Sustainable Bioenergy
Solutions for Tomorrow

Energy Biomass Supply Chain Concepts Including Terminals

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Abstract

Sustainable Bioenergy Solutions for Tomorrow (BEST) is a public-private research program launched in early 2013. BEST crosses traditional business area boundaries and joins the strengths of forest and energy sectors, complemented by the know-how of technology and consulting companies and research organizations. The program partners currently consist of 22 companies and 12 research organizations. The duration of the program is four years (2013-2016) with an annual budget of roughly 4 M EUR.

This report summarises key findings and most remarkable outcomes of the Work Package 3 (WP3) Biomass on the way to the bio-product mill. WP3 consists of three tasks: TASK 3.1 Combining measurements and other quantity and quality data to enable management of the supply value chain of bioenergy raw material, TASK 3.2 Terminal concepts and modelling of terminal-based supply chains and TASK 3.3 Resource and cost efficiency of the supply chain.

Critical evaluation of measurements as a part of supply chain is monitored together with new research findings of measurement technology and systems. Terminals are carefully studied from cost, layout and location point of views and different size classes were investigated. New technologies were developed and examined especially for measurements and stump lifting as well as truck transportation. Storing of biomass along the supply chain is critically investigated as well, drying functions and quality changes are first time connected to the ERP to enable value based allocation of the feedstock and revolutionary FastTrack supply is suggested to be implemented for logging residues.

Enterprise Resource Planning (ERP) is used as an approach, in which all results of the WP3 are drawn together. Definition and relations of the information are described as a result. The results of the BEST WP3 enable new generation of the bioenergy feedstock management and control. Some parts of the results are already implemented in the actions and procedures of Finnish bioenergy companies.

Keywords: Forest biomass, forest energy, energy wood, supply chain, bioenergy feedstock, simulation, optimisation, measurement, resource management.

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1. BIOMASS FOR ENERGY - TODAY AND TOMORROW

Lauri Sikanen, Natural Resources Institute Finland, Timo Melkas, Metsäteho Oy & Kaisu Leppänen, Spinverse Innovation Management

Forest biomass has gained a remarkable position as an energy source in forest-rich countries, like Finland and Sweden. These countries also run forestry on a sustainable basis, resources are increasing and ecological sustainability has been improved remarkably, especially during the last two decades. Added value created by forest industries is well spread in society because of private forest ownership and the high price of wood material, by independent entrepreneurs taking care of forest operations and logistics as well as the large number of relatively well-paid workers in factories and power plants. Forest biomass is also used for energy by cooperatives and entrepreneurs, which are generating high added value and fortifying local economies by replacing imported oil in heat and energy production by local wood in decentralised energy production in hundreds of Finnish municipalities and communities.

Logistics is crucial in the bioeconomy. Biomasses have a loose structure and production is decentralised. Transportation generates significant value addition simply by moving biomasses from their origin to the place of use or refining. This added value can be also considered as a cost in the value chain. Logistics, including storing, is an important part of the bioeconomy. Cost savings are achieved by building logistic systems as effective as possible and gains can be realised by understanding all features and characteristics of harvested biomasses and minimising losses while maximising benefits in logistic systems.

The BEST programme invested remarkable resources to develop the logistics of biomasses by simulation, systems analysis and quality assessment. That investment seems to have been recouped quickly by sophisticated enterprise resource planning approaches developed in BEST. Quality assessment of biomasses was taken to the next level by utilising modern ICT and weather models. Even biomass measurements legislation will be changed by the results of BEST.

The future of forest biomass for energy is now threatened by climate politics. It has been argued that the use of forest biomass is not helping fast enough in the mitigation of carbon dioxide emissions. The future of forest biomass for energy is tied to international climate politics, which presents unpredictable situations. The use of forests for energy will continue, but growth is dependent on political decisions. We must hope that all positive aspects, like the renewability of wood as an energy source, boost local economies, employment of rural people and this potential healer of the trade imbalance is not lost because of difficulties agreeing on short-term climate politics.

2. BIOMASS TERMINALS – WHAT KIND AND WHERE?

2.1. THE CONCEPT OF TERMINAL IN THE SUPPLY CHAIN

Jyrki Raitila, VTT Technical Research Centre of Finland & Olli-Jussi Korpinen, Lappeenranta University of Technology

MAIN OUTCOME

Terminals are needed to balance temporal differences of supply and demand over time in the supply chain. In biomass logistics, the need for terminals is the highest when the peak seasons of heating and harvests are short and non-simultaneous. Terminal solutions are case-dependent and based on different factors.

MOTIVATION

If forest-based fuel demand increases, as it seems, new logistical solutions are needed. Most of the increase in use is expected to take place in large heat and power production units which set special requirements for supply as both procurement volumes and transport distances increase. Biomass fuel terminals broaden the spectrum of available supply options by offering cost-effective large-scale biomass storage and processing options for securing the fuel supply in all conditions.

CONCEPT

The concept of a biomass terminal can be considered as a stopover for biomass between the origin and destination points in the supply chain. It can be separated from power plant yards and roadside storages (or farms) so that at least one logistical operation precedes (e.g. road transportation) or follows (e.g. measurement at plant reception) the terminal in the chain. Usually, terminals are required somewhere between the roadside storage and the plant because there is a lack of sufficient space to store or handle the biomass. A terminal can also boost the transportation performance by enabling intermodality or by levelling the unstable need for transport capacity.

WHY TERMINALS?

Traditionally, a biomass terminal has been seen as an additional logistical stage increasing the costs to the supply chain. Despite this impression, the utilisation of biomass terminals in practice has increased steadily in recent years (Strandström 2016). A terminal is usually established when one or several of the following factors become meaningful in biomass procurement:

- Balance factors: Direct supply of biomass fluctuates significantly and is incapable of meeting the more regular demand at the same time.
- Resource/capacity factors: The supply chain can perform with less resources (e.g. vehicles, machines, workforce) needed to achieve the same desired output than a supply chain without a terminal.
- Quality factors: The terminal can upgrade the quality of biomass from the level of a supply chain based on direct deliveries.
- Synergetic factors: The terminal can be used for other business purposes during the low-season of biomass storages or, e.g., a backhaul transportation of some other product is enabled (i.e. made economically feasible) by the terminal.

- Legislative factors: E.g. storing at roadside is periodically prohibited due to environmental reasons or the terminal is prerequisite for obtaining permission to build a new plant (e.g. in urban area).

The increasing use of forest fuels inevitably makes transport distances longer because new bioenergy capacity is built in densely populated areas while untapped wood sources are in rural areas. Because biomass is space-demanding and bulky, more efficient logistical methods are needed. The terminal offers security of supply for a fuel user and it can level out fuel quality and quantity fluctuation.

BALANCING SUPPLY AND DEMAND

Biomass supply and demand on a daily or weekly basis is often imbalanced because biomass harvesting depends on harvesting seasons and weather conditions. With regard to forest fuels, wood harvesting takes place all year round but the schedule of harvesting operations determines what kind of wood is directly available. Balancing has to be managed by storages. However, there are end-users that need a steadier raw material flow for their processes, and the number of bioproduct mills of this type could be increase in the future. For example, a Finnish bioethanol plant with relatively steady demand for straw residues as feedstock would be a challenging combination. In Northern Europe, straw is collected within a short harvest season in August and September, and the harvested feedstock should be stored until the end of the following summer. Should the end-user be an energy plant, the storage- and quality-related challenges would basically be almost the same, although the most biomass is needed already during winter months. On the other hand, there are certain regularly provided biomass types, for example residues from the wood processing industry that do not need terminals or stores to balance their demand.

Typical biomass types or feedstocks and their end-users, and the estimated need for terminals in the supply chain are presented in Table 1. Some of the combinations do not exist in Finland yet, and some of them exist only on a minor scale.

Table 1. Typical examples of temporal fluctuation (strong, moderate, light) of demand (D) and supply (S) through the year with different combinations of biomass and end-users. The estimated needs for buffer terminals in each case is indicated by cell shadings (dark shading = more need, light shading = less need).

Feedstock	End-user		
	Heating plant	CHP Plant	Bioproduct mill
By-products, Municipal solid waste	D strong, S light	D moderate, S light	D & S light
Primary forest biomass	D strong , S moderate	D & S moderate	D light, S moderate
Agricultural crop residues	D & S strong	D moderate, S strong	D light, S strong

2.2. TERMINALS IN SWEDEN AND FINLAND

Jyrki Raitila & Matti Virkkunen, VTT Technical Research Centre of Finland

MAIN OUTCOME

Biomass terminals in Finland and Sweden were surveyed in order to learn what kind of biomass terminals there are in these countries. They were also localised and the main characteristics were compared.

MOTIVATION

In many ways Finland and Sweden are similar as far as forestry and bioenergy concepts are concerned. Both countries are the world leaders in supplying woody biomass and using it for energy production. However, there are some characteristics and differences that both countries can learn from. Therefore, a proper biomass terminal survey was worth conducting.

WHAT KIND AND WHERE?

According to a Swedish study (Kons 2015) there are 270 terminals run by forestry companies and forest owners' associations that handle fuelwood in Sweden. The largest terminal had an area of 20 ha and the smallest only 0.1 ha. Overall, 74% of these terminals had areas of less than 2 ha and only 8% of all terminals are larger than 5 ha. The total forest fuel volume supplied through the studied terminals was 7.8 TWh (28 PJ at MC 50%) which is about 55% of all wood chips and hog fuel used in energy plants (Kons et al. 2014; Swedish 2008).

In general, the most pronounced differences were observed between terminals with areas of <5 ha and those with areas of >5 ha. Terminals of <5 ha accounted for 65% of the country's total terminal area, and more than half of the country's total forest biomass output was handled in terminals of <2 ha. Comminution was performed at 90% of all terminals (Kons 2015).

The ≥5 ha terminals were generally better equipped than smaller ones. The most common piece of equipment across all terminal size classes was a wheel loader (Kons et al. 2014). This is similar to the situation in Finland. Larger terminals often have a weighbridge for weighing incoming and outgoing wood loads. Comminution of woody biomass is usually done with mobile machines. However, the largest terminals have also invested in stationary machinery such as grinders or chippers.

The Finnish terminal network consists of 202 terminals supplying annually 6.4 TWh of forest fuels (23 PJ at MC 50%) which is about 45% of all forest fuels delivered to power and heating plants. Medium-sized terminals (1-3 ha or 10 to 100 GWh/a) dominate in the total number of terminals in Finland. Roughly two thirds of forest fuel is supplied through these medium-sized terminals (140 terminals). A very small share is delivered through small terminals (<1 ha or 1 GWh). However, the amount of wood supplied through the 15 largest terminals alone (200 to 400 GWh/a) accounts for one third of the material. The largest terminals are usually owned by energy companies and they serve a single power plant in their vicinity. Finnish biomass terminals are presented in Fig. 1.

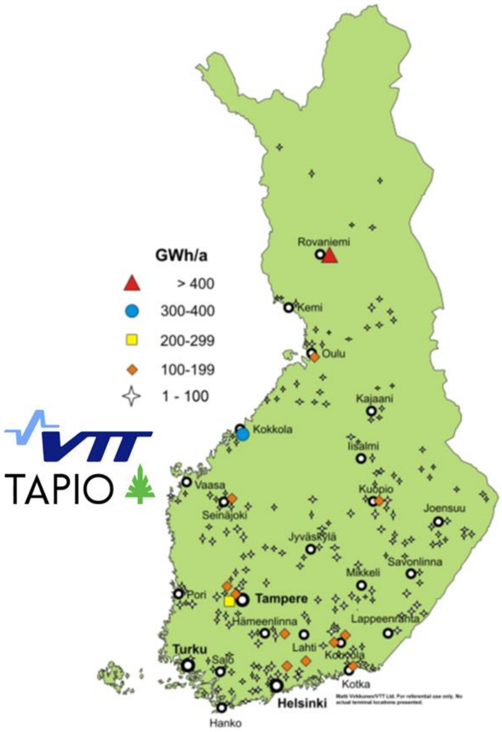

Figure 1. Biomass terminal locations in Finland.

Despite the similarities in wood fuel supply conditions in Sweden and Finland, the terminal supply strategies differ greatly in these two countries. One of the major differences is the vast utilisation of energy wood railway transports in Sweden: 45 Swedish terminals have a direct connection to railway and 95% of forest biomass lies within the procurement areas of terminals. In Finland the railway transport of wood fuel is very rare, while truck transport dominates in all wood fuel supplies. The terminal network in Finland is also significantly more scattered and focused around the most populated areas (Virkkunen & Raitila 2016). Current Swedish biomass terminals (sites marked with green dots) are presented in Fig. 2.

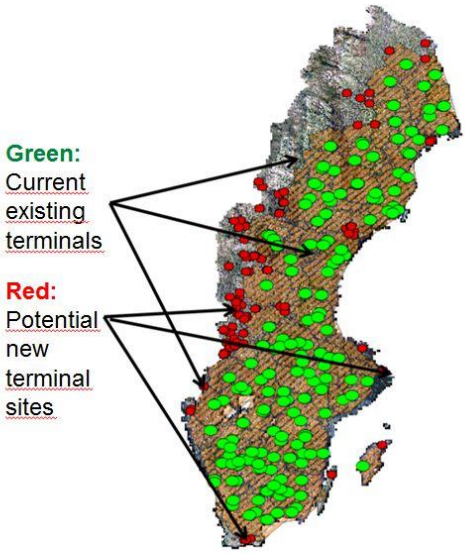

Figure 2. Biomass terminal locations in Sweden (Enström et al. 2013).

Another difference between Finnish and Swedish terminals is the size distribution of the terminals. Whereas in Sweden the small 0–2 ha terminals dominate both in terms of number (154) and total output (4.5 TWh or 15.3 PJ), in Finland most of the wood fuel is delivered through a few large terminals. In total, about 30% of the largest terminals in Finland supply over 70% of annually delivered wood fuel (Virkkunen & Raitila 2016).

If a terminal is expected to handle all available forest fuel resources with equal shares and average efficiency, a nominal output of 24 GWh/ha/a can be expected from such a terminal (Virkkunen et al. 2015). An area-output analysis reveals that small Swedish terminals operate very efficiently. However, in larger size classes the efficiency of land use compared to delivered amount of fuel is significantly reduced. On the contrary, in Finland the largest terminals use their space efficiently and they are the most efficient terminals.

2.3. EFFECTIVE LARGE SCALE TERMINAL

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MAIN OUTCOME

Field studies were conducted to gather information on well-functioning terminals, their machines, logistics and infrastructure. Based on the survey, work studies and cost calculations of different terminal functions, supply costs of woody biomass through terminals were defined. Finally, the most effective terminal supply chains were compared with direct supply chains from forest to plant.

MOTIVATION

As discussed before, biomass terminals have an important role in balancing supply and demand of solid biomass. With well-planned locations and functions they can also increase the efficiency of logistics. In fact, terminals with high volumes and cost-effective operations do not necessarily cause extra costs to the supply chain but can instead, in some occasions, be more economical than traditional direct biomass supply chains.

COMPARISON OF DIFFERENT SUPPLY CHAINS

The terminal targeted in the study is a large feed-in terminal with a processing capacity of 400 GWh of wood fuel per year, located at the vicinity of a CHP-plant. In the terminal a stationary chipper and a stationary grinder are used for the comminution of fuelwood. Both are electrically powered. Feeding of the comminution machines can be done either with a material handler or by the arriving trucks while they unload.

The schematic layout of a feed-in terminal is presented in Fig. 3. The terminal consists of four specific areas: Roundwood storage, storage for ready-made fuel (chips, hog fuel, fuel manufacturing site (chipping, grinding and material receiving (weighbridge and a registration device for arriving and departing loads). The exemplar terminal has a railway connection and two railway tracks entering the terminal. Comparative studies of biomass terminals show clearly that economies of scale make investments in infrastructure and machines more feasible and terminal operations more effective (Virkkunen et al. 2015). As the annual amount of processed biomass increases, stationary machines become more economical and often electrical power for the comminution machinery becomes applicable, as the operation environment is more of the type of a well-established industrial site instead of a mere temporary storage and handling site for biomass. Therefore a large scale biomass terminal was chosen for this study.

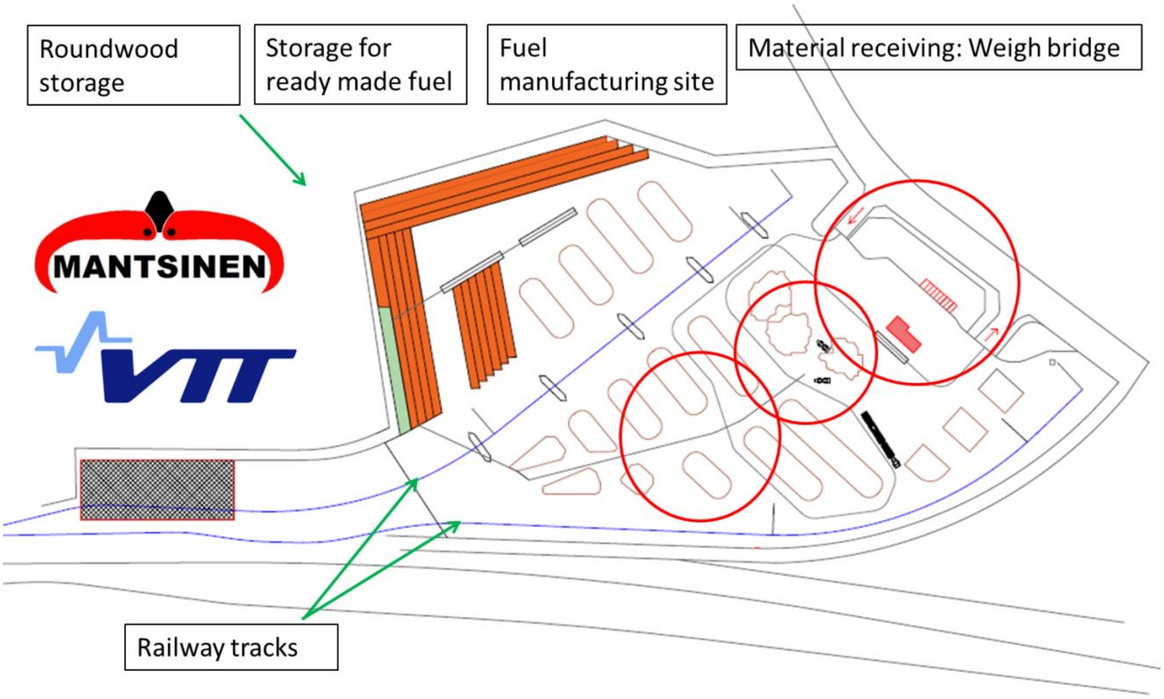


Figure 3. A schematic layout example of a feed-in terminal.

For this study, the supply costs were calculated for five different terminal supply chain options and for a direct supply chain based on the chipping at roadside method. The wood material consisted of delimbed small-diameter stems harvested from pre-commercial thinnings in all studied supply chain options. The presented costs include all machine costs related to the supply chain from the harvesting site to the plant. 12.6 €/MWh (Luke 2016) roadside price of delimbed stems is also included in the supply cost. Applied other costs are included in the calculation (Table 2).

Table 2. Other costs of forest fuel supply chains.

Other costs	€/MWh	Applied to
Capital tied to storages	0.20	Terminal chain 4
Terminal maintenance	0.20	Terminal chain 1, 2, 3, 4 and 5
Weighbridge station + management	0.09	Terminal chain 1, 2, 3, 4 and 5
Terminal field investment	0.20	Terminal chain 1, 2, 3, 4 and 5
Direct supply chain management	0.25	Reference chain

Terminal chain 1: Wood is transported (80 km) from a harvesting stand to a terminal, where the truck unloads the load to a storage near a chipper. From storage to comminution wood is transferred with a material handler. Chips are loaded with a front loader and transported to the end-user (5km) with a chip truck. The chips are then unloaded into an unloading hopper with a walking floor discharger of the truck.

Terminal chain 2: Like chain number 1, except the truck feeds the chipper directly from its load space.

Terminal chain 3: Like previous chains, except the truck unloads the load into a semi-automatic feeder, which feeds the comminution machine.

Terminal chain 4: Like chain 1, except that the truck unloads the load to a seasonal terminal storage pile. Wood is later transported to comminution and fed to the chipper with a material handler.

Terminal chain 5: Mobile chipper in a terminal moves alongside temporary wood storage piles. The chip truck is loaded directly by blowing the chips into the container of the truck.

Reference supply chain: Wood is chipped at a roadside storage near the harvesting site. Wood chips are transported to a user site (80 km) and unloaded into an unloading hopper with a walking floor discharger.

In the terminal chain where wood is also stored in a terminal (Terminal chain 4), drying of stored wood material is assumed. The wood is expected to dry from the initial 55% MC to 35% MC. This has an effect on the productivity of comminution-based energy content of the comminuted material. Thus, separate comminution costs are presented for direct terminal chain and terminal chipping of dry wood (Table 3).

Table 3. Wood chips supply costs in different supply chains.

	Terminal chipping dry/stored wood, €/MWh	Terminal chipping, direct feed, €/MWh	Roadside chipping, €/MWh
Roadside price of delimbed stem	12.60	12.60	12.60
Initial transport	1.19	1.19	1.21
Unload to terminal (= 0 when directly fed from a truck)	0.26	0.26	
Delimbed stem transfer in a terminal (Terminal chain4)	0.30		
Feed to chipper (material handler/automatic feeder/ truck)	0.41	0.41/0.16/0.52	
Chipping (normal moisture content (50%)/terminal dried wood) (35%)	0.96	1.15	3.16
Loading of chips (waiting of the truck)	0.19	0.19	0.88
Transport of chips from a terminal to the user site	0.88	0.88	
Unloading at user site	0.38	0.38	0.38
Other costs (normal moisture content/terminal dried (Terminal chain 4)	0.69	0.49	0.25

The lowest supply costs were reached with the Terminal chain 3, mainly due to cost savings in the feeding of the chipper by utilising the semi-automatic feeder. The second lowest costs are reached when feeding the chipper with a truck, followed by the Terminal chain 1, where the chipper is fed with a material handler (Fig. 4).

Terminal chain 5, chipping with a mobile chipper in a terminal yielded the highest total costs. Although this is a fairly common method applied in terminals, it seems quite uneconomic. This is due to the high operation costs of a diesel powered chipper and long waiting times of the trucks that are loaded simultaneously with the chipping.

The costs of the reference chain – supply with a supply chain based on roadside chipping – has the second highest costs, mainly due to high chipping costs compared to chipping with a stationary chipper in a terminal. Also, it is important to note the costs of the loading time of the truck which is directly linked to the productivity of chipping.

