INFRES – Innovative and effective technology and logistics for forest residual biomass supply in the EU (311881)

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Development potential of inventions in forest biomass harvesting – D 6.3

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Content

Preface

Natural Resources Institute Finland (Luke) is coordinating a research and development project 'Innovative and effective technology and logistics for forest residual biomass supply in the EU – INFRES'. The project is funded from the EU's 7th framework programme. INFRES aims at high efficiency and precise deliveries of woody feedstock to heat, power and biorefining industries.

INFRES concentrates on developing machines for logging and processing of energy biomass, as well as transportation solutions and ICT systems to manage the entire supply chain. The aim is to improve the competitiveness of forest energy by reducing the fossil energy consumption and the material loss during the supply chains. New hybrid technology is demonstrated in machines and new improved cargo-space solutions are tested in chip trucks. Flexible fleet management systems are developed to run the harvesting, chipping and transport operations. In addition, the functionality and environmental effects of developed technologies are evaluated as a part of whole forest energy supply chain.

This publication is a part of the INFRES project. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2012-2015] under grant agreement n°311881.

This report presents the results of a Delphi study conducted in autumn 2014. The project studied the future potential of some selected technologies and inventions that can be applicable for forest biomass harvesting. These technologies are related to the fields of automation, robotics, computer vision, information technology (IT), propulsion systems, and modular mechanical engineering. Many of them are applied in other industries, and their pioneering into the forestry brand is in some cases quite recent. The panels of experts participating in this study cover most of the European region, and their responses gave insights into possible directions for technological development.

Maria Riala, Dimitris Athanassiadis, Pedro la Hera, Judit Rodriguez, Vantaa, Finland, January 2015

Title	**Development potential of inventions in forest biomass harvesting**
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Abstract	This report presents the results of a Delphi study, which explored the future potential of selected technologies in forest biomass harvesting. Delphi is an expert method of futures studies. It is based on the assumption that pooled expert opinion gives a more accurate view of the future than the views of individual experts. Our expert panel consisted of forestry researchers, engineering researchers, machine manufacturers and companies in the biomass harvesting chain. The experts were from all over Europe. The data includes 22 responses. The technologies from other fields that were seen as having the greatest potential in forest biomass harvesting were “Hybrid electric power system”, “Self-operating machines”, and “Ultra-low emission engines”. From technologies developed within forestry, “Automated loading of biomass harwarders”, “Open forest street map”, and “Machine vision” were thought to have the greatest likelihood of being in use by 2030. The inventions the experts most wanted to be adopted by 2030 were “Open forest street map” and “Machine vision”. There is significant overlap between the two categories. The open answers in the study revealed a number of barriers to adopting new technologies into forest biomass harvesting. Some of the barriers were cultural, other economic, while yet other were technical or questioned the benefits that could be gained from these inventions. Taking into account the barriers is important in development and implementation of new technologies, because if there is no market demand, it seems new technologies can fail.
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1 Introduction

Afforestation and natural succession have increased the EU's forest area by around 0.4% per year over recent decades. In EU, forests and other wooded land now cover 155 million ha and 21 million ha, respectively, accounting together for more than 42 % of EU land area (European Commission 2014). This contributes to 5% of the world's forest (European Commission 2013a), and presents a great diversity of character across regions.

According to estimates of the National Renewable Energy Action Plans, EU Member States plan to mobilise significant additional domestic biomass resources (76 Mtoe[1] in 2006 to 113 Mtoe in 2020) for heating and electricity generation (European Commission 2013b). If this is achieved, the amount of wood used for energy purposes in the EU would be equivalent to total wood harvest at present. Forestry will continue to be the predominant source of biomass supply, with a projected overall share of over 66% out of total biomass used for renewable energy in 2020 (European Commission 2013b).

Mechanisation of forest operations has been the main reason of productivity increase in the last 50 years. Current forestry equipment is multifunctional and productive. At the same pace with mechanisation, environmental problems and concerns have been increasing not only due to damage to the soil and residual trees, but also due to fuel consumption and emissions from the machinery during forest operations. The emission reduction is a key issue for forest machine industry and R&D efforts have been put to reach EU's emission directive for diesel engines

The competitiveness of the forest industries greatly depends on the development of forest machinery, tools and equipment with the aims of:

- reducing or mitigating impacts on soil (compaction, rutting, soil displacement), residual trees and atmosphere
- reaching higher productivity
- reducing consumption of fossil fuels and improving the energy balance
- decreasing the negative impact on operator's working environment (ergonomic, health and safety of forest workers)
- adopting advanced measurement and control systems to optimize the utilization of the forest biomass and to increase its value.

The introduction of forest machines and techniques with innovative technology for the harvesting and extraction of forest biomass will improve harvesting productivity, reduce fuel consumption and greenhouse gas emissions and not endanger sustainability of forest management (even if more volume has to be removed from the forest). Profitability and competitiveness of the forest contractors and the forest industry will be increased as more biomass is harvested at a lower cost.

In this report the term **invention** is used for commercially promising products that are based on new sciences or technologies. The term **innovation** is used for products that have already been

[1] Mtoe= million tonnes of oil equivalent, equals 41.868 GJ or 11.63 MWh

introduced in the forest machine market and are also an outcome of science and/or technology.

The future potential of inventions is assessed by the means of futures studies. Futures studies uses a variety of methods with which researchers try to make sense of the future or try to chart new future possibilities. The methods used can be quantitative (e.g. trend extrapolation, mathematical modelling), or qualitative (e.g. scenario writing, futures workshops, looking for weak signals, i.e. interesting things which might have a big impact on the future) (Kuusi et al. 2013).

In this study we use the Delphi method, which is an expert survey method (Kuusi 2003). It was developed in the 1950s in the RAND corporation, which is connected with the US defence industry (Linstone & Turoff 2011). The basic idea of Delphi method is that group opinion has a better chance of being correct about future than individual experts do. The future estimates produced by Delphi method are further improved because it removes the negative aspects of group communication, such as domination by few talkative group members.

The key features of Delphi are anonymity, iteration, controlled feedback, and statistical aggregation of group responses. While there is general agreement on these criteria, there is a lack of clear definition of what is a Delphi study. The key features mean that the participating experts are anonymous, in the sense that their statements cannot be connected to their identity. Often names are used in reporting to improve credibility of research. Iteration means that the respondents either answer a second round of questions, or have a chance to revisit the survey. Controlled feedback consists of some form of information about what the other respondents have thought about the issue. Combined with iteration this gives the respondents the opportunity to change their answers, if the responses of others are convincing enough. The last feature, statistical aggregation of group response, means that the opinions of all experts are included, not just opinions of the most talkative ones (Rowe & Wright 1999). In a Delphi study the quality of experts is also more important than the quantity of experts (Kuusi 2003)

Traditional Delphi method is aimed at consensus, which is one of the weaknesses of the traditional Delphi method. Nowadays the focus tends to be on finding out well-founded views of the future. Different types of Delphi methods have been developed. In Argument Delphi, the differences in viewpoints are the starting point, and they serve as a basis for synthesis. The participants then argue for different viewpoints (Kuusi 2003). Delphi can also be dissensus-based, i.e. use as heterogeneous group of experts as possible and focus on the variety of opinions (Steinert 2009). In a Disaggregative policy Delphi the responses of experts are clustered with the tools of cluster analysis. These clusters can be used for example for creating alternative scenarios (Tapio 2002). Asking about both probability and desirability of events or developments is standard in Delphi studies. It is possible that experts estimate the probability of desirable events higher than they should, so this provides a tool for evaluating the results (e.g. Kuusi 2003).

