ To some extent

13. What would motivate your company to invest in a new technology, such as the proposed DURAWOOD plasma-based wood coating system?

    - □ *Market/consumer pressure to increase the performance of our wood coating systems*
    - □ *Environmental and social responsibility*
    - □ *To gain a competitive and marketing edge*
    - □ *To provide an effective alternative to solvent- borne coatings*
    - □ *Other- please* state_____
      _____
      _____
      _____

14. Would your company be willing to invest 30.000 € in a new plasma-based wood coating system?

    - □ Yes, if the technology enabled us to improve the performance of water borne coatings.
    - □ No

□ It depends. Please expand

_____
_____
_____
_____

□ Other, Please comment

_____
_____
_____
_____

15. Please add any comments you might like to make:

_____
_____
_____
_____
_____
_____

Thank you very much for your collaboration!

If you would like to enter the free draw to win a Barcelona Football jersey, simply include your email details:

_____

Annex II- Questionnaire for plasma equipment manufacturers

Dear Respondent!

Thank you for taking the time to complete this very simple questionnaire that is part of the work being carried out by the DURAWOOD project, which is being funded by the European Commission and which aims to develop a new technology for improving the performance of wood coatings systems. Your responses will be treated with utmost confidentiality and will only be used for the purposes of helping us to ensure that the needs of industry are taken into account adequately during the development work of the

proposed tool. For more information about the DURAWOOD project, please visit: www.durawood-fp7.eu

16. Please indicate your company's sector of activity: (Multiple answers possible)
    - □ *Manufacturer of open-air plasma equipment.*
    - □ *Manufacturer of open-flame equipment.*
    - □ *Manufacturer of Corona equipment*
      Manufacturer of Plasma equipment
    - □ *Manufacturer of vacuum Plasma equipment*
    - □ *Other pre-treatment technologies, please state*_____

17. *Do you also manufacture equipment for coating applications?*
    - □ *Yes, please state the type of coating*_____
      _____
    - □ *No*

18. *Which coatings do your customers apply after the pre-treatment? (multiple answers possible)*
    - □ *Paints*
    - □ *Varnish*
    - □ *Lacquers*
    - □ *Adhesives*
    - □ *Our customers don't apply any coating after the pre-treatment*
    - □ *I don't know*
    - □ *Other coating(s), please state*_____

19. In which sectors is your equipment applied? (multiple answers possible)

    - □ Automotive Sector
    - □ Packaging Sector
    - □ Food Sector
    - □ Medical Applications
    - □ Wood processing activities
    - □ Other(s), please state_____

20. What typically is the size of your clients? (multiple answers possible)
    - □ Mass production industries
    - □ Medium sized enterprises
    - □ Small enterprises

- □ Tailor-made solutions

21. What is considered as an acceptable market price for your products?

- □ 0 -5.000 €
- □ 5.001-10.000 €
- □ 10.001 – 20000 €
- □ 20.001-40.000 €
- □ >40000 €

22. Please rank the importance of the following characteristics for your customers in terms of pre-treatment equipment: (Very important, Quite Important, Not Important, Not so important, Not important at all).

- □ Easy to use and install
- □ On-line
- □ Low cost
- □ Fast
- □ Low Maintenance requirements
- □ Low Consumable cost
- □ Compatible with a wide range of substrates
- □ Efficiency of pre-treatment
- □ Stability of pre-treatment
- □ Modular or expandable
- □ Compliance with standards (ISO or EU Directives)
- □ After sales services

Please add any other characteristics that your customers would value

23. Have you ever developed equipment for pre-treating wood derivates (e.g. furniture, wooden structures for buildings, packaging, etc.)?
    - □ *Yes*
    - □ *No*
    - □ *No, but we plan to do so in the future*

8a *If yes*, To your knowledge is this equipment commercially available?

- □ Yes –*Then finish questionnaire, and this should pop up then: Thank you for your time- you do not need to complete the rest of the questionnaire).*

□ No

8a1). *If no*, In your opinion, why is such equipment not commercially available?

- □ Technical Reasons (such as insufficient adhesion, pretreatment stability or energy requirements...)
- □ Market Reasons (lack of demand, no business niche or excessive market cost of technology...)
- □ Don't know
- □ Other reason(s), please state_____

24. Would your company value incorporating equipment for optimising the pre-treatment of wood into its product line?
    - □ Yes
    - □ No, please state why
    - □ To some extent

25. Could you indicate the market price that potential customers might be willing to pay for wood pre-treatment equipment?