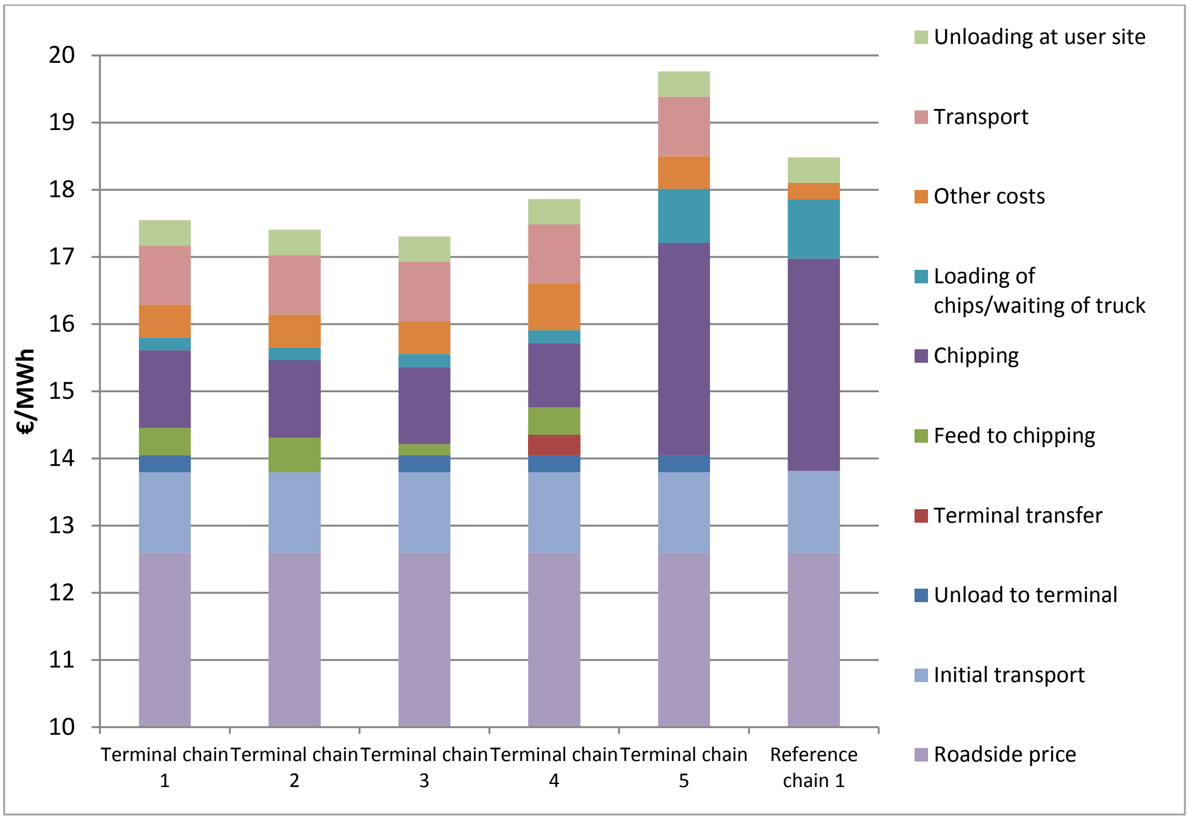


Figure 4. The aggregated costs for each individual supply chain option (Terminal options 1 to 5 and the reference supply chain).

Naturally, investing in infrastructure in the terminal is costly. However, once the electrical connection is established comminuting woody biomass is significantly more economical. Electricity-powered chippers and grinders are also more environmentally friendly and quieter than diesel-powered machines. The downside is that usually electrical machines are stationary and thus new arrangements are costly and require long investment periods.

CONCLUDING REMARKS

As seen in Fig. 4, fuelwood supply through terminals can be very cost-competitive compared to traditional supply routes directly from forest to plant. However, effective terminals have to be large enough in order to pay off investments in infrastructure and machines. The larger terminal size means decreased production costs. This also implies there are too many small terminals in Finland and Sweden if just production costs and handling of wood chips are concerned. Increases in terminal size will likely require cooperation between wood fuel suppliers. The future will show whether there is actual will to do this. There is no technological or software bottleneck foreseen – the required soft and hardware is easily available.

2.4. NEW TRANSPORT SOLUTIONS AND LOADING MODELS FOR ENHANCING THE SUPPLY CHAIN EFFICIENCY

Pirjo Venäläinen, Antti Korpilahti & Heikki Ovaskainen, Metsäteho Oy

MAIN OUTCOME

This was a pioneer study to develop working models for loading of uncomminuted bioenergy to trucks. The aim of this study was to create systematic working models for loading logging residues and stumps to bioenergy trucks to increase payload. The optimal load weight and its relation to transportation distance was also a point of interest. Four different working models were developed. The drivers with certain working models reached about 3 tonnes higher payloads. The optimum load size in relation to driving distance and loading time was calculated.

Two transport studies analysed impacts of different vehicle sizes on transport costs. Higher transport weights are the most cost efficient in transport of comminuted material and on longer transport distances. Further, the potential of HCT (High Capacity Transport) trucks is better on routes with good quality road connections, and hence in transport between terminals and points of use.

MOTIVATION

In the future, use of terminals will be a more and more common practice in the bioenergy supply chains, as the comminution of loose biomasses will be performed at the terminals. Load sizes of bioenergy trucks are often under the allowed total payloads. Over decades, a variety of compressing devices have been tested for loading of higher loose biomass payloads into bioenergy trucks, but the benefits of the devices, either the cost, time consumption or extra weight point of views, have not proved to be profitable. The development of working models aims at the use of existing machines and devices in such a way that higher benefits are reached.

Aiming for a large payload is not always the most cost-efficient choice. The transportation distance as well as loading time along with the payload size should be considered. The critical question is how much time it is beneficial to use for loading and compressing a load if the driving distance is short? This means that if a lot of time is used for loading a high payload for a short driving distance it might be beneficial to make loose loads instead of using a long compressing time. Therefore, it is possible to find an optimal balance between driving distance and loading time.

In Finland, the total allowed weight of articulated vehicles was raised to 68 tonnes (vehicles with 8 axles) and to 76 tonnes (vehicles with 9 axles) in October 2013. At the same time, the national trial project with even higher weights and bigger dimensions (High Capacity Transport, HCT) was launched. The aim of the two transport studies were to find out how new vehicles and HCT can improve the efficiency and economy of forest energy material transport.

WORKING METHODS AT ROADSIDE STORAGE FOR OPTIMISING THE COSTS OF TRANSPORTATION OF UNCOMMINUTED BIOMASS

EXPERIMENTS

Twelve truck drivers participated in the working model study (Ovaskainen & Lundberg 2016) and the data was collected in Southern and Eastern Finland between April and September 2015. The data set included 12 stump loads and 11 logging residual loads. The loading events were recorded by a video camera for later performed time and observation studies. To compare the drivers, the payloads were weighted. Drivers' loadings were observed and analysed with the payload weights and the loading times.

The minimum costs for transport were calculated using Metsäteho's truck transport cost calculation sheet. The calculation sheet was modified to biomass transport form from the settings of log transport. All parameters were changed to correspond to the features of typical biomass truck driving work.

RESULTS

For stump material two different working models were described depending on the size of the stump: for small- and normal-sized stumps. The working model for normal-sized stumps was divided into two working models to achieve a large payload and an average payload with minimal loading time. For logging residues it was only necessary to describe one working model. Working models consisted of systematic ways of work and different types of compressing methods and actions performed with the grapple. The average loading time for one tonne for stumps was 2.7 minutes and for logging residues 2.2 minutes. On average, the payloads of effective working models were approximately 3 tonnes higher compared to normal loads.

The optimisation results indicate that the longer the driving distance is the larger the payload should be (Fig. 5). With shorter distances it is optimal to use less time for loading even though large payloads will not be achieved and, instead, use the saved time for driving of extra loads.

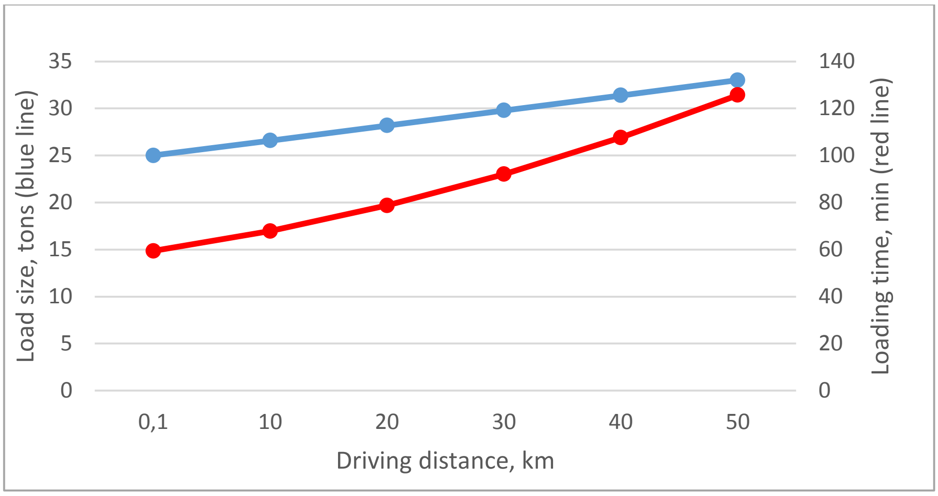


Figure 5. Blue line indicates the optimal load size when loading time is used according to loading time curve (red line). For example, if the transport distance is 30 km, the payload should be 30 tonnes at least.

For over 50 km transport distances the load space should be fully loaded with 64-tonne trucks. The driving distance versus driving time optimisation is very dependent on the loading time. If the optimal load size is reached in a shorter time on a specific distance, the extra time could be used for reaching even higher payload or transporting a little longer distance. Reaching a 64-tonne payload is a very time consuming task if the moisture content of the biomass is under 35 %.

FLEET DEVELOPMENT FOR BIOMASS TRANSPORTATION BY ROAD

Two transport studies were carried out during the BEST project. The calculations of the first study (Korpilahti 2015) showed that in transport of uncomminuted logging residues and stump wood, neither 60-tonne nor 68-tonne vehicles could fully reach their carrying capacities even with the maximum load spaces. Even though the load densities and volumes of small-size trees and tree sections can vary notably, they have better potential in gaining bigger loads with higher vehicle weights.

When transporting forest chips with a 68-tonne vehicle, a load space from 125 to 140 m^3 is large enough to fully utilise the vehicle's load capacity. With a 76-tonne vehicle, the calculations suggest that it would be necessary to have almost the maximum load space. The potential of HCT (in this case

90 tonne) vehicles was only estimated for forest chip transport. Again, the carrying capacity can be easily reached. The transport cost calculations indicate that bigger vehicles bring more cost savings on longer transport distances (Fig. 6).

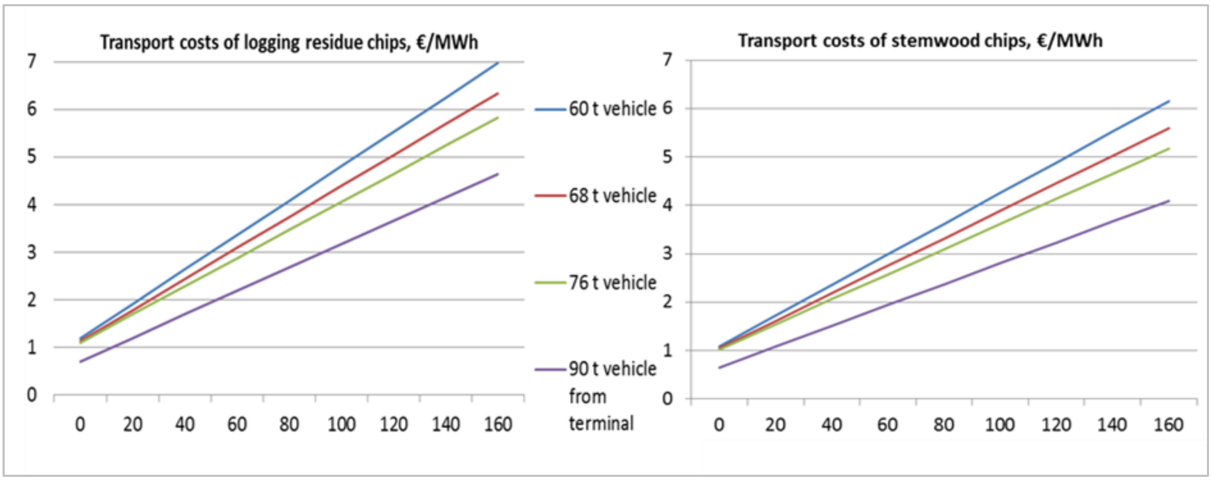


Figure 6. Transport costs of forest chips with different vehicle total weights and transport distances.

In the second transport study (Venäläinen & Poikela 2016), the aim was to describe the present state and realised development in the long-distance transportation fleet as well as to set up a scenario for future development. The study focused on forest chip transport due to better saving potential with new vehicles. This potential is not only delivered through more efficient use of load space, but also due to the growing trend of chipping in terminals (today, the share of terminal chipping is about 1/3). Terminals are located along better road connections than roadside storages and therefore could be suitable even for HCT vehicles.

HCT vehicles (in case of 90-tonne gross weight) are not realistic in all forest chip transport, since roadside chipping still dominates (with ½ of all chipping). Transport cost comparisons for different fleet size distributions were generated. A questionnaire was sent to transport companies to find out the present state with the fleet size distribution both in forest chip and industrial wood transportation (scenarios A and B in the Fig. 7). Fleet distribution with HCT vehicles (scenario C) was generated so that it would bring 10 % savings to the current costs. This would require 20 % of transport to be carried with 90 tonne vehicles. With the current volume of energy chip transport (15 TWh), the HCT scenario would bring annual savings of 6 million € (Table 4). Finland’s National Energy and Climate Strategy (Ministry of Employment and the Economy 2013) has set the target of forest chip consumption for 2020 to 27 TWh. For that volume, the potential annual savings with HCT would amount to 11 million €.

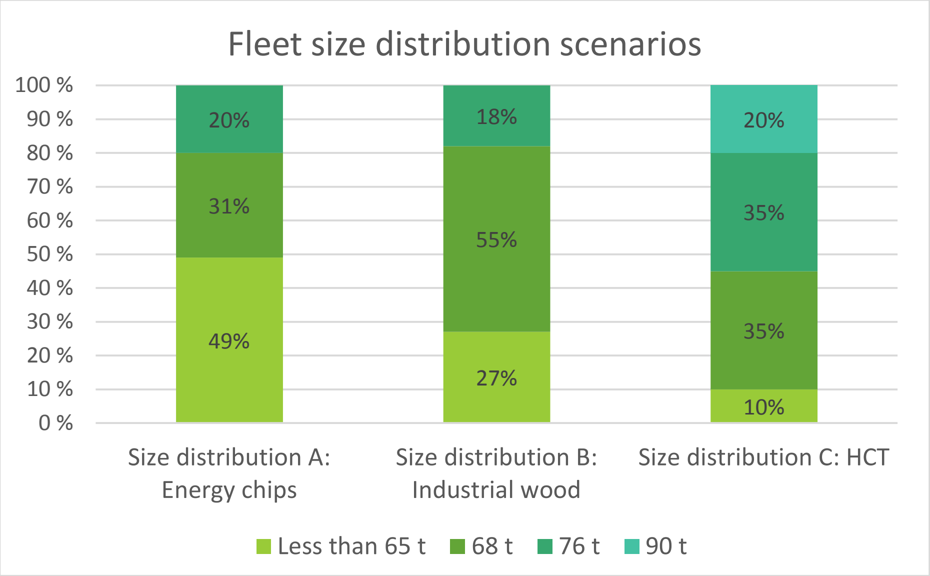


Figure 7. Studied transport fleet size scenarios.

Table 4. Transport costs of forest chips with different fleet size distributions.

FOREST CHIPS	**2014/2015**	**2020T**	**2020MS**
Forest chip volume TWh	15.2	27	58
Size distribution A: Energy chips			
Transport costs A million €/a	61	108	233
Transport costs A €/MWh	4.01	4.01	4.01
Size distribution B: Industrial wood			
Transport costs B million €/a	60	106	228
Transport costs B €/MWh	3.94	3.94	3.94
Size distribution C: HCT			
Transport costs C million €/a	55	98	210
Transport costs C €/MWh	3.61	3.61	3.61
Change A/B			
Transport costs million €/a	-1	-2	-4
Transport costs million €/a %	-1.9 %	-1.9 %	-1.9 %
Transport costs €/MWh	-0.08	-0.08	-0.08
Change A/C			
Transport costs million €/a	-6	-11	-23
Transport costs million €/a %	-10.0 %	-10.0 %	-10.0 %
Transport costs €/MWh	-0.40	-0.40	-0.40

Assumed transport distance is 100 km
T=target, MS=maximum sustainable
Unit costs per vehicle size: Korpilahti 2015

CONCLUDING REMARKS

The results of work model analyses and cost calculations indicate that there is potential to improve energy wood logistics efficiency by new transport solutions. Applicable truck loading work methods improve the efficiency of uncomminuted material, whereas larger truck sizes (including HCT) improve cost efficiency of comminuted material. In supply chains via terminals, both of these solutions can be applied. Since more and more chipping is taking place in terminals, the relevance of the studied solutions is expected to grow.

2.5. ASSESSING THE PERFORMANCE OF BIOMASS TERMINALS AND SUPPLY SYSTEMS WITH SIMULATION APPROACHES

Olli-Jussi Korpinen & Mika Aalto, Lappeenranta University of Technology

MAIN OUTCOME

The biomass terminal's operations at different times and under different conditions were assessed by simulating the solutions proven to be promising in cost-analyses. The results indicate that the solutions are applicable, if the traffic and processing inside the terminal is fluent. This calls for the thoughtful terminal design. Congestions inside the terminal may have significant impact on 1) the performance and profitability of the terminal itself and 2) the transportation system that it is connected to.

MOTIVATION

Feedstock supply to a large power plant or a bioproduct mill tends to be a complex system if it is not totally based on direct deliveries between the biomass source (e.g. forest or a farm) and the end-user (e.g. plant yard). A system including terminal operations may include multiple feedstock sources, and it can be dependent on other systems, such as roundwood or pulp chip transportation. Also factors based on natural phenomena with significant variation over time (e.g. moisture content of biomass) should be taken into account in comprehensive systems analyses. There can be various business models for terminals in the future, affecting the throughput rate of biomass and thus requirements for, e.g. storage space (Fig. 8), which is difficult to identify with traditional analysis methods.

To study time-dependent elements in the terminal operations, a dynamic simulation model of a feed-in terminal was designed and implemented. The model included opportunities to enter size- and layout-specific parameters (i.e. objects moving distances and speeds), machine productivities, parameters determining the monthly volumes of inbound and outbound biomass deliveries, and even source data about the quality changes (moisture) of the biomass stored in season storage.

This chapter presents two approaches to use the simulation model in evaluation of a terminal's functionality. Both approaches are based on the terminal layout presented in Fig. 8. The layout was scaled to represent an area of 8 ha, and the distances between the places of operations were calculated according to this scale. Rail deliveries were excluded from the model.

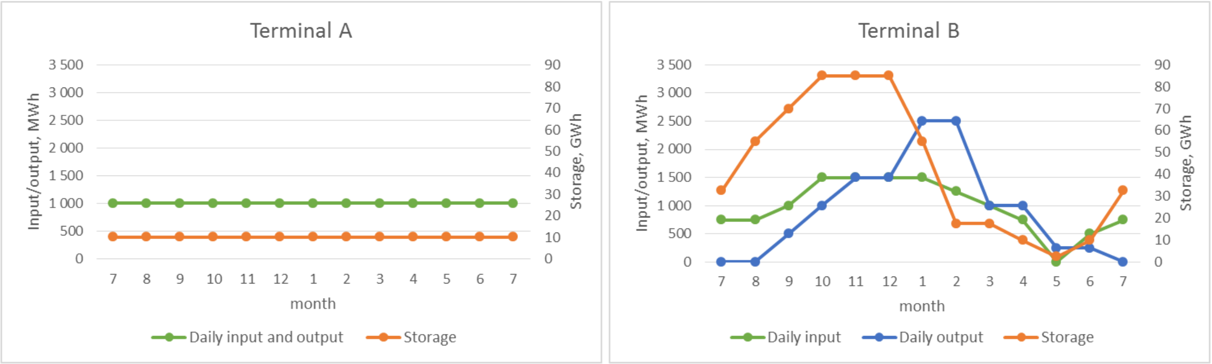


Figure 8. Arriving and departing feedstock volumes (as energy content, MWh) per day and storage volumes (as energy content, MWh) at two example terminals with equal throughput volumes corresponding to 400 GWh per annum.

EVALUATION OF TERMINAL STORAGE SIZING AND FLUENCY OF OPERATIONS

Two studies were carried out including only throughput and processing of stem wood, and they were related to terminal chain concepts explained in chapter 2.3. The principal objectives were to assess the need for storage space and fluency of transport operations in scenarios including different timing of supply and demand. Therefore, maximum storage sizes and total number of trucks allowed in the area were unlimited.

Study 1 - Configuration

In the first study, the scenarios were following:

- “Basic”: the demand by the plant(s) is in accordance with typical fuel consumption of a Finnish biomass-CHP plant and delivery rate to the terminal is highest before the frost-heave seasons in spring and autumn and at lowest in late spring and early summer.
- “Steady”: deliveries to the terminal and fuel demand by plant(s) are on a continuous and steady basis all year.
- “Harvest Intensity”: the demand from terminal equals the “Basic” scenario but deliveries are based on harvest intensity of stem wood (i.e. monthly variation in pine and birch harvest volumes). The scenario includes sub-scenarios where the intensity is delayed with a given number of months representing the period of storing the wood at roadside.
- “Peak”: delivery rate to the terminal equals the rate of the “Basic” scenario but fuel deliveries to plant(s) exist only in peak-season of terminal-derived fuels, i.e. December–March (95%) and May (5%).

The distribution of annual inbound and outbound biomass deliveries in each month is summarised in Fig. 9. Each simulation run was defined to start on 1 July and end on 30 June.

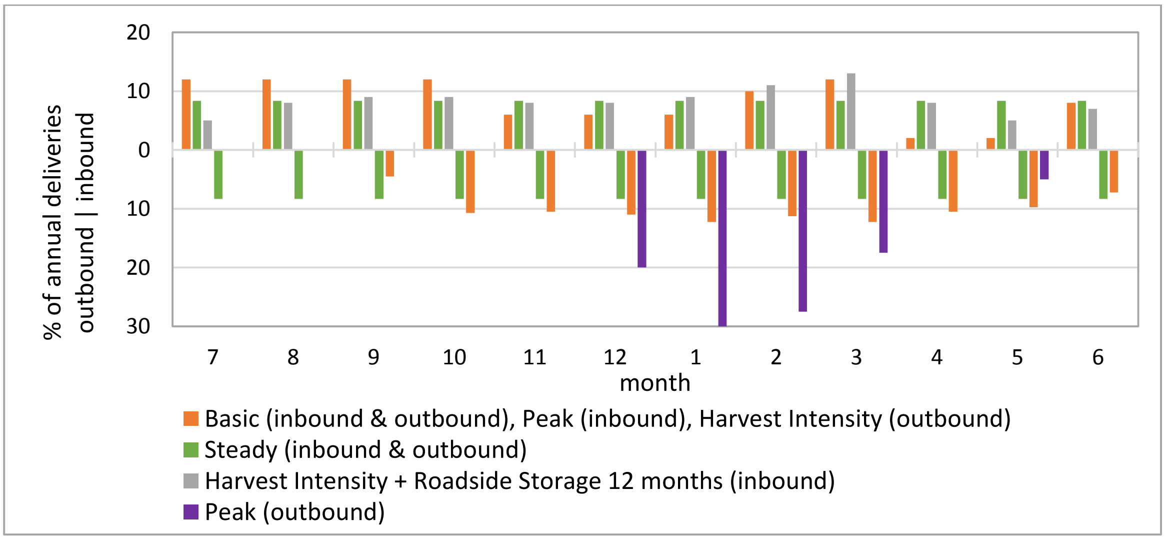


Figure 9. Monthly distribution of inbound (upward stacks) and outbound (downward stacks) delivery volumes at the terminal according to simulation scenarios

The operation rules were in accordance with Terminal chain 5, where the inbound roundwood trucks proceeded to the season storage after the weight measurement, and unloaded the stems into the storage pile. The outbound chip trucks were loaded by one or two mobile chippers, depending on the total need for chips in each month. The number of chippers and chip trucks feeding the plant were adjusted so that the demand was fulfilled during the respective month. This was also done for work shifts. In one-shift mode, terminal operations were possible Mon–Fri 8:00AM–4:00PM and in two-shift mode Mon–Fri 7:59AM–11:59PM. Chip trucks were allowed to unload at the plant also after the end of the shift. Inbound deliveries were allowed anytime. Initial parameters including productivities and transport distances are presented in Appendix I. It was determined that 1 m^3 of chips as bulk volume equal 0.96 MWh of energy (moisture content of 35%, density of 300 kg/m^3 and calorific value of 19 MJ/kg). Secondly, it was assumed that fuel properties are not changed during storage at the terminal.