There have been shifts towards online, real-time Delphis for a while (Steinert 2009). Real-time Delphi reduces the time a Delphi process takes, and has particular advantages when synchronised participation or a smaller number of respondents are required (Gordon & Pease 2006). Real-time Delphi has also been claimed to reduce drop-out rates and be more accommodating to expert availability. The main difference between real-time and standard Delphi studies is immediate feedback, which is given to the respondents in the real-time version. Real-time Delphi can also result in more comments from the experts in comparison to the standard version (Gnatzy et al. 2011). There are different ways to perform real-time Delphis (Gordon & Pease 2006; Gnatzy et al. 2011).

The main purpose of this Delphi study was to analyse the likelihood and desirability that certain inventions would become commercially used by 2030, and also to assess whether certain enabling technologies could be adopted into forest biomass harvesting. These technologies are related to the fields of automation, robotics, computer vision, information technology (IT), propulsion systems, and modular mechanical engineering. Many of them are already being applied or adopted in other industries, and some of them are at the early stages of development.

2 Method and materials

2.1 The survey

This study used the real-time Delphi method. The data was collected with an online survey, using the eDelfoi tool (https://edelfoi.fi/). The tool is developed by an open community in Finland, with participation from the Finnish Society for Futures Studies. Before the collection of data, Maria Riala participated in three workshops organised by the developers of this tool in Finland, and got a lot of help on both planning a Delphi study and on technical features of the tool.

The survey (Appendix 1) consisted of two parts. In the first part experts were asked if some of the following technologies had potential for use in forest biomass harvesting:

- self-operating machines
- remote control of operating machinery
- hybrid electric power system
- use of sensors to improve machine functionality
- ultra-low emission engines
- machines with a modular structure
- machine operated by gestures and advanced human-machine interfaces

The respondents had to choose one of four alternatives

- already used
- good potential
- some potential
- no potential

In the second part of the survey, experts were asked to assess the probability of adoption, desirability of adoption and commercial potential of six inventions which have not yet been commercialised. All of these were defined in the survey. The details can be seen in appendix 1.

- machine vision[2];
- automated loading of biomass harwarders;
- cheap pneumatic delivery of wood chips;
- hybrid chipper;
- efficient solar dryer-sieve
- open forest street map

The survey was in English, and fluency in English was a requirement for the participating experts. The online tool gave instant feedback to the respondents by letting them see the answers and comments of others and see how their responses changed the distribution of all responses. Appendix 1 does not show all the functions of the online version, but includes all questions from the survey. The online survey also allowed us to include links to videos associated with a specific technology or to embed them, which meant that shorter explanations for technologies were sufficient.

The enabling technologies in this survey are technologies which are currently in use in other fields, and which might in the future also be used in forest biomass harvesting. Trends in machine technology and a list of possible enabling technologies were provided by VTT (Kiviniemi 2014). Some of the technologies included in this study are presented in the journal International Industrial Vehicle Technology (iVT 2014) in articles about developments in vehicle technology. These technologies were discussed within the WP 6 team, and the list was narrowed down.

The inventions, which are the topic for most of the Delphi survey, are based on the work done in WP 2 “Future technology, logistics and storage of forest energy” of the INFRES project. WP 2 focused on radical innovations and inventions in different parts of forest biomass production chain. The analysis of future potential of inventions in our project was initiated by taking the list of inventions and innovations collected in WP 2 (Prinz et al. 2013) and picking out those that were at the development or idea stages. We wanted to focus on inventions which might become successful, not the ones that have already achieved some level of success. Inventions in the very early stages of development are most likely not on the list, because the respondents might not be aware of these.

This process resulted in a list of 22 inventions. These were further divided by the stage of value chain they belonged in. The stages were harvesting, forwarding, transportation, chipping, storage and management. The expert rankings from WP 2 along with the authors’ opinions were used to narrow down the list to one invention per each stage of value chain, i.e. six innovations in total.

In this study, the experts assess both probability and desirability of adoption, because something probable can either be a thing the experts want or something they want to avoid. This helps with interpreting their statements. We also asked the experts to rank the commercial potential because this might give a third, alternative perspective.

[2] “Machine vision” refers here to computer vision mounted on forestry machines, and the video image is being processed to produce information in real-time.

2.2 The sample

In terms of geography, Nordic and Baltic countries, Central Europe and Mediterranean countries were included in the Delphi sampling frame. During the selection of the expert panel, INFRES consortium partners (some 60 people) were asked to identify experts that were either forestry researchers, engineering researchers, engineers engaged in machine manufacturing or personnel working in companies in the biomass supply chain. Including these professional categories ensured that we would get a wider expert view, which included also experts outside forestry.

A mailing list from the Cost Action FP0902 was used as the basis for finding potential respondents within the forestry researchers group. This mailing list was also used to increase the geographical spread of respondents, as it had names from countries in which INFRES participants did not have contacts.

Finding experts within the other professional categories proved to be surprisingly difficult. The Mediterranean region is underrepresented, mainly because of the requirement that the respondents should be fluent in English. For Central Europe, engineering researchers had to be searched for through websites of German universities and a research institute. Thus, knowledge of English could not be guaranteed. Finding of the contacts was so laborious that we did not find enough participants in the couple of months allocated for the search in spring, and had to postpone data collection until autumn.

Invitations were sent to the respondents on 2 September, 2014 by email through the eDelfoi-website. The invitations were personalised according to professional category. In total, 120 invitations were sent. They are broken down by geographical region and professional category in Table 1. Some of the respondents, particularly in the Mediterranean region, were contacted also separately by INFRES members who knew them. Reminders were sent out on 16 September. Those who had not responded were reminded that they still had time to fill in the survey while those who had responded were informed that they could now see more comments by others, giving more scope for iteration and feedback. The respondents had until 28 September to answer.

Table 1. Invitations sent

	Nordic and Baltic	Central Europe	Mediterranean
Biomass/ Forestry researchers	15	17	15
Engineering researchers	12	12	4
Engineers in machinery companies	9	9	7
Personnel in the biomass supply chain companies	11	5	4
Total (120)	47	43	30

2.3 The data

At the end of the data collection process, 29 responses were registered. However, some of those were completely empty, resulting in 22 usable responses. The response rate for usable responses is 18 %.There were large variations between regions with the fewest responses coming from Central Europe. For Mediterranean, the response rate was 27 %, which was mainly thanks to personalised contacts from the INFRES researchers. The usable responses are shown in Table 2. In this, the expertise areas are chosen by the respondents, and there is some mismatch between their and the authors' estimates. For example, people the authors thought were all engineers engaged in machine manufacturing classified themselves as forestry, engineering or machine manufacturing experts. The experts' own classifications are used in the analysis, because they are probably more accurate. Five experts did not answer the background questions. The anonymity settings of the survey tool were strong, and there is no information about the experts who did not fill in their background information, and it is not possible to tell which region they come from. In terms of countries, our respondents include people from Austria, Croatia, Finland, France, Italy, Latvia, the Netherlands, Norway, Portugal, Slovenia, Spain, and Sweden.

