New protection technology to substitute creosote for the protection of railway sleepers, timber bridges, and utility poles (CreoSub)

FINAL REPORT

Title of the research project	New protection technology to substitute creosote for the protection of railway sleepers, timber bridges, and utility poles
Coordinator of the project	Ulrich Hundhausen

BASIC PROJECT DATA

Project period	01.07.2014-30.06.2017
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URL of the project	

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Germany Agency for Renewable Resources (FNR)	244 456 EUR

Other public funding:	No
Other funding:	338 000 EUR (industrial funding)

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DEGREES (if relevant)
Degrees earned or to be earned within this project

Year	Degree	Sex (M/F)	Name, year of birth and year of earning M.Sc., D.Sc., etc. Degree	University	Supervisor of thesis, supervisor's organization
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PROJECT SUMMARY REPORT

Creosote is one of the oldest industrially used and most effective wood preservatives, mainly used in heavy-duty applications outdoors with high demand to safety and service life, such as railway sleepers, utility poles, and timber bridges. Creosote however is controversial within the European Commission due to its toxicity and its approval for future use is questionable. Besides its strong biocidal effect, creosote confers hydrophobicity to wood, which counteracts crack formation and thereby reduces the risk of infestation by wood destroying microorganisms; this dual function is special for a wood preservative and makes great demands on finding substitutes.

The project CreoSub aimed at the development of alternative protection systems that show a better health and safety profile than creosote. With this objective, the efficacies of new preservatives against wood destroying fungi were investigated, impregnation processes were optimized, and physical and chemical properties of wood treated with the systems were examined. As an alternative protection technology to wood preservatives, the applicability of encapsulating wooden poles by extrusion of WPC (Wood Polymer Composite) or HDPE (High Density Poly Ethylene) onto the pole was investigated. Finally, the environmental impact of railway sleepers, utility poles, and timber bridge elements made of wood treated with new preservatives were assessed in life cycle analyses (LCA).

The use of wood plays an important role in the EU's ambition to stimulate the green shift, i.e., a shift towards a greener economy than today. A ban of creosote bears the risk that entire key markets for wood will be lost to non-renewable materials. Against this background, CreoSub's findings provide important data to assess the potential of the new protection systems to substitute creosote as wood preservative in heavy-duty applications outdoors.

1.1 Introduction

1.1.1 Background

Creosote is one of the oldest and most effective wood preservatives. The European Commission has however restricted the use of creosote during the last years due to environmental and health concerns. Creosote was added to Annex 1 (list of approved substances) of the European Biocidal Products Directive (BPD) in 2013 for an initial period of five years. This means that the use of creosote is still allowed for specific applications but it is highly controversial within the European Commission. Creosote's listing in Annex 1 of the BPD, i.e. the permission to use creosote as wood preservative also after 2013, was justified with the lack of alternatives and significant socio-economic reasons.

Besides its biocidal effect, creosote confers hydrophobicity to wood. The latter counteracts crack formation and thereby reduces the risk of decay. At the search for alternatives, the property of providing hydrophobicity is of special importance considering that highly effective biocides like CCA (copper chrome arsenic) and other chromium containing biocides have been forbidden due to their toxicity in Europe during the last years. Today's mostly used water-borne wood preservatives do not provide sufficient protection in many heavy-duty applications outdoors. Creosote's duality of being both biocidal and water repellent is special for a wood preservative and makes great demands on finding substitutes. The current lack of alternative wood protection systems bears the risk that entire key markets for wood, namely railway sleepers, utility poles and timber bridges, will be lost to non-renewable materials. This would not only hit the European timber industry hard, but also the users of creosote-treated wood. Wood has an excellent cost-benefit ratio and several favourable technical properties as compared to other materials.

1.1.2 Objectives

The overall objective of CreoSub was to develop new bi-functional wood protection systems based on modern, environmentally acceptable biocides in combination with hydrophobic wood-based components with secondary functions. These systems will substitute creosote in the production of railway sleepers, utility poles, and timber bridge components.

The scientific objectives were to assess the new protection systems regarding their:
- impregnation behavior,
- leaching profile,
- efficacy against wood destroying fungi,
- influence on mechanical properties,
- influence on metal corrosion,
- influence on electrical conductivity,
- influence on gluability,
- and environmental impact.

The technological objective was to develop production processes of railway sleepers, timber bridge components, and utility poles treated with new wood protection systems from laboratory to industrial scale, and to assess the performance of the products in laboratory with accelerated methods and under real conditions in the field. This implied to individually consider process-related, economic and environmental aspects for each of the three different product groups mentioned above.