Study 1 - Results

As a clear contrast to the “Steady” scenario (having only minor storing demand), “Peak” was the most demanding scenario in terms of the principal study objectives. Before the beginning of the deliveries of comminuted fuel from the terminal, the volume of season storage rose up to 88 500 m^3_{solid}, which corresponds to over 50% of the expected annual throughput of the terminal (Fig. 10). The storage peak of 55 500 m^3_{solid} in the “Basic” scenario took place in November and was more moderate than that of the “Peak” scenario. However, the peak record was even lower in all subscenarios of “Harvest Intensity”. The most space-saving sub-scenario contained a storing period of one month (or 13 months) at the roadside. Similar storage development at the terminal was found also in the sub-scenario with 12 months roadside storage. In these sub-scenarios the largest size of terminal storage was, in the beginning of October, at ca. 30 000 m^3_{solid}.

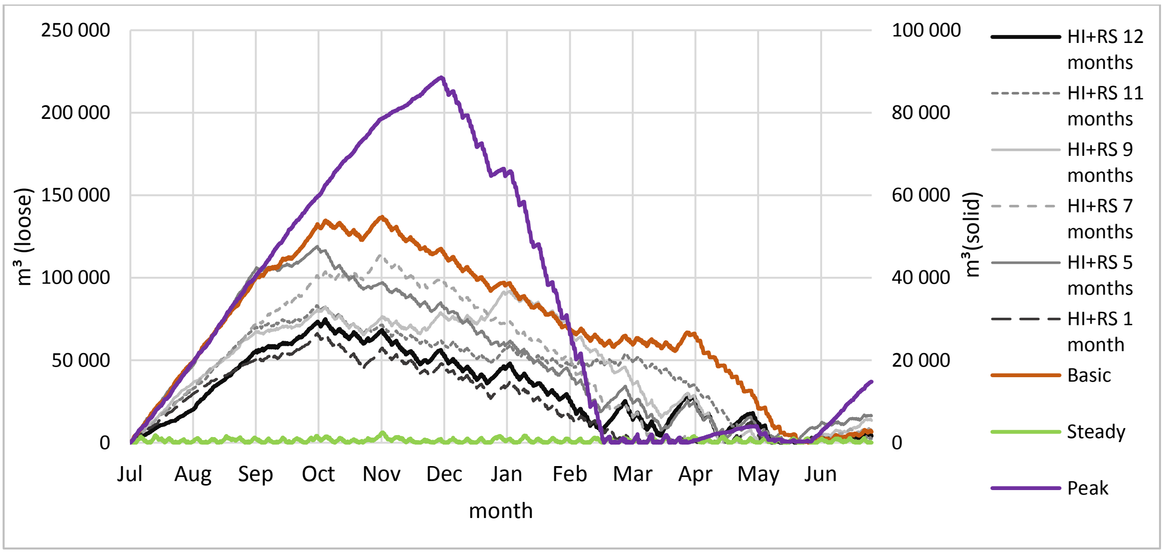


Figure 10. The progress of storage volumes (uncomminuted stems) in simulation scenarios of Study 1. HI = Harvest Intensity, RS = the period of roadside storage preceding the delivery to terminal in scenarios of HI.

Considering the average visiting times of roundwood trucks (inbound deliveries) and chip trucks (outbound deliveries) at the terminal, the differences between all scenarios were marginal (Fig. 11). However, the relatively large range between the maximum and minimum times in the “Peak” scenario indicates that there were occasions where both arrival and departure of trucks were congested, mainly due to the limited number of unloading and loading places at the terminal.

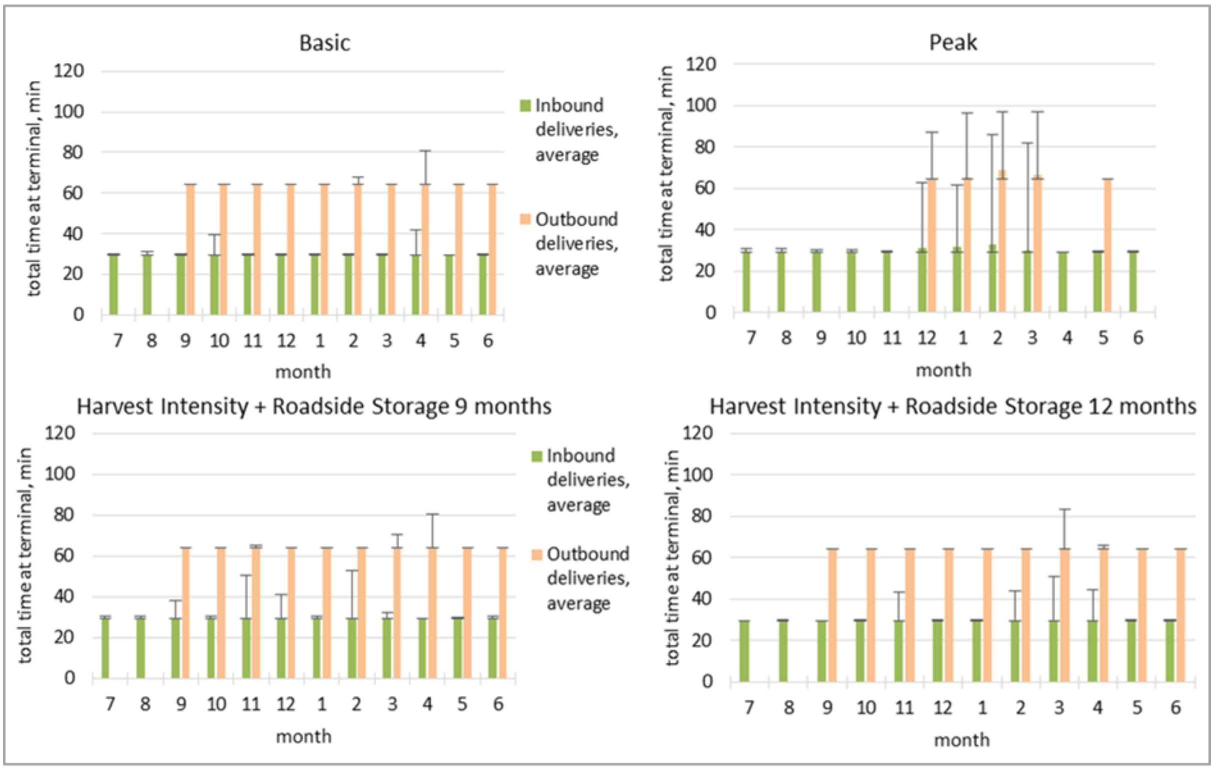


Figure 11. Time consumption of trucks at the terminal in simulation scenarios “Basic” and “Peak” and in two sub-scenarios of “Harvest Intensity”. Error bars denote the range between minimum and maximum visit times at the terminal.

Study 2 - Configuration

In the second study, the “Basic” scenario from the first study was taken in further consideration by taking into account the use of a semi-automatic feeder and a stationary chipper, which is represented by Terminal chain 3 in the cost-analysis. The feeder-chipper combination was given 50% faster productivity. On the other hand, the truck was not allowed to leave the unloading place next to the feeder until the load was fully comminuted. A shorter distance between the gate and near storage (100 m) saved some time from the “Basic” scenario, which included only mobile chipping at the season storage. Altogether scenarios as variants of “Basic” were used in this study:

- “Mobile”: presented in the first study as “Basic”.
- “Stationary, shifts”: mobile chipping is replaced by the stationary feeder-chipper system. The system operates in two shifts i.e. Mon-Fri 8.00-24.00.
- “Stationary, open 24-h”: mobile chipping is replaced by the stationary feeder-chipper system. The system is able to operate any time.
- “Combined, shifts”: like “Stationary, shifts” but the inbound deliveries taking place in June-August are directed to season storage and the stored biomass is comminuted by a mobile chipper when a chip truck enters the storage to load biomass.
- “Combined, open 24-h”: like “Combined, shifts”, but the terminal is able to operate any time.

Study 2 - Results

There was no great variation between the scenarios in the runtime development of storage size in general (Fig. 12). In the “Stationary” scenario the monthly demand was, however, fulfilled faster than in “Mobile”, because of a vast amount of comminuted fuel available in the beginning of demand (1 Sept.) and relatively fast loading speed of the front loader. This means that only one chip truck would probably have been enough for feed-in transportation as far as there was ready-made fuel at the terminal.

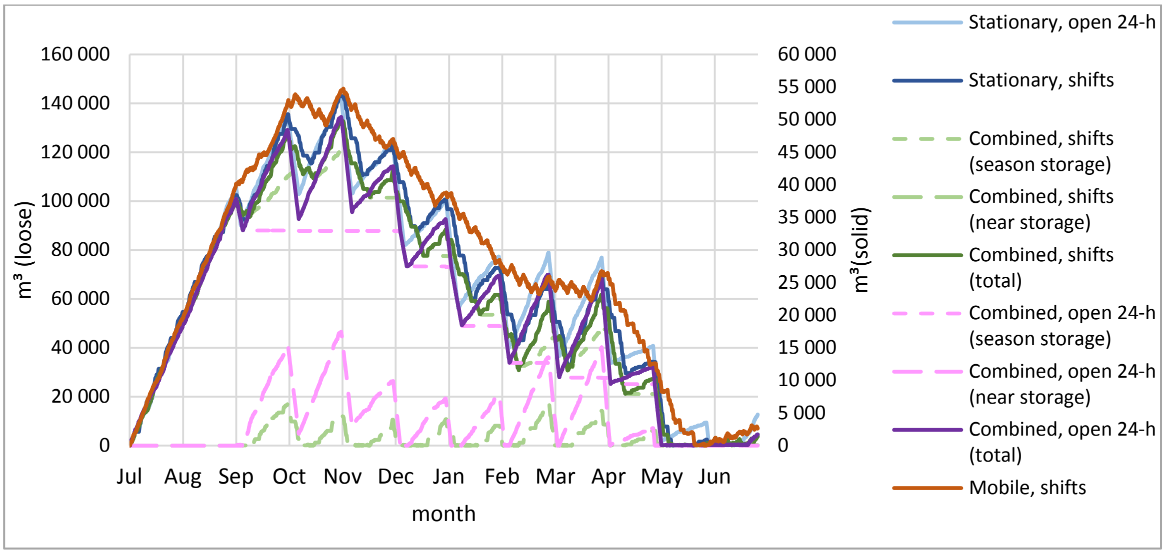


Figure 12. The progress of storage volumes in scenarios of Study 2.

Despite the rapid feed-in traffic from the terminal, the hot chain of unloading trucks and the feeder-chipper system caused some serious queuing problems in “Stationary, shifts”. The trucks were jammed at the terminal during the peak-supply months so that, in some cases, the trucks had to wait almost 40 hours, including at least one off-shift period (Fig. 13). Such occasions were so busy that also the average waiting time raised to almost 10 hours. In “Combined, shifts” this problem was solved with the use of season storage during the low-demand season, but it still existed from September to March.

The waiting times fell drastically due to the change from two shifts to a 24-hour-open terminal. The average and the range between minimum and maximum visit times of inbound-delivery trucks were greater than those of “Mobile” (see “Basic” in Fig. 11), but they were still on an acceptable level. The average visit times varied principally between 25 and 45 minutes, while the longest times in “Stationary, open 24-h” and “Combined, open 24-h” were approximately 2 h 45 min, taking place in March and September, respectively.

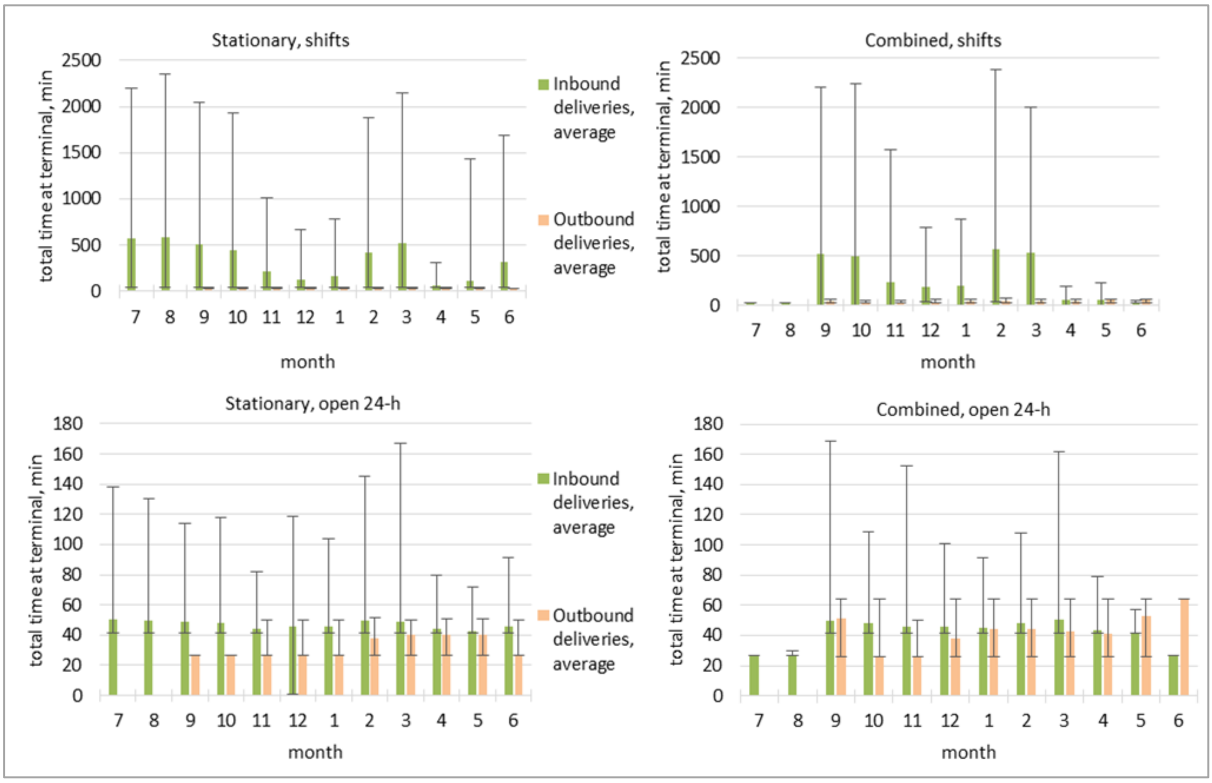


Figure 13. Time consumption of trucks at the terminal in scenarios of Study 2 (excl. "Mobile" scenario). Error bars denote the range between minimum and maximum visit times at the terminal.

EVALUATION OF THE OPERATIONAL MODEL FOR UNCOMMINUTED BIOMASS DELIVERIES

Study 3 - Configuration

In the third study, the focus was on the time usage of an energy wood truck transporting uncomminuted logging residues to an intermediate terminal. Previously (chapter 2.4) it had been reported that on short transport distances it would be beneficial to make a lighter payload in a short time at the roadside than to use more time loading when aiming at higher payloads.

The objective of this study was to include also the time that trucks spend at the destination (i.e. terminal) and, accordingly, analyse how sensitive the loading method decision is to circumstances at the terminal. In this simulation study, the setup was mostly the same that was used in studies 1 and 2. However, the runtime period was limited to January only, and all biomasses were transported to the stationary chipper (like in Terminal chain 3). Logging residues' moisture content was set to 50%, and the terminal was assumed to be always open. Trucks' time consumption at the roadside was fixed to 60 minutes when the payload was 24 tonnes, and 90 minutes when the payload was compressed up to 30 tonnes. It was also assumed that the truck spends in total 60 minutes for travelling from the roadside to the terminal and back. Unloading of both payload types was assumed to last 30 minutes. The two alternative methods were then analysed in the following scenarios:

LRT: Logging residues are transported to a terminal that does not receive any other deliveries in the period. Total amount of deliveries corresponds to 49 GWh, i.e. the fuel demand in January in the "Basic" scenario of Study 1. One chip truck is used for final delivery from terminal to plant(s).

LRT + ST(300): like "LRT", but the terminal receives at the same period 300 timber trucks delivering delimbed stem wood to the stationary chipper. Two chip trucks are used for final delivery from terminal to plant(s).

LRT + ST(500): like "LRT", but the terminal receives at the same period 500 timber trucks delivering delimbed stem wood to the stationary chipper. The total amount of delivered biomass approximately corresponds to the fuel demand in January in the "Peak" scenario (120 GWh). Two chip trucks are used for final delivery from terminal to plant(s).

Study 3 - Results

Quick loading at roadside produced 16% faster round trips than the alternative method aiming at higher payloads, when there were no deliveries of other biomass included in the scenario (Fig. 14). The 24-t truck (i.e. truck with 24-t payload) was capable of less than three-hour round trips on average, while the average round trip time of the 30-t truck was ca. 3 h 20 min. The maximum waiting times at the terminal were ca. 2 h 45 min. The distribution of visit times in both cases is presented in Fig. 15.

The round trip times of the 30-t truck were shorter on average, when other traffic was included at the terminal. Because the need for the 30-t trucks was ca. 170 less than that of 24-t trucks, the sparser arrival interval shortened average queuing times by 34% in "LRT + ST(300)" and by 42% in "LRT+ST(500)". This time-saving of the 30-t trucks overruled the saving being gained at roadside by 24-t payloads. The difference between minimum and maximum visit times increased from the "LRT" scenario.

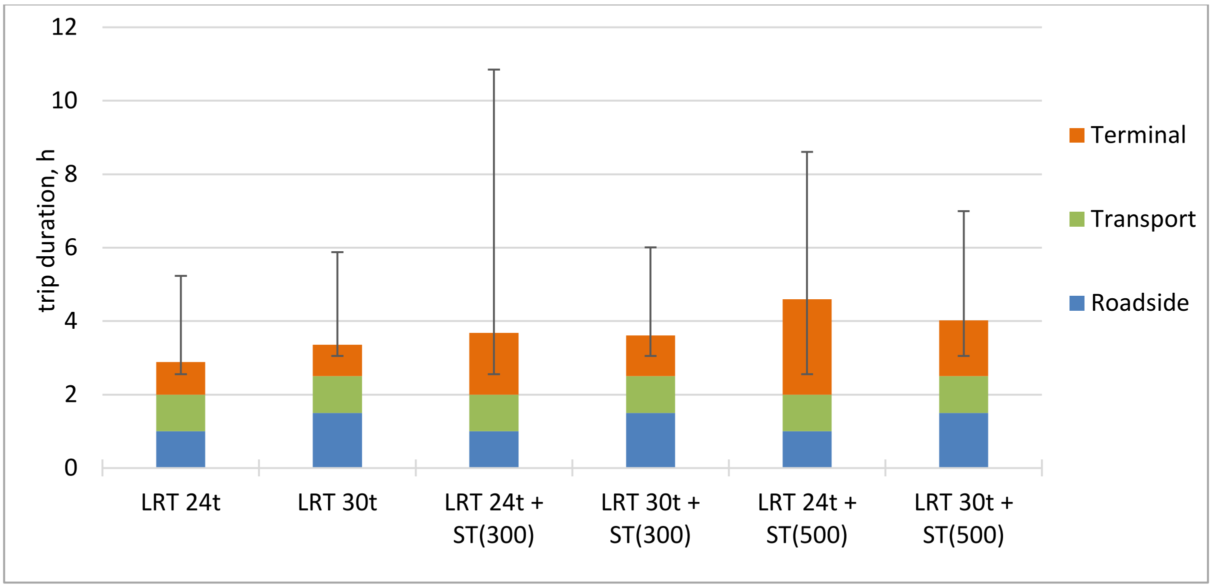


Figure 14. Logging residue truck's round trip times with different payloads and different cases of other inbound deliveries to terminal. 24-t = 24 tonnes / 30-t = 30 tonnes payload of logging residue truck (LRT). ST(300) = terminal chipper receives in addition 300 stem wood truck deliveries per month. ST(500) = terminal chipper receives in addition 500 stem wood truck deliveries per month. Error bars denote the range between minimum and maximum round trip times.

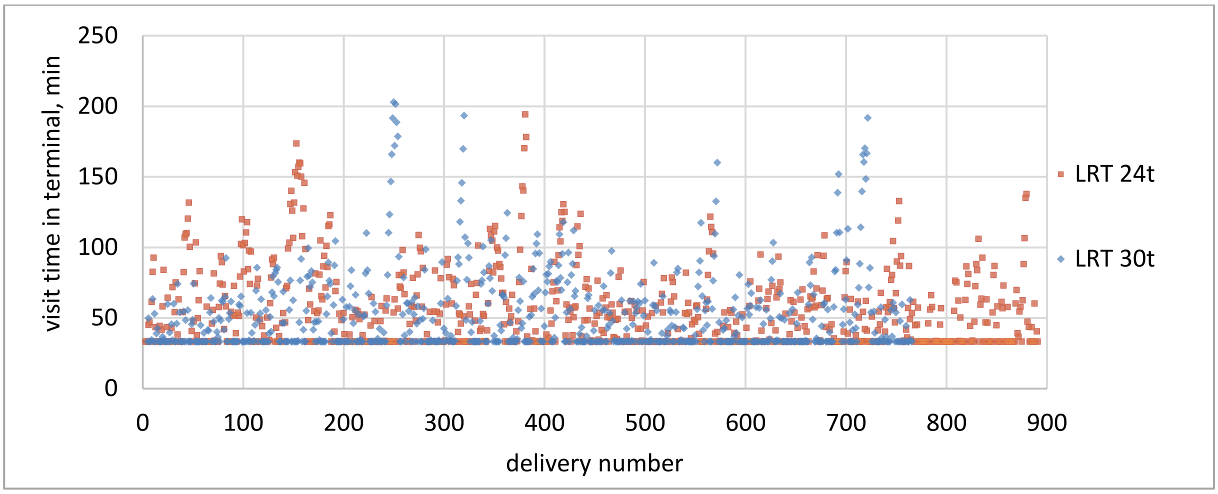


Figure 15. Logging residue truck's visit times in terminal according to the delivery count. 24-t = 24 tonnes / 30-t = 30 tonnes payload of logging residue truck (LRT).

