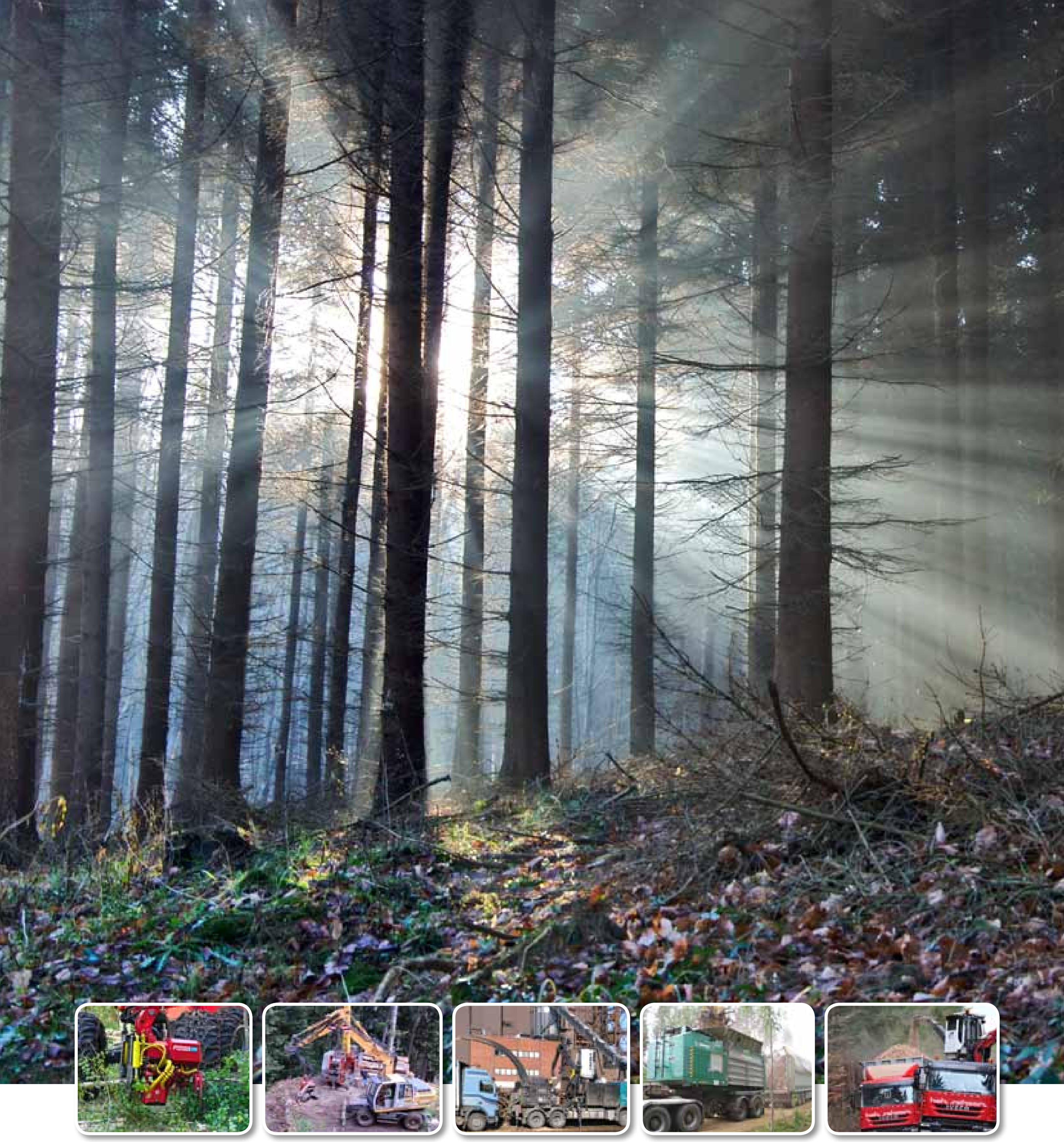

Innovative, effective and sustainable technology and logistics for forest residual biomass

Summary of the INFRES project results

www.infres.eu

Contents

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Abbreviations
CTL = cut to length
FTE = full time equivalent
odt = oven dry ton
m³ = solid cubic metre
ton = 1,000 kg (metric ton)

VTT-M-03711-15

Highlights of the INFRES project

INFRES has been seeking, studying, developing and transferring a multitude of technologies and methods to improve the efficiency, sustainability and quality of forest-based biomass supply for energy use and biorefining. This work has included the identification of new technologies and innovations and the further development and demonstration of existing ones. The emphasis has been to accelerate the development of forest based biomass supply in order to reach the ambitious targets for forest energy set by many member countries.

Over 20 technology demonstrations have been performed to ascertain how systems perform in the varying conditions in Europe. Hundreds of professionals have attended the fairs, seminars and demonstrations carrying the message to even larger audience.

To show the pathway to the biofuture, a number of arising innovations has been identified by leading experts in the forest energy and technology sector. The hybrid technology, autonomous machines and systems that assist the operator to use the machine efficiently are considered to have a promising future also in the forest biomass supply.

The quality management of biomass along the supply chain was found to be extremely important in field studies and demonstrations. Good management of stockpiles, improvement of fuel quality by drying and screening impurities from the energy biomass enhance the performance of the entire system. By using weather data-based prediction models, the moisture content of biomass can be estimated at any given time and optimal delivery times can be planned.

Integration of biomass supply to other forest and transport operations by using the same base machinery and transportation fleet increases the capacity utilization of expensive machines. This is very important, because the demand of energy feedstock varies seasonally and, without work opportunities in harvesting and transport of other goods, the annual utilization of capital intensive supply system falls below economic viability. Creative business models, in which, for instance, biomass is dried by using the excess heat of other businesses, brings mutual benefit for several sectors.

INFRES aims:
The INFRES develops and demonstrates technological and logistical solutions that reduce the fossil energy input in the biomass supply by 20% and reduce the raw material losses by 15%. The cost of supply can be cut by 10–20%, and the CO_2 emissions of feedstock supply will diminish by 10%. With the novel technologies and efficient transfer of best practices between the countries in the consortium and other countries with similar natural conditions, the volume of forest biomass supply for energy and biorefining can be substantionally higher in the future.

Increasing supply volumes of feedstock also increase transport distances and the costs of transport. To counteract this development, the use of larger trucks and seasonal drying of raw material were found to be efficient. However, many factors affect the optimal design of the transportation fleet. The management of biomass chipping and transportation can be assisted with modern fleet management software. Considerable savings in transportation costs can be achieved by GPS-assisted navigation, route optimization and timing of deliveries. Also, new business models, where entrepreneurs operating on a same area exchange storage information and deliver jointly to their clients, can reduce the overall transport distances and costs of supply. The challenge for the adaptation of new technologies in biomass sourcing is the very small size of the enterprises.

This publication summarizes the key results and findings of the INFRES. Together with the extensive material found at the www.infres.eu, it gives a deep insight into the current status and development trends of forest biomass sourcing for energy production.

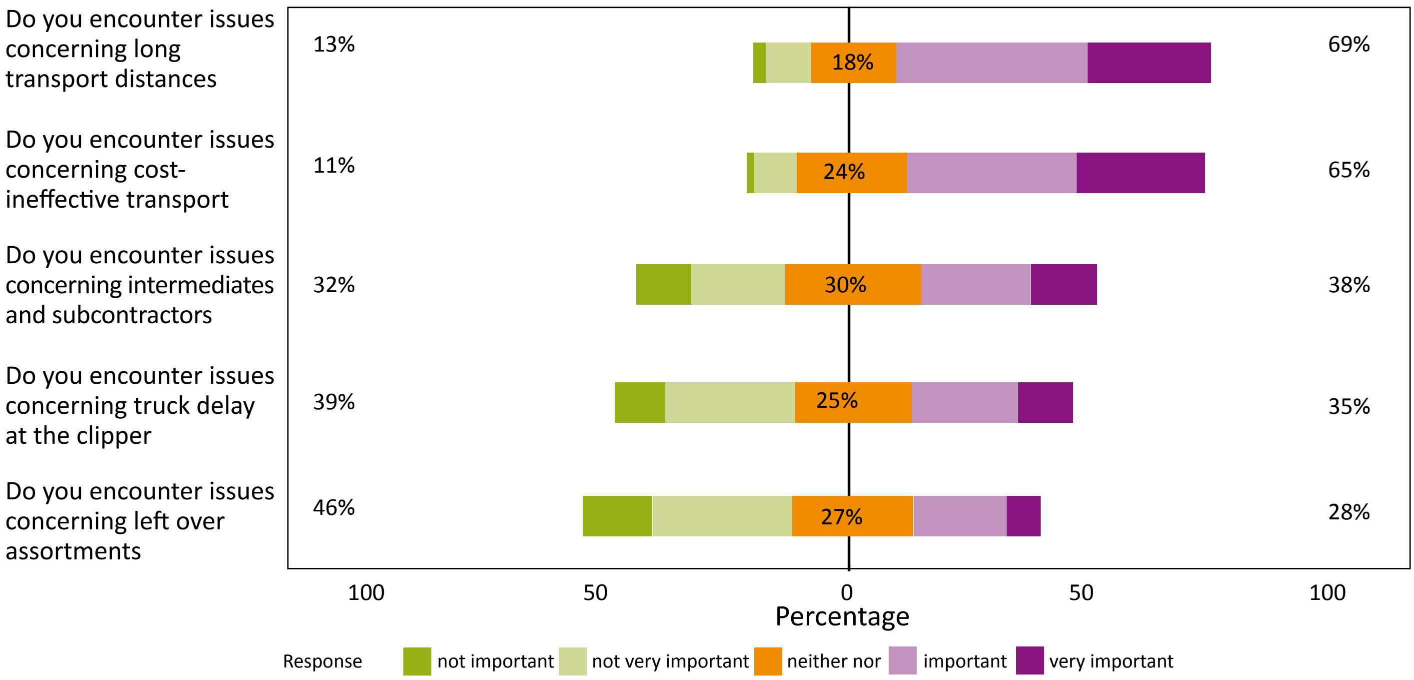
Prof. Antti Asikainen, coordinator
Natural Resources Institute Finland - Luke

Development of technology and quality improvement of forest biomass

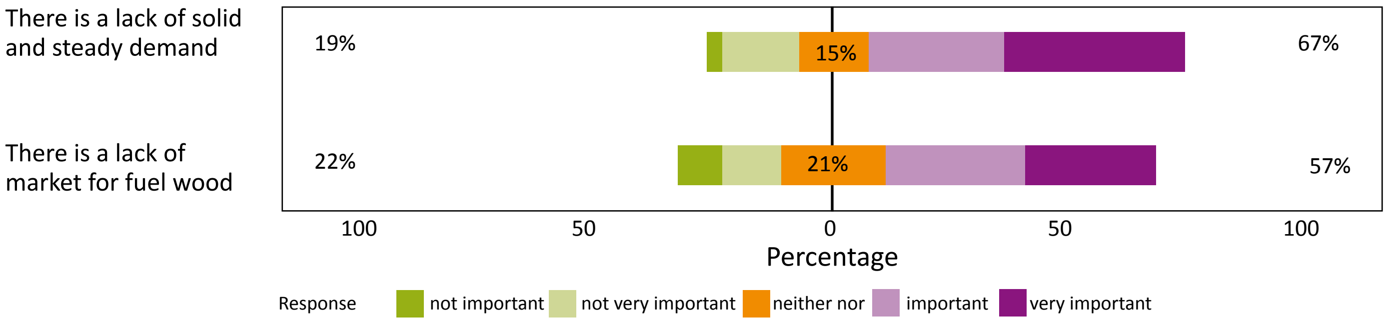
Diversity of bottlenecks in Europe's fuel wood supply chains – a closer look

Efficiency in forest wood supply can be hampered by bottlenecks all along the chain from the forest to the plant or the mill. These bottlenecks can be of an infrastructural, technological, organisational, logistical or social nature. For example, access to energy wood can be limited by insufficient forest road networks, as well as by difficult terrain conditions. Furthermore, cost efficiency in the forestry business can be endangered by technological limitations, such as fuel consumption and machinery reliability. Discrepancy between demand and supply capacity, lack of markets for forest wood and communication and coordination deficiencies are further possible bottleneck types. Apparently, these are only a few of a much larger number of possible bottlenecks in the forest wood supply chain. So which bottlenecks do people, working in Europe's wood supply chain, consider to be the most important? Are there common bottlenecks throughout Europe, or how and why do they differ from each other? To clarify these questions, an online survey was carried out in which 206 participants from eight countries and nine types of organizations expressed their opinion concerning the topic of bottlenecks.

People working in Europe's wood fuel supply chains consider both transport-related issues, such as long transport distances, and the lack of either a market for fuel wood or solid and steady demand to be the most important issues. Different demand for wood fuel in summer and winter and the absence of long term contracts cause large uncertainties in the business. Fragmented forest ownership affects the wood fuel supply chain both in physical accessibility of the areas where feedstock grows and in the accessibility of wood fuel on the market. Owners often do not wish to sell wood fuel, or the amount they can sell is too small to allow a cost-effective operation. Lack of landings and storing space, thus limiting operation size, are common bottlenecks throughout Europe too, as well as a lack of maintenance of the forest road network, especially common in Southern Europe. Whereas Nordic respondents are mostly concerned about low load densities, Central and Southern European respondents call for a rise in legal gross vehicle weight to Nordic standards in order to increase their truck load capacities. However, South Europeans are clearly aware of the inability of their current narrow road networks to handle larger trucks. Due to topographic and climatic reasons, concerns about steep terrain are more important to



People working in Europe's wood supply chains consider transport-related issues, such as long transport distances, cost-inefficient transport and small legal gross vehicle weights to be the most important bottlenecks in wood fuel supply.



The absence of markets for wood fuel and the lack of a solid and steady demand are among the most important bottlenecks in Europe's wood fuel supply. Different demand for wood fuel in summer and winter and the absence of long-term contracts cause major uncertainties in the business.

Austrians, Italians and Spanish, whereas Finns and Swedes are much more concerned about swampy terrain, rewetting and freezing of stored wood fuel. An alarming issue is the reported bias in society toward forest utilization. While forest protection and reforestation are clearly positively connoted, harvesting is not. Especially among people from urban backgrounds, any kind of forest culture seems to be missing.

It can be concluded that transport, unstable demand and lacking or poorly organized market and fragmented forest ownership are the common European bottlenecks, even if they cause different problems in different countries. Solutions to these problems can only be a combination of technological improvements, adaptions of the legal framework and policies in terms of subsidies and wood mobilization measures, as well as raising public awareness for forest utilization.