1.2 Results and discussion

Water repellent agents are of special interest at the search for alternatives to creosote. In this regard, the performance of tall oil impregnated wood samples was analyzed in CreoSub that had been exposed in both in-ground trials and above-ground trials for a decade. Tall oil is a bio-based by-product in the Kraft process of wood pulp manufacture, which is mostly burned for energy generation today. The results revealed that raw tall oil or tall oil derivatives alone without the addition of biocides do not provide sufficient protection in heavy-duty applications outdoors; consequently, the main focus in CreoSub was on oily systems containing inorganic and organic biocides.

Laboratory decay tests according to EN 113 included 6 oil- or water-borne preservatives in up to 4 concentrations (Figure 1). The systems were tested against the white rot fungus *Trametes versicolor* and the brown rot fungi *Poria placenta, Coniophora puteana*, and *Lentinus lepideus* for 16 weeks. The results of the EN 113 tests gave initial indications for the required minimum uptakes (retentions) of the new systems that are necessary to sufficiently protect Scots pine (*Pinus sylvestris*) and European beech (*Fagus sylvatica*) against wood destroying fungi.

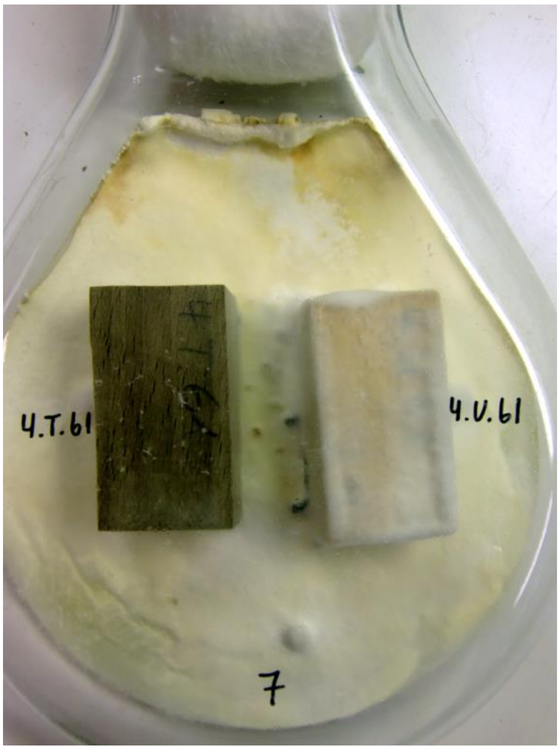

Figure 1. Decay test Kolle flasks (a special container for cultures) according to EN 113: preservative-treated beech wood (left) and untreated reference (right)

In addition to laboratory tests in Kolle flasks, laboratory decay tests in ground contact (Use Class 4) were carried out according to ENV 807. The investigations were done parallel at the University of Göttingen/Germany and NIBIO/Norway in different soil types. Potential decay was assessed by determining the mass loss and dynamic modulus of elasticity (stiffness). The tests included samples of pine and beech impregnated with 8 treatments in up to 6 concentrations. The test duration was double the duration given by the standard since the preservatives are meant to preserve wood in heavy-duty applications outdoors. The results of the EUV 807 tests gave important information on required preservative retentions under real-use conditions, and on the up-scaling of impregnation processes.

The laboratory results obtained in CreoSub must be verified outdoors and will therefore be successively supplemented by data from field tests during the next years. EN 252 stakes were installed at test sites in Norway, Germany, and USA to cover different soil and climate conditions. Though the stakes have been exposed and evaluated for approximately two years by the end of CreoSub, it is too early to draw reliable conclusions. According to EN 252, the minimum test duration is five years. The project partners will therefore follow up the performance of the test stakes during the next years.

Besides the investigations on biocidal efficacy, the ability of the preservatives to protect wood from crack formation under accelerated weathering conditions has been being investigated. Preliminary results of the ongoing test indicate that the new oil borne systems are as effective as creosote.

In addition to the small samples in laboratory and field tests, Norwegian utility companies are planning to erect 120 poles at two sites in coastal and interior Norway right after the project end to establish profound documentation on the performance of two of the most promising new preservatives under real-use conditions. The poles will be frequently inspected for decay and preservative migration during the next 20 years until 2037.

The driving force behind the legislative movement to ban creosote from the European market are health and environmental concerns. In this context, the stability of the preservatives against water leaching are of particular interest. Oily products showed less leaching of copper than water-borne products in tests according to EN 84 (Figure 2). Leachates from a study on full size railway sleepers are currently analyzed.