CONCLUDING REMARKS

The results of the three studies indicate that promising solutions for terminal and transport operations (presented in chapters 2.2 and 2.4) can be adapted to practice, but not without certain limitations. Especially the hot chain between the stationary chipper and truck deliveries requires flexibility from other parts of the system when throughput volumes are high. Instead of strict workshift thinking, the possibility for full-time operation should be enabled at least periodically (peak seasons) to avoid congestion of inbound deliveries, whenever trucks are expected to feed the chipper directly (e.g. Terminal chain 3).

The light payload option (24 t) of logging residue deliveries was feasible only when there was no extra waiting time to unload at the chipper. If the terminal is open for a shorter time per day, or the workshift of the truck driver is limited to, e.g., nine hours, it is beneficial to apply the lighter payload option to gain three round trips instead of two. In such cases, where the truck driver can decide between two or more alternative working methods, advanced information about the conditions at the destination (e.g. terminal or fuel reception at plant) would be precious. If such information is not available, another option is to create a "fast lane" at the terminal for these kinds of deliveries. However, other traffic can still delay urgent deliveries if the chipper is occupied at the moment when the truck enters the terminal.

In large terminals which are capable of investing more in machinery, a hybrid model of both stationary and mobile chipping options would be recommended. In this solution, the stationary chipper would be responsible for the base load of comminuting, and the mobile chipper would assist especially at times when the biomass feed is too fast for the stationary chipper.

2.6. EFFICIENT OPERATION MODELS FOR USING FEED-IN TERMINAL AS A PART OF FOREST CHIP SUPPLY

Kari Väätäinen, Robert Prinz, Juha Laitila & Lauri Sikanen, Natural Resources Institute Finland, Luke and Jukka Malinen, University of Eastern Finland

MAIN OUTCOME

Terminal based forest chip supply can effectively balance work opportunities and reform the fuel supply towards more stable year-round activity with relatively low additional costs compared to conventional direct fuel supply. While using terminal supply as a part of forest fuel deliveries, studied simulation scenarios revealed the impacts of alternative fuel supply set ups and quality changes of the fuel on the operations performances and supply costs.

MOTIVATION

How using feed-in terminal as a part of forest chip supply will change the operations compared to traditional direct forest chip supply? What are the impacts of terminal aided chip supply on the utilization of supply fleet, year-round working opportunities for supply personnel, response to power plant's fuel demand and costs of the forest chip supply? These were the target questions to be answered by precision system analysis model developed by Luke (Fig. 16) (Väätäinen et al. 2017).

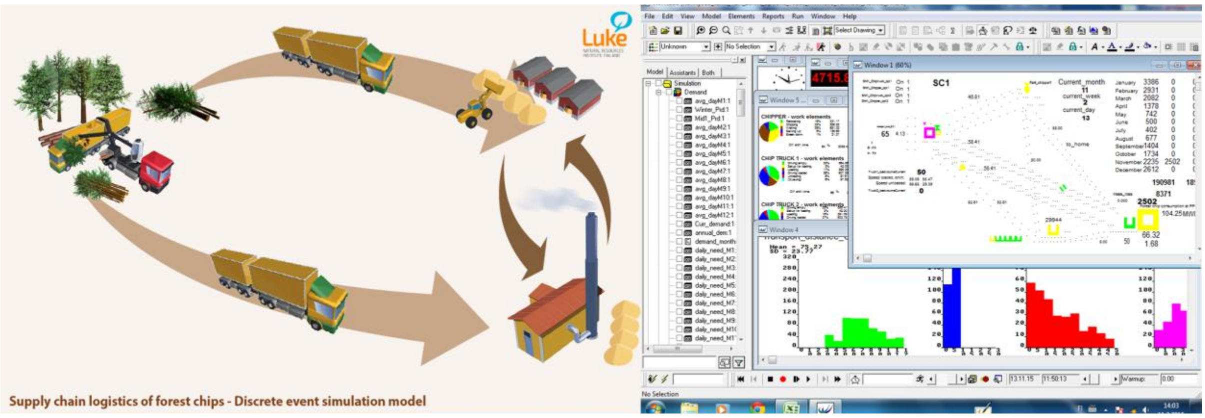


Figure 16. Discrete-event simulation based system analysis model for supply chain logistics of forest chips.

CASE-STUDY ENVIRONMENT AND SCENARIOS

To explore the pros and cons of feed-in terminal based supply chain, a combined heat and power plant (CHP plant) using 517GWh of forest chips supplied by four supply chains within a 100 km operation radius was selected as a case environment for the study. Storage size at fuel reception was set to 6,000 MWh. Each supply chain had one mobile chipper and two chip trucks with 50 solid-m^3 load space. The productivity of the chipper was 50 m^3/E$_0$.

Supply of forest chips from spruce dominated logging residue roadside storages was distance oriented. During low heating season supply of forest chips were carried out from mid and long distances, during mid seasons (spring and autumn) chips were transported mainly from mid distances and during high season allocation was mainly for short and mid distances. Average transport distance was 60-64km depending on the study scenario. Moisture content of chips varied through the year following the findings from earlier studies. Average moisture content was 47% with a 25%-65% variation.

Inbound and outbound terminal transports were controlled by the defined alarm levels of power plant's buffer size. If an upper alarm level of 90% was reached, inbound terminal transports were activated. If buffer size decreased below the lower alarm level (40%) during the simulation run, outbound terminal transports to power plant were started. The size of feed-in terminal was not predetermined, thus terminal area was defined after simulations. Consequently, the area was 4.7 ha having 50 GWh capacity of forest chips. One operator was managing terminal activities having the responsibility of establishing the heaps of chips, loading trucks and maintaining the terminal area.

If the supply of forest chips by the contractors did not meet the demand of the power plant, a supplement fuel was introduced to fulfill the requested gap of energy. The supply cost of the supplement fuel was set to 8.0 €/MWh resulting in 4.4% higher cost compared to direct fuel supply.

Four main simulation scenarios were examined. At first, conventional direct fuel supply was compared to terminal aided fuel supply. Both the supply of contractors' own chip trucks and a separate shuttle truck with 60 m³ load space to conduct outbound terminal transports were compared. In addition, the location of feed-in terminal, dry matter loss of terminal stored material as well as moisture changes of terminal stored chips were examined. Model construction, operation environment, scenario presentation and cost parameters are presented more detailed in Väätäinen et al. (2017).

EFFICIENT TERMINAL BASED SUPPLY OPTIONS

The study revealed that with a relatively low additional cost, a feed-in terminal could be introduced to the conventional forest chip supply. By introducing a feed-in terminal and a shuttle truck for the transports of terminal-stored forest chips (scenario 1C), the total supply cost was 1.4% higher compared to the direct fuel supply scenario 1A1 (Fig. 17).

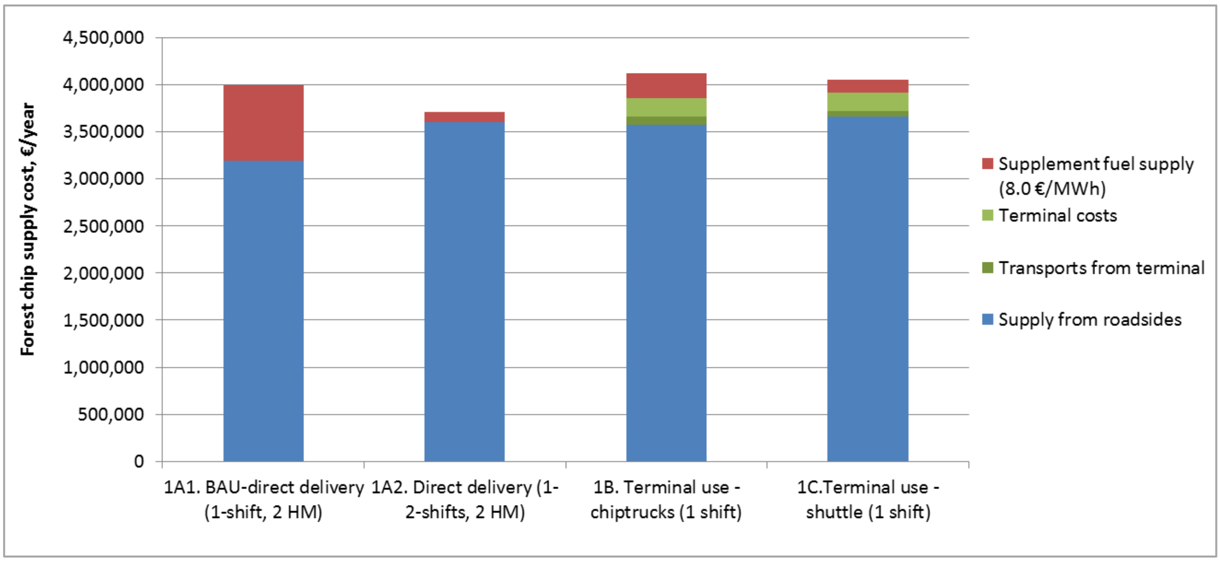


Figure 17. Forest chip supply costs of one year for four main scenarios. All scenarios' fuel supply is operated with one shift except in scenario 1A2, which has 2-shift supply during the high fuel demand. 2 HM = two holiday months for suppliers.

The fuel supply in terminal scenario 1C using a separate shuttle operating in outbound terminal transports met relatively well the fuel demand of the power plant though the year. Forest chips were emptied from terminal during the calendar week 10, thus disabling to secure the fuel supply to power plant during March (Fig. 18).

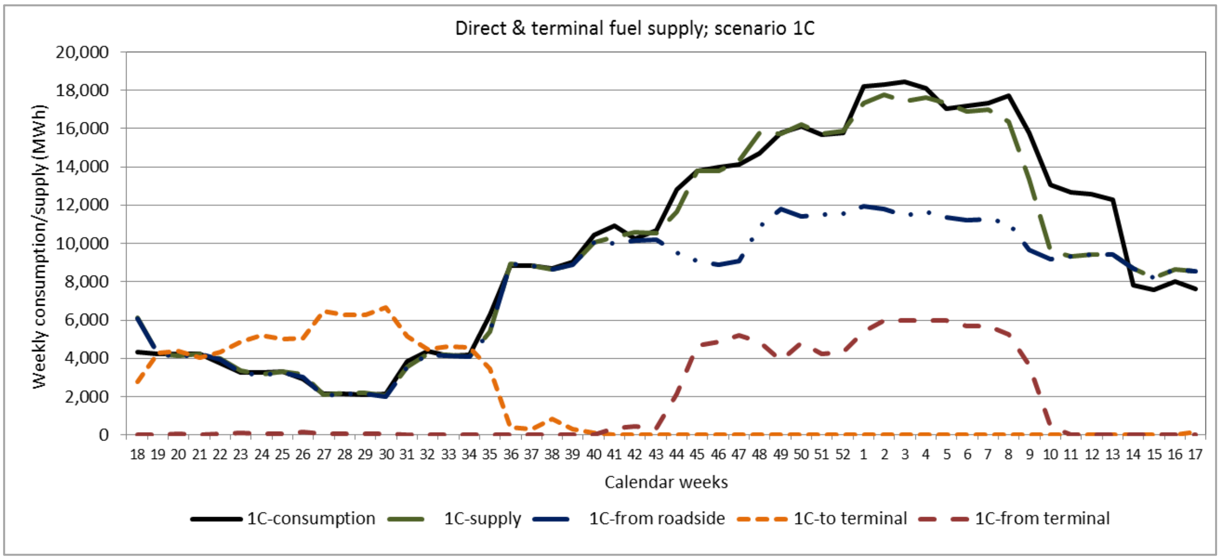


Figure 18. Weekly level statistics for the forest chip demand and transports during 1 year in the scenario 1C, where terminal outbound transports were carried out by a separate shuttle truck.

In terminal scenarios, the supply costs increased 1–2% if the cost of the terminal investment increased 30%, the distance to the terminal increased from 5 km to 30 km or the total annual use of a terminal truck decreased 1,500 hours. Moreover, an increase from 1%/month to 2%/month in the dry matter loss of terminal-stored chips increased the total supply cost 1% (Väätäinen et al. 2017). The magnitude of the cost decrease was at same level as previously presented in case the changes of studied factors were to opposite direction. Results have been presented in more detailed in Väätäinen et al. (2017).

LET´S SECURE THE FUEL SUPPLY WITH THE *BEST* SYSTEM SET UPS OF TERMINAL BASED FUEL SUPPLY

It is well known that additional terminal operation, storing, extra handling of material and other terminal costs increases supply costs compared to direct forest chip supply. However, the main interest can be directed to the alternative system set ups which can improve the operational environment and cost competitiveness of terminal based fuel supply. Yet, some operational improvements cannot be monetarized such as smoother year-round working opportunities to operating personnel in fuel supply. Cost compensation can be gained through the higher annual use of a fuel supply fleet and more secured fuel supply to power plants by decreasing the need for supplement fuel, which can be more expensive at a time of the highest fuel demand.

When difficulties occur in fuel supply or demand increases rapidly over the direct supply capacity, terminal aided fuel supply can secure the supply efficiently. This might well be crucial both for the power plant and fuel suppliers to manage and plan the operations in a cost efficient way. As an example, the presented simulation model could be modified to various cases to identify the most cost efficient operation models and system set ups to be introduced in practice.

2.7. ENHANCED STUMP WOOD LOGISTICS

Asko Poikela & Heikki Ovaskainen, Metsäteho Oy, Juha Laitila, Natural Resources Institute Finland, Luke

MAIN OUTCOME

Root saving lifting method solves many challenges in stump wood logistics. Quality is excellent both in the remaining site and in the power plant. Also load size of long-distance transport rises remarkably. Lifting outside traditional season opens a faster supply chain from harvest to combustion.

MOTIVATION

Stump wood potential for energy generation is more than 2 million m^3 per year. Consumption of stumps has been less than a half of that. Using stumps as a considerable energy source alongside logging residues cuts the pressure to supply roundwood on that process. The wood quality of stumps is very good but it requires a long storage period. Soil disturbance can be minimized by developing lifting technology. Nutrient losses have been taken into consideration by limiting lifting on soils without nutrient scarcity and by lifting only up to 70% of the potential. Quality can be maximized and soil disturbance minimized by developing lifting technology.

FOCUS ON THE BEGINNING OF SUPPLY CHAIN

The challenges in stump wood supply chain are in lifting technology, soil contamination of the stumps and in the transportation efficiency. BEST made remarkable efforts to develop the stump logistics along whole supply chain. First trials focused on post-lifting technology, compression at the roadside and screening on terminals. Compression proved much too inefficient and screening quite expensive, even if quality enhancement was remarkable. After that groundwork it was clear that winning both cost and quality problems requires new solutions for stump lifting.

Two different solutions were tested. First was harwarder mounted device that chops and vibrates the stump during lifting to minimize soil disturbance and foreign matter. Another excavator based device separates stump wood and root collars from roots in one or two pieces (Fig. 19). Latter alternative proved to be more efficient both on quality and productivity point of view and it was found as potential solution for challenges in stump logistics.

Logistics based on root saving lifting method opens a scene on totally new consept. Firstly, lifting season is possible to widen on both ends. All that removal exploits best drying season between April and July and is therefore potential energy wood for next warming season. Secondly, soil saving method might also enable to haul both logging residues and stumps at the same time.

High quality throughout the whole supply chain is essential for land owners and end users to see stumps as notable energy source. That target seems to be solved by new consept. Last challenge is to develope lifting productivity to expected level. That work was started by formulating work models suitable for stump lifting. Remarkable productivity enhancement requires also further development of lifting device.

Figure 19. Soil disturbance and impurities can be minimized leaving roots in place.

CONCLUDING REMARKS

Clear benefit on enhanced supply chain was very low ground disturbance level (< 10 %). Also drying was fast despite of large particle size. Productivity rate of lifting work was not competitive to conventional methods. As compensation on moderate productivity rate, payload size on long-distance transport increased more than 30 % compared to stumps lifted traditional way. Impurities in combustion decreased as low as 4 – 0,4 % depending on storage time (2 weeks – 3 months).

3. MEASUREMENT OF BIOMASS - TONNES AND CUBICS TO MEGAWATTS

3.1. MWh – ROADMAP AND MEASUREMENTS IN TERMINALS

Timo Melkas, Metsäteho Oy & Jouni Tornberg, Kajaani University of Applied Sciences – Measurepolis

MAIN OUTCOME

The MWh roadmap introduces present forest-based raw material supply chains for small-size stem wood, logging residues and stumps and their proportions. It also presents current measuring methods and measurement needs at the different stages of the supply chain as well as potential measuring methods of the future biomass terminal concept and supply chain.

MOTIVATION

The objective of the MWh roadmap was to describe and to create procedures to define the heat value and energy content of energy wood at different stages of the supply chain from the cutting area to the plant (Melkas & Tornberg 2015 a).

During the research program, measurement and estimation methods of moisture content and volume, including soft sensor methods, have been developed as well as calculation methods of MWh and real-time controlling of heat value in the supply chain. Best practices have been selected for the future biomass terminals. The methods for monitoring the quality of the raw material during the supply chain have been studied as well (Fig. 20).

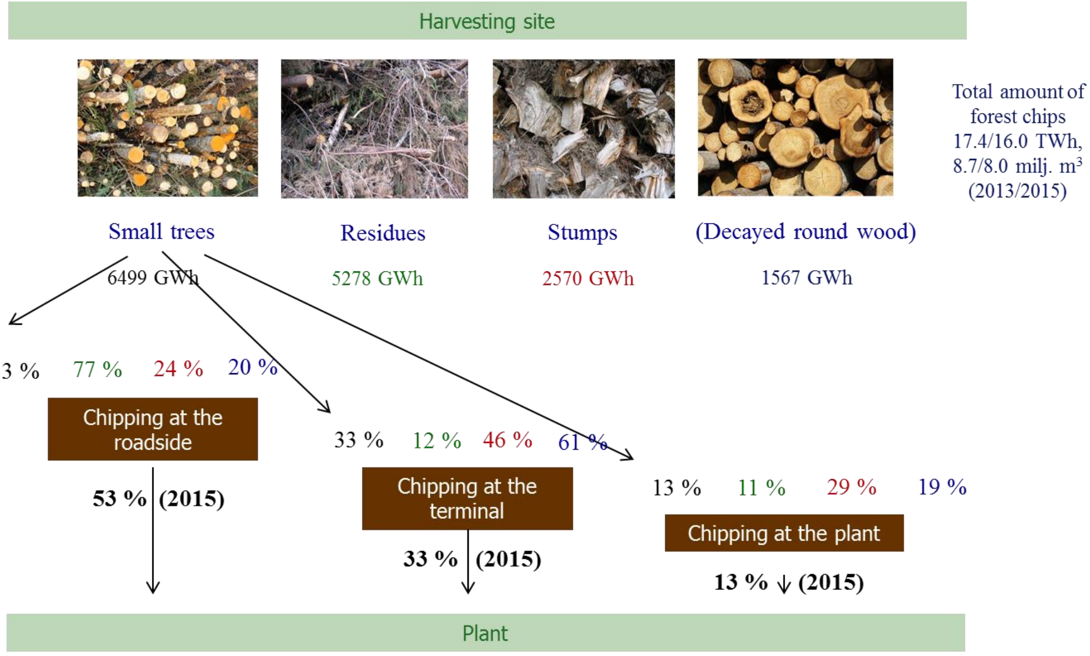


Figure 20. Energy wood supply chains and different material proportions in year 2015.

The main idea of an efficient energy wood supply chain (Fig. 21) is that all measurements are performed while the material is being handled or transferred in the supply chain. The most important measuring points are 1) at the stand (incl. preliminary information of the stand) during the cutting, 2) at the roadside during unloading (forwarders) or loading (trucks), 3) in reception of the terminal or the plant (incoming material). In addition, the moisture content is estimated by drying models in every stage throughout the supply chain. With the use of an efficient feedback system to the suppliers, we can guarantee better material quality to the end users and also optimise the energy wood supply chain (at the lot level). Also drying models can be calibrated based on the feedback information (moisture measurements at the terminal or plant).

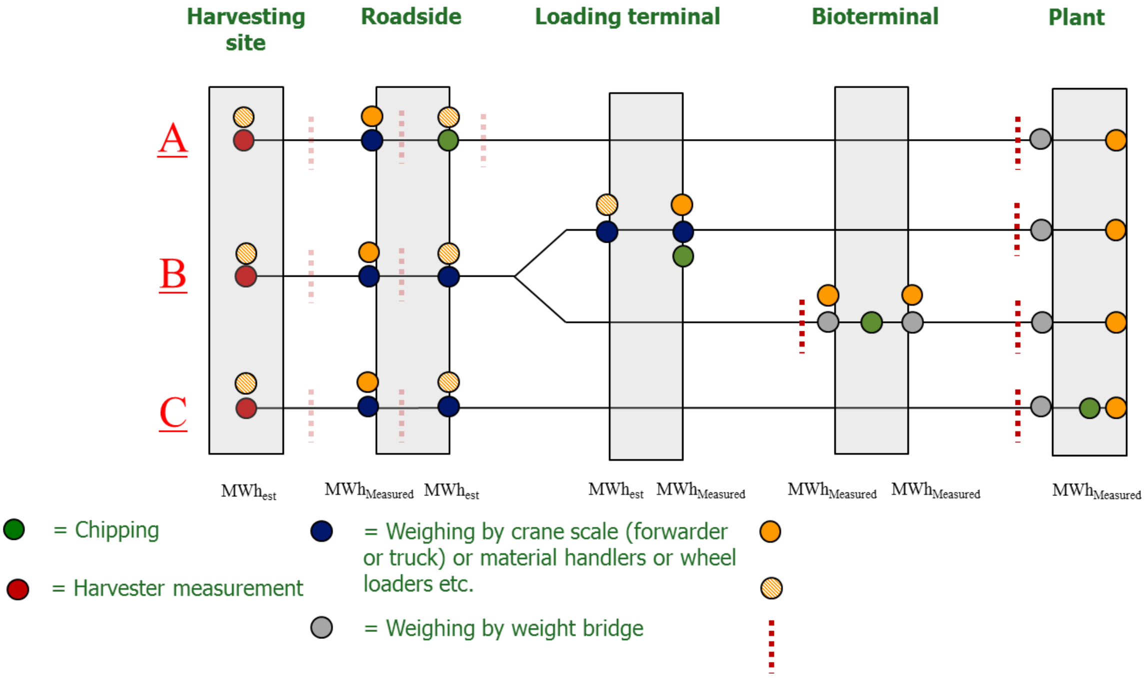


Figure 21. One example of a supply chain description for small-sized stem wood and potential measuring points.

3.1.1. Measurements at biomass terminals

In the biomass terminal studies by VTT (Virkkunen et al. 2015), terminals were divided into different categories, each of which have several size classes. According to that study biomass supply terminals may have different functions, depending on the purpose, size and infrastructure of the terminal.

When considering potential measurements in future biomass terminals, terminal size and how raw materials are supplied to the terminal and shipped from the terminal will be increasingly important. For this reason, potential methods of measurement at different terminals are presented in this study by size class using the following size groups, based on the annual fuel output: Small – 0.1 TWh, Medium – 0.3 TWh, Large – 1.0 and 0.7 TWh.