Table 2. Usable responses (n=22)

	Nordic and Baltic	Central Europe	Mediterranean	No background info
Forestry	3	3	4	-
Engineering	2	0	1	-
Machine manufacturing	0	0	2	-
Biomass harvesting	1	0	1	-
No background info	-	-	-	5
Total	6	3	8	**22**

The respondents were overwhelmingly male, only one of the people who filled in background questions was female. This was to be expected, as forest biomass harvesting is a very male dominant field. Most (8) of the respondents had worked in their current field for 5-10 years. The others had longer experience, 4 each had worked in their field for 10-20 years or for over 20 years. Twelve of the respondents had their highest degree from forestry, two from engineering, and one each from agriculture, business and chemistry.

The experts were asked to rate their expertise on forest biomass harvesting and related machinery, on machine technology in general, and on developments in information technology. The results are shown in Table 3. Respondents seem to be qualified to assess the development potential of inventions, as they have good knowledge of the current situation. When the expertise ratings were cross-tabulated, 15 of the experts had at least good knowledge in at least one of the fields, and only 2 had some or lower level of expertise in all fields. The overall expertise level is a little lower for information technology, which could indicate that assessments related to inventions in this category can be more uncertain. The list of experts who allowed us to publish their names can be found in appendix 2.

Table 3. Expertise of respondents in different fields, excluding those who did not answer background questions

	Expert	Good knowledge	Some knowledge	Little knowledge
Forest biomass harvesting and related machinery	5	7	4	1
Machine technology in general	2	9	5	1
Development in information technology	0	7	8	2

From the data it can be seen that two experts, who had started answering earlier, completed their answers after the reminders. It is possible that others made smaller changes to e.g. wording of their comments. In any case, this indicates that there was iteration, i.e. the experts revisited the survey. It can also be noticed from the comments that the experts read the comments of others, which means that they received the feedback. This is shown by comments which state that they agree with other specific comments, which they could not do if they had not read the comments. These aspects of the data show that the real-time Delphi worked and included the key features of Delphi. It should be noted that it is difficult to know for sure how much the opinions of others influenced the opinions of the experts.

The data was analysed by simple frequencies and cross-tabulations using SPSS. The number of data points is small, so possibilities for quantitative analysis are limited and it is not possible to find statistically significant differences. The comments were analysed by qualitative means, e.g. by looking for emerging themes and barriers. The comments included in this report were edited to improve clarity. Spelling mistakes were corrected and abbreviations were replaced with full terms. Comments which included both barriers and other discussion were divided so that the barriers are discussed in a separate section.

3 Results

3.1 Enabling technologies

Not all experts assessed the potential of all enabling technologies (Figure 1). Some technologies were seen as already in use in forest biomass harvesting. This was most commonly thought to be the case for “Use of sensors to improve machine functionality”. Over half of the respondents thought sensors were already used in forest biomass harvesting. “Remote control of operating machinery” and “Machines with modular structure” were also often seen as already used.

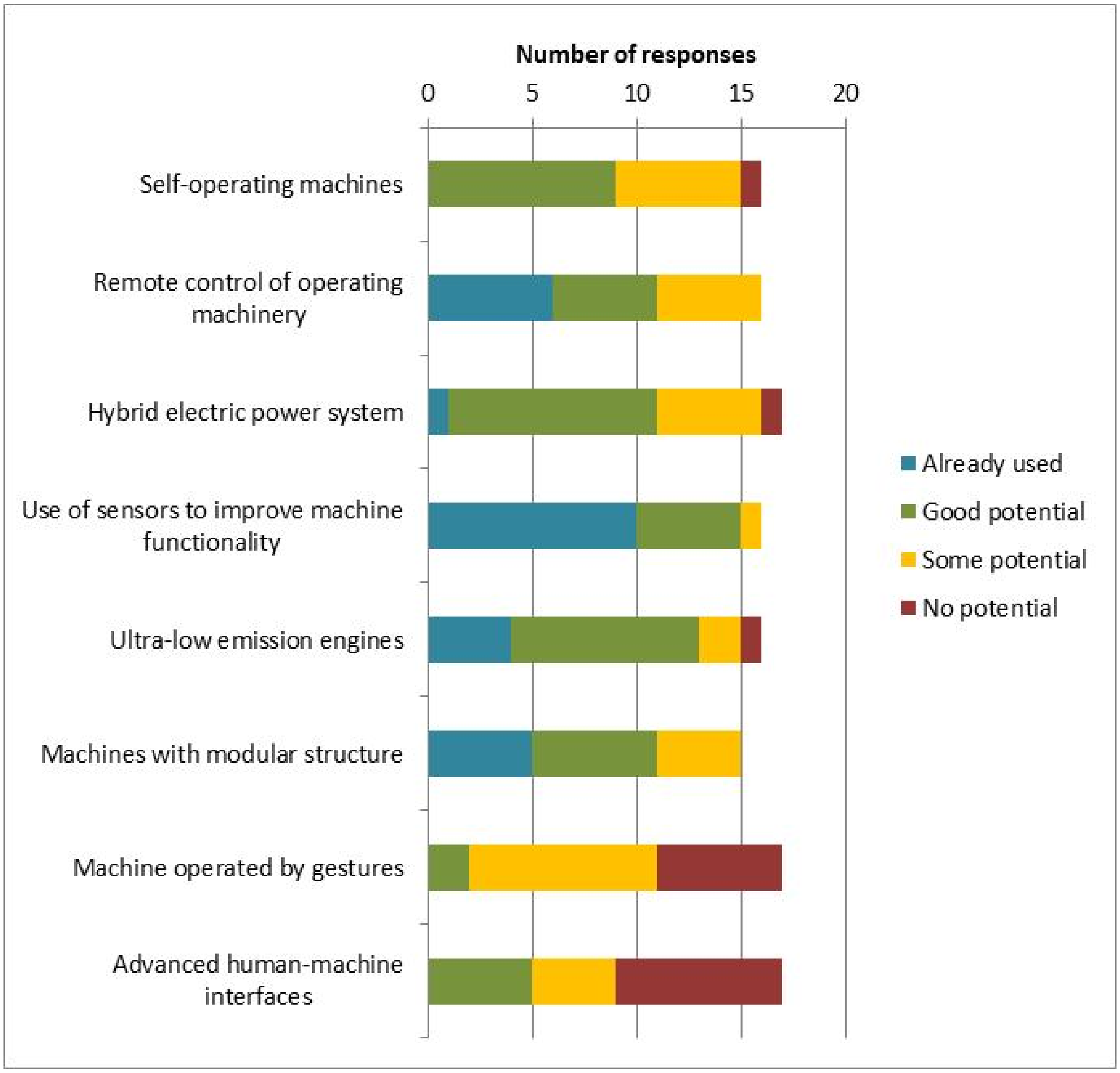

Figure 1. Potential of enabling technologies in forest biomass harvesting

At least some experts saw all technologies as having good potential for use in forest biomass harvesting. The ones seen as having good potential most often were “Hybrid electric power system” (10 experts), “Self-operating machines” (9 experts), and “Ultra-low emission engines” (9 experts). Good potential is the most common evaluation also for “Machines with modular structure” (6 experts).

The experts saw “Machine operated by gestures” and “Advanced human-machine interfaces” as the technologies having the least potential. The main problem with applying these in forest biomass harvesting was the time-frame, as the experts thought it would take more than 20-30 years before they would be in use.

Forestry experts rated more technologies as being already in use than the other professional groups. They though five technologies were already in use, and most of the others had good or some potential. They thought “Remote control of operating machinery”, “Hybrid electric power system”, “Use of sensors to improve machine functionality”, “Ultra-low emission engines”, and “Machines with a modular structure” were already used in forest biomass harvesting. It should be noted that there were considerably more foresters than other professional groups, which gives a greater chance than some of them perceive a technology as already used. The engineering researchers said that only "Remote control of operating machinery" and "Use of sensors to improve machine functionality" were already used. Biomass harvesting experts agreed about "Use of sensors to improve machine functionality" being in use, and also thought that "Machines with a modular structure" were already in use. The one machine manufacturer who answered this question thought that none of these technologies was in use.