    - □ 0 -5.000 €
    - □ 5.001-10.000 €
    - □ 10.001 – 20000 €
    - □ 20.001-40.000 €
    - □ >40.000 €
    - □ I am not sure

26. Please add any comments you might like to make:

_____
_____
_____
_____
_____
_____
_____

Thank you very much for your collaboration!

If you would like to enter the free draw to win a FC Barcelona Football jersey, simply include your email details:

_____

Annex III- Cover letter for questionnaire survey

Dear Sirs,

We are currently working on an applied research and development project called DURAWOOD, which is being funded by the European Commission. The project aims to develop a cost-effective, ecological, high performance wood coating system, offering low fungicide content via the treatment of wood with electrical gas discharges (plasma). This new technology will help to overcome some of the limitations of water-borne coatings in terms of susceptibility to discolouring and damage by mould and blue stain fungi. It will be of significant value in light of the Paints and Coatings Directive (2004/42/EC) that requires the replacement of solvent-borne coating systems with water-borne coatings for outdoor wood preservation purposes.

In order to ensure that the needs of industry are taken adequately into account during the development work, we would be most grateful if you could take just two minutes of your time to complete a few simple questions. You can answer these questions on-line simply by clicking this link:

www.surveymonkey.com/s/wood_products_manufacturers

All responses will be treated with utmost confidentiality and will be used for the sole purpose of helping us to design the most suitable and versatile tool to meet the needs of industry.

As an appreciation for your collaboration, all respondents who wish to do so can enter a free draw to win a FC Barcelona Football jersey!

Thank you in advance and best wishes,

NAME

For more information about the DURAWOOD project, please visit: www.durawood-fp7.eu

Annex III- On-site visits semi-structured questionnaire

Title: Development of a novel solvent-free coating process for wooden facades

Acronym: DURAWOOD

Grant Agreement Number: 232296

ON SITE-VISIT INDUSTRY REPORT

Name of the company:

Location:

Date:

Authors:

Brief description of company

Briefly describe the company and process

Products

Size of company

Volume of product per year (m^3/year)….

Impacts of Paint Directive (2004/42/EC) on your industry

Changes in composition of products (in case of solvent or water borne coating producers)

Changes in manufacturing process

Increase of price per product

Changes in the coating purchased towards more environmentally friendly formulation (for wood producers)

Kind of species of wood used in your industry

List of species and their use (furniture or building structure)

Where the company buys the wood

Differences in wood quality depending on the origin

Specific problems to coat this species of wood

Kind of coatings used for wood in the industry and related coating processes

Kind of coatings used – water borne or water solvent, others…

How the company applies the coating: On line/Off line/ automated…..

Time between the product is manufactured and the application of the coating.

Problems related to the use of coatings. Problems related to the application of water borne solvents in the manufacturing process.

Purpose for coating the wood: Extend the durability of wood for outdoor conditions, To waterproof wood, Enhancement of aesthetics of wood (gloss…), To modify the colour of wood, To protect wood against fungi or mould, To improve the mechanical properties of the wood

…….

Performance of coating used for wood.

Water borne solvent – Problems related to their performance: less durability, more damage by mould and blue stain fungi…..

Solvent based coating: Problems related to their performance

Which durability of coated wood is acceptable- Do you offer a warranty about the durability- do you feel market pressure towards greater durability? Does the price of the items you sell depends a lot on the durability announced?

Parameters to improve – waterproof, damage by mould……

……

Wood decaying fungi

Main wood decaying fungi of wood

Problems caused by fungi in wood

Socio-economic aspects, market drivers, etc.

Interest of company to invest in Durawood system- what would motivate them to invest? (legislative pressure, market/consumer pressure, to gain a competitive edge, etc.)

Price that company would be willing to invest in DURAWOOD system

Minimum performance requirements that they would expect from such a solution

Have the invested in any alternative solutions? If so, are the satisfied with this solution, are there any limitations to this solution?

Are they aware of any alternatives technology/competing technologies?

Are they aware of any plasma-based technologies on the market?

How it fits in their operations/ modifications needed

Have they ever been approached by clients who request novel/improved wood coatings?

Would they be interested in finding out more about DURAWOOD in the future?