In small terminals (0.1 TWh/a) weighing is done during material handling by using timber scales, loader scales and material handlers. A weighbridge is not used. Estimation and prediction of moisture is done based on drying models. Chipping is usually performed before delivery and feedback from the plant's reception (measured MWh's and weight from weighbridge) to the entrepreneur will be sent utilising a feedback system. One example of such terminal is a small transshipment terminal.

In medium-sized terminals (0.3 TWh/a) weighing is done likewise during material handling by using timber scales, loader scales and material handlers. A weighbridge is not used. Weighing of forest chip and measuring of the frame volume can be done in the conveyor belt after chipping (applied also for mobile chippers) or alternatively the frame volume can be measured in the truck based on different kinds of sensors (laser scanners, kinetic sensors). Moisture content is estimated by using soft sensor methods. At the medium size terminals stock accounting is also used. One example of such terminal is a medium-size feed-in terminal.

In large terminals (1.0 TWh/a) weighing of incoming and outcoming material is conducted with a weighbridge. Weighing and measuring of the frame volume of forest chips is performed in the conveyor belt or measuring of frame volume of the forest chips in the truck. Meanwhile, moisture content is measured by using soft sensor methods or it is based on online measurements of the moisture content. Also the foreign matter is measured by an online measurement system. A stock management system takes care of the amounts of coming and delivered materials by also taking into account the moisture variation of the storages. One example of such terminal is a large fuel upgrading terminal.

In large terminals (0.7-1.0 TWh/a), the measuring is done basically, following the same principles as above, but the measurement system does not include, e.g. the online detection of foreign matter and there is no automatic material sorting based on quality. One example of such terminal is a large satellite terminal.

Different types of terminals and their facilities are presented more specifically in Table 5 in the biomass terminal study by VTT (Virkkunen et al. 2015; Melkas & Tornberg 2015 b).

Table 5. Measurements at the biomass terminal.

	Small terminal 0.1 TWh/a E.g. small transhipment terminal	**Medium size terminal 0.3 TWh/a** E.g. medium size Feed – in terminal	**Large terminal 0.7 TWh/a** E.g. large Satellite terminal	**Large terminal 1.0 TWh/a** E.g. large Fuel upgrading terminal or Satellite terminal	
Reception	-	-	Weighing by weighbridge (Online measuring of frame volume of the load, Moisture based on soft sensor methods)	Weighing by weighbridge (Online measuring of frame volume of the load, Moisture based on soft sensor methods)	**Feedback from plant to the supplier for every delivery (energy wood lot)**
Unloading	Weighing by timber scale or log handler scale	Weighing by timber scale or log handler scale	-	-	
Whole wood storage	Moisture based on drying models	Moisture based on drying models	Moisture based on drying models	Moisture based on drying models	
Crushing / Chipping	Mobile crusher/chipper Weighing (conveyor belt) + frame volume → moisture	Mobile crusher/chipper Weighing (conveyor belt) + frame volume → moisture	Mobile crusher/chipper Weighing (conveyor belt) + frame volume → moisture On-line measuring of foreign matter and moisture	Crusher / Chipper Weighing (conveyor belt) + frame volume → moisture On-line measuring of foreign matter and moisture	
Other processing/ upgrading	-	-	Sorting based on moisture. Sieving of foreign matter.	Sorting based on moisture. Sieving of foreign matter. Other processing (drying, sealing, blending)	
Storing of comminuted wood	(Wireless sensors for moisture and temperature estimation of storages and chip piles)	(Wireless sensors for moisture and temperature estimation of storages and chip piles)	Wireless sensors for moisture and temperature estimation of storages and chip piles	Wireless sensors for moisture and temperature estimation of storages and chip piles	
Loading	Chipping straight on to the truck - weighing by timber scale From chip storage - weighing by loader scales/wheel loader	Chipping straight on to the truck - weighing by timber scale From chip storage - weighing by loader scales/wheel loader	Weighing by weighbridge	Weighing by weighbridge Online measuring of frame volume and moisture	
Measuring devices (cost estimate)	Timber scale (5000 e), Log handler scale (15000 -20000 e), Loader scale/Wheel loader (15000 -20000 e), Moisture sensor 10 e/kpl , Weighing (conveyor belt) + frame volume (50 000 e)	Timber scale (5000 e), Log handler scale (15000 -20000 e), Loader scale/Wheel loader (15000 -20000 e), Moisture sensor 10 e/kpl , Weighing (conveyor belt) + frame volume (50 000 e)	Weighbridge (120000-150000 e) Volume estimation (20000-30000 e) On-line measuring of foreign matter (250 000 e) On-line measuring of moisture (60 000 e) Moisture sensor, 10 e/kpl, Weighing (conveyor belt) + frame volume (50 000 e)	Weighbridge (120000-150000 e) Volume estimation (20000-30000 e) On-line measuring of foreign matter (250 000 e) On-line measuring of moisture (60 000 e), Moisture sensor 10 e/kpl Weighing (conveyor belt) + frame volume (50 000 e)	

3.2. MOISTURE MEASUREMENT SOLUTIONS

In the future new raw material delivery concepts, e.g. bio-terminals, present needs to develop new cost-effective measuring methods for biomass quantity and quality. Important measurable variables are weight, moisture content, volume, particle size and foreign matter.

Moisture is an important quality parameter of wood chips, strongly influencing heating value and consequently the price of fuel chips. Fast and reliable methods for moisture determination would therefore be valuable.

In the laboratory the moisture content is determined by the oven-drying method defined, e.g., in international ASTM standards, European CEN standards and, for industrial wood chips, in Scandinavian SCAN standards. The samples are weighted before and after drying to obtain the dry mass (SCAN 1994, CEN 2008). The energy content determination is based on the measurement of weight and moisture. The weight of biomass is measured during forwarding and transporting and volume is usually based on common conversion factors. If the energy content of the raw material can be defined in real time, the timing of deliveries can be optimised and the quality of the raw material for biofuel can be improved.

Moisture measurement can be based on electromagnetic radiation such as IR/NIR technology, microwaves, X-rays or NMR technology. The variety of available technologies is quite large and some new technologies such as NMR, microwaves and X-rays have broken into the market in the last few years (Österberg et al. 2014). In the BEST programme these technologies were evaluated and applied for moisture measurements in the raw material value chain.

The measurement systems presented in the following chapters were utilised in BEST programme.

3.2.1. Senfit BMA and BMx Biomass Moisture Analysers

Pekka Jakkula & Mikko Vuolteenaho, Senfit Ltd.

MAIN OUTCOME

Senfit Ltd. has developed microwave-based moisture instruments for laboratory and online analysis. Senfit BMA is a desktop model having good correlation in moisture range 15–70%mc to Loss-on-Drying (LoD) reference, when calibrated for each measured material grade. Online biomass moisture analyser (BMx) produces fast and reliable moisture measurement results. The measured values can be transferred in real-time to the plant fuel management system for use in fuel logistics and process control.

Senfit BMA and BMx

BMA is a desktop microwave-based moisture measurement device (Korhonen et al. 2016). The measurement range of the instrument is 0 %–70 %. The instrument is tuned for 400 g ± 5 g biomaterial samples placed in a plate-shaped measurement bowl. The bowl is inserted in the measurement chamber. The moisture measurement of the sample takes a few seconds. The sample preparation is recommended to be done according to the European Standard EN-14780.

Senfit BMx is an online biomass moisture analyser (Fig. 22) where sample processing and moisture measurement is integrated in the same device. The flow-through sensor is used as a measuring unit. The measurement system consists of a screw-type sampler with optional refiner and melting element, a BMx moisture sensor and an operation and data acquisition unit. The device can be installed as a continuous bypass line to the process material flow or used manually by the truck drivers bringing material to the plant. The device can also be integrated into the fuel management system of the plant, which enables the measurement data to be transferred directly to the system in real time.

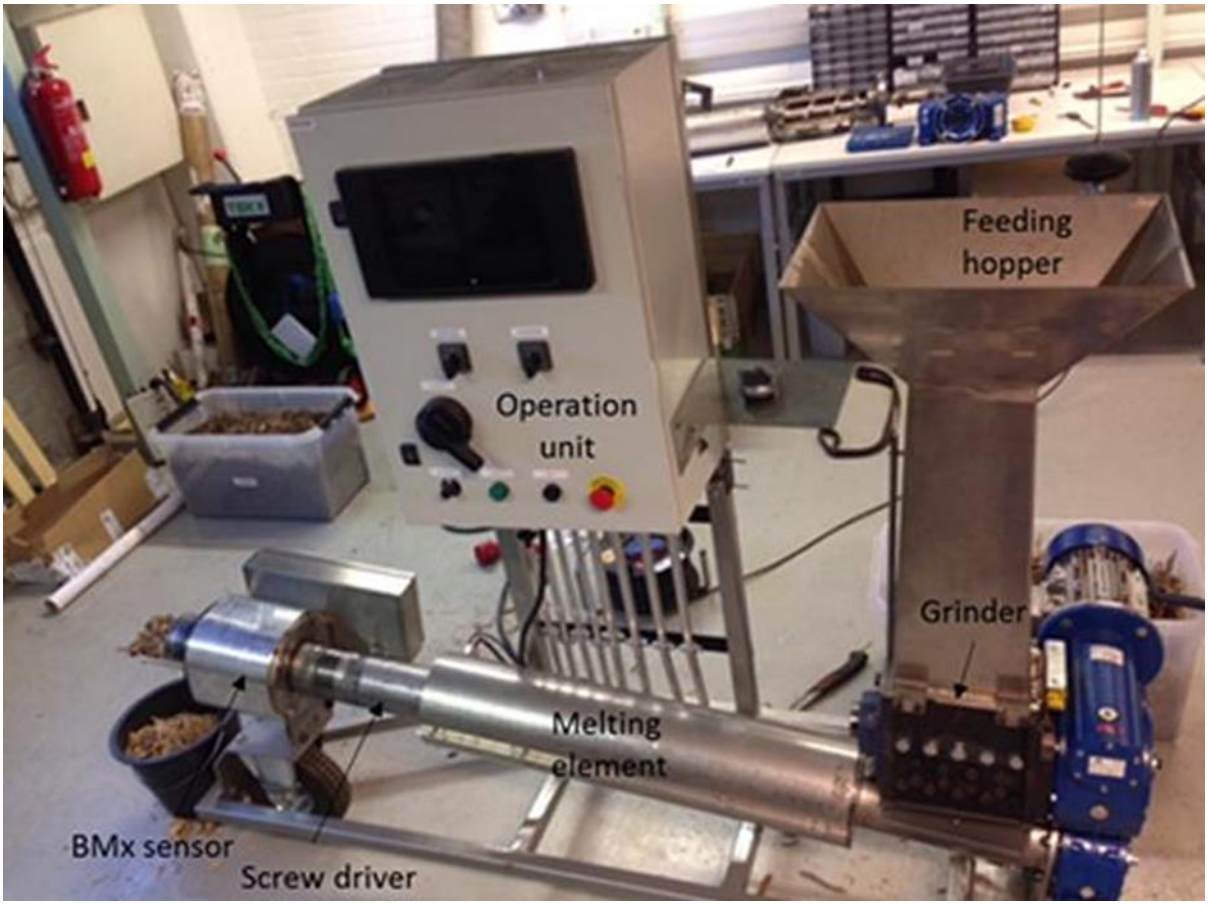


Figure 22. Senfit BMx test system.

In this study the samples (15 litres) were fed to the feeding hopper. Before analysing the moisture, every sample was mixed and ground into smaller fractions according to the standard. The measurement device was calibrated for each fuel grade (stumps, logging residues, bark) separately. Control samples (300 g) for the oven drying were taken from the sensor output. The aim was to take an as representative sample as possible of each load.

Results and conclusions

Typical test results are shown in Fig. 23. Measured material is ground stump, forest residues and bark. As can be seen the measured values follow well the laboratory results

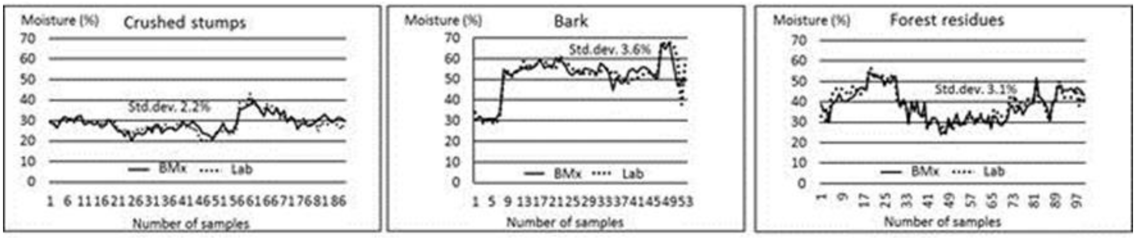


Figure 23. Moisture content of different materials measured with BMx and in laboratory.

Online biomass moisture analyser (BMx) produces fast and reliable measurement. The measured values can be transferred in real-time to the plant fuel management system for the use in fuel logistics and process control. For calibration purposes, it is necessary to collect enough samples – at least

30 samples with the broadest possible moisture variation from each fuel grade. The device can be used to measure moisture in any fuel grade. The aim was to gather at least one hundred measurement points for each fraction to make sure that measurement accuracy was reached. However, due to practical reasons, this was not achieved in all fuel grades. The sample size should be appropriate to the device. The prototype was designed for the 10-litre samples. In the production model, the hopper will be increased to meet the user's needs.

Since moisture variation inside the sample can be significant and fast, in the calibration attention must be paid to the allocation and exact timing of samples (oven drying vs. moisture measured by device). Blockages of the device were eliminated by improving the mechanics and running reliability during the project. In the future, the objective is to develop a device that operates as an independent unit connected to a plant's fuel management system and produces accurate information about moisture content of energy wood grades.

In the final stage of this project the goal is to improve measurement accuracy with materials having strong differences like bark and bare wood.

3.2.2. Valmet MR Moisture Analyser

Jouni Tornberg & Petri Österberg, Kajaani University of Applied Sciences - Measurepolis

MAIN OUTCOME
The Valmet MR Moisture Analyser utilises Nuclear Magnetic Resonance (NMR) for moisture analysis solutions. It measures absolute water content accurately by detecting resonance signal of hydrogen atoms from free water molecules. The device measures virtually any sample containing water in a couple minutes regardless of particle size and material type, except material containing ferromagnetic metals.

The performance of the Valmet MR Moisture Analyser (Fig. 24) compared to the oven drying reference method (Loss-on-Drying, LoD) has been studied by Skogforsk and the University of Oulu.

Moisture measurement evaluation by Skogforsk (Fridh 2014) was carried out on stem wood and logging residue chips, and wet basis moisture content ranged from 17% to 65%. On average the Valmet (Metso) MR Moisture measurement overestimated the moisture content by 0.15 percentage points for wood chips and 0.11 percentage points for residue chips. A linear regression with reference moisture as the dependent variable and NMR measurement as the independent explained 98.8% of the variation for stem wood chips and 99.1% for residue chips. In both cases a 95% confidence interval covered less than ±2.5 percentage units. The standard deviation of repeated measurements on a sample with the Valmet MR Moisture Analyser was 1.0 percentage points for wood and 0.6 for residue chips.

Moisture was measured in standardised 0.8-litre containers, which limits the length of the wood chips that can be measured without further sample preparation. The Metso device is easy to use and a single measurement requires 120 seconds, allowing quick measurement, even if multiple samples are needed.

The University of Oulu (Österberg et al. 2016) used five different biomaterials in the study at three moisture content levels. After instrument calibrations, the difference and variation of the measurement results for parallel samples and the repeatability of the NMR instrument were estimated. Reasonable agreement between the measurement methods was achieved. In summary, the NMR moisture measurement instrument Valmet MR Moisture provided results that were in fair agreement with the reference results. The difference between the NMR instrument and the LoD reference method was 1.0 ± 3.8 %mc on average.

The performance of the Valmet MR Moisture NMR instrument, that is, both its uncertainty and the difference in results compared to the LoD method, varies according to the biomass type and its moisture content: the difference varied in the range of -0.9 to 3.0 %mc and the uncertainty was in the range of 1.8 to 4.1 % mc with a 95% confidence level.

The best results from the point of view of both difference from the LoD reference method and uncertainty were achieved with the ground stump samples. The deviation of the NMR instrument results from the oven drying results was the largest with the bark waste samples and this occurred both for bark waste samples that had been stored for several months and for fresh ones. The uncertainty of the measurement was poorest with the pruning residue samples and was nearly double those of the other four sample materials.

Figure 24. Valmet MR Moisture Analyser.

3.2.3. Inray FUEL - Solid Fuel Quality Analyser

Janne Kovanen, Inray Ltd.

MAIN OUTCOME
Inray Ltd. has developed a new progressive way for solid biofuel quality control that utilises x-ray technology. Online x-ray scanning of biofuel enables more accurate fuel quality data for process control and fuel trade. The Inray Fuel online measurement system analyses in real-time moisture, foreign matter content and calculates energy content for the whole batch.

The measurement system includes a power feeding and controlling unit, processing computer and proprietary software (image recognition, signal processing, analysing and controlling algorithms). The measurement device consists of an X-ray source, detector, power controller and signal processing module. The X-ray tube sends radiation above the conveyor belt and the detector reads radiation below the belt. The X-ray tube is set so that radiation penetrates the fuel flow and so the entire fuel mass is measured. Measurement resolution can be very high, so conveyor belt speed is not a limiting factor. Image analysis can be made for every detected stripe or single picture so the x-ray scanning method can be used to detect fast changes in process. In practise, one-minute-average calculation for moisture has been seen suitable for reporting purposes in fuel receiving. A basic principle of the measurement is shown in Fig. 25.

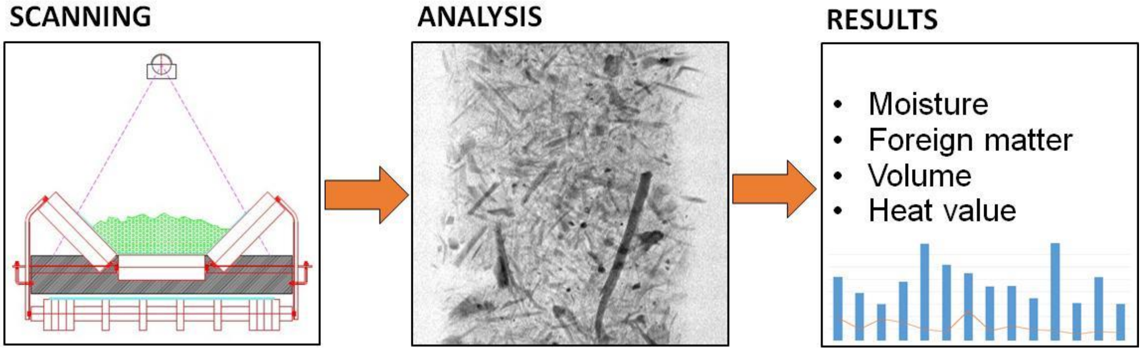


Figure 25. Inray Fuel X-Ray measurement principle.

The Inray Fuel system was installed at UPM-Kymmene Plc's Kaipola biopower plant (117 MWth) in Finland in November 2013. The target was to demonstrate the Inray Fuel online X-ray scanner in a relevant environment with challenging solid biofuels for moisture and foreign matter measurement. Measurement location was at the fuel receiving area in a belt conveyor after a biomass grinder. UPM-Kymmene Plc organised an intensive test period from the 10th to 13th of March 2014 where online measurement was compared to current sampling-based practises. Tested fuels were logging residues, stem wood chips, whole tree chips and ground stumps. Fuel quality of a total of 45 truck-loads was determined.

Results show that the current practise is inaccurate because of high moisture content variations within a truckload, which makes reliable sampling challenging. The Inray Fuel system was found to be more accurate than current methods because online measurement eliminates moisture variations, enables foreign matter analysis and more accurate energy content analysis.

In a second part of the project Inray developed algorithms for low-density foreign matter detection. Low-density fine soil particles like sand, clay and mud are blended with solid bio fuel during its processing and they are rarely removed from oven samples before drying. The only good method to estimate their share inside a truck batch has been ash content analysis but the amount of fuel in these tests is even smaller than in a standard oven test. So for this purpose Inray developed new algorithms for X-ray software. Development was made possible by intensive testing by scanning clean fuel and gradually adding small amounts of soil particles into the fuel. Tests were driven at a separate conveyor so the same fuel was scanned many times with different foreign matter content. PCA (Principal Component Analysis) analysis was carried out for a large number of calculated parameters and the most meaningful ones were used to develop calculations for foreign matter content. This calculation can estimate foreign matter content of a fuel batch online quickly and with sufficient reliability.

3.2.4. NIR–method with integrated measurement of surface temperature and colour

Sami Siikanen and Pekka Teppola, VTT Technical Research Centre of Finland

MAIN OUTCOME

On-line NIR-spectroscopy measurement of biomass moisture, e.g. on conveyer belts before fuel inputs of boilers, can now be developed to be more precise in different operation conditions such as cold winter temperatures. The use of an additional camera enables the NIR-spectrometer calibration model to work independently from biomass colour – especially darkness and lightness changes in a moving sample flow.

MOTIVATION

The possibilities of NIR spectroscopy in biomass moisture measurement have been already commercially utilised by different companies around the world. The NIR spectroscopy has its advantages but also many challenges have remained unsolved in the practical use of the method.

NIR spectroscopy, advantages:

- Fast, non-destructive method with no need for sample preparation;
- Enables in-line monitoring from moving sample flows;
- No need for extra (e.g. density) measurement;
- Both low- and high-resolution NIR spectroscopy can be used for biomass measurements (such as energy density, ash content);
- For moisture measurements, even a sensor with a few (2-5) wavelength channels can be adequate if the moisture level is below 40%. In this case, the sensor price is only a fraction compared to a high-resolution spectrometer. For higher moisture levels, more wavelength channels are needed pointing to the use of multivariate models.

NIR spectroscopy, challenges:

- Surface measurement, information depth 100 µm – 1 mm (depending on the wavelength and sample material): representative measurement of the entire sample is impossible;
- Alien material and objects (sand, snow, plastic) cause disruptions but not as much as in mid-infrared;
- Chemical absorption phenomena are often combined with physical phenomena such scattering, opacity, brightness and other types of phenomena. To guarantee the selectivity of NIR measurement can be challenging due to variation of temperature, and colour and variation of chemical and physical phenomena. In many cases, NIR calibration models work only in a limited usage. Our objective was to broaden this operational window to include changes in sample temperature and colour (especially brightness and color).

Extraction of moisture level from NIR spectra

Background. Water exhibits two notable absorption bands in the NIR spectral range (1445 and 1950 nm). Cellulose has a strong absorption band at 2120 nm. The ratio between the water and cellulose band areas correlates positively and selectively with the true moisture level (used widely in paper moisture analysis). The ratio is described in Fig. 26. The moisture-selective feature is calculated as the ratio

$$WCR = Aw/Ac, \qquad (1)$$

where WCR = water cellulose ratio,
Aw = water band area and
Ac = cellulose band area

In Fig. 26:

- A_w is the yellow area between the blue spectrum and cyan baseline.
- A_c is the green area between blue spectrum and cyan baseline.
- The baseline level *mb* is calculated at a location where little absorption occurs.