Storage and sorting of wood fuel – a big step towards maximum efficiency

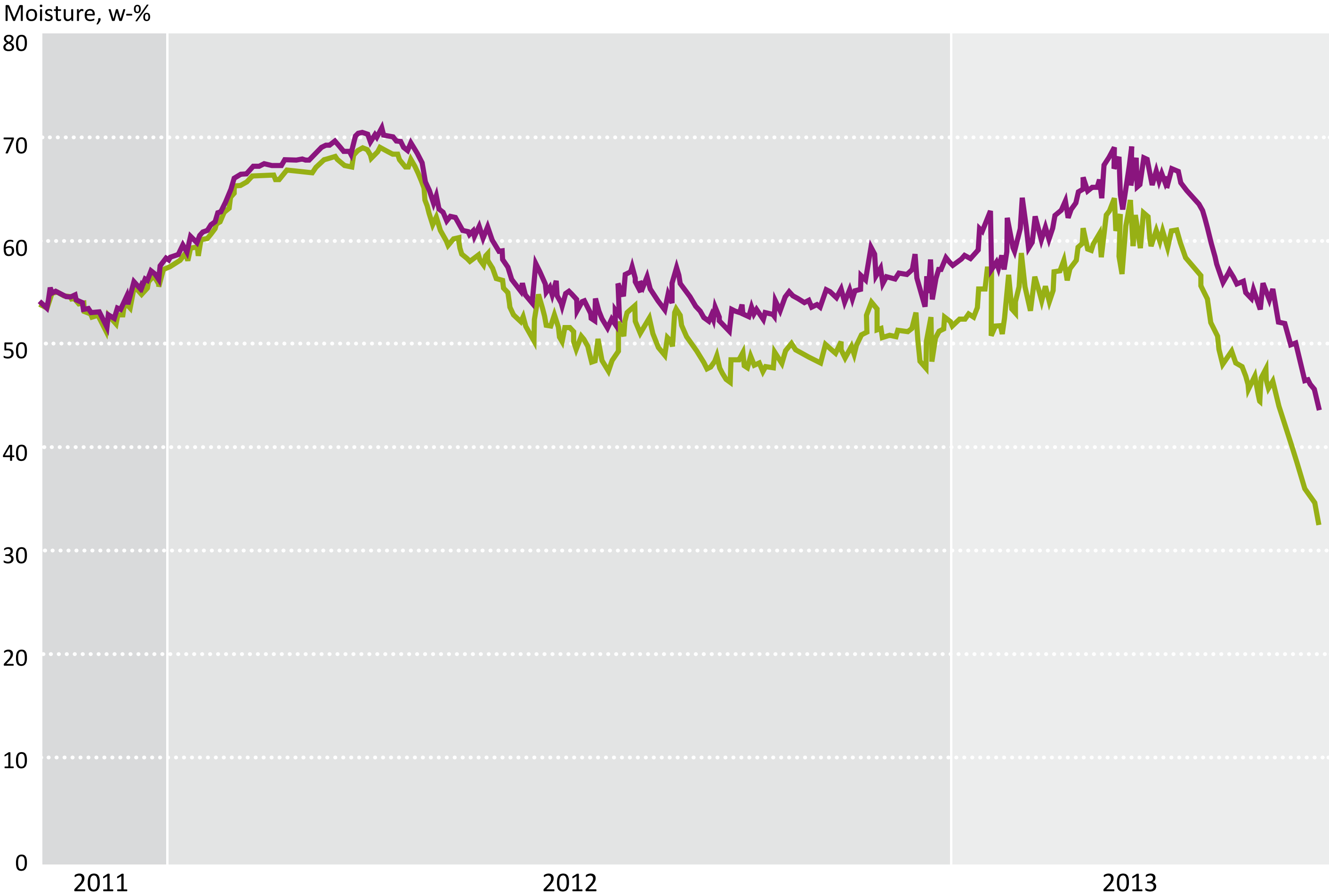
Wood is usually harvested throughout the year, but mainly consumed in winter. It also requires seasoning in storage in order to lower the moisture content of the fuel. Biomass can be stored either comminuted (as chips or firewood) or uncomminuted (whole trees, stem wood and logging residues). As we know, drying wood in piles by natural air drying is the cheapest method significantly to reduce the moisture content. But how to efficiently determine a pile's moisture content? How can a wood fuel supplier keep track of the piles' drying performances?

Models for the drying process come into play. In order to develop those, continued scaling experiments are the state of the art approach in monitoring the drying performance of stockpiled primary forest fuels. Employed for the first time on a large scale, this approach enabled recording drying performance data in greater detail than ever before. Metal frames on load cells were filled with material, thus working like a giant permanent scale. Load and weather data were linked and used to formulate drying models, where drying is a function of weather variables. Data recorded during 33 drying cycles at four experimental sites in three countries, covering logwood, logging residues, whole trees and stumps and five tree species was used to formulate models. Included in a wood fuel procurement software, drying models can improve the wood fuel supply chain by helping the supplier to find and choose those piles that are drier and thus have a higher net calorific value for delivery. That way the supplier can better meet their customer's demand and optimize transport in terms of energy amounts. Furthermore, drying models can be used to formulate recommendations concerning optimum storage times for different regions, assortments, and species under different drying conditions. All in all, this kind of multivariate drying model can help to further increase the efficiency of the entire wood fuel supply chain.

Determination of wood chip quality, especially of its moisture content and particle size, is of major importance at any heating or power plant. Until now, samples have had to be analysed in laboratory, causing a delay in the quality assessment of the material supplied. Machine vision is a technology that could enable automated and immediate assessment of a load during delivery.

Different camera types were tested to identify the shapes and size of chips, as well as the moisture content of the material. Distinguishing wood chip types, determining moisture differences, detecting impurities and determining the particle size of wood chips with machine vision technology using visible light (RGB-images) was carried out. The machine vision technology is based on colour tone value differentiation, and is thus affected by ambient factors such as lighting, the moisture content of chips, geometry and camera settings. A major drawback of visible light technology is its inability to work online. Thus, it would not be possible to employ this technology on a running conveyor belt. Furthermore, determination of moisture content was not accurate enough. However, volume determination with TOF-cameras (time of flight)

Metal frames on load cells, working like bygone large, permanent scale, are the state-of-the-art technology in monitoring wood fuel drying performance. Load data gained this way can be linked to meteorological data so as to develop wood fuel drying models.



Drying performance of Finnish logging residue piles. Notice moisture content derived from load weight (green line) and moisture content corrected for dry matter losses (purple line). Due to dry matter losses, moisture content of the pile was underestimated initially. Drying models for logging residues have to take into account the effect of dry matter losses due to biological processes.

Moisture content can be effectively detected with near infrared technology (NIR). Notice wood chips on a conveyor belt (left), half of the particles spray-wetted (slightly darker colour shade). In NIR, the wet area has a relatively higher red component (centre). On a moisture map, red/blue colours indicate high/low moisture contents (right).

Machine vision is a technology that could enable automated and immediate assessment of wood chip quality during delivery. A test rig for different camera technologies was set up and material supplied by all INFRES partners was used for calibrating.

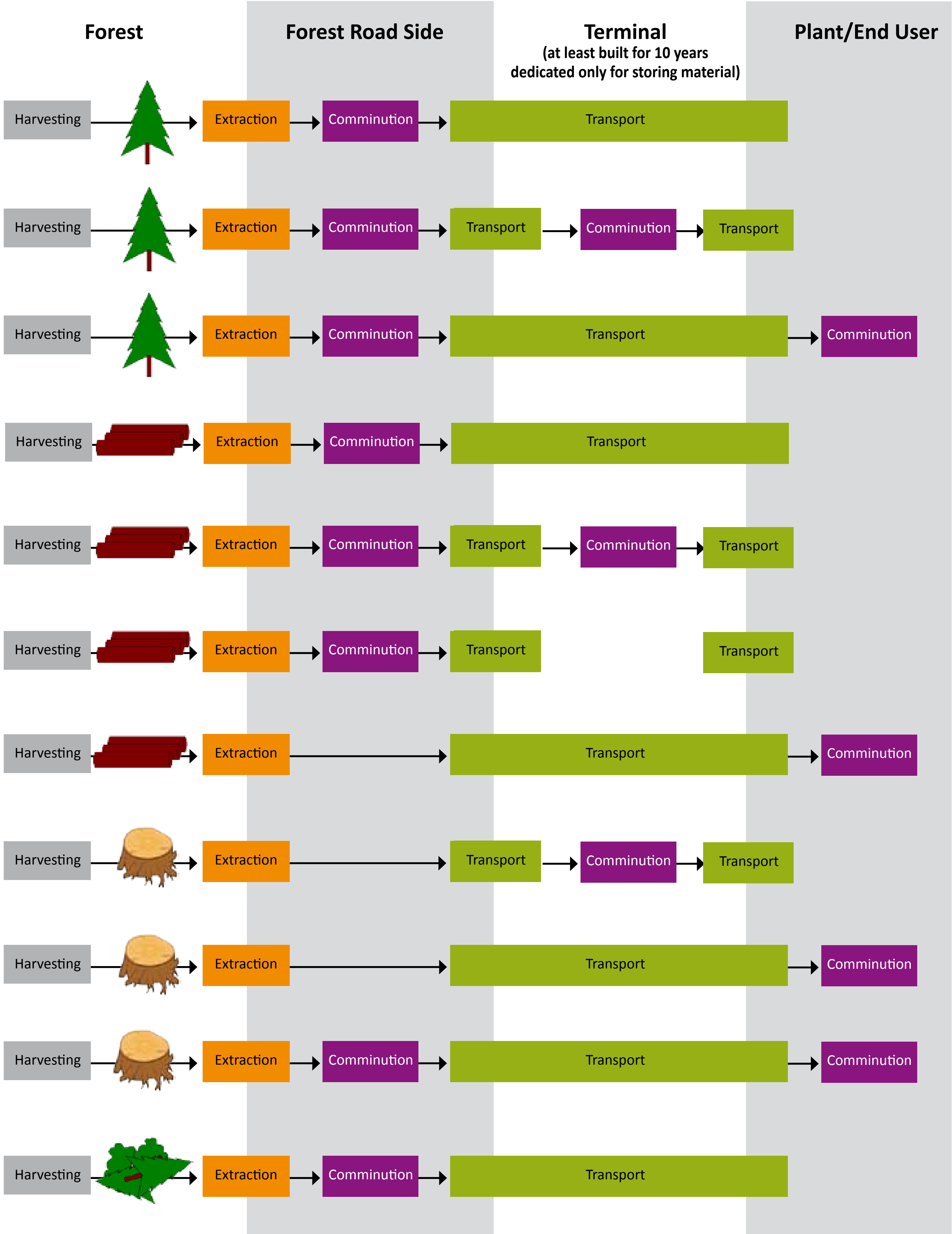
proved to be fairly accurate (± 10w-% on wet basis). Contrary to visible light technology, near infrared spectroscopy (NIR) provided much more accurate results in terms of moisture content and the detection of foreign objects. More importantly, NIR technology proved to work online and could, therefore, be used at a power plant or wood fuel terminal where wood chips are moved on a conveyer. A small drawback is the inability to give reliable moisture information with regard to frozen materials. Concluding, NIR spectroscopy is a promising alternative for assessing fuel wood quality at a plant.

Forest wood supply networks – how to re-engineer and optimize the network

A supply chain network can be considered as a complex system of processes and related materials, in the case of wood fuel processes such as harvesting, forwarding, comminution and transport and wood in different states of processing. Entrepreneurs often have to decide which type of supply chain to employ for a certain operation. Therefore, machinery has to be selected and its operations coordinated and balanced. More than one option to choose from is the rule rather than the exception.

In order to provide entrepreneurs with a simple, flexible tool with which to compare different supply chains, a spreadsheet-based tool was developed. Calculations were based on a formal approach called "technology matrix", where the inputs and outputs of a system are balanced in a quadratic matrix and a unique solution is provided. There are two requirements for using this scheme. Firstly, sketching has to be process-oriented; split into processes such as harvesting, forwarding, etc. Secondly, processes have to be sketched location-oriented; e.g. harvesting takes place in the forest, chipping takes place on the forest road. The machine type employed does not matter at this stage. When using the tool, data on the processes productivity, cost and fuel consumption has to be filled in. From this data, the operation duration, cost, fuel consumption and CO_2 emissions of the supply chain are calculated. Pairwise calculation allows comparison of two different supply chains.

Eleven basic forest wood supply chains could be classified according to the tree compartment (stump, stem, whole tree and residues) harvested in the forest. In conclusion, current supply chains can be mapped by focusing on processes and where they are located, no matter which equipment or technique is employed. This showed that it is generally a question of where conversion of the fuel wood material to fuel wood chips takes place. Tools like this can be used in order to assess the impact of supply chain design changes, the introduction of new technologies and improvement of existing equipment.



Eleven different, typical wood fuel supply chains could be detected for the material types whole trees, logwood, stumps and logging residues. Generally speaking, the crucial question is where the conversion of the fuel wood material to fuel wood chips takes place.

On a regional level, fuel supply chains have to be optimized in terms of material sources, terminals, transport means, delivery locations, costs and greenhouse gas (GHG) emissions. However, the supply of energy wood is challenging because of high supply costs and rapidly increasing as well as changing demand. Over the last decade, mathematical modelling in forestry started to focus on biomass supply driven by the need to make it more economical. For a case study region in Austria, a multi-criteria optimization problem (chipping location, transport mode and volume and terminals used) has been formulated and solved. The weighted sum scalarization approach was used to derive Pareto optimal points by stepwise changing weights from maximum profit to minimal GHG emissions. Profit had to be maximized and the GHG emissions had to be minimized. The case network included approximately 10,000 sources, 356 storage locations, 119 freight stations and 228 delivery locations with a demand of 700,000 dry tonnes per year. It showed that, if the GHG emissions were to be minimized, 50% of the material should be chipped directly in the forest, 30% at the terminals and the rest at the plant. If the profit weight was set to a maximum, profit doubled, while GHG emissions only rose by 4.5%. Drying material from 40% to 30% moisture content resulted in profit doubling, too. Additionally, drying positively affects both transport costs and GHG emissions. It can be concluded that the strategic optimization of wood fuel supply on a regional level can result in a significant profit increase and GHG emissions decrease. Again, the significant impact of pre-drying material in the forest has to be pointed out. By applying the optimization approach described across Europe, significant improvements in resource efficiency of biomass supply could be achieved.

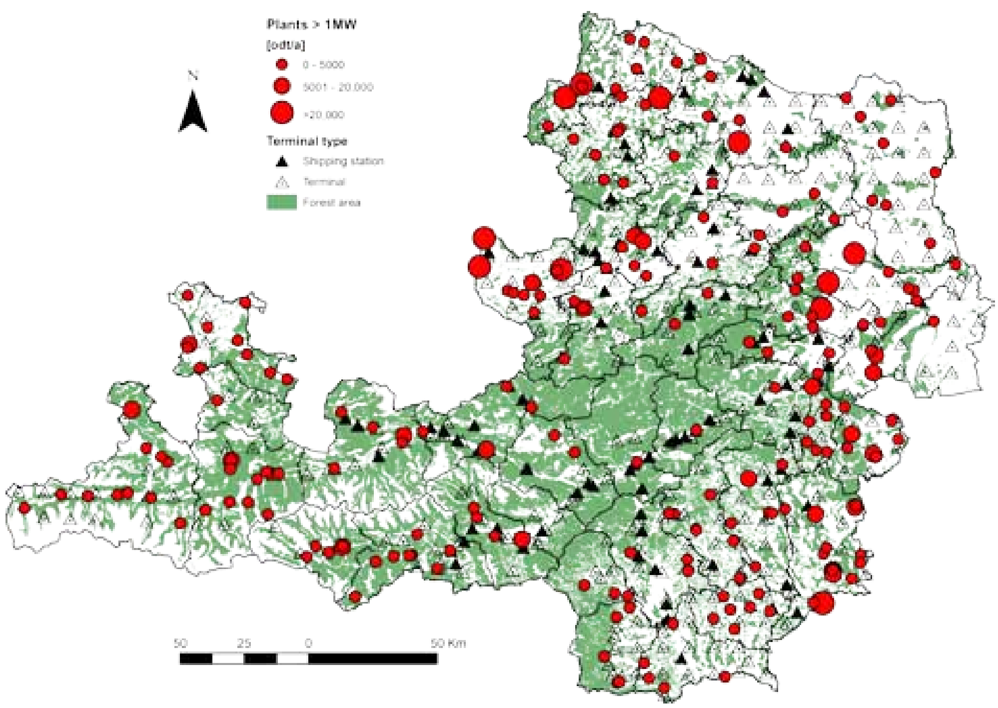
Innovations in forest wood supply – the future has already arrived

During recent years, a number of novel technologies and methods for the utilization of residual forest biomass have been suggested and introduced so as to enhance the performance of forest fuel feedstock supply. Basically, innovations have been grouped into two main classes: Radical innovations that change the operating principle of a system and lead to a technology leap, and incremental innovations that improve the existing systems by enhancing their resource efficiency or reducing their costs in gradual steps. In wood harvesting, radical innovations have been the introduction of the bow saw in wood felling and cross cutting in the 1930s, the chain saw in the 1950s and 1960s and mechanization of the felling, delimbing and cross cutting by using the single grip harvester principle in the 1980s. Once introduced, these technologies have been gradually improved so that their performance levels have risen and e.g. fuel consumption has been reduced markedly.