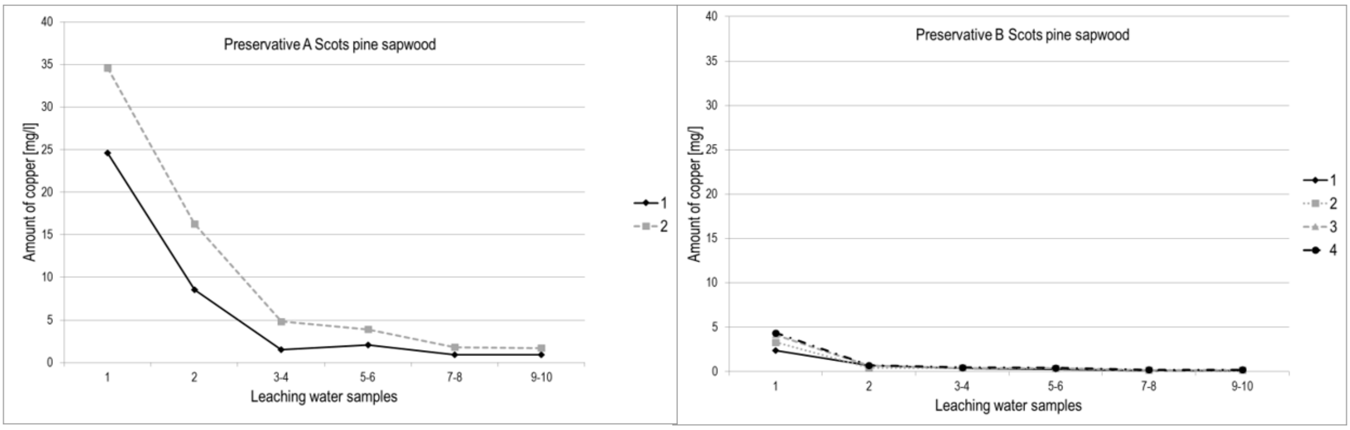

Figure 3. Amount of the biocide Cu in the leachate of pine samples submerged in water for 10 days. Left: pine wood treated with a water-borne preservative, right: pine pine wood treated with an oil-borne preservative.

The development of new preservatives includes to define optimum retention levels, i.e., a minimum level due to efficacy reasons and an upper limit due to economic and environmental reasons. This task was successfully addressed by the University of Göttingen, Koppers, and Lonza in a workpackage on impregnation optimization.

As an alternative protection technology to wood preservatives, the applicability of encapsulating wooden poles by extrusion of WPC (Wood Polymer Composite) or HDPE (High Density Poly Ethylene) onto the pole was investigated. The results showed that bolt insertions are susceptible to water intrusion into the wooden core of the pole. Such a defect would be difficult to detect at an encapsulated pole in service. Another disadvantage is that the surface of the HDPE-barriers is more slippery than a wood surface; this causes difficulties during transport, handling, and climbing of non-wooden poles according to the Norwegian utilities involved in CreoSub.

Investigations on the influence of the new protection systems on mechanics did not reveal any negative impact on the modulus of elasticity (stiffness), 3-point bending strength (static strength property), and impact bending strength (dynamic strength property). Moreover, drilling patterns to improve impregnability were optimized with respect to mechanics.

Electrical conductivity is an important material property for railway sleepers and utility poles regarding signaling and safety, respectively. Investigations in CreoSub did not show any increase in conductivity due to the new preservatives. Other aspects as metal corrosion and gluability are currently investigated.

CreoSub included life cycle analyses (LCA) to assess the impact of railway sleepers, utility poles, and timber bridge elements made of different materials on global warming and toxicity. The analyses considered following stages: the production of raw materials, transport to manufacturing, manufacturing process, use phase emissions, waste processing, and disposal.

Wooden utility poles impregnated with the new preservatives have a significantly lower impact on global warming (CO_2) than poles made of steel, composite (glass fibre reinforced polystyrene coated with polyethylene), or concrete reinforced with 100% recycled steel (Figure 4). Steel poles have clearly the highest effect on human toxicity, mainly due to outputs in the production phase. Also used as railway sleepers, steel has a stronger impact on global warming and human toxicity than impregnated pine, beech, or oak. The same applies to composite sleepers made of fibre reinforced foamed urethane (FFU). Concrete, however, show similar impacts on toxicity and global warming as wood in the conducted LCA studies on utility poles and railway sleepers. An LCA on timber bridge elements compared the environmental impacts of different types of double-impregnated glulam with each other. While the initial impregnation of the pine lamella was done with the same preservative (a copper based salt) for all types of glulam, the second impregnation differed. After gluing the lamella to a glulam, the entire beam was treated with 1) creosote (WEI C) as it is typically done in Norwegian timber bridge design, 2) a linseed oil based product, or 3) or a tall oil based product. Overall, the environmental impacts of the three products were in the same range.