Unfortunately, this approach works only until 30–40% moisture. The reason is that the water absorption peak masks the cellulose peak. As a curiosity, there are also other types of ratio models that take into account the optical path length / scattering / opacity changes but these are not treated here for the sake of brevity. However, the main point being emphasised is that it usually makes sense to use relative models rather than absolute intensity data; although this is not so black and white.

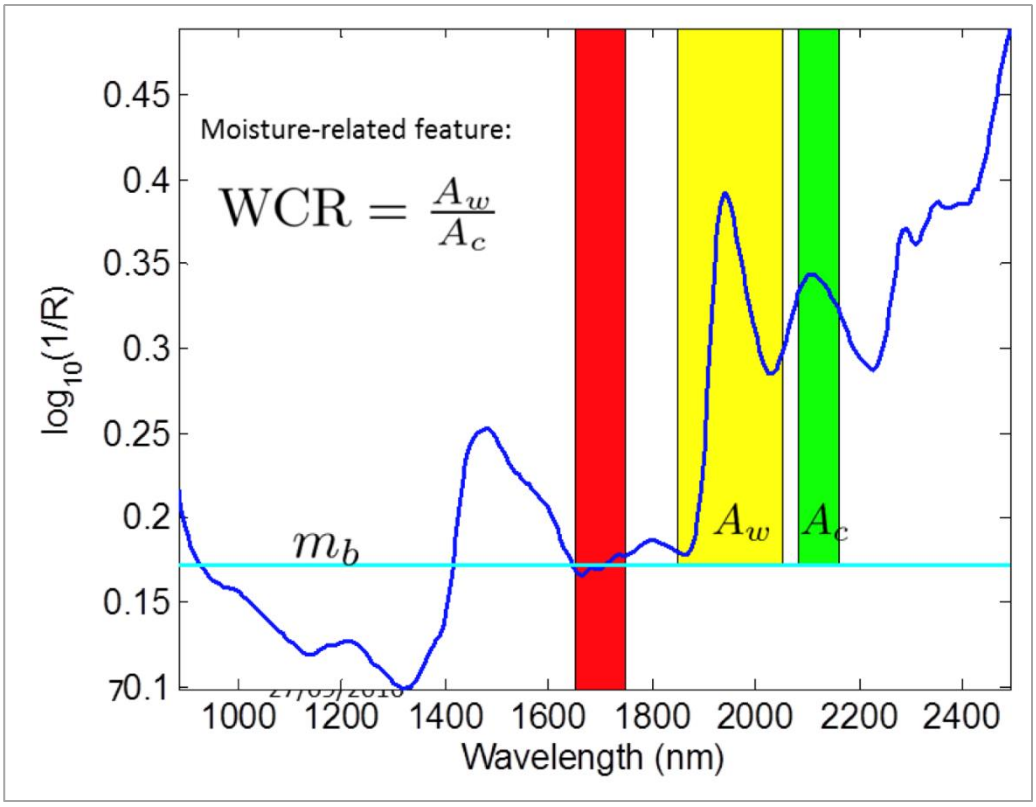


Figure 26. The ratio between the water and cellulose band areas correlates positively and selectively with the true moisture level (used widely in paper moisture analysis).

The alternative method. As an alternative method, we can extend the ratio model to the multivariate case by using a model:

$$\hat{y} = \frac{\hat{\beta}_0 + X\hat{\beta}}{1 + X\hat{\gamma}}, \qquad (2)$$

where $\hat{y}$ = moisture prediction
$\hat{\beta}_0$= regression offset coefficient
X = NIR spectra
$\hat{\beta}$ = regression coefficients for numerator
$\hat{\gamma}$= regression coefficients for denominator

Benefits of rational functions include the elimination of multiplicative light scattering effects and the possibility to model nonlinear phenomena. This method removes the need for the manual definition for absorption and background bands. It is essential that the method is used with a proper way of assessing the model's predictive ability. This can be done via cross-validation. Remember to leave out larger (continuous) data blocks rather than single samples. Leave one out (LOO) can be too optimistic. As follows, we have tested multiple rational function methods below and these results are reported here in brevity.

METHOD REALISATION

Several measurement campaigns were planned in the BEST programme to study the NIR method with integrated surface temperature and colour measurements for on-line moisture measurement. The objective of the measurement campaign was to produce representative and statistically solid data to develop a robust NIR moisture measurement method.

- The main measurement campaign had a goal to study the effect of sample colour on NIR-based moisture measurement and to study the utilisation of VIS spectroscopy in the compensation of errors caused by sample colour and brightness.
- The method was measuring samples of different colours and brightness at different moisture levels; using both VIS and NIR spectra, and trying to find a global moisture calibration model which works over the different colours.
- Samples were four sheets made from binary mixtures (40/60, 60/40, 80/20, 100/0 %) of peat and pulp + 1 white sheet made from pure pine pulp.
- Measurement systems were a SWIR hyperspectral camera (980–2500 nm) and VIS hyperspectral camera (500–800 nm).
- Moisture levels reached 10–70 % w/w.
- We also tested new and more robust methods for the SWIR region alone because the additional VIS camera would generate additional costs.

RESULTS

In the early phase of the project, simple ratio models proved the most useful for the NIR moisture measurement in cases where there were colour and brightness changes. In Fig. 27, we compare several regression techniques with improved performance. It turned out that multivariate methods resulted in the best performance. Both ordinary linear and rational function methods were tested. In the last experimentation, the ordinary (multivariate) linear regression methods outperformed slightly the rational function methods. The latter remains very interesting as there is no need for a separate spectral preprocessing. We also checked ratio models that used water cellulose ratio; both of those were 50–100 % more inaccurate.

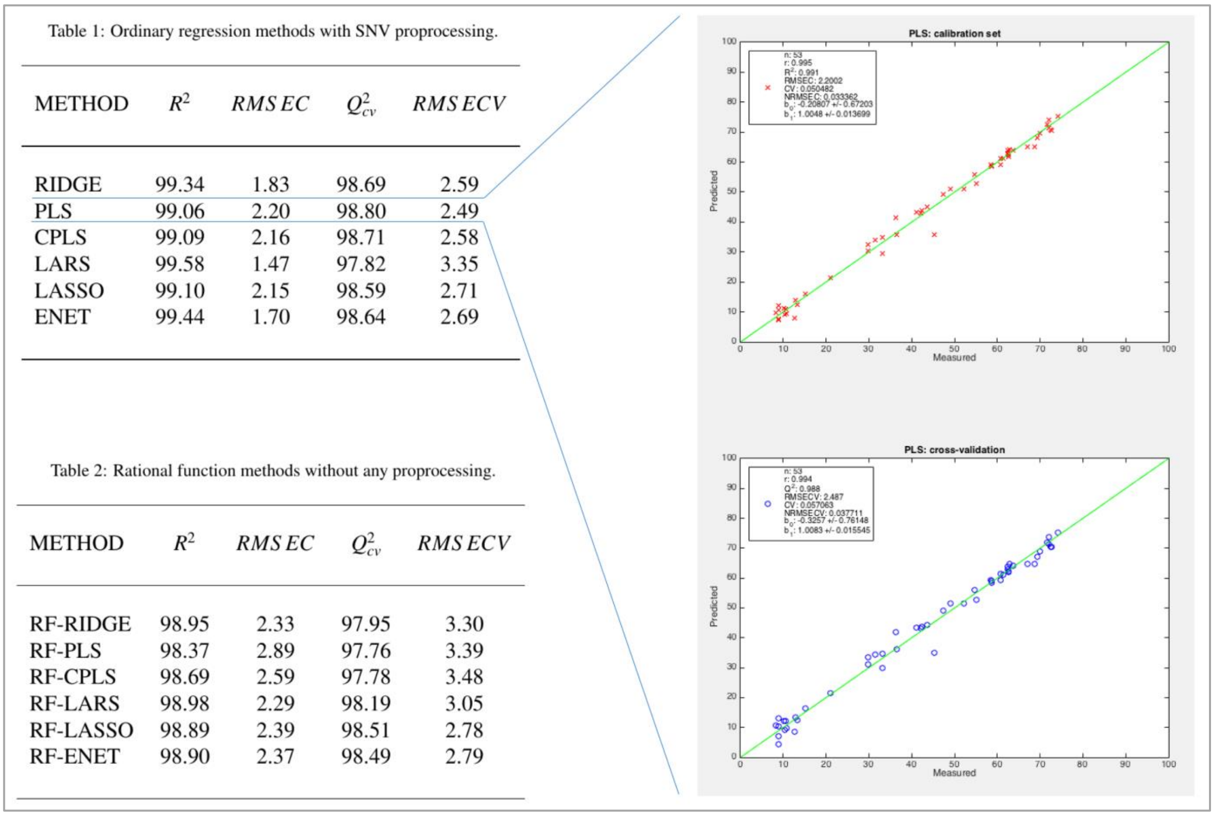


Table 1: Ordinary regression methods with SNV proprocessing.

METHOD	R^2	$RMSEC$	Q^2_{cv}	$RMSECV$
RIDGE	99.34	1.83	98.69	2.59
PLS	99.06	2.20	98.80	2.49
CPLS	99.09	2.16	98.71	2.58
LARS	99.58	1.47	97.82	3.35
LASSO	99.10	2.15	98.59	2.71
ENET	99.44	1.70	98.64	2.69

Table 2: Rational function methods without any proprocessing.

METHOD	R^2	$RMSEC$	Q^2_{cv}	$RMSECV$
RF-RIDGE	98.95	2.33	97.95	3.30
RF-PLS	98.37	2.89	97.76	3.39
RF-CPLS	98.69	2.59	97.78	3.48
RF-LARS	98.98	2.29	98.19	3.05
RF-LASSO	98.89	2.39	98.51	2.78
RF-ENET	98.90	2.37	98.49	2.79

Figure 27. Comparison of different models. Ordinary regression models are with SNV correction and rational function models are without any spectral processing. SNV was needed for ordinary models but not for rational function models. In fact, rational function models were worse with SNV.

We also checked both the model predictions and the model residuals against the sample brightness / peat:paper ratio and we noticed that the models were robust against this covariate information. VIS spectra were used to confirm that. In conclusion, one needs to perform either spectral preprocessing or use a form of rational functions or other relative information in order to compensate for the changes in absolute intensity level changes. The best method was ordinary PLS regression with SNV preprocessing followed by ridge and constrained PLS regression. The best rational function models were RF-LASSO and rational function elastic net.

CONCLUDING REMARKS

Robust SWIR / NIR models can be developed using both existing and new rational function methods. There is no need for additional VIS or brightness measurement, though there is more work to be done with the spatial analyses. For instance, spatial VIS measurements support spatial SWIR / NIR measurements in the studies of moisture / opacity changes. These will be reported and published in the near future.

3.2.5. Soft sensor – method for moisture content determination without sampling

Ari Isokangas, University of Oulu

MAIN OUTCOME

A soft sensor-based method was developed to estimate the moisture content of wood deliveries without the need of sampling. The main principle of the method is based on the relation of weight and volume of a delivery. More sophisticated moisture content determination requires information about the average basic density (wood species). According to results, the developed method works relatively better at high moisture contents where the performance of the traditional method is the lowest. The largest uncertainty of the soft sensor method relates to solid volume estimation. It can be estimated in several ways in order to reduce the moisture content estimation error. Solid volume is typically also the basis of pricing and largest acceptable volume errors are set by law. The results also indicate moisture content measured as a percentage is not unambiguous – the obtained result is also affected by basic density. This probably explains at least part of the challenges related to moisture content determination.

MOTIVATION

The objective was to estimate the moisture content using the available information about wood deliveries without the need of sampling. The moisture determination is typically based on the oven dry method providing delayed results hours after sampling. Typically only one or a few samples per delivery are taken, which corresponds normally to a tiny fraction of batch weight. This may lead to large moisture estimation errors due to raw material quality and moisture variations within delivery. In every case sampling is complicated and makes determination costly. The suggested method considers whole wood delivery as a sample and is insensitive to moisture (and raw material quality) variations within the delivery. The benefits of the suggested method are the capability to measure also frozen raw material, moisture estimation is available immediately for process control and cost savings as sampling is not required.

INTRODUCTION

The soft sensor method estimates the moisture content of wood deliveries on the basis of available information without the need of sampling. A delivery in this context means a unit transport of chips, crushed aggregate, stems or whole trees. The main principle of the method is based on the relation of weight and volume of a delivery. Specifically, it is rather easy to judge whether a piece of firewood in your hand is moist or dry.

The moisture content of a sample is normally expressed in wet basis, which means the relative proportion of water to the wet mass. The oven dry method is usually considered as reference method for moisture content. The mass of water can be obtained by reducing the mass of dry wood after drying in an oven from the wet mass. The soft sensor method considers the whole delivery as a sample and thus drying of water is not an option. However, the mass of water can be estimated indirectly by reducing the mass of wood from the delivery mass. For this reason the solid volume of a delivery and wood density, i.e. basic density, needs to be estimated. Fig. 28 illustrates these important wood properties in this context: basic and green densities.

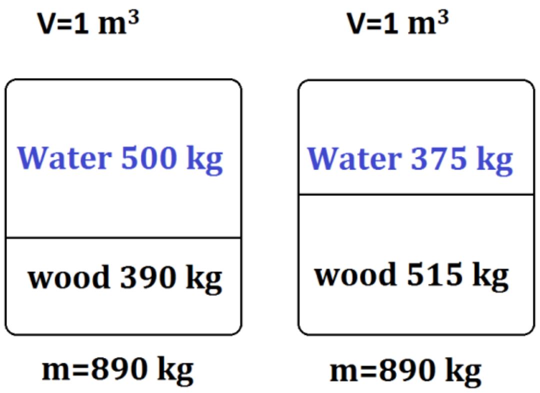


Figure 28. The illustration water (and further moisture content) determination based on basic and green densities. The solid volume is 1 m^3 and the green density 890 kg/m^3 for both, but due to the lower basic density the amount of water and moisture content is higher in the left case.

UTILISABLE DATA

For best performance, the soft sensor method requires the information about the average basic density (i.e. wood species), mass and solid volume of a delivery. The soft sensor method is the most applicable in the wood receiving station where these are typically measured in the following ways.

The mass of a delivery can be measured using plate scales with insignificantly small measurement error. The information of wood species can be obtained e.g. from the seller, harvester data or visually in cases of roundwood or forest residual deliveries. The raw material deliveries can be mixtures of different wood species. Then the shares of wood species can be multiplied by the corresponding basic densities, which are summed for the average basic density of the delivery.

The differences of average basic densities between wood species, except Birch (*Betula* spp.), are rather small in Finland. If the wood species is not known, using the value 400 kg/m^3 is recommended. The solid volume of the wood material can be estimated in several ways depending on the available measurements and raw material type. The stacked volume of roundwood and frame volume of chips or crushed aggregate can be obtained from the physical dimensions of the delivery. There are also commercial machine vision-based measurement systems for this purpose. The stacked and frame volumes can be converted into the solid volume using the conversion factors given by the Finnish Forest Research Institute (Anon 2013a). The Finnish Forest Research Institute has published the green density tables for several types of wood material on the basis of the geographical location in Finland, season of the year and storage time (Anon 2013a). The green density tables can thus be also used to convert weight information into solid volume. The maximum weight and dimensions of truck deliveries are set by law in Finland (Anon 1992).

The maximum possible solid volume of a wood delivery can be set with the help of expert knowledge depending on the transport truck type and raw material type. This information can be utilised in preventing the overestimation of the delivery volumes. The maximum accepted volume errors at 95% confidence level for typical deliveries are given in Anon (2013b) and they are set by law in Finland. The largest acceptable volume estimation depends on delivery size and raw material type. The largest acceptable volume estimation error, e.g. for un-delimbed wood, is 25% for 10– 30 m^3 and 10% for 150 m^3 deliveries. For delimbed wood the corresponding largest acceptable volume errors are 10% and 4%.

MOISTURE CONTENT DETERMINATION IN THE SOFT SENSOR METHOD

After obtaining the information about the volume, weight and basic density in one or several of the ways presented in an earlier chapter, the green density (δ_{green}) of the delivery is first estimated on the basis of mass and solid volume of a delivery

$$\hat{\delta}_{\text{green}} = \frac{\mathrm{m}_{\text{wood}} + m_{water}}{\hat{V}}, \tag{3}$$

where the mass of delivery (m_{wood} + m_{water}) is assumed to be measured without error and $\hat{V}$ is the estimated solid volume of the raw material delivery. The obtained green density can be evaluated against green density tables (Anon 2013 a) and an anomalous green density value may indicate the re-evaluation need of solid volume measurement/estimation. In the winter the volume of snow and ice can be reduced from the measured value. Especially in bioenergy production the mass of frozen water will be burnt and thus there is no need to correct the measured mass.

The green density consists of components of wood and water (Fig. 28). The amount of water per 1 cubic metre of wood (δ_{water}) can be obtained by reducing the estimated basic density from the green density

$$\hat{\delta}_{\text{water}} = \hat{\delta}_{\text{green}} - \hat{\delta}_{\text{basic}}. \tag{4}$$

There can be a large variation in the basic density even within a tree but the required value is the average basic density of the delivery. The estimated masses of wood and water in the whole delivery are

$$\hat{m}_{\text{wood}} = \hat{\delta}_{\text{basic}} \cdot \hat{\mathrm{V}}$$

$$\hat{m}_{water} = \hat{\delta}_{\text{water}} \cdot \hat{\mathrm{V}}. \tag{5, 6}$$

However, it is difficult to estimate the actual mass of water (Eq. 6) directly, but it can be obtained by reducing the mass of wood from the mass of the whole delivery

$$\hat{\mathrm{m}}_{water} = \mathrm{m}_{\text{wood}} + m_{water} - \hat{V} \cdot \hat{\delta}_{basic}. \tag{7}$$

The estimated moisture content of a delivery can be obtained by dividing Equation 7 by the mass of the delivery

$$\hat{MC}_{wet} = \left(1 - \frac{\hat{V} \cdot \hat{\delta}_{basic}}{\mathrm{m}_{\text{wood}} + m_{water}}\right) \cdot 100\%. \tag{8}$$

The moisture estimation uncertainty depends on solid volume and average basic density estimation errors, see Eq. 8. The moisture content estimation error is illustrated in Fig. 29 using the factor *K,* which merges the solid volume and basic density estimation errors as follows

$$K = \frac{\hat{V}}{V} \cdot \frac{\hat{\delta}_{basic}}{\delta_{basic}}. \tag{9}$$

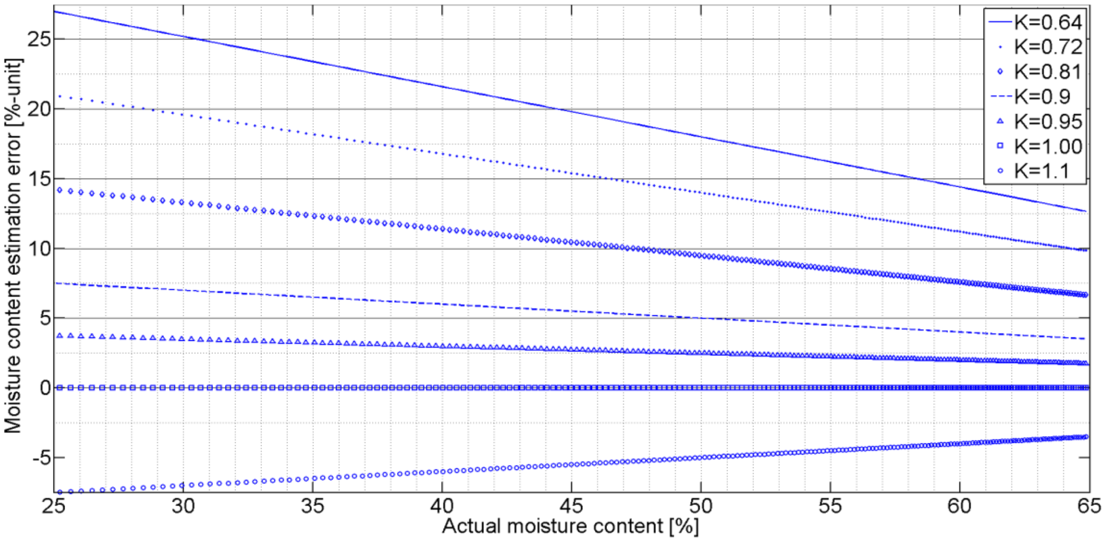


Figure 29. Moisture content estimation error (estimated - actual value) as a function of actual moisture content and factor K, which merges the solid volume and basic density estimation errors.

The same moisture content estimation error can be obtained by several combinations of the basic density and solid volume estimation errors. A K value 0.64 corresponds, for example, to cases when both are estimated 20% lower than the actual value (0.8*0.8 in Eq. 9) or when the other is estimated correctly and another 36% lower than the actual value (0.64*1). The estimation error is maximised when the volume and average basic density are both estimated too high or too low. On the contrary, errors compensate each other if one is estimated too high and another too low.

According to Fig. 29 the soft sensor method performs relatively better at high moisture contents, where the uncertainty of moisture content determined based on samples is the highest. This is because the moisture variation within deliveries is the largest at high moisture contents (Järvinen 2012). At 60% actual moisture content and with ±10% solid volume accuracy the moisture content estimation error is within ±4% units assuming there is no error in basic density estimate (K=0.9 or 1.1 in Fig. 29).

EFFECT OF RAW MATERIAL QUALITY ON ENERGY AND MOISTURE CONTENT

Fig. 30 illustrates moisture content as the function of the amount of water and basic density. According to Fig. 30 the moisture content of 40% can be obtained by 200 kg/m^3 water if the basic density is 300 kg/m^3 or by 465 kg/m^3 water when the basic density is 700 kg/m^3. The absolute amount of water is 2.33 times more in the latter case. Correspondingly, the absolute amount of water 300 kg/m^3 can correspond to the moisture content between 30-50% depending on the basic density range presented in Fig. 30. An even higher amount of water (kg/m^3) can result in a lower moisture content percentage as can be seen in Fig. 30. The basic density can vary remarkably even within a single tree, but at large volumes the average basic density approaches the values known by wood species. Soft sensor method utilises these values whereas the sample basic density can vary remarkable from the average value of a delivery – and affect moisture content as can be seen from Fig 30. This means that the moisture content percentage, in the generally accepted unit, is not unambiguous. The Soft sensor method would allow the representing moisture content also in absolute value, kg/m^3.

Another advantage in illustrating moisture content per volume instead of wet mass is that the effect of moisture on energy content is relatively small compared to the basic density see Fig. 31.