Novel technologies such as sensor technology, automation, electric drives, hybrid technology, and machine vision were assessed concerning their applicability in energy wood supply. From a total of 51 innovations, the five most promising were selected.

1) The "High Capacity Transport (HCT) Truck" is either a 74 tonne or 90 tonne truck with a length of 25 to 30 m. Employing a 90 tonnes truck reduces fuel consumption, GHG emissions and transportation costs per transported tonne by 20% (74 tonnes truck: 10% to 12%). Furthermore, every third truck could be removed from our roads and the number of bypasses for neighbourhood residents reduced.

The study area for optimizing forest wood supply both in terms of profit and emissions on a regional level included 38 forest administrative districts, forest land cover, locations of heating plants categorized into three sizes, terminal locations for storage and shipping stations for railway transport.



2) "Open forest street map" is the concept of building up OpenStreetMap, which is available online and is still being enlarged and improved. Data from already used GPS-units on forest machinery and handhelds could be included. The forest road network could be added into the existing database. Forest roads and their attributes, including storage places and average speed for different classes, would support the decision making process for planning harvesting and transportation processes.

3) The Bracke "MAMA" head is a further development of the C16 felling head and is intended to be used in dense first thinning stands with heights of between 8 m and 15 m in which biomass is cut-to-length and compressed before piling at strip-road side. Harvested biomass density increases by approximately 45% to 70%, whereas, due to leaving nutrients rich needles and small twigs in the stand, harvesting yield decreases 10% to 23%. Due to handling of compressed biomasses, the forwarder pay-loads increased by 20% and and the forwarding productivity increased by 46% at 300 m driving distance (one-way).

INFRES video Bracke "MAMA" head for fuel wood from first thinnings. The cut-to-length assortments are compressed before piling at strip-road side. Thus nutrients-rich needles and small twigs are left in the stand, while, due to compression handling, forwarder pay-loads increased by 20% and forwarding productivity increased by 40%.

4) "Increased Chip Size in the Production Chain" is a concept based on the experience that productivity and fuel consumption per produced tonne decreases when the target chip size is increased. A Bruks 605 chipper increased productivity by 50%, while fuel consumption decreased by 33%, as a result of increasing chip target length from 15 mm to 40 mm.

5) "Hultdins Supergrip II A" is a grapple optimized for easier log picking. With conventional knives, there is always a risk that a piece of wood is clamped between the cross-members and obstructs the closing motion of the grapple. The angled cross members of the A-Grapple feed everything that the tips can grab into the grapple and the rest is fed out. Thus, nothing can get stuck between the grapple arms, and the closing motion of the grapple is uninterrupted.

Considering their high development potential, these innovations might become winning technologies in a few years, as there might be steep learning curves in the adoption of a new technology or method.

The "High Capacity Transport (HCT) Truck" is either a 74 tonne or 90 tonne truck with a length of 25 to 30 m. Employing trucks of this size could reduce fuel consumption, GHG emissions and transportation costs per transported tonne.

Different types of wood fuel piled on load cell suspended metal racks. Notice both covered and uncovered piles of logwood and logging residues. Piles on the right imitate logging residues piles under natural piling conditions.

Case: Monitoring wood fuel drying in Austria, Finland and Sweden

Natural drying is a cost-efficient way to improve the quality of wood fuel. The drying performance of wood fuel was monitored at three locations in Austria, Finland and Sweden. Metal frames on load cells filled with wood fuel, working like big scales, served as a monitoring device. If the weight of the pile decreases, it is drying, if the weight increases, it is rewetting. From this alteration in weight, the actual moisture content of the material can be calculated. 33 drying cycles, between two and sixteen months in length, were monitored. Both broadleaved species (beech, birch and oak) and coniferous species (spruce, pine), covering the material types logwood and logging residues, were studied. This showed that all types of material dry during spring and summer and start to re-wet during autumn. Moisture contents can drop from 20% to 2% within one drying season. The rewetting degree depends on the climatic and material conditions. Logging residues in particular can start to decompose during the storage period and therefore lose energetic potential. It showed that, due to quick drying, the material does not rewet from snow melting in spring. Therefore, if snow cover is removed successfully, material chipped in winter will rewet only to a limited degree. Knowledge of the drying performance of fuel wood is essential for including drying models in fuel wood management tools, which enables interlinked supply chains and continuous dataflow from the forest to the customer.

Case: Semi-automated process analysis of wood chip supply using a fleet management system

Effectively running and organizing wood chip supply for energy purposes is a complex task under constant cost pressure. Thus, detailed analysis and optimization of the main business processes is necessary. Knowledge of every process and its attributes, such as time and fuel consumption, within the work flow is crucial. Support by fleet management systems, offering online process controlling, as state-of-the-art other business fields (e.g. transportation of food or package shipment) has become vital. In a case study carried out together with the Holz Schwarz GmbH in Austria, all business activities along the whole wood chip supply chain have been mapped. Afterwards, fleet management equipment was installed in two trucks for wood chip transport in order to carry out semi-automated time studies. While locations, distances and times were recorded automatically, the drivers provided information on the start and end of each process, as well as on load volume and material specifications. From February 2014 to April 2015, 902 truckloads were documented for analysis. Within this period, the two truck and trailer combinations transported 60,900 m³ loose over a distance of 65,800 km. On average a journey took 3.2 hours from driving empty to the chipping site until finishing unloading at the plant, having a journey length of 73 km and consuming 38.3 litres of diesel. The average loading productivity was 98.8 m³ loose. Additionally, an automated, browser-based reporting system was implemented based on pre-processed fleet management data. This enables the entrepreneur to access daily statistics for each vehicle, providing information on distances, time consumption, loads and fuel consumption. Furthermore, the driver is now able to adapt the calculation schemes according to the key figures derived from this long-term study.

Vehicles equipped with fleet management system.

Adapting existing forestry practices for improved biomass production

Remarkable cost savings possibilities in forest practises

Forest practises were analysed by three European regions that differ substantially in forestry and economic conditions: Northern Europe, Central Europe and Southern Europe. A detailed level analysis of the major supply chains by region was performed. For all supply chains, reference literature was used so as to analyse the major supply chain and cost-relevant aspects and to determine the costs by the different supply chain steps.

The results reveal that there are considerable differences in costs in the different supply chains per region, as well as in the general European region. In Northern Europe, the costs are considerably below the current regional market price and allow better margins for wood chips, whereas in Central and Southern Europe they are closer to or (partly) above the current price level.

A comparison across the Northern EU supply chains shows that the harvest/felling and forwarding/extracting of material represents the largest share of total costs. In Central Europe, the chipping costs and transport costs are relatively high. This is partly due to the lower productivity from mobile chippers that have to move more often, as well as the lower weight limits for trucks in Central Europe. The Southern European chains show the lowest margins of all three regions.

This analysis of supply chains reveals the cost structure of the supply chains and enables technology development efforts to be allocated to the most crucial sections of the supply chains. In Central and Southern Europe, a high potential for cost savings is seen in harvesting, chipping and transport, whereas in Northern Europe it is in harvesting.

Information technology solutions for trade and transport

A study within the INFRES analysed the potential for cost reduction by online auction or trade portals based on the conditions obtaining in South-Western Germany. An online portal provides full market transparency by including the location and properties of wood material piles that can be selected to be purchased for chipping by a wood chip company. Such transparency will allow buyers to consider transport distances and logistics when selecting piles for purchase.

Two different market functioning scenarios in South-Western Germany were compared:

Scenario 1, a "traditional trade scenario" reflecting the current market functioning with limited market transparency, where sellers and buyers act based on established bi-literal relations;

Scenario 2, a "trade based on transparent market scenario", where an online platform provides full market transparency on the supply.

In this second scenario, all forest owners and other material suppliers enter their offered wood piles in an internet-based tool together with the geographic location and a description of basic properties. Such a system could include auction functionality, but the system could also be designed in a way that allows market partners to get into contact and use the traditional way of price finding for the sale. The results reveal that truck transport costs could be reduced by 10% and for chipper relocation cost by 27% under the specific conditions of the study area with its well-developed road network. Thus, while its dimension still depends on the regional conditions, substantial transport cost savings can be one effect of introducing such portals. Apart from this potential of transport cost savings, such portals could reduce the barrier to market entry by small forest owners and could thus contribute to the mobilisation of wood for the energy wood market. In addition, by introducing photo upload and a standardised description of the wood piles, the time that is currently spent on inspecting the piles prior to purchase could be reduced substantially. Therefore, the setup and introduction of such portals has be shown to be an important means of reducing transport costs along the wood chip supply chain; as it can also contribute to the mobilisation of wood from small forest owners, it is strongly recommended.

In South-Western Germany, a fleet management system was demonstrated at a small wood chipping company after being customised to biomass chipping businesses and translated into German for ease of use of the system by a local company. Such a system that includes task management and task optimisation as well as office and mobile system access via the internet offers substantial cost reduction opportunities to bioenergy firms by

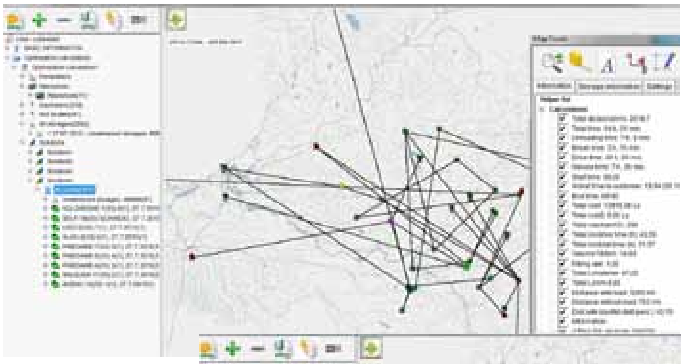
- Routing functions via navigation maps in mobile devices that ensure seamless transport
- Optimised recording of wood chip material properties
- Standardised and fully recorded information exchange between the office and the transport fleet
- Less manual work in the office
- Greatly improved internal calculations and optimisations through reporting

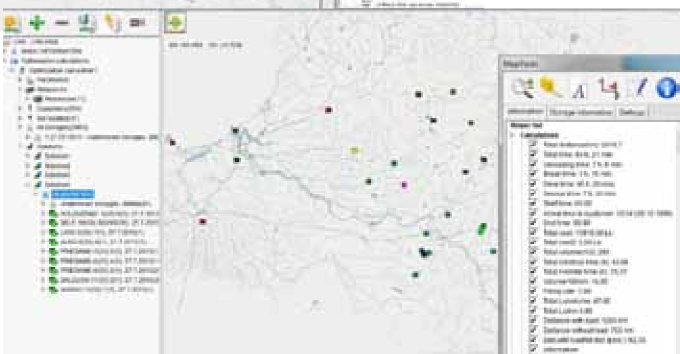
During the INFRES project's cooperation with SMEs, it became apparent that the introduction of such IT solutions is for small companies still a challenge. This challenge for small scale companies includes the necessary investments in advanced IT solutions, the training of staff and adapting of working practices; it will need some time and further efforts. They will, however, contribute to cost reduction, mobilisation of wood and an increase of sustainability of forest biomass supply through a reduction of transport activities and a reduction in fuel consumption that, in turn, contributes to a reduction in emissions.

In is important to emphasise that the introduction of an online or trade portal and the use of fleet management systems offer synergies, as the locations where wood for chipping is available, e.g. along the forest road, can be transferred via an interface from the portal into the fleet management software directly.

Forest road side chipping in Southern Germany.

INFRES video Drying of wood chips by biogas.





A fleet management system was demonstrated at a small chipping company.

From demonstrations to practice

The overall aim of the INFRES project was to make new technology highly visible and accelerate its introduction through the execution of field demonstrations. In particular, three main objectives were reached 1) demonstrate the viability of the innovative concepts developed within the INFRES partnership, showing key stakeholders how these concepts could be successfully applied to their specific work conditions, under real settings; 2) encourage cooperation and information exchange between research institutes and SMEs by engaging them into a joint effort to pursue the same final objective; 3) collect real-life field data for use by the other tasks of the INFRES project.

Different supply chains selected for demonstrations

The demonstrations covered five main subjects, each representing a specific task within the INFRES:

1. Supply chains for the integrated biomass extraction chains for mountain forests, led by BOKU;
2. Smart processing chains for residues, led by ALU-FR;
3. Supply chains for stump wood, led by Luke;
4. Supply chains for small trees from thinning operations, led by SLU;
5. Smart large-scale forest biomass supply chains for liquid fuel production, led by Skogforsk.

Such a schematic description of the organization of demonstrations may give the wrong impression of a rigid strategy in which separate units operated independently of each other. In fact, the contrary was true. Many partners worked on more than one task, which favoured a dynamic exchange of knowledge and competence, and ultimately led to a number of articulate demonstrations that include more than a single supply chain. On average, research institutes worked with three different tasks. In contrast, most SMEs covered a single task, due to the specific characteristics of the product they manufactured. Chains for the supply of forest residues and small trees attracted much more interest than any other chains, and their respective demonstrations were joined by 65% and 50% of the total number of partners involved with demonstrations.

However, readers must be aware that the subdivision into different tasks was somewhat artificial and had the main practical purpose of relieving demonstration management by distributing work responsibilities. Conceptually, it made much less sense, because many of the logistic solutions proposed for large scale biorefineries – for instance – were equally valid for stump wood, small tree and residue supply chains. Similarly, the innovative chippers demonstrated for residue chipping would solve similar access problems and accrue similar efficiency benefits if applied to small tree supply chains. SMEs contribution to the demonstrations was significant.

All demonstrations involved at least one research institute and one SME working in cooperation, and the mean number of project participants involved in the demonstrations was three. Seven demonstrations actually developed as the joint work of four or more partners, and that number only accounts for official INFRES partners, without including opportunity partners picked up along the way in order to obtain mutual benefits and a larger critical mass. Eleven demonstrations had am international character, because they involved INFRES partners from different countries, with one or more of the partners travelling to a foreign country and bringing their know-how and/or technology for testing under new conditions. No projects other than the INFRES offered so many opportunities for trans-border knowledge exchange in the field of biomass supply chains.