A direct comparison between creosote and the new wood preservatives shows similar performances in all LCA; however, one important difference is creosote’s classification by the International Agency for Research on Cancer as a potential carcinogen based on adequate animal evidence and limited human evidence. This classification drives the debate on banning creosote, especially due to causing skin cancer. In an LCA, however, carcinogenicity related to direct skin contact is not addressed. The impact category toxicity is only based on emissions to air, soil and water, which in turn are considered as very difficult to assess due to high uncertainty regarding the characterization factors.

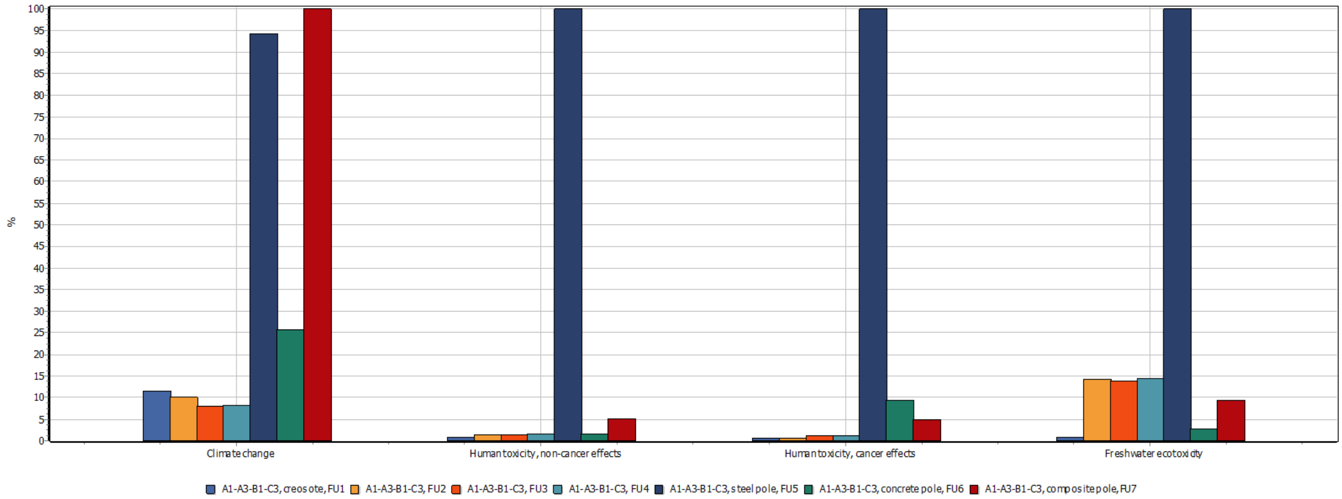

Figure 4. Impact categories (climate change, human toxicity non-cancer effects, human toxicity cancer effects, freshwater) in an LCA on utility poles. The results were normalized and equally weighted. Treatment from left to right: blue = creosote, yellow = new proeservative 1, orange = new proeservative 2, light blue = new preservtaive 3, dark blue = steel, green = concrete, red = composite

1.3 Conclusions

A broad spectrum of chemical and physical systems was investigated in CreoSub. At the project start, some of the chemicals were laboratory formulations, others had reached higher development stages but still had a strong demand for research and development. CreoSub's findings suggest that mineral or bio-based oils in combination with copper and organic co-biocides have the greatest potential to substitute creosote. Two of such systems investigated in CreoSub have been commercialized during the project time (see Chapter 1.4b). In conclusion, CreoSub's objective was obtained within the realms of possibility of a three-years project on wood durability. The results provide important data to assess the potential of the investigated protection systems to substitute creosote impregnated wood.

1.4a Capabilities generated by the project

CreoSub has generated a probable doctoral thesis with the title “Investigations of the properties of oil-borne preservatives as potential substitutes for creosote” at the University of Göttingen, which is going to be defended in 2017. Besides the “short time data”, i.e., those data obtained during the project time, the established field tests in Norway, Germany, and USA will give valuable long-time series on durability of various wood protection systems.