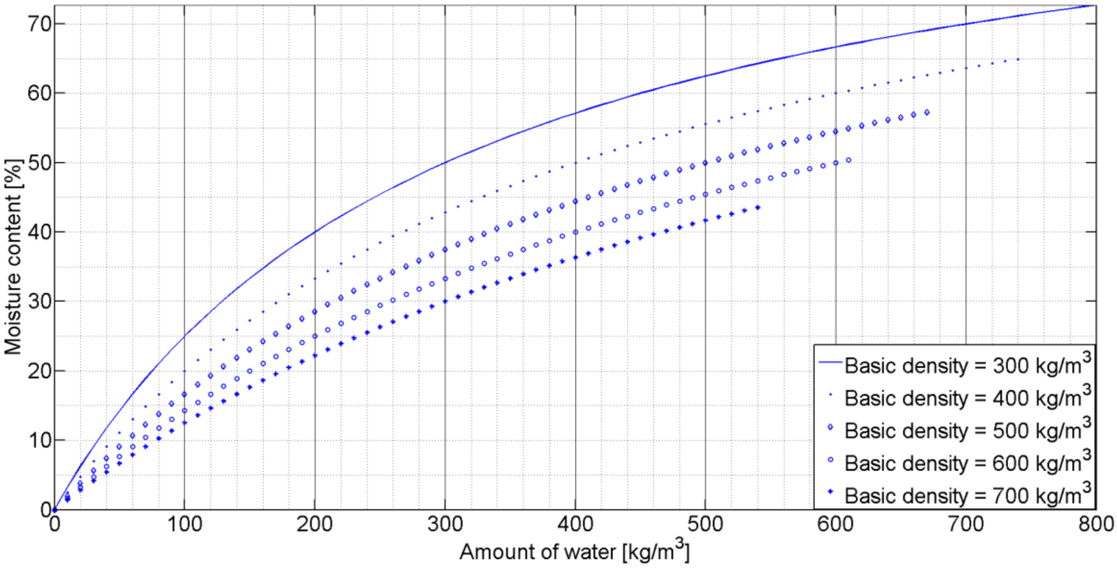


Figure 30. Moisture content as the function of the amount of water and basic density.

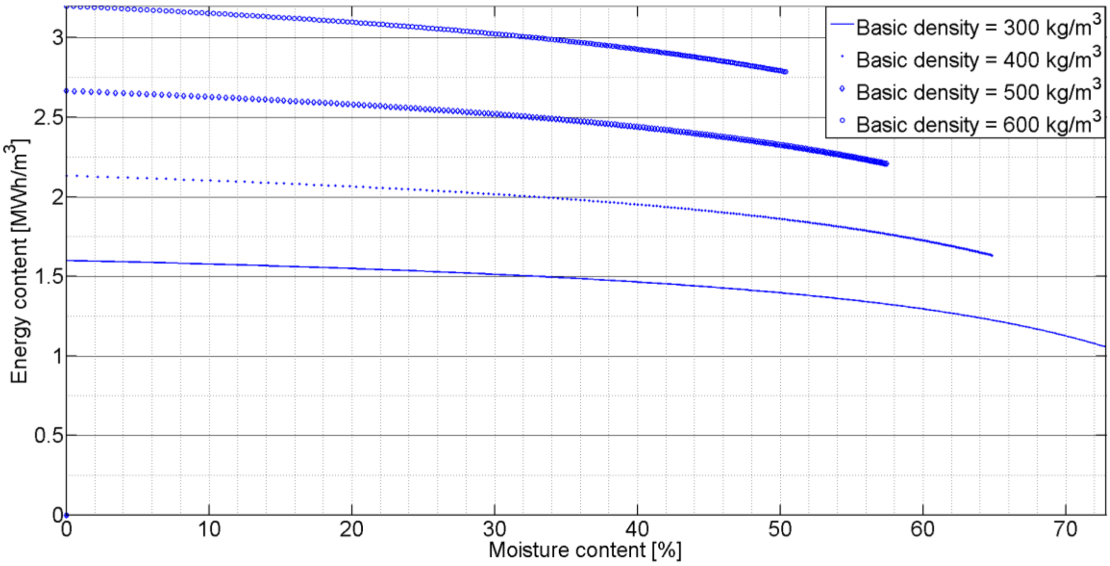


Figure 31. Energy content per one cubic metre of wood as the function of the moisture content and basic density.

CONCLUDING REMARKS

The objective was to estimate the moisture content by using the available information about wood deliveries, without the need of sampling. On the basis of results, the developed method performs relatively better at high moisture contents where the performance of the traditional method is the lowest. For example the highest volume estimation error set by law (20%) leads to a moisture estimation error within ±8% units when actual moisture content is 60%. The benefits of the suggested method are the capability to measure also frozen raw material; moisture estimation is available immediately for process control and reduces costs as sampling work and equipment is not needed.

3.3. VOLUME ESTIMATION FOR WOOD CHIP LOADS

Jukka Antikainen, Natural Resources Institute Finland, Luke

MAIN OUTCOME

Structured light (Kinect sensor) and photogrammetry 3D modelling approaches were studied for estimating the volume of wood chip truck payloads. Modelling methods were tested in a real environment with a moving wood chip truck. Automatic volume calculations for the point cloud analysis were implemented using Matlab, which can be used with both modelling approaches. Structured light measurement process was more error sensitive compared to photogrammetry. Wood chip particle size estimation was also studied using novel texture analysis methods and the results were promising. The measurement setup and the analysis part can be implemented into the real environment use.

MOTIVATION

The aim of this study was to develop and test new inexpensive measuring methods for volume estimation of wood chip loads inside a truck container. The volume is an important feature which should be determined as accurately as possible. If the volume can be measured accurately, the moisture content of the load can be estimated and the value of the load can be determined more reliably. There are several systems available which can measure and estimate the volume of the container optically but those systems are often very expensive and they require fixed installations and safety structures. Therefore, inexpensive optical systems such as structured light and photogrammetry approaches are studied.

MODELLING METHODS

The first modelling method was based on the structured light approach with the Microsoft Kinect sensor (Fig. 32) (Andersen et al. 2012). The sensor was published several years ago and it was originally developed for gaming purposes but nowadays its potential for machine vision application has been recognised. The sensor uses the speckle pattern and structured light approach to produce a depth map of the target. The depth map is calculated inside the sensor and it is capable of 30 frames per second. The scanning accuracy varies along the distance of the measured target. The actual 3D-model is computed using a Graphics Processing Unit (GPU). The model is formed from separate scans which are combined using the Iterative Closest Point (ICP) method. The accuracy of the model also depends on the speed of the calculation and the accuracy rises along with the scans. The sensor is relatively low cost compared to other commercial scanning products which make it even more interesting (Zhang 2012).

Figure 32. The Microsoft Kinect sensor for Windows.

The second studied approach was photogrammetry which is a well-known technique for generating 3D models from a large scene or single target using normal digital images. The main idea of 3D model generation is based on the geometrical properties of the target. The method requires two or more overlapping images from different positions. The target point is transformed into the 3D coordinates by analysing the point location and camera angles from separate images. Photogrammetry has been used for remote sensing applications such as forest inventory, open mines and for modelling buildings or even entire cities. In the forest industry it has been used for estimating the volume of biomass storages in large-scale applications such as in biomass terminals and end usage point storages (Schenk 2005; Balenovic et al. 2015).

EXPERIMENTS

Experiments were done at the Joutseno Pulp mill. The Kinect sensor was installed in a fixed place inside a hangar at the gates of the mill. Data for the photogrammetry modelling was collected at the same point using a Nikon D5100 digital camera. The truck was loaded with four different amounts of wood chips using the front loader (Fig. 33). 3D models (Fig. 34) with the Kinect sensor were generated during the movement of the truck and models with the photogrammetry approach were calculated afterwards from the selected images of the video stream. The filling rates for each load (Fig. 35) were determined from the generated models using the Matlab. The developed analysis algorithm contained automatic point cloud rotation, container border detection and the filling rate estimation using the 3D surface height map.

Figure 33. a) Wood chips were loaded with a front loader and b) the wood chips were measured at the hangar.

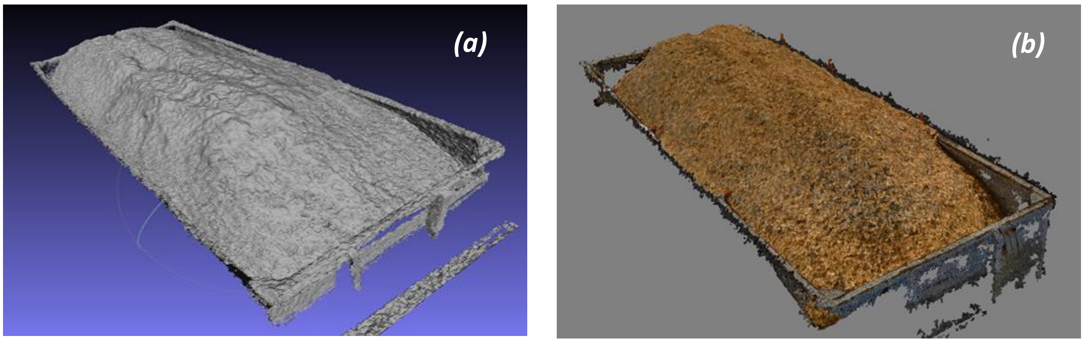
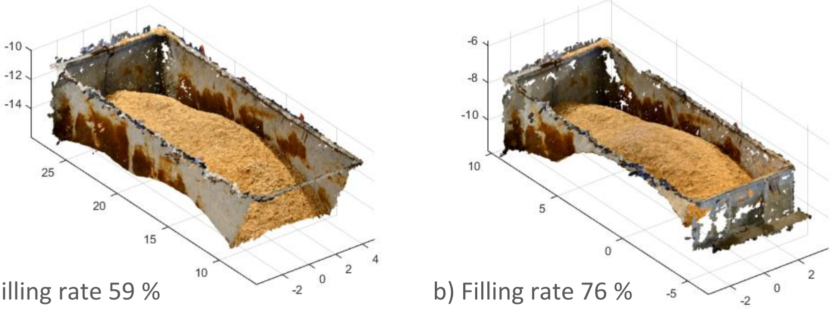
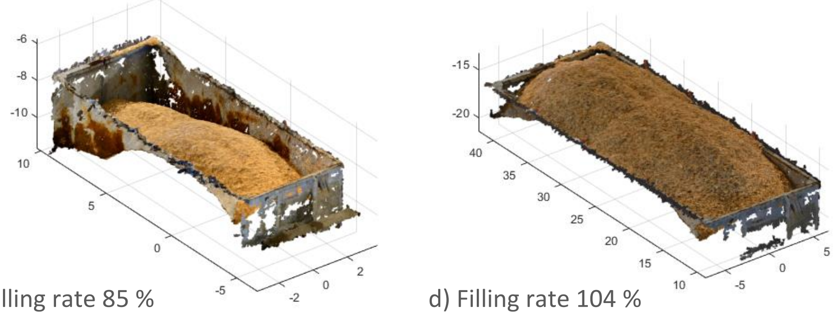


Figure 34. One experimental load, a) 3D model generated with Kinect sensor and b) is 3D model generated using photogrammetry.



a) Filling rate 59 %

b) Filling rate 76 %



c) Filling rate 85 %

d) Filling rate 104 %

Figure 35. Different filling rates for the experimental payloads.

During the experiments it was seen that the Kinect-based measurement is error sensitive in the sense of real-time modelling. Because the main idea for the structured light approach is based on feature tracking and detection and if the inspected target surface has too few details (e.g. peat) the tracking may fail and the measurement will be corrupted. In addition, if the imaging software and the used machine are too slow this may affect the result accuracy, or in the worst case the measurement data will be corrupted. This problem might be solved by storing the measured data and calculating the results after the whole measurement is completed.

TEXTURE ANALYSIS

Various texture analysis methods were studied for estimating quality factors such as particle size, unwanted items and homogeneity of the biomass. The most important studied feature was the particle size, which is a relatively hard task to implement. It required a combination of several different methods including filtering, edge detection, segmentation and classification. Fig. 36 shows the main steps of the process. At first the image was filtered using median and Gaussian filters (Fig. 36, a). After that the image was thresholded using Otsu's method and the mask (Fig. 36, b) was generated. The generated mask was applied to the filtered image and the separate particles were labelled (Fig. 36, c). Each particle was evaluated separately and the sizes were determined (Fig. 36, d).

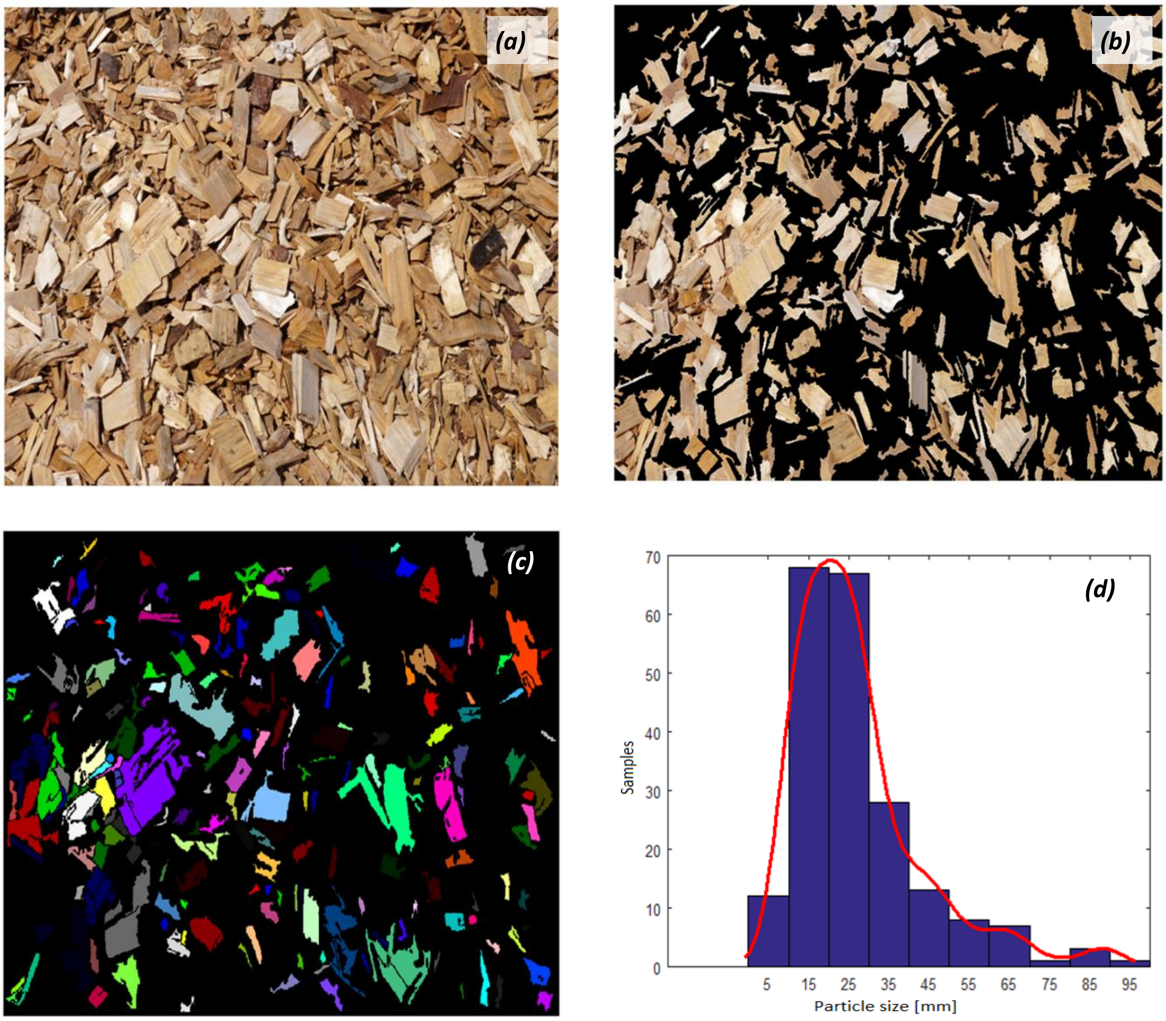


Figure 36. An example particle size estimation, a) an original prefiltered image, b) masked image, c) labelled image after masking and various morphological operators and d) the measured particle size distribution (Figures by Aki Nissinen, UEF).

CONCLUDING REMARKS

Two different approaches were studied and evaluated. The structured light approach with the Kinect sensor works relatively well but there are some drawbacks in the technology such as the effect of direct sunlight which leads to overexposure of the target and the reconstruction cannot be done. Also the real-time generation of the 3D model is not memory efficient and the computational complexity rises dramatically with high-resolution models. However, some of these problems can be solved using novel data management methods and new high-efficient graphics cards with an increasing amount of GPU cores.

The second approach was based on photogrammetry. The approach seems to be very promising for the studied purposes. Images can be taken from a moving vehicle or the images can be taken from different locations around the truck, i.e. over the bridge scale. The method is fast enough for use in the real environment. Photogrammetry offers an accurate and efficient method for volume estimation and it provides good texture quality and resolution for further image analysis tasks such as particle size estimation.

3.4. WIRELESS MOISTURE AND TEMPERATURE MEASUREMENT SOLUTIONS IN WOOD CHIP STORAGE PILES

Jouni Tornberg, Kajaani University of Applied Sciences - Measurepolis & Timo Melkas, Metsäteho Oy

MAIN OUTCOME

Wireless temperature and moisture measurement in wood chip piles offer potential to monitor pile characteristics and quality. Temperature sensors and measurements work well in this application and there are several different providers on the market allowing the detection of temperature changes. Humidity sensors measure air humidity close to the sensor element but not actual moisture content of the material. Present humidity sensors are not presently suitable for wood chip pile applications with wet material.

MOTIVATION

The aim of the study was to determine the utilisation possibilities and functionality of humidity and temperature sensors in wireless monitoring of the quality of wood chip piles. Storage of raw material is an important part of energy wood procurement. Storages are used for balancing the supply and demand; storages are also used to decrease the moisture content of the wood material. It is important to know the temperature and moisture of the material inside the pile in order to better monitor the quality of wood chips and to prevent possible self-ignition. The study was mainly carried out as a state-of-the-art study by interviewing experts and sensor manufacturers and developers. Sensors with the biggest potential were selected for testing in field conditions. Field tests were carried out in co-operation between Karelia University of Applied Sciences, the University of Eastern Finland and VTT (Tornberg & Melkas 2015).

STATE OF ART

Moisture determination using humidity sensors

Moisture is the most important quality factor of wood chips. It has a direct effect on the energy content. Sampling is frequently used to determine moisture content. The representativeness of the measurement volume or sample is thus very important. Sensor-based moisture measurement methods utilise commonly resistive or capacitive sensors. Measurement volume can be quite large, especially with capacitive measuring heads but they are not easy to install inside the pile. Chip sensors are easy to handle but measurement volume is minimal and the measurement principle is based on water adsorption on porous ceramic material acting as capacitive dielectrics. Ceramic material is produced and processed utilising thin- or thick-film technology on a single chip of the size of some millimetres. A typical sensor chip of this type is the Sensirion SHT25 Sensor measuring both moisture and temperature. The Sensirion humidity sensor is based on the measurement of relative humidity utilising capacitive sensor technology.

Temperature sensors

Single-chip temperature sensors use a silicon diode (temperature-dependent forward voltage, Band Cap Sensor). The silicon bandgap temperature sensor is an extremely common form of temperature sensor (thermometer) used in electronic equipment. Its main advantage is that it can be integrated into a silicon chip at very low cost. The principle of the sensor is to utilise silicon diode forward voltage temperature dependence. The calibrated humidity and temperature data can be sent directly from the chip as a digital message to the integrated measurement system. The Sensirion SHT25 temperature sensor is a typical silicon "Band cap" semiconductor temperature sensor.

Data transfer technologies

Wireless communication technologies from the sensor to the base station or reader

Radio wave technology and electromagnetic (inductive) data transfer technologies have been used in many applications to move data from sensor to base station.

Infrared (IR) – technology requires an uninterrupted signal path, used widely in, e.g. remote controllers in home electronics. The technology is not suitable for transferring data from the inside of a chip pile.

Radio wave technology is widely used (ISM frequencies) in several applications including mobile telecommunication, sensor networks, environmental monitoring, etc. Most used frequencies are 2.4 GHz band, 868 MHz and 433 MHz (e.g. car industry). Signal transmittance is tens of centimetres in materials to hundreds of metres in open air. Industrial, Scientific and Medical (ISM) band frequencies are used in data transmission. The use of these worldwide radio frequency bands doesn’t require any authorisation or license and these frequencies were originally intended for industrial, scientific and medical use. The most commonly used frequency ranges, UHF ranges, are the 2.4 GHz band, 868 MHz band (Europe) and 434 MHz band.

Electromagnetic (Inductive) data transfer. The measuring distance is several metres in materials, e.g. in a wood chip pile application. Data transfer technology is an inductive (magnetic field) method. Information can be transferred also through very wet materials, even in water. Reading distance in the material depends on the size of the antenna. For example, if the antenna size is five metres, the reading distance is approximately five metres. Active technology, the sensor unit, requires a battery (Lithium). Existing applications include seawater, construction (concrete), stone materials (ore piles) and soil.

The data transfer from the measuring system to cloud services

Wireless GSM data transfer / communication systems (Fig. 37) are very sophisticated nowadays. Thus, this part of system is very easy to implement.

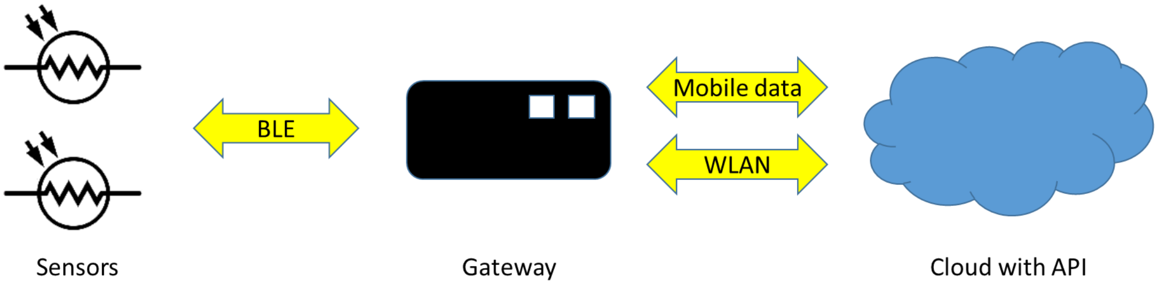


Figure 37. Wireless communication system.

Radio Frequency Identification (RFID) sensors (Smartrac)

Passive RFID technology operates at a frequency of 840 MHz. A sensor element is an antenna that senses the surrounding material. Humidity and electrical properties of the material are the most significant factors in the functioning of the sensor. The sensor element is passive; it takes functioning energy from the reader device through the material. Lightweight and recyclable, it can stay in the process within limits. The sensor strip has a very thin aluminium antenna and an integrated tiny silicon-based microchip; it is a low-cost sensor type. The reading device can sense a large number (tens to hundreds) of sensors. Sensor location data can be determined in some extent. Reading distance from inside the chip pile has not been tested yet.

Potential sensor systems on the market

1) **Seemoto – MeshWorks Wireless Oy (http://www.seemoto.com/fi)**
2) **Trelab Oy (http://www.trelab.fi/)**
3) **Sensire Oy (http://sensire.fi/)**
4) **Haytech Oy (http://www.haytech.farm/)**
5) **SMARTrac Technology Finland Oy (https://www.smartrac-group.com/)**
6) **Inductive data transfer (Electromagnetic induction) - VTT**

Haytech Oy (VTT spin-off company)

The Haytech sensor is a chip-based sensor developed originally by VTT for hay pile application. It uses 434 MHz transfer technology, the reading distance in open space is hundreds of metres; inside the chip pile 2–4 metres. The sensor element is situated on top of a plastic rod measuring about a half metre. The Sensirion sensor measures temperature and humidity and works with a lithium battery for months. It is possible to use the data logger and record observations to the base station and send them every hour or so to the cloud. It offers a real-time monitoring of temperature and humidity. Humidity is measured close to the sensor element, and is not representative of the actual moisture of the material. The Haytech sensor was selected for the field tests in the BEST project.