Six out of eight Mediterranean respondents thought that sensors were already in use in forest biomass harvesting. The Central European respondents had similar distribution, with two out of three thinking they were already in use, while in Nordic and Baltic only two out of six experts thought so. Two of Central European and two of Mediterranean experts thought that "Ultra-low emission engines" were already used, while none of the Nordic and Baltic experts thought so. However, for the most part the experts from different regions had similar views on the current use of these technologies.

There were only small differences in perceived potential between experts from different regions. These are so small and inconsistent that it is more useful to look at the general picture shown in Figure 1. The differences between professional groups were similarly small, emphasising the usefulness of focusing on the compiled answers.

The experts also commented on the enabling technologies. Barriers are discussed separately in a later section, but these comments relate more to the specific technologies.

I think that a machine that is driven by a person but who automatically chooses which trees to log and carry out the work automatically is the way forward – more than one crane is then possible to use.

The simplest machine used also in forestry operations, i.e. tractor, has a modular structure. It may be used with winch, trailer, masticator, etc. So it is not a new idea. The same concept should be applied to the modern machines (forwarder, feller ...), that usually are more specialized for specific task.

I think hydraulic hybrids (or regenerative systems) have more potential than the electric ones as in typical harvesting machine almost all the operations are implemented using the only suitable power train which is fluid power. Why to transform the regenerated energy to form of electricity with poor efficiency as there is also possibility to use hydraulic regeneration.

For instance, there are already remote controlled comminution machines, (e.g. crusher operated from loader) whereas there will be a very long time until we have remote controlled harvesting or extracting machines that do the operations in a more efficient way than with manned machines.

These give an idea on ways in which the technologies could be incorporated into forest biomass harvesting. For example, it is an interesting idea that hydraulic hybrids might be better suited than electric ones, and this might offer ideas for new directions of technology development.

The main difficulty the experts had when assessing potential of technologies was the time frame. All of these technologies might have some potential, but whether or not they would have potential to be used soon was questionable. One expert commented that some of these concepts were so immature that they could be science fiction. This shows one of the difficulties of futures research, i.e. estimating when something might occur or become a realistic alternative.

3.2 Probability of adoption

The invention, which was thought to be most probably adopted by 2030 was "Automated loading of biomass harwarders", which 17 experts thought would be very likely in use. It is followed by "Open forest street map" (14 experts for very likely), and "Machine vision" (13 experts for very likely) (Figure 2). These results are not surprising, as these inventions are closer to commercialisation than the others. For example, there is already a prototype of a hybrid chipper (12 experts though it would very likely be adopted into use) (http://www.cdti.com/content/americas/news.asp?id=669239).

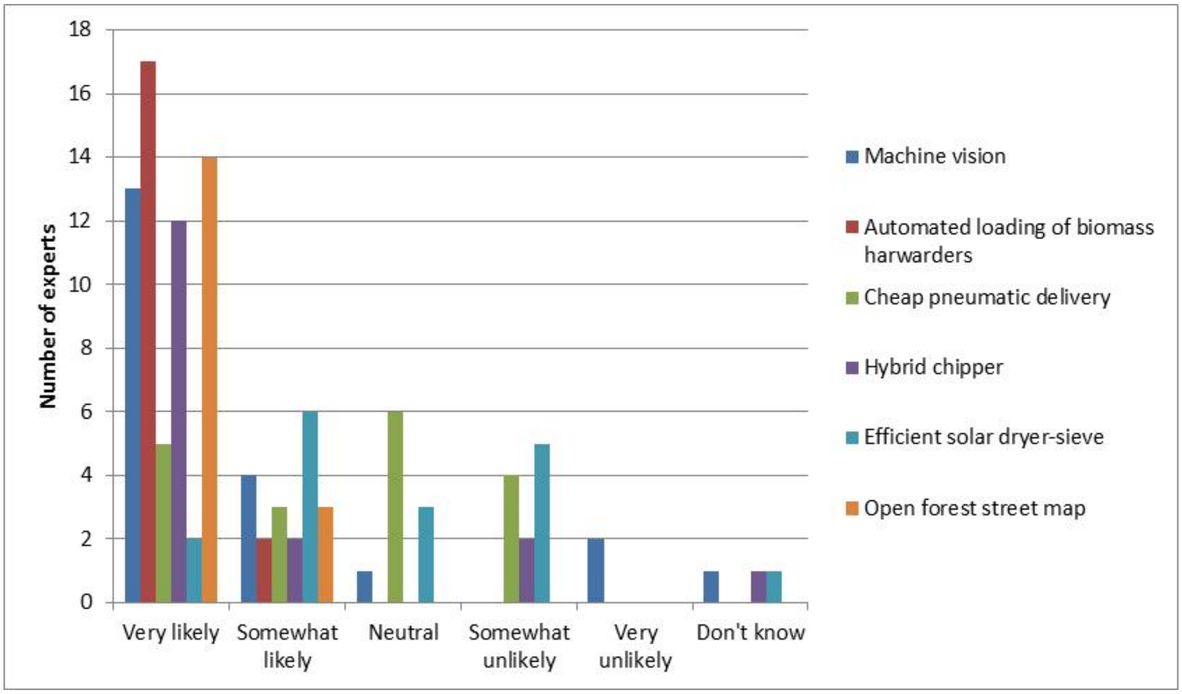

Figure 2. Probability of use in forest biomass harvesting by 2030

The experts gave some arguments to support their opinions on the probability of adopting these inventions into use. Two experts stated that automated loading of biomass harwarders would be easy to do, one of them specifying that this kind of work should be the easiest to automate. Another stated that this could have an impact in the case of automatic loading of a forwarder while driving. The following comment had more details:

Will be potentially a great relief for the truck drivers: ergonomics. Plus reduced weight of the truck as a crane cabin can be avoided and thereby improving the net load.

The arguments of the experts concerning automated loading make a lot of sense, which gives weight to their estimate that it will be used in forest biomass harvesting by 2030.

Only one comment contained a possible explanation for the adoption of an open forest street map. The rest of the comments were about barriers, and are discussed in a later section. The comment about probability of adoption was:

In most countries, I would guess there are attempts to have full coverage road network maps for planning of logistics.

This comment also makes sense, but it is a bit uncertain if the road network maps necessarily need to be open, rather than traditional proprietorial maps. It is also interesting that while many experts thought this invention would quite probably come into use, they did not provide their reasons for this estimate.

Also for machine vision there was only one comment providing reasons why it would probably be adopted. The rest addressed barriers to its adoption. The comment about adoption also raised some scepticism about whether it would be in the market within the time frame specified:

Machine vision is a prerequisite for the development of DSS (decision support systems) and (semi-) automation, and I'm sure there will be great advances within this field. But if it's on the market already within 16 years is not obvious.

The hybrid chipper got more comments about the probability of its adoption. The comments were as follows:

Hybrid is perfect for chipping - because of the highly oscillating load on the “power take-off”

Hybrids will definitely become more and more popular

Not to forget: eventually requirements from either forest owners or (more probably) from industry side to low CO2 impact in the delivered goods. If that adds to the low carbon profile of wooden products (from timber, paper, energy and bio based products) and gives a market premium than it might go fast.