The success of a demonstration can be gauged in many ways, but it depends ultimately on its capacity to convey a clear and useful message to the largest number of stakeholders. Therefore, attendance may represent a proxy – if not an exact measure – of a demo's success. Again, the size of the audiences reached by the different demos showed a steeply growing trend, as recorded earlier on for the number of demos. Demonstrations were attended by almost 3,000 visitors.

New technology for mountain forests demonstrated

Demonstrations of new technology for mountain operations were organized in Austria, Germany, Italy and Spain. A number of different new technologies capable of improving supply chain performance, in terms of lower supply cost, better product quality and reduced site impact were demonstrated. The new full-suspension yarding technology for whole-tree extraction on soft or steep terrain offered the benefits of faster yarding over long distances, minimum soil disturbance and reduced product contamination. Flying high over the soil profile, whole trees reach the landing virtually free of any contamination, and are ready for merchandising into timber product and high-quality biomass. With its six-wheel drive and reduced overall width, the agile chipper-truck could easily

Demonstrations conducted within the INFRES project

Partner	Mountain forests	Logging residues	Stumps	Small trees	Large scale trees
Luke		X	X		X
SLU			X	X	
BOKU	X	X		X	
IVALSA	X	X	X	X	X
ALU-FR	X	X		X	
VTT		X	X		X
CTFC		X		X	
Skogforsk		X	X	X	X
BTG					X
Valentini	X				
Pezzolato		X		X	X
Ellettari			X		
Ecomond					X
Cluster				X	
CSF		X			
Schwarz		X			
Kesla		X		X	X
Antti Ranta Ltd		X		X	X
Fallert		X		X	
Forstware				X	

Modern cable logging operation.

INFRES innovations demonstrated during 2013 – 2015

Research organization	SME	Innovation	Place
Skogforsk, VTT	Valbo Entreprenad AB	Two-stage grinding	Mackmyra, Sweden
Felis, ALU-FR	Fallert, Pezzolato	Smart chippertruck	Ortenau, Germany
Skogforsk, IVALSA	Pezzolato	Smart chippertruck	Hestra, Sweden
Luke	Kärkimurskaus Oy, UPM Forest, Komptech	Two-stage grinding	Mikkeli and Juva, Finland
IVALSA, SLU	Skogtekniska klustret, Pezzolato	Mini-harwarders	Codroipo, Italy
CTFC	Naarva	Multi-tree harvesting	Central Catalonia, Spain
SLU	Skogtekniska klustret	Multi-tree harvesting	Umea, Sweden
Luke, SLU, IVALSA	Ellettari	Stump drill	Evijärvi, Finland
VTT, JAMK, Poke	Metsäkeskus	Chip drying	Jyväskylä, Finland
Skogforsk, SLU	Stockarydsterminalen AB	Terminal logistics	Stockaryd, Sweden
IVALSA	Pezzolato, Valentini	Innovative yarder, smart chipper	Farra d'Alpago, Italy
Luke	Antti Ranta	High mobility truck	Oulu, Finland
BOKU	Naarva	Multi-tree harvesting	Moschendorf, Austria
ALU-FR, IVALSA	Fallert	Chip drying	Vercelli & Bologna, Italy
Skogforsk	-	Large truck	Södertalje, Sweden
SLU	Skogtekniska Klustret	Fixteri	Holmsund, Sweden
CTFC	CSF	Synthetic rope	Central Catalonia, Spain
CTFC	CSF	Press collector	Central Catalonia, Spain
ALU-FR	Ecomond, Fallert	Logistics optimization software	Freiburg, Germany
BOKU	Schwarz	Semi-automated process analysis	Pilgersdorf, Austria
IVALSA, BOKU, CTFC	Valentini, CSF	Full-suspension carriage	Rumo, Italy
Luke	Kesla, Antti Ranta	Hybrid chipper and large truck	Joensuu, Rauma & Jyväskylä, Finland
Skogforsk, SLU, VTT	-	Large truck and terminal logistics	Nykvarn, Sweden

negotiate the narrow roads and constrained landings that characterize the Alpine landscape. The new high-speed enlarged-space forwarder could move the biomass to the chipper when no landing was available on site. Synthetic rope for tractor-powered winches was demonstrated both in Italy and Spain, with the purpose of introducing small-scale contractors to a simple and inexpensive innovation capable of improving work comfort and ultimately reducing worker turnover.

In general, all innovations demonstrated in a mountain setting were designed to alleviate the typical access problems that afflict mountain forest operations: insufficient road density, poor road standards, constrained landing spaces. The solution demonstrated generally involved two main concepts: increasing travel speed and reducing machine size. This was achieved with the full-suspension carriage as well as with the high speed forwarder or the agile truck – both of which were designed to replace less efficient tractors. At a chain level, that translates into simplified, streamlined chains, with fewer intermediate passages and higher overall efficiency.

All demonstrated technology was new to mountain operations and especially suited to the close-to-nature forestry management traditionally adopted in the mountain forests of Europe. The environmentally-friendly technologies shown within INFRES project can help introduce residue harvesting to sensitive forest habitats, to the benefit of increased financial sustainability.

Efficient processing of forest residues – remarkable cost and fuel savings

Four demonstrations were organized in Finland, Italy, Spain and Sweden specifically to address the processing of forest residues – i.e. tops and branches. These demonstrations focused on new handling and chipping technology.

Innovative residue handling technology consisted of enlarged-space forwarders, demonstrated both in Italy

The new high-speed forwarder loading residues in its biomass cradle.

Innovative supply chain was demonstrated based on a new chipper-truck by Pezzolato, which is characterized by high power and compact design.

Press collector was demonstrated in Catalonia, Spain. The collector has a capacity of 40–48 m³.

and Spain. When residues are chipped to a roadside landing, their high bulk density affects the extraction process only, which is not enough to justify proper compaction performed by a bundler. This may offer definite advantages if chipping is performed at the plant, and densification benefits are accrued all along the chain. However, few plants have a stationary chipper available, which has made roadside chipping prevalent. In that case, bundling is too expensive for a benefit that would only be limited to the forwarding activity. A cheaper and cruder densification method is, therefore, preferable, and the use of enlarged-space forwarders with compressing sides offers a better cost-benefit ratio.

The chipping machines demonstrated within INFRES featured highly innovative characteristics aimed at reducing fuel use and maintenance cost. The demonstrations included an innovative chipper fitted with a new disposable knife system and a swing-away counter-knife to minimize damage in the presence of contaminants. The occurrence of metal and stone contaminants is relatively frequent in logging residues. The performance of the new system was compared with that of a conventional system, based on the extraction of loose residues to a landing accessible to standard truck-mounted chippers, deprived of the mobility advantage of the new chipper-truck. On a chain basis, the innovative system allowed a 13% saving on financial costs and a 35% saving on fuel costs. However, the most revolutionary innovation was represented by a compact chipper-truck equipped with a new generation diesel-electric hybrid power pack. As in modern cars, the hybrid technology allowed a dramatic reduction of fuel consumption, marking a quantum leap in forest technology.

In all cases, the demonstrations showed to everyone the well-known benefits of chipping into pre-arranged roll-on containers. Working directly into containers allowed a drastic reduction of interaction delays, and especially waiting for trucks, which is a very common cause of downtime in conventional chipping operations. As a result, machine utilization increased to almost 90%, from a traditional benchmark of around 70%. Chipping into pre-arranged containers should be adopted whenever the transportation distance is moderate and the landing offers enough space for parking and switching containers.

Low-impact stump wood harvesting

Stump wood harvesting techniques were demonstrated in Sweden and Finland, where root recovery represents an important source of energy biomass. However, the demonstrations were not an exclusively Nordic affair, because the Italians also joined by offering their rotary stumper technology.

The rotary stumper demonstration showcased a new stump harvesting concept, an alternative to the classic system based on ripping stumps off the ground with especially-designed claws mounted on excavators. Although very effective, stump ripping results in heavy soil disturbance, which might come some negative effects. Rotary stump extractors are traditionally mounted on tractors and used in Italian poplar plantations after the final harvest and before re-cultivation. The Italian machine is based on a drill, which envelopes the stump and isolates it from the surrounding soil, thus minimizing disturbance during extraction. The Italian rotary stumper was adapted to an excavator to conform with the Nordic working technique, and the demonstrations showed the viability of the new concept for Nordic forest operations and outside poplar stands. The new machine proved an alternative solution for stump harvesting of Scots pine (Pinus sylvestris) in peatland areas under Finnish winter conditions. Productivity was still about 30% lower than reported for the conventional Nordic system, but it is likely to increase substantially once operators familiarize themselves with its use. Furthermore, the new system can also be introduced to selective harvesting, as in thinning or partial forest cuts, which are off-limits to the excavator-mounted ripper claws. While introducing a new Italian machine to the Nordic countries, the demonstration also gave important feedback to the Italians, who as a result of the INFRES tests have now deployed a reinforced excavator-mounted rotary cutter to replace the traditional tractor-mounted units.

Two additional demonstrations targeted the complex issue of product quality, which is quite poor due to the effects of soil contaminants sticking to the extracted root system. That forces operators to discard chipping in favour of grinding/crushing, which normally produces coarse, irregular particles. Furthermore, grinders/crushers are used because they are resilient to the effect of soil contaminants, not because they can remove them from the roots, and therefore the final product is still too coarse and too contaminated to obtain an attractive price.

The demonstrations organized within INFRES showed an integrated grinding-screening process, where stumps are pre-ground, fed to a trommel screen, and finally refined in a second passage through the grinder (i.e. two-stage grinding). In this system, screening has the double function of removing dirt and of separating oversize particles that need to be sent back to the grinder for a second pass. In the demonstrations, two-stage grinding proved able to reduce the ash content of stump wood chips by a factor of three. For this reason, the new system is now being adopted by several contractors both in the Nordic countries and in Italy.

The Ellettari stump extractor is designed for fitting to farm tractor, but here mounted on an excavator.

The Crambo crusher at work in Finland.

Small trees: never so big

The harvesting of small trees for energy accounted for a large number of demonstrations, which took place in Austria, Finland, Italy, Spain and Sweden. These demonstrations showcased seven different units, representing all main small-tree harvesting machines, such as: a feller-buncher, multi-tree harvester, feller-forwarder, harwarder and feller-bundler. All machines were designed to achieve one or both of the following effects that operators try to obtain when dealing with small trees, in order to mitigate the negative effect of reduced piece size, and namely: mass handling (i.e. negotiating more than one tree per cycle) and compacting (i.e. increasing the bulk density of bunched whole-trees). The combination of these two principles was epitomized by the feller-bundler, which would handle multiple trees and compact them into high-density, unitized loads (i.e. bundles).

It is certainly worth noticing that the new machines often produced little benefit in terms of felling productivity alone; the largest gains were accrued in the subsequent work steps, with forwarding representing the main beneficiary. Increased load density determined a substantial increase in forwarder productivity, estimated to be about 15%. Similar gains are expected for chipping or transportation, due to the better handling qualities of unitized loads. Therefore, the benefits of new small-tree handling technology are only appreciated from a chain perspective, and will not emerge as clearly if one maintains a narrow focus on the new felling machines alone.

In fact, many of the new machines demonstrated within INFRES underline an integrated approach to the small-tree issue, and may require introducing substantial changes to traditional work routines and/or silvicultural practice. Small –scale harwarders and feller-forwarders imply the consolidation of previously separated work steps, performed by different machines. The demonstrations showed that integrated felling and extraction offered cost savings of between 15% and 20% compared to the other mechanized options tested previously. Yet, these benefits cannot be achieved without re-designing the whole supply chain. Similarly, introduction of the most promising automatic multi-tree harvester head (i.e. MAMA harvester) requires abandoning single-tree selection and shifting to boom-corridor thinning, which does represent a big change in silvicultural practice. Yet, decisive and permanent progress is best achieved by re-designing whole systems, rather than just inventing a new machine to do an old job within an obsolete production chain.

Multi-tree felling head Naarva Grip , which was demonstrated in Spain and Austria. Photo from Austrian demonstration.

The world of logistics

Logistics are the Achilles heel of modern solid biofuel chains, which require a steady and sustained biomass flow to large user plants. Demonstrations were conducted in Austria, Finland, Germany, Italy and Sweden, and covered all the different aspects of post-harvest handling, including: transportation, storage and moisture content management.

The extra-large truck demonstrations conducted in Sweden and Finland showcased the special new trucks with a gross vehicle weight of 69 and 74 tons, respectively. That represents a 15 to 33% increase over the standard 60-ton trucks. Despite the larger mass and size, the new extra-large trucks proved a viable option for cutting transportation costs and reducing the negative impacts on the environment and traffic. Adoption of extra-large trucks entails a reduction in the number of loads needed to transport a given volume of energy wood, which will be beneficial to other road users as the roads between the terminal and the combined heat and power plant are heavily trafficked. The technical challenges associated with manoeuvring on forest roads can be solved with an ETS (Electronic Trailer Steering) system, demonstrated in Finland. This new device enables controlled hydraulic steering of the trailer's rearmost axles, to improve manoeuvrability and mobility in small forest roads.