CreoSub's findings have been providing important data for the producers of preservatives, the impregnation companies, and the end-users to assess the potential of the investigated protection systems to substitute creosote impregnated wood. More detailed information on the capabilities generated by CreoSub are given under 1.4b.

1.4b Utilisation of results

A direct industrial exploitation of the results was inherent in the project structure: CreoSub included industrial partners covering entire added value chains for the most important products of creosote-treated timer. The results on durability must however be verified outdoors over many years. From a practical perspective, industry and stakeholders cannot afford the time required by nature to demonstrate comparable long-term performance of creosote, which has 100 years of empirical evidence. However, both the research and industrial project partners have always been aware of the necessity for long-time evaluation of product performance, and therefore initiated field tests with guaranteed funding for future inspections beyond the end of CreoSub.

Norwegian utility companies are planning to establish field tests with full size poles Norway right after the project end. One of the pole treatments will be done by the project partner Fürstenberg-THP who established wordwide's first impregnation plant for Koppers' natural oil based creosote substitute in summer 2017. The other pole treatment comes from the project partner Lonza Wood Protection who built a semi-industrial impregnation plant during the project duration for its oil-based preservative that is on the cusp to commercialization.

1.5 Publications and communication

a) Scientific publications

1. Articles in international scientific journals with peer review

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2. Articles in international scientific compilation works and international scientific conference proceedings with peer review

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3. Articles in national scientific journals with peer review

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4. Articles in national scientific compilation works and national scientific conference proceedings with peer review

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5. Scientific monographs

Stolze H (2016). Specific sorting of beech and pine sapwood according to criteria for testing the elasto-mechanical characteristics. Bachelor thesis, University of Goettingen, Wood Biology and Wood Products

6. Other scientific publications, such as articles in scientific non-refereed journals and publications in university and institute series

Gellerich A, Bollmus S (2014). Mögliche Alternativen zur Kreosotbehandlung von Bahnschwellen. Proceedings of Deutsche Holzschutztagung, Braunschweig, Germany. 18-19 September 2014. p 71-76

Hundhausen U, Mahnert K-C, Bollmus S, Militz H (2014). CreoSub: New protection technology to substitute creosote in railway sleepers, timber bridges, and utility poles. Proceedings of the 10th Meeting of the Northern European Network for Wood Science and Engineering. Edinburgh, Scotland, 13-14 October 2014. p 116-121

Hundhausen U, Mahnert K-C, Gellerich A, Militz H (2014). CreoSub – New protection technology to substitute creosote in railway sleepers, timber bridges, and utility poles. Proceedings of the 45th annual meeting of the International Research Group on Wood Protection. Utah, USA, 11-15 May 2014. IRG/WP 14-30644

Alfredsen G, Flæte P-O (2015). Tall oil - Performance after a decade of exposure. Proceedings of the 46th annual meeting of the International Research Group on Wood Protection. Viña del Mar, Chile, 10-14 May 2015. IRG/WP 15-30672

Mahnert K-C, Hundhausen U (2016). Encapsulation of poles to prevent moisture uptake - a laboratory test. Lisbon, Portugal, 15-19 May 2016. IRG/WP 16-40753

Starck M, Gellerich A, Militz H (2016). Impregnation of railway sleepers – Pressure gradient and transversal penetration. Lisbon, Portugal, 15-19 May 2016. IRG/WP 16-40731

Starck M, Gellerich A, Militz H (2016). Neue Schutzsysteme zur Substituierung von Kreosot für Bahnschwellen. Proceedings of Deutsche Holzschutztagung, Dresden, Germany. 22-23 September 2016. P 247-262

Tellnes L G F, Hundhausen U (2016). Life cycle assessment of creosote treated wood and tall oil treated wood with focus on end-of-life. Proceedings of the 47th annual meeting of the International Research Group on Wood Protection. Lisbon, Portugal, 15-19 May 2016. IRG/WP 16-50320

Mahnert K-C, Hundhausen U (2017). Review on protection of timber bridges in Norway and other countries. Proceedings of the 48th annual meeting of the International Research Group on Wood Protection. Ghent, Belgia, 4-8 June 2017. IRG/WP 17-40809

Starck M, Gellerich A, Militz H (2017). Penetration behaviour of different hydrophobic carrier substances for oily wood preservatives in Beech and Scots pine sapwood. Proceedings of the

48th annual meeting of the International Research Group on Wood Protection. Ghent, Belgia, 4-8 June 2017. IRG/WP 17-40804