The comments were an interesting mix of technical comments, and more societal or industry level observations. Taken together, these give quite a good picture of why hybrid chippers will quite likely be used in forest biomass harvesting in the future.

The experts thought that “Efficient solar dryer-sieve” and “Cheap pneumatic delivery” were the inventions with the lowest probability of being in use by 2030. Interestingly, the probability ratings for the “Efficient solar dryer-sieve” did not vary by region. It could have been assumed that it would be more probably used in the Mediterranean, but this was not the case. As could be expected from their lower probability of adoption, these mainly had barriers listed in the comment section, and they are discussed in more detail later on.

For probability of adoption there were no clear differences between experts from different country groups or with different expertise. This difference from the question on enabling technologies is interesting.

3.3 Desirability of adoption

The desirability ratings for the adoption of these six inventions are shown in Figure 3. It is quite similar to Figure 2, in that the same inventions are close to the top. “Open forest street map” and “Machine vision” are thought to be particularly desirable. The same inventions, “Cheap pneumatic delivery” and “Efficient solar dryer-sieve” are again those with lowest rankings. Experts seem to be uncertain if they should be adopted or not.

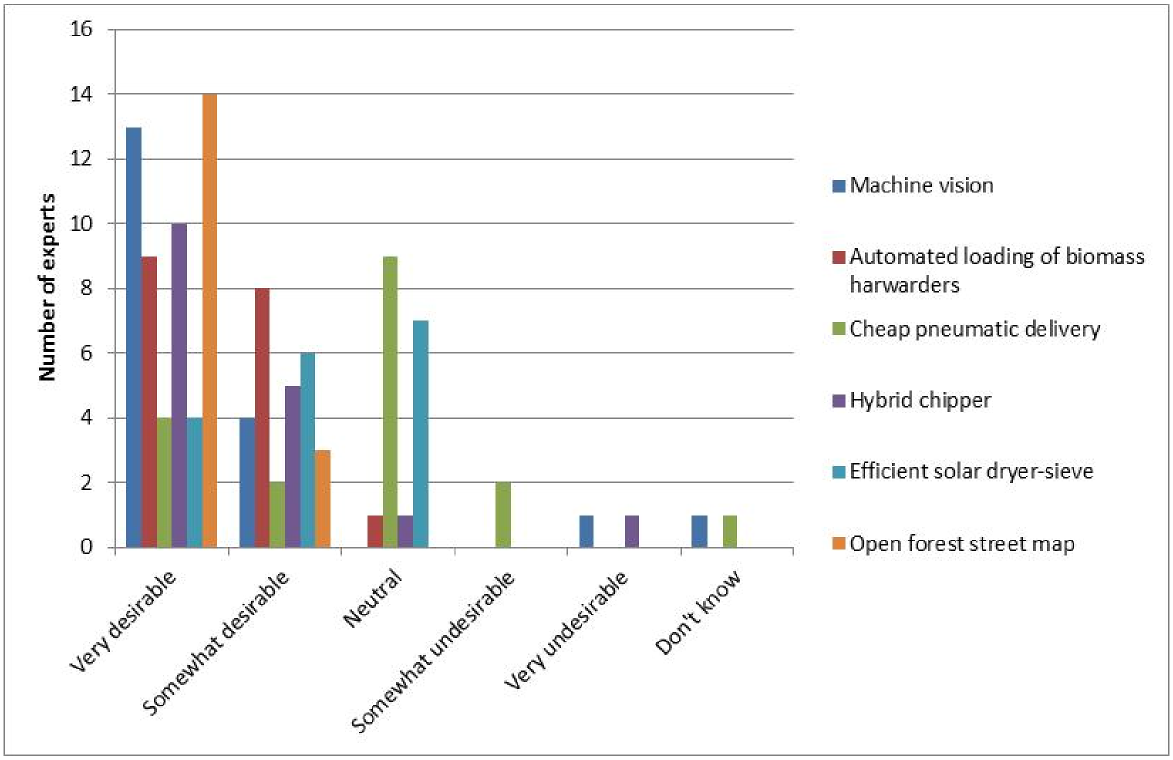

Figure 3. Desirability of use in forest biomass harvesting by 2030

There are two interesting exceptions. For “Automated loading of biomass harwarders” and for “Hybrid chippers” the desirability rating is considerably lower than their probability rating. They are still deemed desirable, but not always very desirable. This indicates some level of uncertainty among the experts, probably about the benefits the inventions can bring. The comments related to “Automated loading of biomass harwarders” stated that if it is easier, cheaper and safer it should be adopted. The underlying interpretation of this is that it is not yet proven that these improvements can be achieved with automated loading.

“Open forest street map” was deemed the most desirable invention to be adopted into use. The main reasons the experts gave for its desirability were that it would improve efficiency in logistics, and that it would adopt already existing features of urban logistics for forest logistics.

The desirability of machine vision inspired the following comments:

It will assist the harvesting operator in making better decisions and have better communication with the forest owner based on accurate data instead of discussions on feelings and opinions on what is good/bad for the forest. The problem is that forest owners do not have uniform opinions on their forest management.

Precise data that can be used to handle the economic transaction and improve planning.

It will provide valuable support for operator decisions, as well as provide required info for semi(automation).

Its main advantages seem to be that it would improve accuracy of harvesting operations and thus help with operator decisions and planning. These would help make forest biomass harvesting more efficient.

The comments relating to desirability of hybrid chipper concerned its impact on CO_2 emissions:

Less CO_2 emissions, better LCA [life-cycle assessment] of wood bioenergy against fossil sources.

Decrease of CO_2 impact is good as such, but there has to be a requirement or a market incentive that pays for it. Until now that is difficult to foresee.

The latter comment shows some scepticism, i.e. the idea that even though decrease of CO_2 impact would be good, if the market is not willing to pay for that, it will not happen. Just the benefit of lower CO_2 emissions is insufficient to have an impact on the probability of commercialising hybrid chippers.

For efficient solar dryer sieve the comments relating to desirability stated that:

Drying first with a clean, cheap and abundant energy it will be good, but it´s a dream for the moment

More energy efficient drying is highly desirable, but it does not necessarily has to be this invention.

The interpretation is that while improving energy efficiency of drying is desirable, there are different ways it can be used, and this is not necessarily the best. It should be noted that the survey did not have a video of this technology, because we were unable to find one, and thus it might have been difficult for the experts to understand what this technology comprises.

There were some differences between regions in terms of desirability of adopting these inventions. “Machine vision” was more desirable in the Nordic and Baltic region, while “Automated loading of biomass harwarders” and “Cheap pneumatic delivery” were less desirable in Nordic and Baltic than in other regions. Hybrid chipper was less desirable in Mediterranean than elsewhere, and the “Efficient solar dryer-sieve” was most desirable in Central Europe.

There were also small differences between experts from different fields. Engineers and machine manufacturers saw “Automated loading of biomass harwarders” as less desirable, and foresters were more positive towards “Cheap pneumatic delivery” than other professional groups. There were no clear differences for other inventions. This would seem to indicate that differences between regions are greater than differences between professional groups.

3.4 Commercial potential

The commercial potential is again rather similar to the probability and desirability rankings (Figure 4). “Automated loading of biomass harwarders” is thought to have the greatest commercial potential, followed by “Machine vision”. “Cheap pneumatic delivery” and “Efficient solar dryer-sieve” are again seen as having the lowest potential. “Cheap pneumatic deliver” has been most often ranked as the one with lowest potential, while “Efficient solar dryer sieve” has the lowest average rank. There are no noteworthy differences between regions or professional groups.