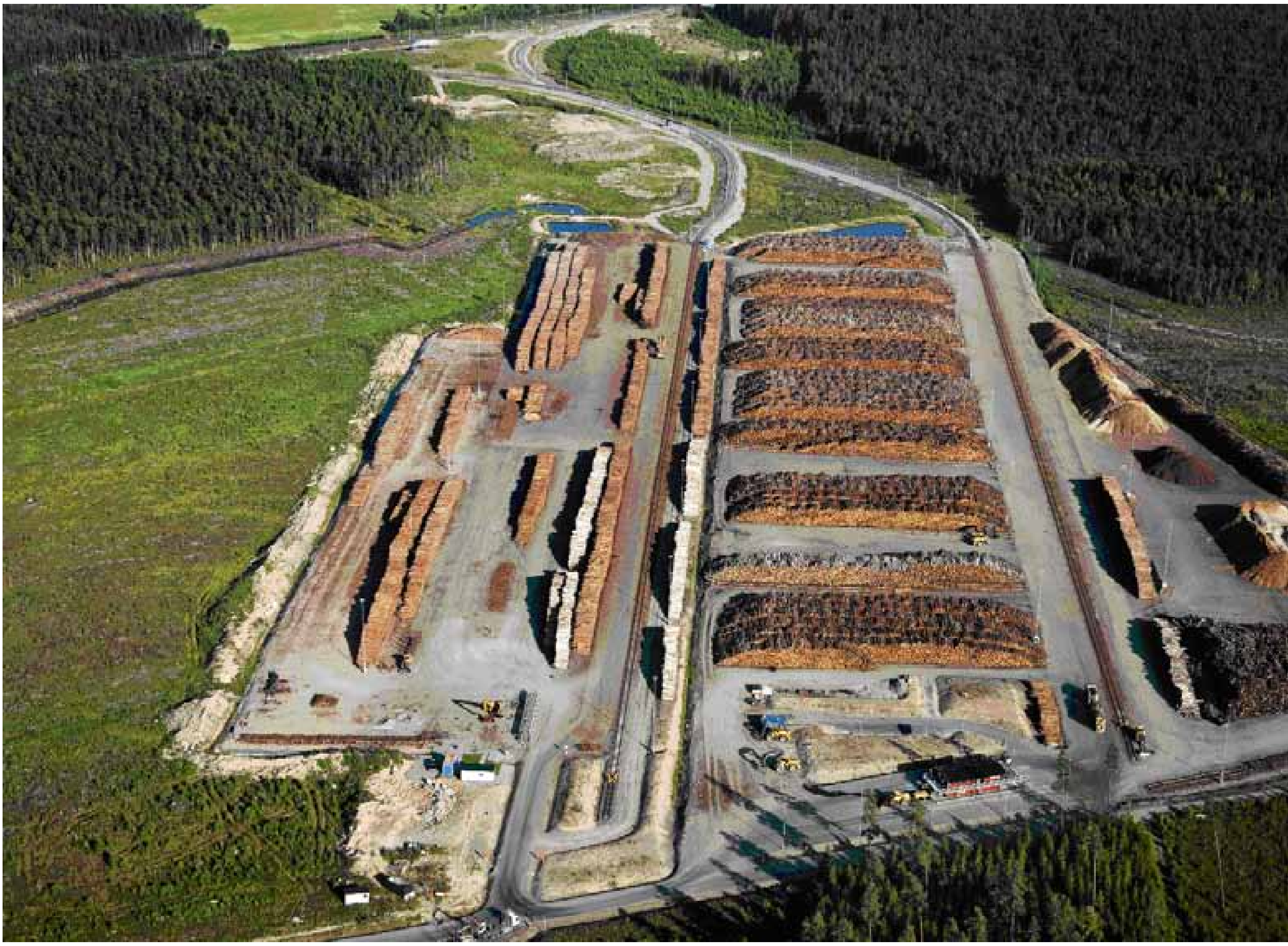
Transportation cost is also reduced through route and payload management, both of which were demonstrated within INFRES. Demonstrations in Austria, Finland and Germany showed the benefits obtained through computer-optimized routing using two different software packages specifically designed for forest biomass applications. Further demonstrations focused on payload management, which was achieved with on-board truck scales (Finland) and moisture-content meters (Italy).

The demonstrations of logistics also covered intermodal transportation and the use of terminals for storage and trans-loading. A new terminal was investigated, with a triangular connection to the main track that enabled trains coming from any direction to leave towards any chosen direction as well. The research associated with this demonstration showed that it is often rational to merge small terminals and locate them in strategically important places, in order to accumulate a large enough throughputs to repay investments.

Finally, demonstrations in Finland, Germany and Italy focused on active drying. That is the most effective way to reduce product immobilization and weather dependency, but it has always been too expensive for commercial use. However, the increased value of good quality chips and the larger availability of low-cost excess heat have changed the game and are making active drying a viable technique for the rapid production of quality chips with guaranteed moisture content. Simple dryers can be obtained by modifying old freight containers or barns, and connecting them to a heating plant to absorb excess heat. The investment and running costs of a dryer determine how feasible such a drying method is as part of the wood fuel supply chain. The operation is especially viable when using low-cost residual heat from power plants and when drying fresh chips that have not been pre-seasoned in the field; otherwise the immobilization cost raises the overall cost.

INFRES video **High mobility chip truck in Finland.**

Bird´s eye view of a timber and energy wood terminal in Sweden.



Case: Full suspension carriage - Valentini

When slope gradient exceeds 40%, ground-based harvesting technology cannot offer good results and cable logging remains the favourite solution. Cable yarding is the most common steep slope harvesting technique worldwide, and is especially popular in the Alps. On steep terrain, cable yarding is the cost-effective alternative to building an extensive network of skidding trails, and results in a much lower site impact compared to ground-based logging. On the other hand, cable yarding is inherently expensive, because it is normally deployed on difficult sites. For this reason, cable logging offers lower profit margins compared to ground-based logging. This justifies a stronger optimization effort, supported by a deeper knowledge of technical cost and market rates. In particular, biomass recovery from yarding sites is only viable if whole trees are extracted. In that case, trees are processed at the landing, where residual biomass accumulates, ready for recovery as wood fuel. However, current yarding technology is penalized when attempting whole-tree extraction over long distances. To compensate for distance, one should increase the yarding speed, which is too dangerous when a long load is dangling under the carriage. That may cause excessive solicitation of the cable set up, and result in an accident if the load hits one of the standing trees at the sides of the yarding corridor. The obvious solution consists in lifting trees horizontally under the carriage, suspended from two points. That requires a double carriage, composed of two separate elements working in tandem, each with its own lift line. Such carriages already exist, but they are all motorized. This means that one of the carriage elements contains a diesel engine, which is used for powering both lift lines through a hydrostatic or electric transmission. Installing a diesel engine on a carriage incurs several drawbacks, such as a marked increase in tare weight, high purchase cost and trisk of fuel spills along the line. For this reason, Valentini have developed a new carriage devised for full load suspension without the help of a diesel engine. With

the new carriage, the lift line is powered by the mainline, which wraps around a dedicated parabolic capstan co-axial with the lift line drum. The mainline then exits the capstan and connects to the haulback line to form the classic closed loop. By reeling in the haulback line on the yarder winch, the lift line spools out. Conversely, when the mainline is reeled in on the yarder winch, then the lift line spools in, lifting the load. This system is not new and has been adopted by several other manufacturers for their products. However, the novelty of Valentini's project is that the lift line drum can be disconnected from the capstan and braked, so that it is now possible to operate two identical carriages in tandem. By alternately braking and disconnecting the two lift line drums, one can use the lift lines independently, as required by effective work practice. Compared to the motorized alternative, the new tandem carriage is 40% lighter and 33% cheaper to purchase. Furthermore, by removing the on-board diesel engine, overall fuel consumption is reduced 20%. This new technical solution is increasing the viability of biomass recovery, and in general the financial and environmental sustainability of wood harvesting from remote mountain forests. The carriage was demonstrated in Northern Italy on June 2015 at an event arranged jointly by Valentini, CNR IVALSA and BOKU.

INFRES video

Case: Hybrid chipper

Comminuting is an important element of forest fuel supply procurement, because the size reduction of wood biomass from its initial form into finer particles improves transport economy and is essential when feeding modern biomass boilers. Comminution productivity and energy use are determined by machine-level factors; an increasing interest in novel solutions reducing the fuel consumption is brought to the discussion, and hybrid systems capable of evening out the power peaks of the work cycle are of great interest among machine manufactures. A new hybrid technology chipper, Kesla C 860 H, chipping pulpwood and logging residues, was studied in the INFRES case study. Productivity, fuel consumption, the quality of the chips and noise of the chipping operation was measured and analysed. The study results were compared to findings from previous studies examining conventional tractor-powered Kesla C 4560 LF and truck-mounted C 1060 A drum chippers. During the time studies, both the chipper and hybrid system were working well and the truck mounted chipper was also capable of operating in constricted roadside landings. Chip quality was good and suitable for demanding users with residential small-scale boilers. Compared to the truck-mounted chipper, the hybrid chipper's fuel consumption was lower per chipped 1,000 kg (dry mass) pulpwood and logging residues. The average chipping productivity (kg, dry mass per maximum engine power kW) was 93 kg/kW when chipping pulpwood with the tractor-powered Kesla C 4560 LF chipper, 56 kg/kW for the truck-mounted Kesla C 1060 A chipper and 70 kg/kW for the Kesla C 860 H hybrid chipper. With logging residues, the average productivity was 37 kg/kW for the truck-mounted Kesla C 1060 A chipper, and 82 kg/kW for the Kesla C 860 H hybrid chipper. The productivity results of this study must be considered to be preliminary because the amount of chipped wood and assortments was rather small. The hybrid system, is under continuous development, and a follow up-study is needed for the precise determination of the productivity, fuel consumption and operating costs.

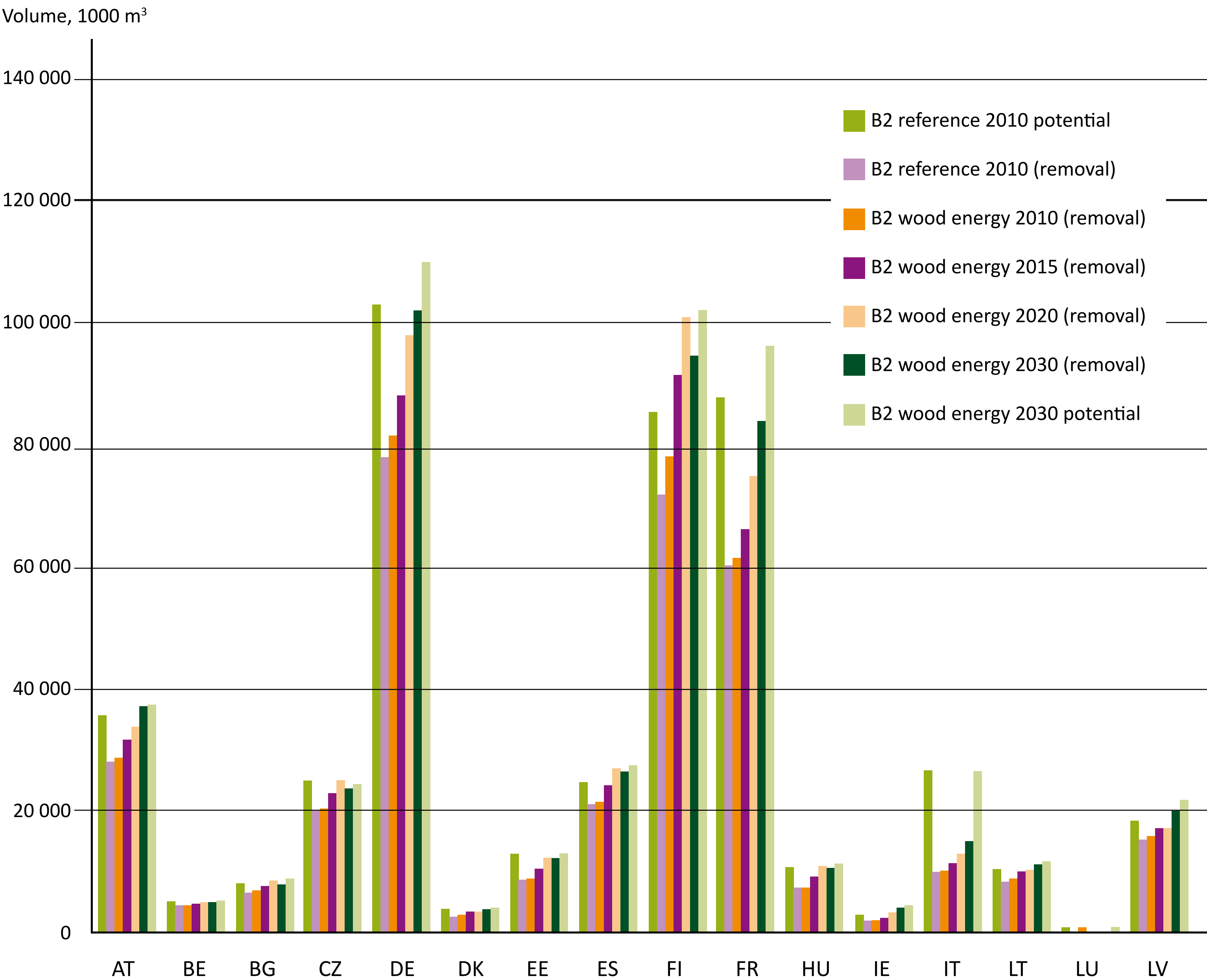
Sustainability of forest biomass feedstocks

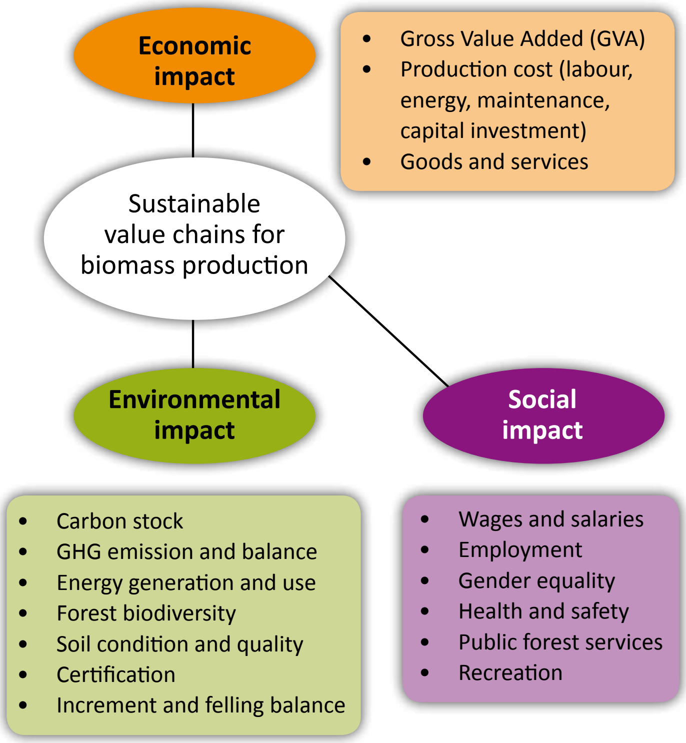
The INFRES sustainability impact assessments compare differences in economic, environmental and social impacts of the business-as-usual situation and future technological innovation scenarios as developed within INFRES. Most of these innovations are aimed at forest operations, logistics and chipping procedures. INFRES thus covers the complete value chain from the forest to the incineration in the energy facilities.

Impacts of different scenarios and for all European regions need to be comparable among each other. For this reason, the same indicators and indicator definitions for calculating impacts on sustainability are chosen. Indicator values are calculated for each process, and aggregated per module and per chain alternative.

What is the European wide potential of INFRES innovations? In INFRES, we focused not only on the economic, environmental and social sustainability impacts of individual forests or machine systems, but also upscaled and compared European-wide impacts of current versus new supply chains. With this, the overall effect towards the INFRES goals becomes apparent.

Exemplary value chains have been designed for four EU regions, namely Northern EU (NEU), Central EU (CEU), Southern EU (SEU) and Eastern EU (EEU).