Tellnes L G F (2017). Uncertainty in life cycle assessment of preservative treated wood – copper and freshwater ecotoxicity. Proceedings of the 48th annual meeting of the International Research Group on Wood Protection. Ghent, Belgia, 4-8 June 2017. IRG/WP 17-50331

b) Other dissemination

Anonymous (2013). Kreosot må erstattes med treimpregnering. In: Skogindustri (industry magazine). www.skogindustri-arkkiv.no, published unknown, accessed 01.06.2017

Gurandrud K J (2013). Kreosot må erstattes med treimpregnering. In: TREindustrien (industry magazine). http://trenytt.no/kreosot-m%C3%A5-erstattes-i-treimpregnering, published 05.12.2013, accessed 01.06.2017

Seehusen J (2013). Det beste impregneringsmiddelet blir forbudt. In: Teknisk Ukeblad (industry magazine). https://www.tu.no/artikler/det-beste-impregneringsmiddelet-blir-forbudt/275309, published 05.12.2013, accessed 01.06.2017

Hundhausen U (2014). CreoSub. In: Treteknisk Informasjon (industry magazine). 1: p 9

Hundhausen U (2014). CreoSub - New protection technology to substitute creosote for the protection of utility poles, railway sleepers, and timber bridges. Presentation at REN's R & D seminar (REN Faggruppe og åpent FoU møte). Oslo, Norway, 6. February 2014

Hundhausen U (2014). CreoSub. Presentation at Innovation Norway's seminar on timber bridges "Dialogmøte trebruer". Oslo, Norway, 27. August 2014

Hundhausen U (2014). CreoSub - New protection technology to substitute creosote for the protection of utility poles, railway sleepers, and timber bridges. Presentation at the 64th WEI-IEO Congress. Utrecht, The Netherlands, 12 September 2014

Anonymous (2016). Fant sunnere alternativ til kreosot. In: Byggmesteren (industry magazine). https://byggmesteren.as/2016/08/26/fant-nytt-alternativ-til-kreosot/, published 26.08.2016, accessed 01.06.2017

Anonymous (2016). Jakter fremtidens impregnering av treboroer. In: Byggeindustrien (industry magazine). http://www.bygg.no/article/1284859, published 26.08.2016, accessed 01.06.2017

Hundhausen (2016). Status for bruk av kreosot som trebeskyttelsesmiddel. In: REN-Nytt (industry magazine). 3: p 19-21

Hundhausen U (2016). CreoSub. Presentation at REN's seminar on electricity grid net (REN Faggruppemøte). Gardermoen, Norway, 19. April 2016

Hundhausen U (2016). CreoSub - New protection technology to substitute creosote for the protection of utility poles, railway sleepers, and timber bridges. Presentation at meeting of WoodWisdom project DuraTB. Oslo, Norway, 5. October 2016

Hundhausen U (2017). Ny beskyttelsesteknologi for å erstatte kreosot som impregnering av jernbanesviller, trebroer, samt el- og telefonstolper (CreoSub). In: Treteknisk Informasjon (industry magazine). 1: p 13-14

Schønhaug B H (2017). Jakter ny impregnering – Forskere er på jakt etter et stoff til å impregnere stolper med, som kan erstatte kreosot. In: energiteknikk (industry magazine). http://energiteknikk.net/2017/05/jakter-ny-impregnering, published 22.05.2017, accessed 01.06.2017

1.6 National and international cooperation

The project's international approach and the strong involvement of two suppliers of different wood protection systems provided a sound platform for finding viable alternatives to creosote, which was the motivation of all industrial partners for participating in CreoSub.

Development and commercialization of new wood protection systems require a coherent documentation of their performance. Round-Robin approaches are recommended in this regard, which were followed in CreoSub by conducting durability testing parallel in Norway, Germany, and partly the U.S.

Both the national and the international cooperation between the partners went smoothly and were characterized by mutual trust.

Creosote's status is widely discussed, not only in Europe but also the U.S. CreoSub has been presented at several conferences, congresses, seminars, and workshops (see 1.5 b). This has led to many interesting contacts and discussions also with non-partners, i.e., companies, administrations, and research institutes.

Ulrich Hundhausen was invited by Prof. Kjell Arne Malo to present CreoSub at a meeting of the WoodWisdom project DuraTB in October 2016 (see 1.5 b). This resulted in a new research proposal on timber bridges (H2020-NMBP-2016-2017) including partners from both consortia.