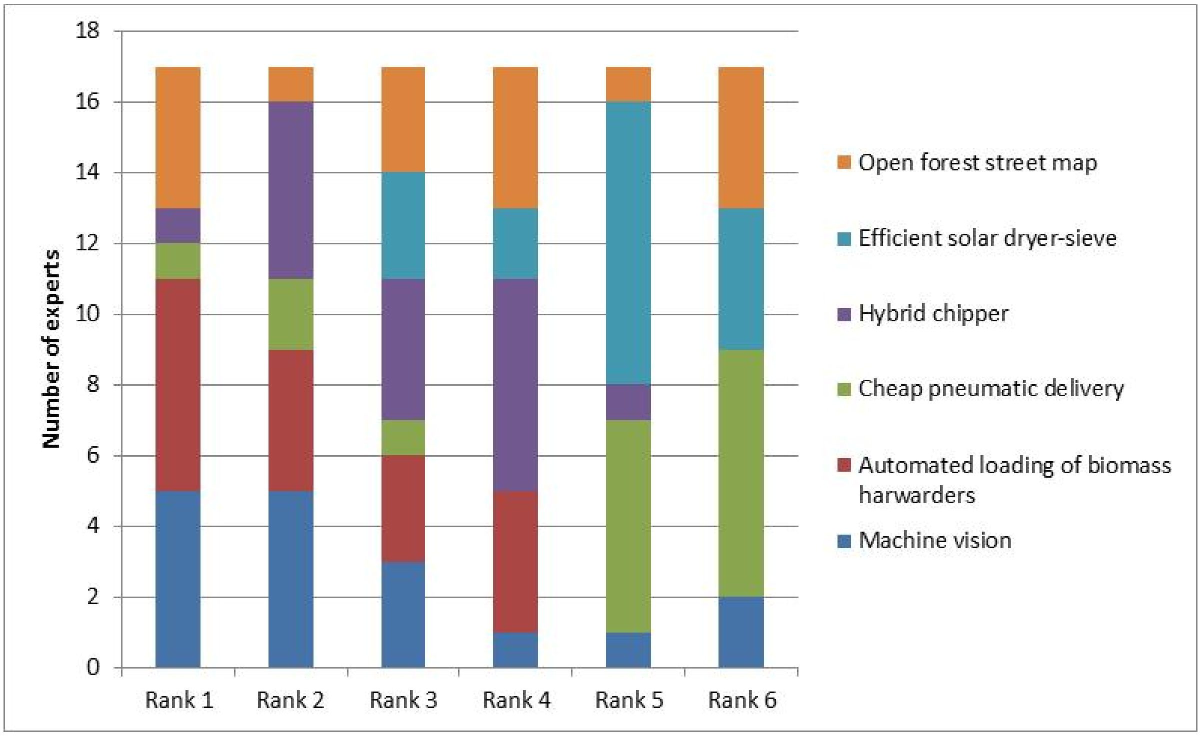

Figure 4. Commercial potential of inventions. Rank 1 the best commercial potential, rank 6 the worst commercial potential.

3.5 Barriers

The experts listed and commented upon many barriers for adopting these technologies and inventions. By looking at them qualitatively we can uncover the most serious barriers for adopting these technologies and inventions.

3.5.1 Enabling technologies

More general barriers, discussed in the context of enabling technologies, tended to relate to timing. The experts commented that the technologies in this part were so immature, that they would not be used in forestry in the near future. This applied particularly to “Machine operated by gestures” and “Advanced human-machine interfaces”, which were also seen as having the least potential for implementation. Other more general issues limiting entry to market are expressed concisely in the following comment:

> *New techniques have to be low investment and low maintenance and easily understandable in order to get a quick acceptance by the market. (Of course apart from the evident: must have potential to be cost effective and/or reducing workload/improving ergonomics.)*

3.5.2 Adoption of inventions

Mostly, the comments related to particular inventions, not development of innovations in general. The barriers related to “Machine vision” were an interesting mix of different issues. One expert pointed out that forest owners do not all have the same opinion on how their forest should be managed. The same expert had the following insightful comment on probability of adopting machine vision:

> *The concept relies on acceptance by the forest owner: in our country we're used to forest owners who insist on doing the marking of trees which have to be felled themselves. They want to be responsible for the choice of trees and also do not have sufficient trust in the entrepreneur: he might not be too knowledgeable and or might be tempted to cut down more trees and/or the better trees. Of course this is also related to the way the timber is sold. In our country, most of the time as standing stock. Furthermore it might be "easier" to develop for monocultures than for mixed stands and/or broadleaves. I'm pretty convinced that such systems will be very effective in plantations and in any case will help to better measure the trees that are felled and give information on the remaining stand.*

On the basis of this comment, one of the main barriers for adoption machine vision is the type of stand. Machine vision might work better in softwood dominated Northern Europe. Cultural issues relating to how timber is traded are also important. The other barriers mentioned were that it was unlikely that this would be adopted within the time frame given, and that machine vision might not provide enough gains in biomass harvesting to offset its costs.

For "Automated loading of biomass harwarders" the barriers mainly related to whether or not it would be sensible to adopt this technology. It was generally thought to be quite easy to adopt. There were doubts if this would reduce man and machine hours per production unit. An expert suggested that it might increase efficiency when loading a forwarder and driving at the same time, but that it would be difficult to increase efficiency when loading trucks at roadside. Another expert wanted test results showing that the operator would have good view of his work when standing on the ground, when compared to sitting in a crane cabin. In sum, the experts thought automated loading still required more research on its potential benefits.

"Cheap pneumatic delivery" was one of the inventions with a reasonably low probability of adoption. There were also more identified barriers for adopting this. There were questions about the distance over which this could be used, volumes, speed, competition with traditional pellet deliveries, cost efficiency, and energy demand. One expert disagreed with the use of pneumatics:

> *At the moment pneumatics, especially the compressors, are operating in such a poor efficiency that any other transportation method might be better.*

In sum, it seems that cheap pneumatic delivery requires more research and development before it is a viable option.

"Hybrid chipper" was thought rather likely to be adopted. Nevertheless there were some obstacles to its adoption. One expert thought that if it would improve the low carbon profile of wooden products and give a market premium it could be adopted fast. Another questioned the use of electricity with poor batteries and super capacitors, when it would be possible to use a hydraulic accumulator. This might be an interesting alternative development idea.

"Efficient solar dryer-sieve" was also thought not that probable for adoption, and a number of barriers were listed. It was thought to be undeveloped ("a dream for the moment"), and not proven to be economically efficient. One expert stated that this might work in some parts of the world, and another that while more energy efficient drying is desirable, another method could be used. A detailed comment sums a number of barriers, and two other experts agreed with this:

The extra cost related to the handing (spreading out and collecting), and the capacity (drying speed related to volume needed per time unit, and area available) and the reliability of the drying (what happens if there is a very cloudy, rainy summer).

In sum, efficient solar dryer-sieve faces a number of barriers, mainly technological and economic.

The barriers discussed in the context of the “open forest street map” were quite different from others. They related mainly to the quality of data fed into the system.

The bottleneck is the quality of the data. Lengths, locations etc. is no problem, but the bearing capacity of the road is. Both because it is difficult to assess, and because it changes depending on the weather (assuming that forest roads are gravel roads). So the largest need is to have such an interacting map, in which road status is updated in relating to weather data. This requires naturally very good road quality data, and good models for how various road qualities are influenced by various weather conditions.