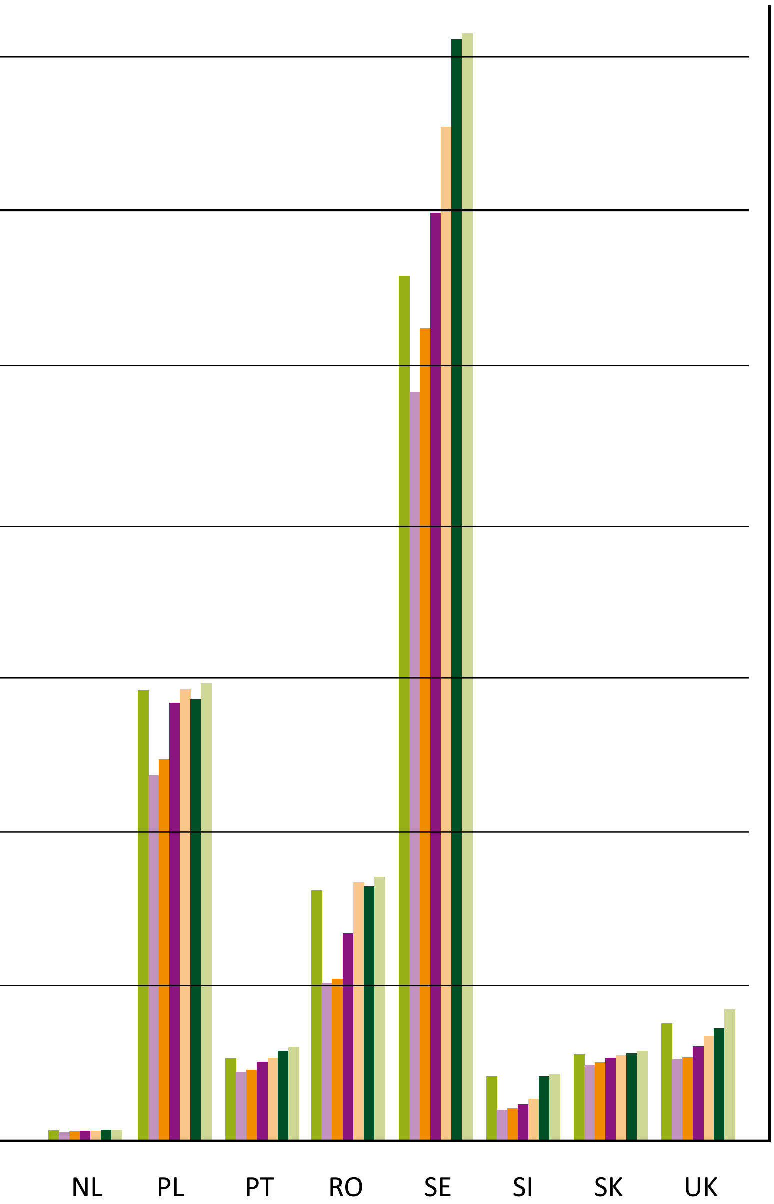
- CEU: Austria, Benelux, Denmark, France, Germanys
- NEU: Sweden, Finland, UK, Ireland Estonia, Latvia, Lithuania,
- SEU: Bulgaria, Italy, Portugal, Spain, (no data available for Cyprus, Greece, Malta)
- EEU: Czech Republic, Hungary, Poland, Slovak Republic, Slovenia

Choice of scenarios

According to Eurostat, for 2010 the net annual increment of forests in EU28 was 779 million m³ (over bark), of which 489 million m³ (under bark) (62% of annual increment) were harvested with 90 million m³ under bark. (11.5% of the fellings) destined for fuelwood. INFRES focuses on small-dimensioned assortments, which are not in demand with other industrial sectors for higher value-added wood product streams. We assumed that out of these 90 million m³ of fuelwood, approximately 25–30 million m³ come from forest wood chips (i.e. chips from small-dimensioned assortments such as harvest residues and stumps). Traditional firewood was excluded.

Availability of increased primary forest biomass:

Potentials for available biomass never exceed annual increment and were based on EFISCEN results for EUWOOD and EFSOS II studies. These volumes were adjusted for the INFRES project by imposing stricter restrictions for stump harvesting on top of the EFSOS II restrictions: only in final fellings, stumps were included in the potentials in countries where it was practiced in 2010 in INFRES, i.e. Finland, Sweden, UK. Harvestable material from pre-commercial thinnings was added to the removal volume. Protected areas were always excluded.



Comparison of 2010 reference and 2030 Wood energy forest potential, against B2 reference 2010 removal (solid bar) as well as B2 Wood Energy removals for 2010, 2015, 2020, 2030. The removals do not include volumes from pre-commercial thinning. Potentials do include volumes from pre-commercial thinning.

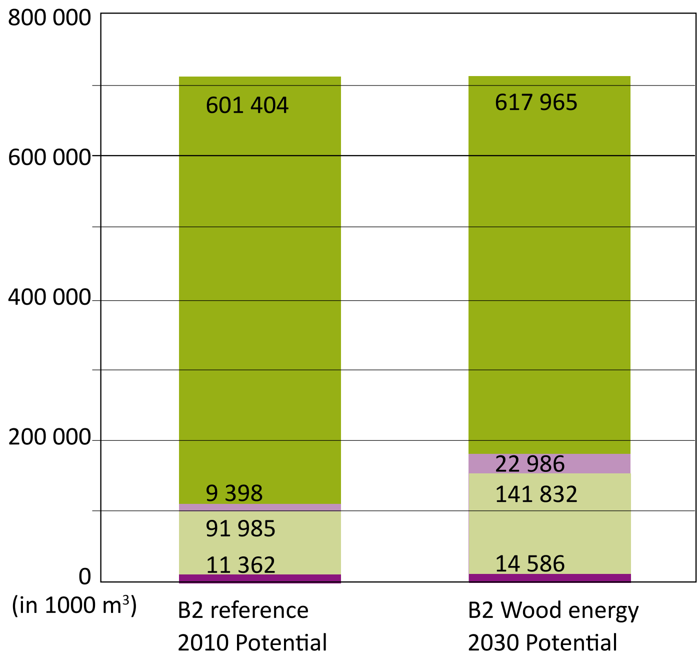
The INFRES scenarios:

- **INFRES 2010 baseline:**

The basis for INFRES 2010 potential is the “Real Forest B2 Reference potential” from EUWOOD project (2010 constraints). It includes the amount of material that could be harvested based on 2010 existing constraints which excludes protected areas, peatlands and poor sites. It also includes technical constraints such as that a maximum 70% of harvest residues can be harvested. This is the sustainably and technically potential available material (“Potential”).

- **INFRES 2010, 2015, 2020, 2030 Wood energy scenario:**

For modelling these years, the calculated potentials and removals were based on the “B2 Promoting wood energy potential: High mobilisation scenario” from EFSOS with less strict environmental constraints than in other scenarios and an assumed higher technological efficiency.

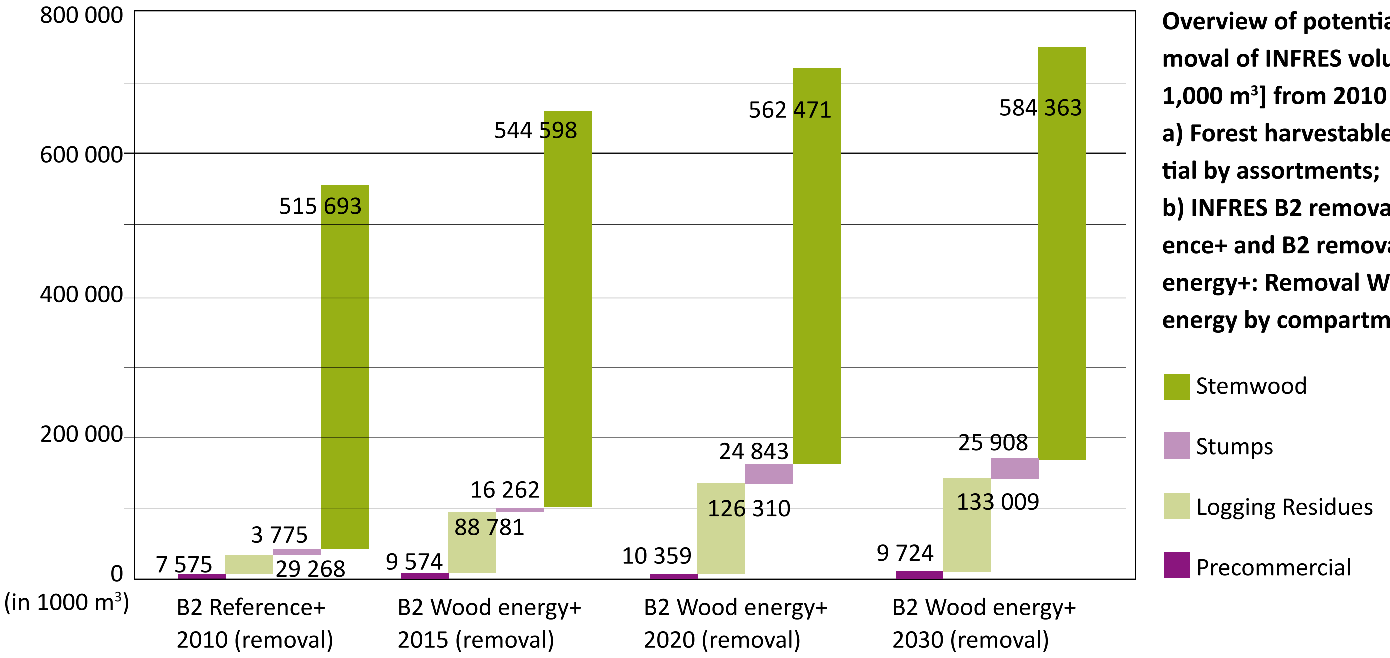


Final selection of machine innovations and their potential for application across Europe.

Scenarios/machines	NEU	CEU	SEU	EEU
Antti Ranta, enlarged truck space	x	x		
Swedish big truck (Skogforsk)	x (SE, FI)			
Pezzolato (chipper)	x	x	x	x
Narva multitree harvester head	x	x	x	x
Press-collector	x	x	x	x
MAMA felling head	x	x	x	x
Kesla hybrid chipper	x	x	x	x
Demonstrations of two-stage comminution of stumps	x	x	x	x

Improving harvesting technologies, as well as storage and mill/plant operations: increased supply of forest biomass.

INFRES Goal [Mm³]	INFRES Goal [TWh]	Small-dimensioned assortments and stumps [Mm³]	Stemwood [Mm³]	Total [Mm³]	Scenario [m³]
27 [25-30]	50 (180)	41 [covers INFRES goal]	516 [for other uses]	557	B2 reference+ 2010 (removal)
37 [35-42]	70 (25.2)	115 [covers INFRES goal]	545 [for other uses]	660	B2 Wood energy+ 2015 (removal) EU
65 [60-72]	120 (432)	162 [covers INFRES goal]	563 [for other uses]	724	B2 wood energy+ 2020 (removal)
162 [150-180]	300 (1,080)	169 [covers INFRES goal]	585 [for other uses]	753	B2 wood energy+ 2030 (removal)



Overview of potential and removal of INFRES volumes [in 1,000 m^3] from 2010 to 2030: a) Forest harvestable potential by assortments; b) INFRES B2 removal reference+ and B2 removal Wood energy+: Removal Wood energy by compartment.

On top of this, INFRES also calculated "B2 Wood energy+ removal" which had, in addition to "B2 Wood energy removal", also 2/3 of volumes from pre-commercial thinnings, as calculated in the potentials. Two thirds reflect, the harvestable amount of logging residues, and is the same share as for harvest residues. This reflects the INFRES focus on improving small-dimensioned wood availability for bioenergy assortments.

European wide sustainability impacts measured against INFRES goals

Annual supply of forest biomass

The amount of small dimensioned assortments available, such as materials from pre-commercial thinning, harvest residues, and stumps could be considerably increased from used 25–30 million m^3 and available 41 million m^3 in 2010, to 162 million m^3 in 2015, and 168.6 million m^3 in 2030.

Turnover from feedstock supply is generated as the sum of the following: value of the biomass supplied to the heat or power plant [assumption: energy price of 34 EUR/m^3 in 2010 (EUROSTAT, weighted average) plus the value of providing the services of the bioenergy supply chain [assumption: production cost].

Value of small-dimensioned timber supply chains per scenario, compared to INFRES goal

Reduction in fuel consumption

Reduction in fuel consumption is related to improved productivity per handled m^3 of wood as well as to changes in technology, such as a hybrid engine. The INFRES goals are to reduce fuel consumption in harvesting by 10%, in chipping and transport by 20% each.

Harvesting:

The harvesting goal has been well exceeded for selected systems. Most successful was the introduction of the NARVA and the MAMA harvesting system in pre-commercial thinning and thinning replacing conventional single-grip harvester at 6.5 m^3/h with 1.7 l/m^3 replaced by a NARVA multistem-head at 7.4 m^3/h with 1.5 l/ m^3 (12% reduction) and replaced with a MAMA felling head at 8.2 m^3/h with 1.3 l/ m^3 (24% reduction).

The use of harvesters (6.5 m^3/h at 1.7 m^3) instead of chain saw fellings (0.7 m^3/h at 0.8 l/ m^3) in pre-commercial thinning is less expensive but (depending on productivity) more fuel intensive. A balance is struck at motorsaw productivities up to 0.3 m^3/h for motor-manual systems, where the ratio tilts and mechanised systems can be less thirsty. Then fuel consumption is 1.8 l/ m^3, and thus higher for motor-manual fellings than for mechanised fellings. Motor-manual fellings are very widespread in CEU, SEU and EEU.

INFRES innovations calculated potential reductions ranging from 12 % to 24%.

Chipping

A mixture of harvest residues, logs and tops was the basis for conventional chipping (average productivity of 20 m^3/h and 1.15 l/ m^3 fuel use) and the new Pezzolato and Kesla hybrid chippers. Chipping trials with the Pezzolato chipper were successful, with productivity increases to 37.5 m^3/h (up to 46%) and reductions in fuel use to 1.06 l/ m^3 (up to 8 %). These fuel use reductions have the same trend in reducing GHG emissions.

Initial results of the Kesla Hybrid chipper are an exception to the pure rule of increasing productivity equalling a decrease in fuel consumption, as in this case a completely new technology (hybrid engine) was used. In that case, the productivity increase of the prototype machine was 39% from an average 20 m^3/h to 33.3 m^3/h. This fuel reduction was up to 18% for mixed assortments from an average 1.15 l/ m^3 to 0.94 l/ m^3. The initial results of the prototype hybrid chipper are promising, and further improvements are to be expected as the technology and operation matures. With that, the INFRES goal of 20% reduction was approached, but not yet reached.

Transport

Improvements in transport were mainly tested for Finland and Sweden with special exceptions of exceeding the legal maximum load of 60 tons with the following trucks: Antti Ranta truck with optimized load volume (69 tons), High Capacity Transport (HCT) vehicles (74 tons), tilting container truck and megaliner for logs (90 tons).

The goal was a reduction of fuel use by 20% by increasing payloads. The performance of the different trucks was:

- *74 ton chip truck* has a payload of 55 tons compared to a conventional payload of 44 tons (for a 60 ton truck). This reduces energy consumption by 13% from 22.6 ml/ton*km to 19.6 ml/ton*km.
- *69 ton chip truck* has a payload of 44.5 tons compared to a conventional payload of 39.8 tons (for a 60 ton truck). Reductions in fuel consumption were 12% from 60 l/100km to 53 l/100km.
- *90 ton timber truck* has a payload of 66 tons compared to a conventional payload of ca 38 tons. Fuel reductions of 21% namely 2.6 l/ton*km in comparison to 3.3 l/ton*km for conventional trucks have been shown in earlier studies of ETT project.

Productivities are expected to improve with longer distances for the chip trucks than those shown for the 22km (for 74 tons) and 40km (for 39 tons) distances in these trials. In general, the current reductions in fuel use were between 12% and 21%, with a potential for further optimisation.