Other interesting points were that this would require some way to motivate truck drivers to update the map. The map would also require information about the degree of maintenance of the road. One expert pointed out that the type of trucks used would also need to be used as a variable. Whether or not the trucks have central tyre inflation in place can also have an impact on the feasibility. The open forest street map seems to require some more development to address these issues relating to data quality.

In summary, there a successful innovation requires cost or time savings in comparison to current technologies. Reliability is also important. Other questions to take into account are the regional cultural habits in forest harvesting and trading, and the needed updates to work with an innovation (“Open Forest Street Map”). Finally, an external aspect that affects potential innovations is market priorities. For example, the more value a market gives to CO_2 savings, the faster the hybrid chipper will be developed.

4 Conclusions

Overall, it seems that the experts’ opinion is that technological development in forest biomass harvesting will continue in the coming years. Some technologies from other fields were deemed to have more potential than others in forestry. “Hybrid electric power system”, “Self-operating machines”, and “Ultra-low emission engines” were thought to have the greatest potential for use in forest biomass harvesting. These are already quite well developed in other fields, and on the basis of our study it seems that they will probably become adopted also in forestry. The directive concerning low emission engines is promoting the introduction and development of this technology also in the forest energy sector.

In terms of probability of adoption, “Automated loading of biomass harwarders”, “Open forest street map”, and “Machine vision” were thought to have the greatest potential. They were also thought to be the most desirable inventions, so it is possible that there is some dependence between these two assessments. However, the inventions that were thought to be the most probably adopted are also the ones that are furthest developed, and might for example have already existing prototypes. Thus, it is possible that the experts just evaluated their potential realistically.

We also identified a number of barriers to adopting these technologies. The barriers, as discussed above, include a wide variety of issues. Some are more cultural, e.g. acceptance might depend on ways of doing harvesting and ownership of forest. Some are more technical, while yet others revolve around the need for more test results to show that there would be benefits from adopting these. The barriers need to be taken into account in product development. For example, it might not be useful to market machine vision to harvesting companies, if the forest owner in any case wants to decide themselves which trees to harvest.

References

European Commission, EU forests and forest related policies. http://ec.europa.eu/environment/forests/home_en.htm 2014, (accessed October 2014).

European Commission, A new EU Forest Strategy: for forests and the forest-based sector. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. http://ec.europa.eu/agriculture/forest/strategy/communication_en.pdf 2013a, (accessed October 2014).

European Commission, Commission staff working document. http://ec.europa.eu/agriculture/forest/strategy/staff-working-doc_en.pdf 2013b, (accessed October 2014).

Gnatzy, T., Warth, J., von der Gracht, H., Darkow, I.-L., Validating an innovative real-time Delphi approach – A methodological comparison between real-time and conventional Delphi studies. Technological forecasting and social change, 2011, vol. 78, pp. 1681-1694.

Gordon, T. & Pease, A., RT Delphi: An efficient, "round-less" almost real time Delphi method. Technological forecasting and social change, 2006, vol 73, pp. 321-333.

IVT, http://www.ivtinternational.com/ 2014, (accessed November 2014).

Kiviniemi, T. Personal communication with Maria Riala, 2014.

Kuusi, O. Delfoi-menetelmä (The Delphi method). In M. Kamppinen, O. Kuusi & S. Söderlund (eds) Tulevaisuudentutkimus – Menetelmät ja sovellukset (Futures research – Methods and applications), Suomalaisen kirjallisuuden seura, Helsinki, Finland, 2003.

Kuusi, O., Bergman, T. & Salminen, H. Miten tutkimme tulevaisuuksia? (How do we study the futures?), 3rd edition, Tulevaisuuden tutkimuksen seura Ry, Helsinki, Finland, 2013.

Linstone, H. A. & Turoff, M. Delphi: A brief look backward and forward. Technological forecasting and social change, 2011, vol. 78, pp. 1712-1719.

Prinz, R., Asikainen, A., Holzleitner, F., von Hofsten, H., Enström, J., Fogdestam, N., Eliasson, L., Johannesson, T. and Nordfjell, T. 2013. Technology push – technologies for the residual biomass Harvest for the future – D2.1. http://www.infres.eu/en/results/ (accessed November 2014).

Rowe, G. & Wright, G. The Delphi technique as a forecasting tool: issues and analysis. International journal of forecasting, 1999, vol. 15, pp. 353-375.

Steinert, M. A dissensus based online Delphi approach: An explorative research tool. Technological forecasting and social change, 2009, vol. 76, pp. 291-300.

Tapio, P. Disaggregative policy Delphi: Using cluster analysis as a tool for systematic scenario formation. Technological forecasting and social change, 2002, vol. 70, pp. 83-101.

Tapio, P., Paloniemi, R., Varho, V. & Vinnari, M. The unholy marriage? Integrating qualitative and quantitative information in Delphi processes. Technological forecasting and social change, 2011, vol. 78, pp. 1616-1628.

Appendix 1 – the survey

Please note that the survey of course looked different in the online version.

Welcome to our survey!

This survey is concerned with the future of forest biomass harvesting and the development potential of new inventions. It forms a part of the research project "Innovative and effective technology and logistics for forest residual biomass supply in the EU – INFRES", which is coordinated by the Finnish Forest Research Institute. More information about the project can be found at http://www.infres.eu/

The first part of the survey consists of a short evaluation of the potential a few technologies from other fields might have in forest biomass harvesting. Forest biomass harvesting includes the collection of logging residues and small diameter trees from forests for use in energy production.

The main part of the survey asks you to evaluate six inventions in the light of the probability of their success and the desirability of their adoption.

In the end there are a couple of background questions.

We hope you will also look at the comments provided by other experts. If you feel you do not know enough about a particular question to answer it, you can skip it. You can move between questions and edit your answers through the numbers at the bottom of the page.

If you have any questions, please contact researcher Maria Riala at **maria.riala@metla.fi**

(NEXT PAGE)

Enabling technologies

Technological development of large machinery is not limited to forestry. These technologies are to some extent already in use in other fields. We are interested in their potential in forest biomass harvesting. Please drag the technologies in the boxes you think are appropriate, each technology into only one box. You can also comment on your reasoning and see the comments of others in the box below.

More information about the technologies:

Self-operating machines - Full automation of machines is already more advanced in fields such as mining and harvesting of crops. In forestry, machines, such as forwarders and harvesters could be made self-operating.

Remote control of operating machinery - Often, a first step towards full automation is the use of some form of teleoperation. This is done usually to introduce the new design (imagine of a machine with no cabin), and the way it can be operated. One form to operate machines in this form is by remote control, where an operator stands close to the machine or further away giving commands through teleoperation.

Hybrid electric power system - Hybrid electric power systems do not rely only on fuel, and as a result produce less emissions. More information for example at https://www.youtube.com/watch?v=4kFsJx_TR3c

Use of sensors to improve machine functionality - Most modern automated tasks run according to computer algorithms. These algorithms compute instructions according to the systems status measured with sensors. Many machine functionalities can be improved in this form, by combining sensors and computer algorithms. This is known as computer controlled systems.

Ultra-low emission engines - New restrictions on emissions allowed for vehicles are leading to development of new types of engines with lower emissions. Developments revolve around fuel quality and combustion technology.