Increase in manpower

Following the same calculation method as when calculating the value of services for "Turnover in feedstock supply", we arrived at the following results:

Relative additional employment for small-dimensioned timber supply chains, measured as Full time equivalent (FTE) per m^3, is 0.00097 FTE/m^3 for pre-commercial thinning, 0.00069 FTE/m^3 for harvest residue supply chains, 0.00018 FTE/m^3 for stump supply chains. 'Additional' means in addition to employment already in place in the traditional roundwood forest wood chains: pre-commercial thinning by harvester, forwarding of harvest residues, pre-commercial thinning of whole trees and stumps, chipping of the same assortments, and transport of chips to heat plant.

As a disclaimer, the values presented only show trends, not predictions. The reader needs to keep in mind that the data basis was very rough European averages as well as initial results from very few demonstration cases. The variation in productivities and performances throughout Europe and for various machine systems is enormous, and data was rather scarce. Nevertheless, the result shown can give a very good indication of potential impacts, if the recommended innovations are implemented on a broad basis throughout Europe.

Fulfilment of INFRES goals on increase in manpower

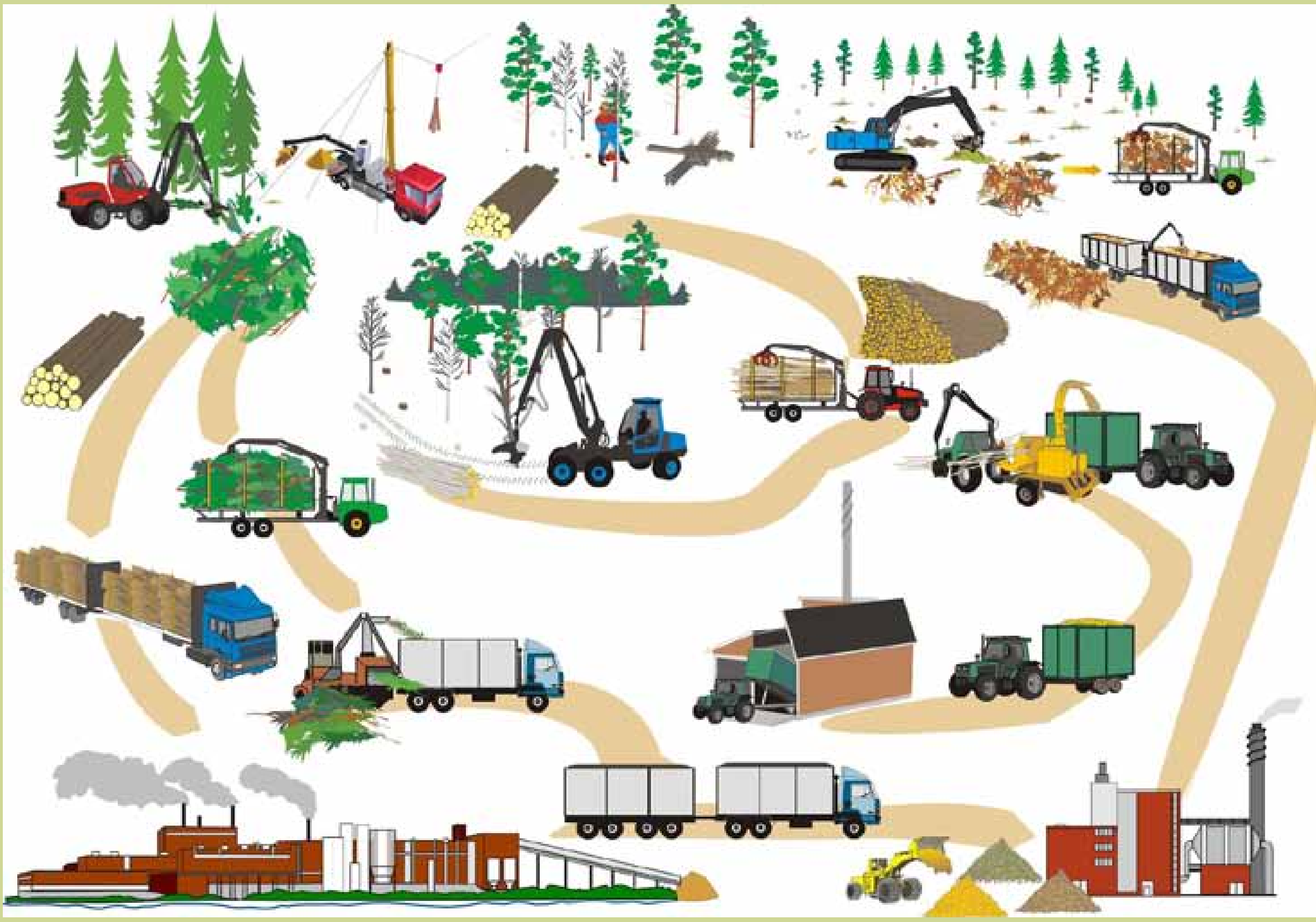
	2010 (BAU)	2015	2020	2030
INFRES Goal: Increase in manpower (including spin-offs)	11,000 FTE	15,000 FTE **+36%**	27,000 FTE **+145%**	65,000 FTE **+490%**
Increased manpower from additional volumes and improved harvesting technology	+74,938 FTE	+211,461 FTE	+297,980 FTE	+311,132 FTE

Case: Cost estimation of forest fuel procurement in INFRES regions

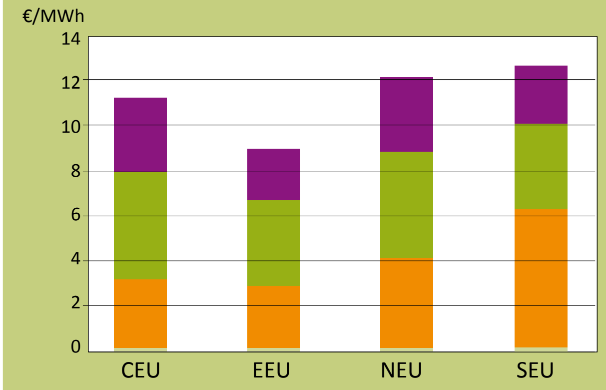
The Natural Resources Institute Finland, Luke, has estimated the forest fuel procurement costs, consisting of forest wood harvesting, chipping and transportation costs. In order to enable better comparison of costs between four selected INFRES regions (Northern Europe - NEU, Central Europe - CEU, Southern Europe – SEU, Eastern Europe - EEU), supply chains were standardised. The dominant supply chain for stemwood and stem and crown biomass from early thinning in Europe is the chain based on roadside chipping. In this chain, felling and bunching are carried out by a harvester, off-road transport by a forwarder and chipping by a mobile chipper. As regards logging residues, the chain piling of logging residues by the harvester is considered to belong to the logging residue supply chain. Stumps are extracted by an excavator, forwarded to roadside and crushed by a mobile grinder. Other chains include motor-manual felling, cable yarding and skidding. Transportation is carried out by a truck & trailer combination with a transportation of chips to the end-using facility. In order to better compare the chains, a transportation distance of 60 km is assumed for all calculated chains. Overhead costs and production costs are not included. The value added tax is 0% within all calculations.

As a result of the cost estimations, supply costs for logging residue chips are €8.5-12.2/MWh. Wood chip supply costs from thinning are €9.3-15.9/MWh for conifer stem chips, and €8.5-16.6/MWh for broadleaved stem chips. Supply costs for wood chips from conifer stems from final felling are €8-€10.8/MWh. The estimated supply cost examples for chips from conifer stems from final felling for different supply chains in Eastern Europe were calculated. The highest costs occur for chips from manual felling in combination with skidding logging (€16.9/MWh), whereas the traditional cut-to-length operation (with harvester & forwarder) has the lowest costs with €8.4/MWh in the selected Eastern European countries. Supply costs for wood chips from conifer stumps are €11.4-13.1/MWh

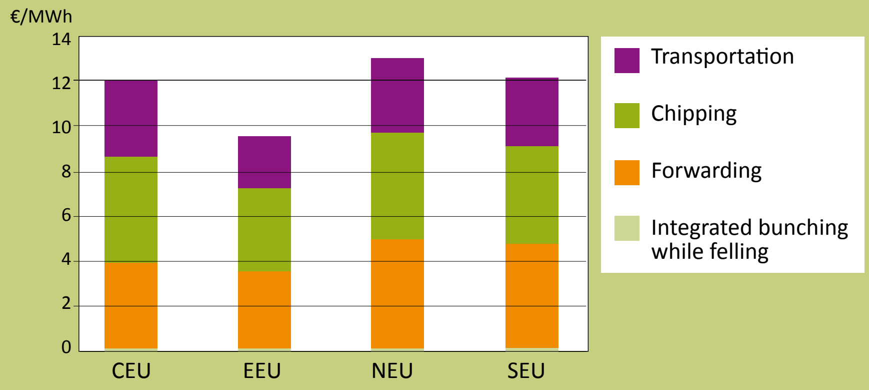
However, in general there is great variation of estimated costs between different supply chains in defined INFRES regions, within each country and within NUTS regions of selected countries. Therefore, the calculated costs should be seen as estimates with high uncertainties and a number of limitations when using the results.



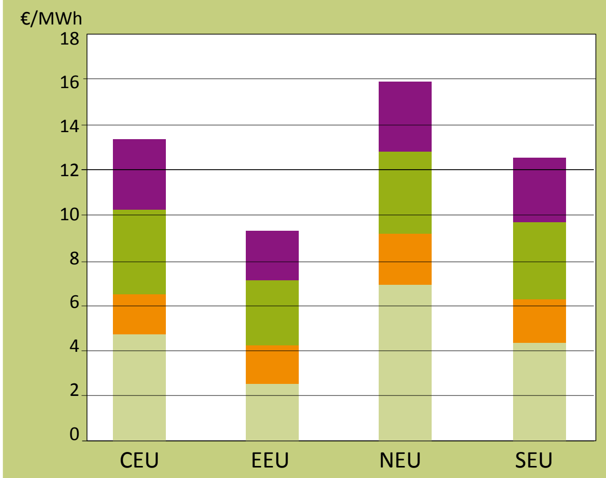
Estimated supply costs for logging residues chips from conifers delivered to the plant.



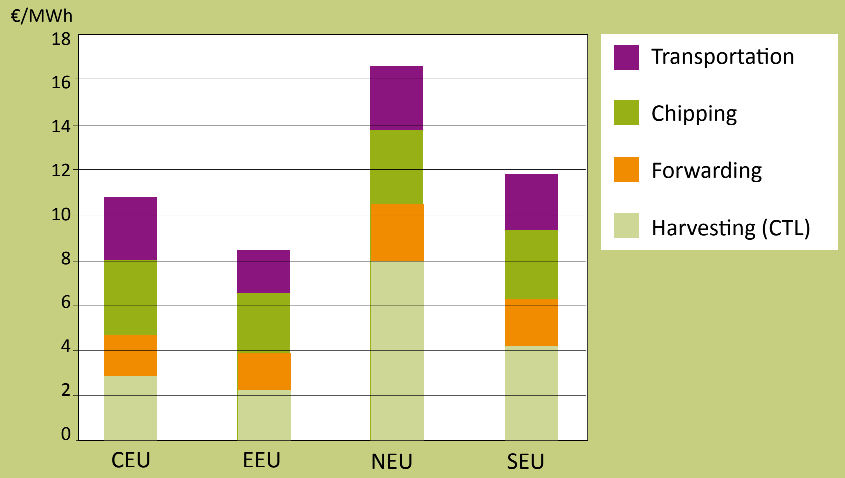
Estimated supply costs for logging residues chips from broadleaves delivered to the plant.



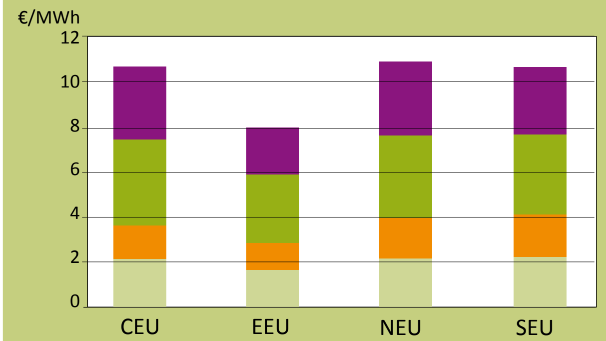
Estimated supply costs for chips from conifer stems from thinning. CTL=cut to length



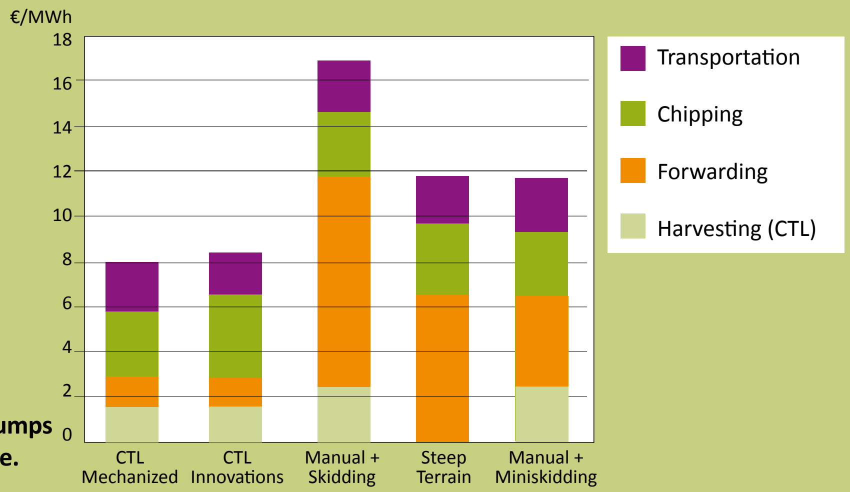
Estimated supply costs for chips from broadleaved stems from thinning. CTL=cut to length



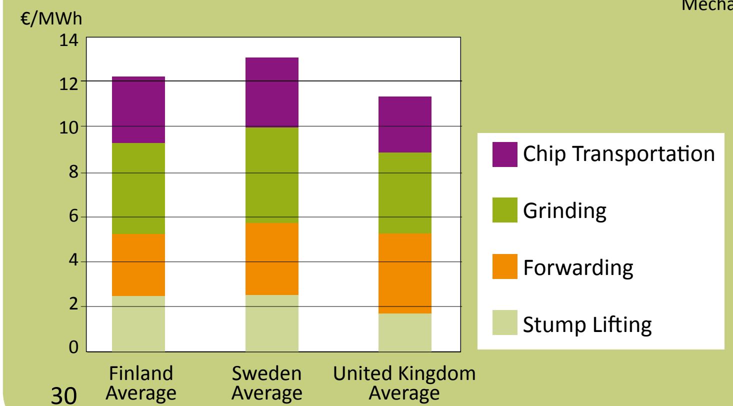
Estimated supply costs for chips from conifer stems from final felling. CTL=cut to length



Estimated supply cost examples for chips from conifer stems from final felling for different supply chains in Eastern Europe. CTL=cut to length



Estimated supply costs for chips from conifer stumps in Northern Europe with grinding at the roadside.



Technology foresight and barriers to innovation

Technological and economic barriers in innovations

Innovation is a key factor for the development and progress of a company in all sectors. In the forest technology sector, barriers and drivers that influence innovation activities and the diffusion of new products have not been studied extensively. Companies in this sector are mostly small and medium-sized (SME) enterprises, but typically sell their products on the world market. Their activities include the production of machine parts and even whole machines. Typically, these companies are located in rural areas and make an important contribution to the local labour market and the local economy and development. Their existence is essential also for the European Union.