Machines with a modular structure - Machines with modular structure include both coupled systems (where for example cab can be detached from the rest of the machine) and machines which can switch between different functions. An example is here https://www.youtube.com/watch?v=r95Oz2SrOFA

Machine operated by gestures - Controlling systems with gestures, such as body movement, head movement, hand movement, eye movement, could be used for controlling the motion of cranes, vehicle, attachments and harvesting heads. This is currently used in industries such as automotive, mining, defense, entertainment, and gaming. An example can be seen here https://www.youtube.com/watch?v=gB-qIjhFR8c

Advanced human-machine interfaces – Machines can be controlled for example by using the mind https://www.youtube.com/watch?v=ogBX18maUiM or by muscular electrical activity https://www.youtube.com/watch?v=W6PznRXhDdw These are already being adopted in e.g. entertainment and military industries.

Grouped into: Already used in forest biomass harvesting, Good potential for use in forest biomass harvesting, Some potential for use in forest biomass harvesting, No potential for use in forest biomass harvesting

(NEXT PAGE)

Machine vision - probability of adoption

The basic idea of machine vision is to have 2D/3D laser scanning of trees during logging. Thereby, more precise information about forest inventory and remaining trees will be available. The tool helps the operator to decide how many and what kind of trees need to remain in the forest stand or will have to be removed. In your opinion, how probably will machine vision be in commercial use by 2030? Give your opinion on the scale, and comment on the most important barriers to adoption in the comment box below.

An embedded video showing machine vision http://www.youtube.com/watch?v=tLbWXvF9prw

(NEXT PAGE)

Machine vision – desirability

The basic idea of machine vision is to have 2D/3D laser scanning of trees during logging. Thereby, more precise information about forest inventory and remaining trees will be available. The tool helps the operator to decide how many and what kind of trees need to remain in the forest stand or will have to be removed. In your opinion, how desirable it is that machine vision will come into general use? Give your answer on the scale, and in the comments box, describe the main benefits adopting this invention will have.

The same embedded video about machine vision
http://www.youtube.com/watch?v=tLbWXvF9prw

(NEXT PAGE)

Automated loading of biomass harwarders - probability of adoption

Often, a first step towards full automation is the use of some form of teleoperation. At the moment, remotely controlled and automated loading devices for harwarders are under development. In your opinion, how probably will automated loading be in commercial use by 2030? Give your opinion on the scale, and comment on the most important barriers to adoption in the comment box below.

An embedded vision about teleoperation https://www.youtube.com/watch?v=Qd3rs3ZF2a8

(NEXT PAGE)

Automated loading of biomass harwarders – desirability

Often, a first step towards full automation is the use of some form of teleoperation. At the moment, remotely controlled and automated loading devices for harwarders are under development. In your opinion, how desirable it is that automated loading will come into general use? Give your answer on the scale, and in the comments box, describe the main benefits adopting this invention will have.

The same embedded video about teleoperation
https://www.youtube.com/watch?v=Qd3rs3ZF2a8

(NEXT PAGE)

Cheap pneumatic delivery - probability of adoption

The system is to be used in order to supply wood chips to locations with poor accessibility. The invention proposes a cheaper pneumatic delivery of wood chips. In your opinion, how probably will cheap pneumatic delivery be in commercial use by 2030? Give your opinion on the scale, and comment on the most important barriers to adoption in the comment box below.

An embedded video about pneumatic delivery http://www.youtube.com/watch?v=eSBgnVY-Qjg

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Cheap pneumatic delivery – desirability

The system is to be used in order to supply wood chips to locations with poor accessibility. The invention proposes a cheaper pneumatic delivery of wood chips. In your opinion, how desirable it is that cheap pneumatic delivery will come into general use? Give your answer on the scale, and in the comments box, describe the main benefits adopting this invention will have.

The same video about pneumatic delivery http://www.youtube.com/watch?v=eSBgnVY-Qjg

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Hybrid chipper - probability of adoption

Hybrid electric power systems do not rely only on fuel, and as a result produce less emissions. There are on-going developing efforts for a hybrid power engine within a wood chipper. In your opinion, how probably will hybrid chippers be in commercial use by 2030? Give your opinion on the scale, and comment on the most important barriers to adoption in the comment box below.

An embedded video about hybrid electric power systems https://www.youtube.com/watch?v=4kFsJx_TR3c

(NEXT PAGE)

Hybrid chipper – desirability

Hybrid electric power systems do not rely only on fuel, and as a result produce less emissions. There are on-going developing efforts for a hybrid power engine within a wood chipper. In your opinion, how desirable it is that hybrid chipper will come into general use? Give your answer on the scale, and in the comments box, describe the main benefits adopting this invention will have.

The same video about hybrid electric power systems https://www.youtube.com/watch?v=4kFsJx_TR3c

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Efficient solar dryer-sieve - probability of adoption

The basic idea behind this idea is to have a solar dryer, e.g. greenhouse-based with flat screening capabilities. Thereby, wood chip quality is improved with low investment and operation costs, depending on sun radiation conditions. In your opinion, how probably will solar dryer-sieve be in commercial use by 2030? Give your opinion on the scale, and comment on the most important barriers to adoption in the comment box below.

(NEXT PAGE)

Efficient solar dryer-sieve – desirability

The basic idea behind this idea is to have a solar dryer, e.g. greenhouse-based with flat screening capabilities. Thereby, wood chip quality is improved with low investment and operation costs, depending on sun radiation conditions. In your opinion, how desirable it is that solar dryer-sieve will come into general use? Give your answer on the scale, and in the comments box, describe the main benefits adopting this invention will have.

(NEXT PAGE)

Open forest street map - probability of adoption

The basic idea behind this concept is to have a digital forest road network available, coming from the concept of building up OpenStreetMap which is available online and still enlarged and improved. It should support the phase of operational and strategic planning of forest biomass supply, round wood supply and other branches of forestry logistics. In your opinion, how probably will open forest street map be in commercial use by 2030? Give your opinion on the scale, and comment on the most important barriers to adoption in the comment box below.

An example can be found here: http://www.openstreetmap.org/#map=13/62.5931/29.8290

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Open forest street map – desirability

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An example can be found here: http://www.openstreetmap.org/#map=13/62.5931/29.8290

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Commercial potential of inventions

These inventions have different levels of commercial potential. Please order them according to your opinion of their potential, and comment on your reasoning below. 1 has the highest commercial potential, 6 the lowest.

Rating by moving the variables around

(NEXT PAGE)

Background questions

Where do you live? (drop-down menu with all countries the survey was sent to)

How long have you been working in your current field? (0-5 years, 5-10 years, 10-20 years, More than 20 years)

What is your main expertise? (Forestry, engineering, machine manufacturing, biomass harvesting, other)

What was the main subject for your highest education (for example forestry, economics)? (Open-ended question)

How would you rate your expertise on forest biomass harvesting and related machinery? (Expert, good knowledge, some knowledge, little knowledge, no knowledge)

How would you rate your expertise on machine technology in general? (Expert, good knowledge, some knowledge, little knowledge, no knowledge)

How would you rate your expertise on developments in information technology? (Expert, good knowledge, some knowledge, little knowledge, no knowledge)

What is your sex? (Man, woman)

Can we include your name in the reporting of results? It will not be connected to your answers. If yes, please write your name in the box, if no, leave it blank. (Open-ended question)

Appendix 2

These experts gave their permission for listing their names in reporting. 8 wished to remain anonymous.

Jose Luis Carvalho

Helmer Belbo

Fabio Ricci

Kees Boon

Dolset (company name)

Matevz Mihelic

Dinko Vusic

Leonardo Nocentini

Arnaud Villette

Michael Stauder

Andis Lazdiņš

Jyri Juhala

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