In their development work, companies within the forest technology sector are facing barriers to innovation that can stop or delay the introduction of new products and concepts into practice. Even after introduction, some new products succeed while others fail. Companies assess the performance of an innovation using specific criteria that are related to customer relations, product development process, financial performance, and company benefit. Customer relations i.e. customer satisfaction, high product performance level and meeting of quality guidelines are the most important. Company benefit (e.g. growth of demand of the products of the company) also seems to be prioritized.

The most important barrier to innovation is a lack of financing, especially for new high-risk projects. This is further supported by the fact that the forest technology sector is a small market and that development costs are high. A lack of skilled engineers is occasionally seen as a barrier as well.

The most important solution to overcoming barriers seems to be collaborations with customers, both to get a feel for what customers want, but also to better introduce new technology in a sometimes reluctant and conservative world. Furthermore, collaborations with universities and research institutes are becoming more important, as those will help unlock additional funding for the development of new innovations.

Drivers of innovations are tied to competitiveness (to stay on top, offer the best products, stay one step ahead of competitors). A genuine "passionate" interest in product development seems to be an important driver as well.

According to experience from harvesting operations, users and scientists identify innovations that increase the productivity of the operations, reduce the cost and are flexible (can work in most conditions) as successful. On the other hand, innovations that are poorly marketed, require complicated logistics, can only be used in specific conditions and have a low productivity are considered to be a failure.

Potential of innovation and inventions

Inventions that gain commercial acceptance become innovations. Within the forest technology sector, the competitiveness of new or improved equipment in harvesting and extraction of forest biomass greatly depends on satisfying some basic conditions: They must:

- reach higher productivity than state of the art equipment;
- reduce consumption of fossil fuels and improve the energy balance of the forest biomass;
- reduce the negative impact on operator's working environment (ergonomic, health and safety of forest workers);
- increase the value of the forest biomass and the profitability of forest contractors and
- reduce or mitigate impact on the soil (compaction, rutting, soil displacement), residual trees and atmosphere.

The implementation potential of new products as well as their probability and the desirability of adoption were assessed with a Delphi survey, a tool of futures studies. The Delphi survey is a technique for gathering data from a panel of experts within their domain of expertise. It is a repetitive process during which the experts are allowed to revise their opinions based on the responses of the other experts in the panel. The aim is that at the end of the process consensus is reached.

As expected, some innovations that are already used in other sectors were deemed to have more potential than others to be adopted in harvesting and extraction of forest biomass. "Hybrid electric power system", "Self-operating machines", and "Ultra-low emission engines" are thought to have the greatest potential for use. 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 of equipment that have not yet been commercialized, "Automated loading of biomass harwarders", "Open forest street map", "Hybrid chipper" and "Machine vision" are thought to have the greatest probability of becoming commercially accepted. Open forest street map is a digital forest road network available online to the contactors without or with only a small fee in order to support the phase of operational and strategic planning of forest biomass supply, round wood supply and other branches of forestry logistics. They are also thought to be the most desirable inventions. Additionally, the inventions that are thought to be those most probably adopted and have the highest commercial potential are also the ones that are furthest developed, and might for example already have prototypes.

However, a number of barriers to adopting these technologies exist. Some barriers are cultural, e.g. acceptance might depend on ways of doing harvesting and the ownership of the forest. Other barriers are more technical, while yet others revolve around the need for more test results to show that there would be benefits from adopting the inventions. 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 wants to decide themselves which trees to harvest.

Risk assessment and measures to overcome barriers to the commercialization of inventions

In the INFRES project, some objectives are identified:

- Develop and demonstrate technological and logistical solutions that reduce the fossil energy input in the biomass supply by 20% and the raw material losses by 15%.
- The cost of supply can be reduced by 10–20% and precision of supply improves the economic outcome of CHP production by 10%.
- The CO_2 emissions of feedstock supply will diminish by 10%.
- With the novel technologies and efficient transfer of best practices between the countries in the consortium and other countries with similar natural conditions, the volume of forest energy supply in EU27 by 2015 will be 30% higher than today.

As an example, and departing from the estimation uttered in the European "Promoting wood energy scenario" that 71 million oven dry tons (odt) of logging residues and 51 million odt tons of stumps would be needed to be extracted in 2030, it can be calculated that the total amount of fuel that would be needed could reach 570 million litres of diesel (assuming 4.8 l/odt in stump harvesting, 2.9 l/odt and 2.4 l/odt in forwarding of logging residues and stumps respectively). If INFRES objectives are to be realised, this would mean that fuel consumption would be cut by 115 million litres of diesel.

In order to overcome the barriers that would contribute to the realization of the risks, a number of measures have to be taken.

Considering measures to overcome barriers that manufacturers face when developing an innovation, the following should be prioritized:

- Proper allocation of resources for product development and improvement of the business profitability
- Ascertaining how markets and trends are developing
- Cooperation with other firms within horizontal structures in industrial districts, with customers (forest companies) to ensure product sales, feedback for further development and with scientists, educational institutes and universities
- Ensuring favourable financing instruments (e.g. affordable and secured loans)
- Subsidies or grants to compensate high-risk investments, particularly for small innovative companies

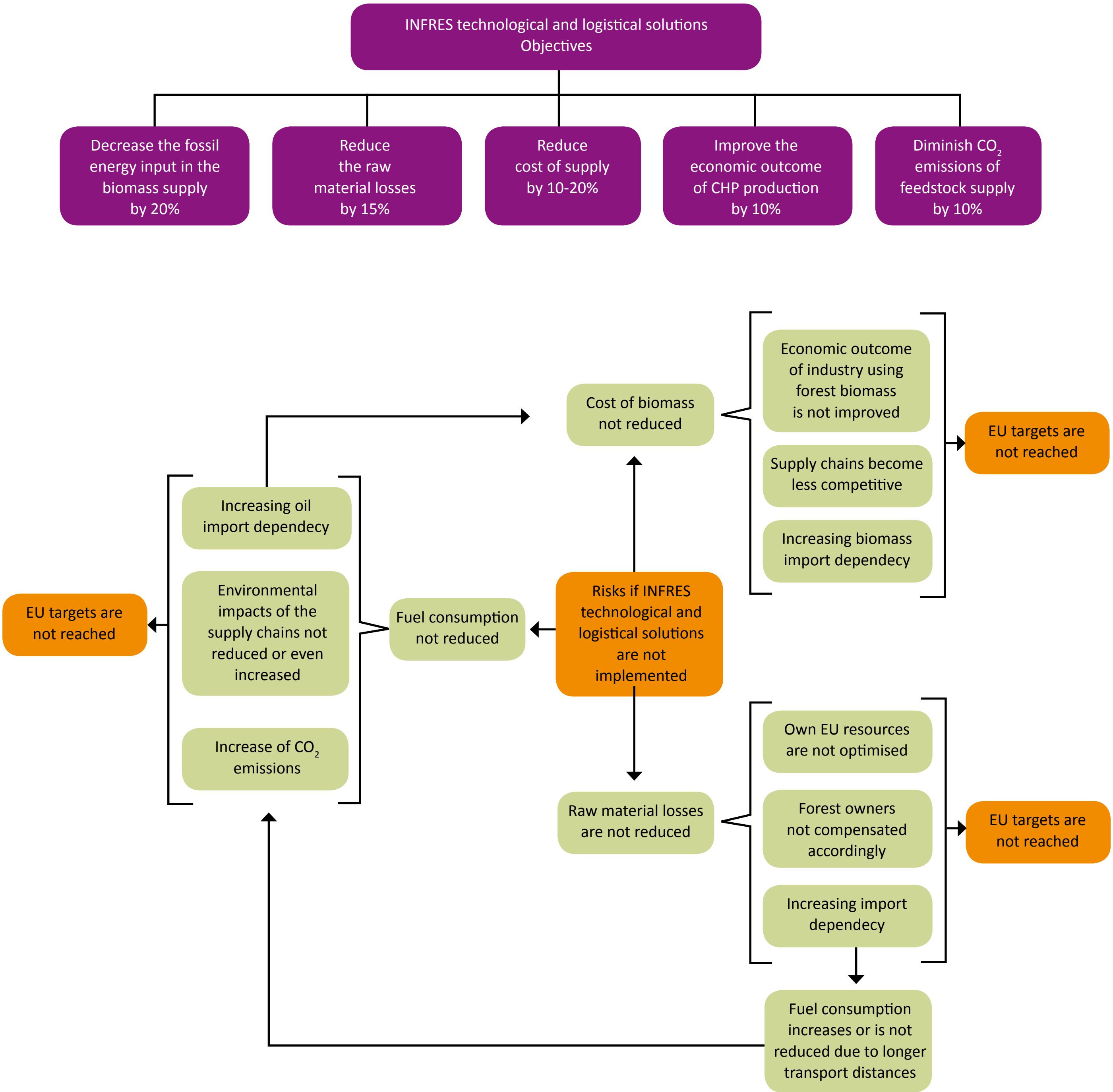
These measures are mainly in the hands of the manufacturers themselves, with some of the policy makers who may contribute by financing instruments or compensations for high-risk investments.

Considering measures to overcome barriers found during the implementation or use phase the following should be prioritised:

- Collaborate with existing dealers and service networks
- Secure expert help provided by the manufacturer
- Mount demonstration actions to show and promote equipment
- Choose a machine that is properly adapted to the site (size of trees, topography, etc.) with a good service deal and reliable service network
- Evaluate whether – through small low-cost changes – (i.e. different tracks, add another axel or bogie to improve bearing capacity, tire size, air-pressure change in tires, knife-change) a machine can be made suitable for a specific environment
- Contact contractors and forest companies
- Ensure enough working hours for expensive machines by good planning and management
- Draft long term contracts that could ensure realistic prospects for profitable business

In this case, there is a good mix of the main actors of the measures between forest companies and manufacturers. It means that both have to work, sometimes together, to overcome the barriers detected. Besides the main actors of the measures, other stakeholders (policy makers, researchers) can take actions to promote or accelerate the implementation of those measures in order

Potential risks associated with not bringing the demonstrated technological and logistical solutions to practical application along with their consequences.



to ensure reaching the commitments of the UE regarding forest biomass and wood supply chains.

If the technological and logistical solutions demonstrated during the INFRES project are not implemented or if their implementation is delayed considerably, then the realisation of energy and environmental targets in Europe cannot be achieved. Nor will sustainability and cost efficiency gains in the biomass supply chains be realised.

Successful innovations: increase productivity of the operations, reduce the cost and are flexible.

Failed innovations: are poorly marketed, require complicated logistics, can only be used in specific conditions and have a low productivity.

Selected list of INFRES publications

INFRES Reports

Development of technology and quality improvement:

Technology push – technologies for the residual biomass harvest for the future
A prediction model prototype for estimating optimal storage duration and sorting
Full supply chain performance and re-engineering report
An operator tutoring system for optimal blade maintenance

Adapting existing forestry practices for improved biomass production

Customers and markets of forest biomass of the future
Adapted forestry practices for improved biomass recovery
Coupled vs. De-coupled Logistics for Wood Chip Production
Test bench model for logistical business analysis
Novel business and service models of the forest biomass supply
Analyses of forest management systems for increased harvest of small trees for energy purposes in Sweden

From demonstrations to practice

Demonstration reports 1 – 3

- Two stage grinding of woody biomass
- Smart chipper demo in Germany
- Pezzolato chipper truck demo in Sweden

Demonstration reports 4 – 7

- Efficiency of integrated grinding and screening of stump wood for fuel at roadside landing with a Crambo 6000 grinder equipped with a star screen
- Harwarders for thinning hardwood plantations in Italy
- Multi-tree harvesting head in Catalonia
- Studies and demonstration on the use of a novel prototype harvester head in early fuel wood thinnings

Demonstration reports 8 – 23

- Stump drilling demo in Finland
- Forest biomass recovery in Alpine forests
- Success factors for forest fuel terminals
- Demonstration of a High Capacity Vehicle for chips transport at Political week in Almedalen
- Drying of wood chips in a warm air dryer
- Lipe Multipurpose Chip Truck and Semi-trailer Equipped with Electronic Trailer Steering System
- Harvesting operations in hard wood dominated stands using the energy wood felling head Naarva EF28
- Studies and demonstration on the use of a bundle-harvested system in early fuel wood thinnings
- Semi-Automated Process Analysis of Wood Chips Supply using a Fleet Management system
- Joint demonstration of the large nine axle chip truck – trailer unit and the hybrid chipper
- Un-motorized full suspension carriage
- Transport logistic software for wood chip firms, demonstrated in Germany

- Wood chip drying using biogas heat in Germany
- Using synthetic cable for wood and biomass extraction in Catalonia
- Comparative of a conventional forwarder and press collector in Catalonia
- Demonstration of good terminal logistics and high capacity transports at Söderenergi's receiving biofuel terminal in Nykvarn, Sweden

Prototype of hybrid technology chipper
Location barter may reduce forest fuel transportation cost
Destinering och lägesbyten för att effektivisera transporterna av skogsflis [in Swedish]

Sustainability of forest biomass feedstocks
Description of the assessment framework with indicator and scenario specification
Impact Assessment on Carbon dynamics, forest growth and productivity, water quality, and biodiversity
Report documenting sustainability impacts of scenarios for different fuel sources and procurement technologies
Biomass from forests – cost estimation of complete supply chains
Sustainability impacts of increased forest biomass feedstock supply – a comparative assessment of technological solutions with three different impact assessment methods

Technology foresight and barriers of innovation
Technological and economic barriers to introduce and apply innovations in forest energy sector
Development potential of inventions in forest biomass harvesting
Plan for promoting the demonstrated systems and technologies for further development

INFRES Newsletters

1. Customers and markets of forest biomass
2. Forest Biomass recovery and improvements
3. Four successful international supply chain demonstrations
4. Assessing bioenergy and its EU-wide impacts
5. Fuel wood quality optimization through drying models and sorting tools
6. Specification of wood chips and hog fuel by EN ISO 17225 standards
7. More demonstrations in 2013-2014: stumps and small trees
8. Supply chain performance and re-engineering
9. Demonstration Galore
10. Technological and economic barriers in innovations
11. Potential of innovation and inventions
12. Risk assessment and measures to overcome barriers to the commercialization of inventions

INFRES video

Demo of testing the NAARVA EF28 in Austria:
German version:
https://www.youtube.com/watch?v=FVq2lucRyrU
English version:
https://www.youtube.com/watch?v=aGdZeXLbFB4

Demo of the prototype MAMA-head
https://www.youtube.com/watch?v=EJePXT0fmTg
Demo of the multipurpose wood chip semi-trailer
https://www.youtube.com/watch?v=VDeomnxaC6E

Demo of Biogas woodchip drying
Demo of Full suspension carriage - Valentini
www.infres.eu

All INFRES publications (list of scientific papers, reports, newsletters, posters, videos and presentations in the conferences and seminars) are available on INFRES web at www.infres.eu.

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Harvesting of energy wood in thinnings, Spain.

Chipping operation in Germany.

Grinding and screening of stump wood, Finland.

Modern cable yarding operation, Italy.

Monitoring of fuel wood drying, Austria.

A truck leaving the scales at the terminal, Sweden.

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Innovative and effective technology and logistics for forest residual biomass supply in the EU

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