CONCLUDING REMARKS

Temperature sensors and measurement systems work well and there are several different applications on the market allowing the detection of the rise of temperature and overheating of chip piles. Humidity sensors measure air humidity close to the sensor element but not actual moisture content of the material volume. Present sensors are not currently suitable for the wood chip pile application with wet material (wood chips with moisture content approx. > 30 %). Moisture estimation is quite successful if the material is rather dry (e.g. hay or straw). The biggest challenge in wireless data transmission is transmission from the sensor to the base station outside the pile. The signal has to pass through the material for several metres. Radio wave technologies with IS band 434 MHz offer the best transmittance and have potential as a technology for real sensor array measurement systems in this application**.**

3.5. CONCEPT FOR BIOENERGY RAW MATERIAL QUANTITY AND QUALITY MONITORING AND MANAGEMENT

Henna Karlsson, Prometec Solutions Ltd.

MAIN OUTCOME

An operating model and concept for the efficient quality control of woody biomass was developed and approved by both biomass suppliers and end-users. In the concept the quality of all incoming and outgoing raw material is monitored and truck-specific quality information is used for supply chain management and control including terminal processes.

MOTIVATION

Reliable biomass moisture and energy content determination is a global problem of energy plants using biomass. Based on field experience of Prometec, error in quality control causes approximately 2% unit error in moisture results, which causes approximately 5% unit error in biomass energy content calculation. The major problem in quality control of the solid biofuels is sampling. According to Technical Research Centre of Finland (VTT) studies, 80% of the error is due to sampling and the remaining 20% is due to incorrect handling of samples and their measurement (Järvinen 1998 & 2012). In addition, biomass moisture determination is very slow due to the standard oven-dry method which gives results after 24 hours. The results cannot be used in biomass supply chain management or to control the terminal processes.

THE STUDY OF THE QUALITY CONTROL CONCEPT

At the beginning of the study the terminal type was selected. Type of selected terminal is a solid biomass reception and upgrading terminal, where the terminal receives small-diameter roundwood and wood chips and those materials are stored and processed in the terminal. This kind of terminal is planned to start in Kajaani Renforssin Ranta in 2017. Processing could include chipping, grinding, natural drying on the storage piles, or warm air drying to upgrade wood chips for industrial processes. Finally, the stored or processed biomass is transported from the terminal to the bigger power plant, smaller district heating plants, as well as biorefineries (Fig. 38).

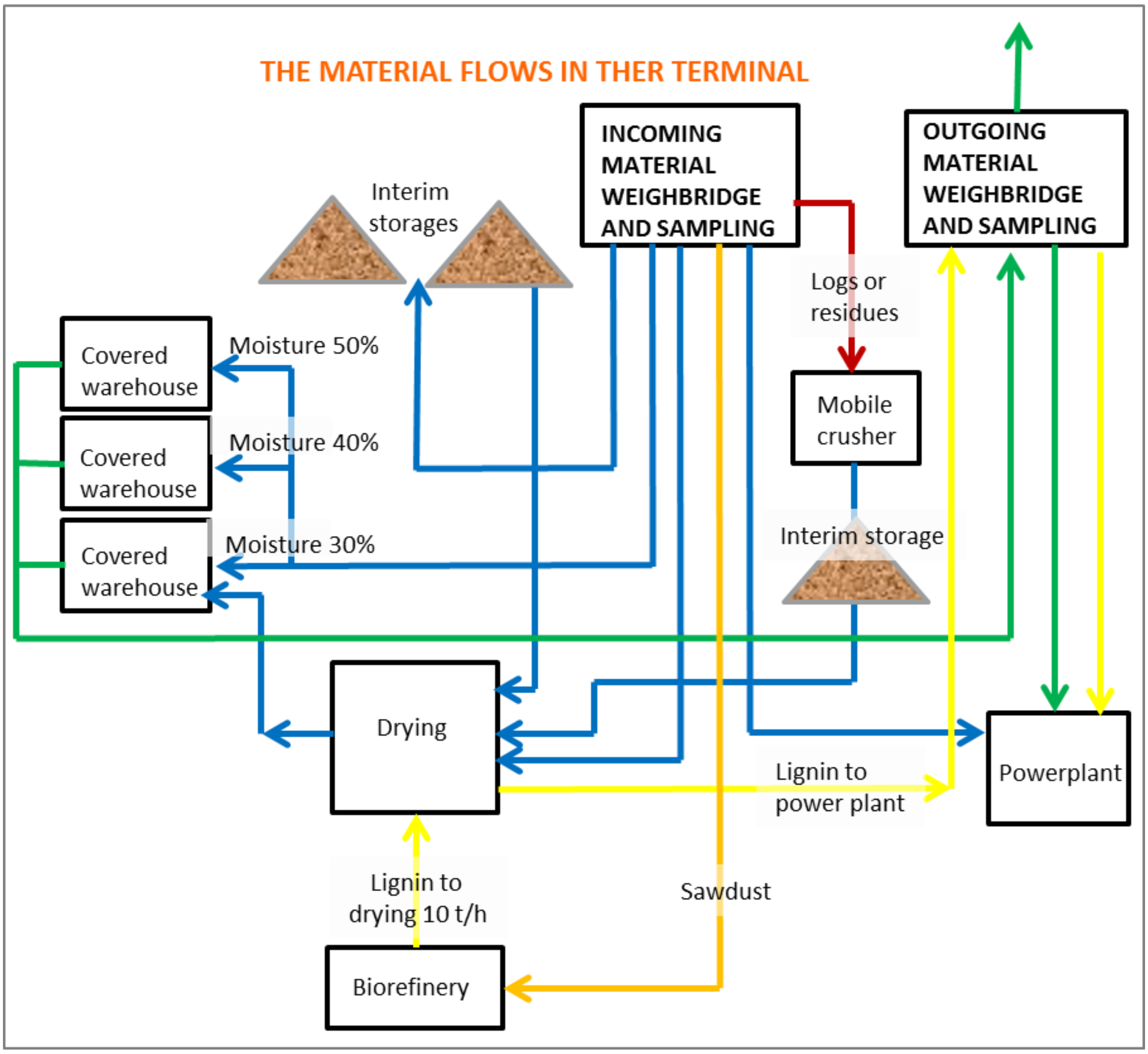


Figure 38. The material flows and material processing in the selected terminal type.

Next the definition of the measurements needed in the biomass quality control and the measuring points in the terminal concept were made. There are different needs for measurements in the terminal: When the incoming or outgoing biomass owner is changed, very accurate moisture and energy content information are needed for the payment basis. But if the information is used for logistical purposes or terminal process control, lower accuracy data is sufficient.

EXPERIMENTS

Two different types of fast moisture measurement technology were tested in this study. The first one was based on microwave technology and the other one was based on NRM technology. Both of those technologies were applicable for fast analysis of wood chip moisture content and they are accurate enough for truck-specific measurements. The description, some test results and the applicability of these devices is found in chapter 3.2. A plan was made for how those measurements can be handled in practice and how all the measurement data is utilised in this quality control concept.

Tests and studies were also conducted if the material bulk density could be used to predict biomass moisture content. The data was collected from three power plants where all biomass trucks were weighed and the volume estimation of wood chip load inside the truck was made by truck drivers. The bulk density for each truck load was calculated based on the load weight and volume.

$$BD_{ar} = (m_2 - m_1)/V, \qquad (10)$$

where

BD_{ar} = bulk density of arriving truck load
m_2 = arriving truck load weight
m_1 = empty truck weight
V = volume of material in truck load

In comparison, samples were also taken manually from each truck according to standard SFS-EN 14788 and moisture was analysed by using fast moisture measurement devices. One example of correlation between bulk density and moisture for logging residue is shown in Fig. 39.

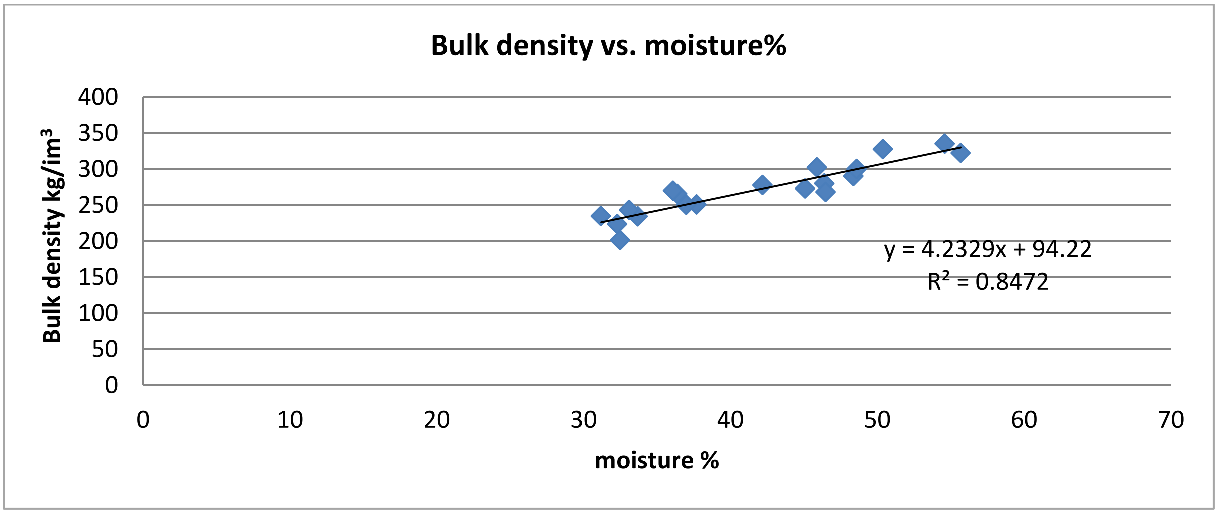


Figure 39. The correlation between bulk density and moisture for logging residue.

Based on these tests correlation between bulk density and moisture is linear. Correlation is material-specific because basic density varies between tree species and tree sections and therefore it has to be defined for each material type. When the weight and volume of trucks is known, the moisture can be calculated from the bulk density. For example, the model shown in Fig. 39 was used to predict incoming logging residue truck loads' moisture contents by calculating the moisture from the bulk density data. The samples were taken from those same trucks and moisture contents were analysed from the samples by the fast measurement technology. In figures 40 and 41 the correlation between analysed data and predicted data is shown.

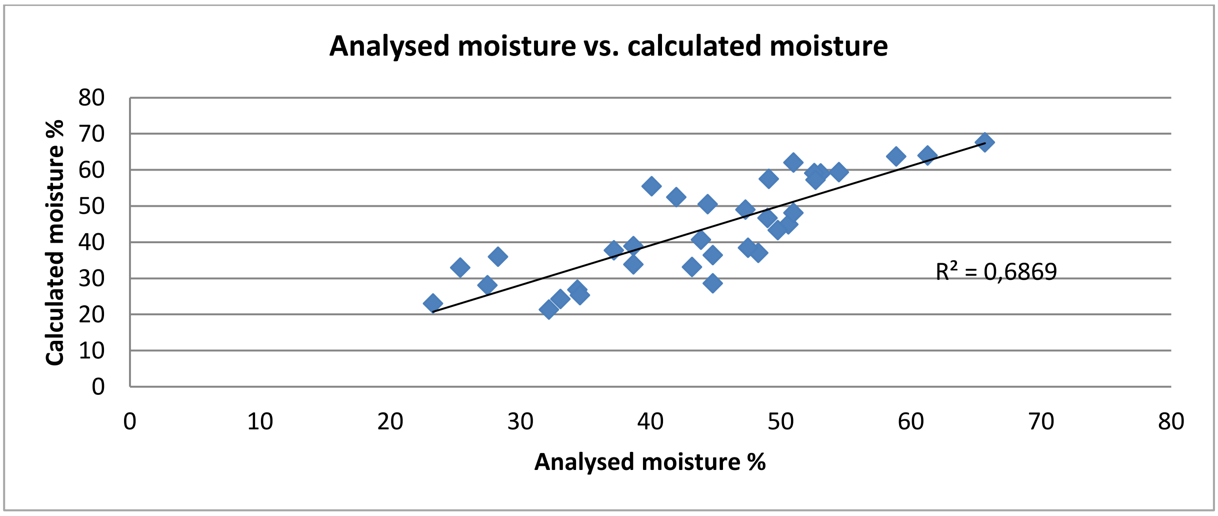


Figure 40. The correlation between analysed data and predicted data.

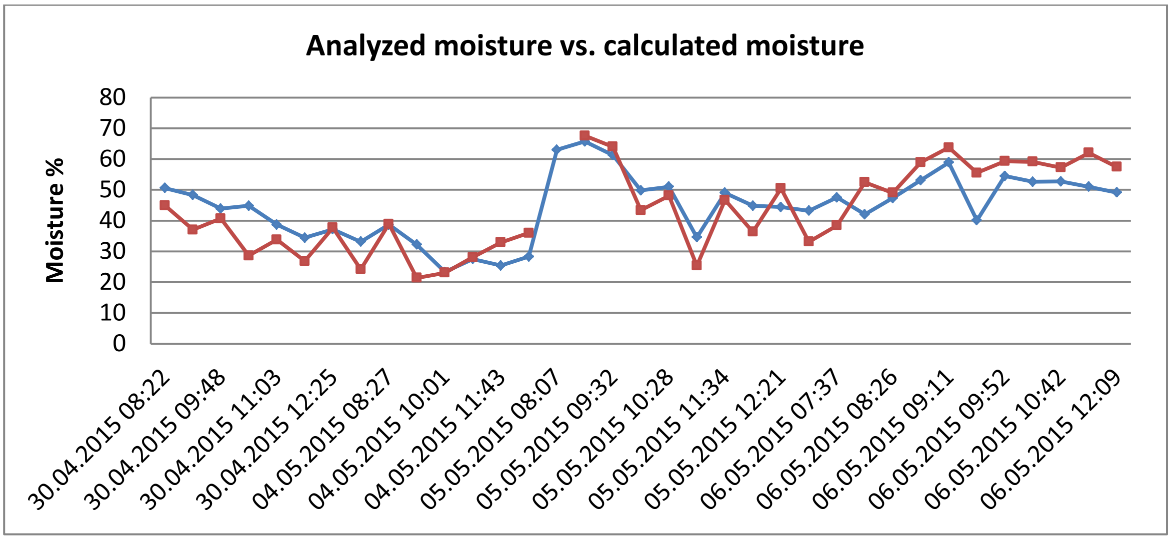
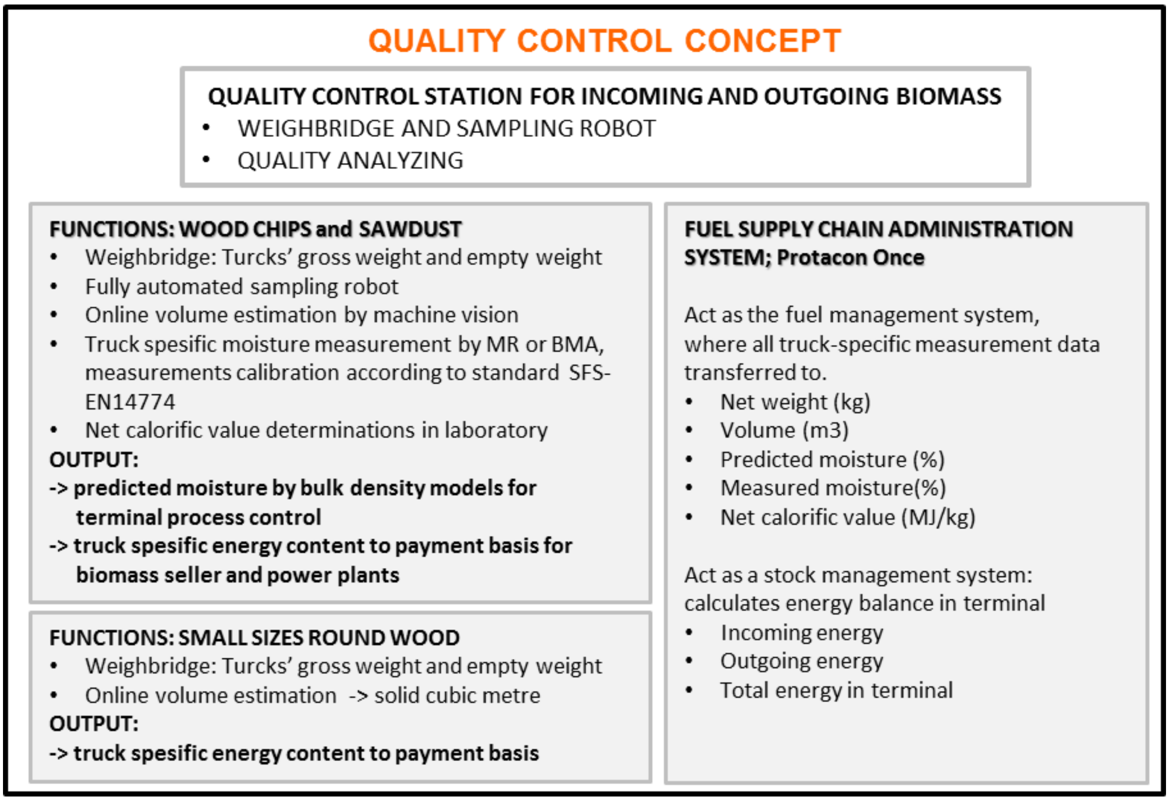


Figure 41. Correlation between analysed moisture and calculated moisture for logging residue. Blue dots are analysed moisture results and red dots are predicted moisture results. The analysed moisture is on average 44.1% and calculated moisture is on average 44.4%.

Results showed that this mathematical model based on the linear correlation of bulk density and moisture can be used to predict moisture of incoming truck loads. This information could be used for logistic management in the terminal but it is not yet accurate enough for use in assessing payment. A more accurate mathematical model could be obtained by using online volume estimations and automated sampling.

CONCEPT FOR QUALITY CONTROL IN BIOMASS TERMINAL PROCESS



QUALITY CONTROL CONCEPT

QUALITY CONTROL STATION FOR INCOMING AND OUTGOING BIOMASS
- WEIGHBRIDGE AND SAMPLING ROBOT
- QUALITY ANALYZING

FUNCTIONS: WOOD CHIPS and SAWDUST
- Weighbridge: Turcks' gross weight and empty weight
- Fully automated sampling robot
- Online volume estimation by machine vision
- Truck spesific moisture measurement by MR or BMA, measurements calibration according to standard SFS-EN14774
- Net calorific value determinations in laboratory

OUTPUT:
-> predicted moisture by bulk density models for terminal process control
-> truck spesific energy content to payment basis for biomass seller and power plants

FUNCTIONS: SMALL SIZES ROUND WOOD
- Weighbridge: Turcks' gross weight and empty weight
- Online volume estimation -> solid cubic metre

OUTPUT:
-> truck spesific energy content to payment basis

FUEL SUPPLY CHAIN ADMINISTRATION SYSTEM; Protacon Once

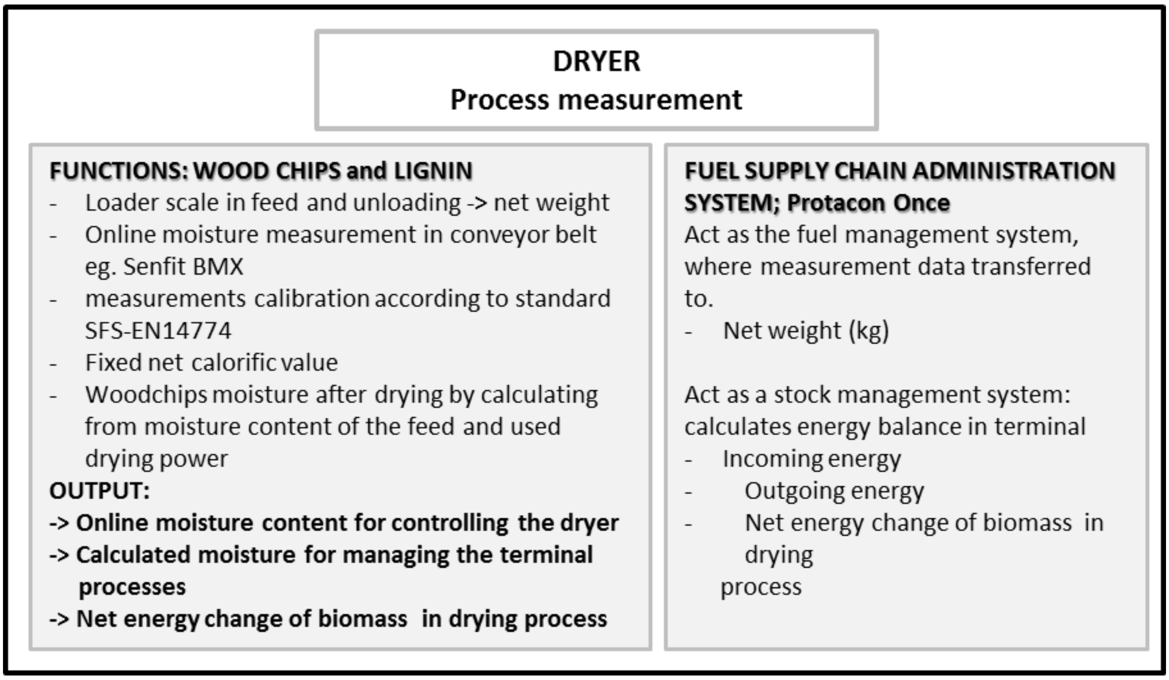
Act as the fuel management system, where all truck-specific measurement data transferred to.
- Net weight (kg)
- Volume (m3)
- Predicted moisture (%)
- Measured moisture(%)
- Net calorific value (MJ/kg)

Act as a stock management system: calculates energy balance in terminal
- Incoming energy
- Outgoing energy
- Total energy in terminal

Figure 42. Quality control concept for all incoming and outgoing biomass of Bioterminals.

In Fig. 42 the quality control concept developed in this project is shown. With this concept quality of all the selected terminal incoming and outgoing chipped biomass is analysed. All trucks are weighed and samples are taken straight from the truck by Prometec's fully automated sampling robot. At the same time the load's volume is detected by a machine vision system. Predicted moisture of each truck load is obtained by using bulk density models. Predicted moisture can be used for terminal logistic and process control. Truck-specific energy content for payment basis is obtained by using fast moisture measurement technology and then calculating the energy content using the net caloric value analysed once a month for each biomass type.

All incoming small-sized roundwood trucks are weighed and the solid cubic metres calculated using machine vision volume measurement. Then the energy content is determined by means of conversion tables. All the information is used for logistic purposes and for monitoring the energy balance of the terminal.



DRYER
Process measurement

FUNCTIONS: WOOD CHIPS and LIGNIN
- Loader scale in feed and unloading -> net weight
- Online moisture measurement in conveyor belt eg. Senfit BMX
- measurements calibration according to standard SFS-EN14774
- Fixed net calorific value
- Woodchips moisture after drying by calculating from moisture content of the feed and used drying power

OUTPUT:
-> Online moisture content for controlling the dryer
-> Calculated moisture for managing the terminal processes
-> Net energy change of biomass in drying process

FUEL SUPPLY CHAIN ADMINISTRATION SYSTEM; Protacon Once
Act as the fuel management system, where measurement data transferred to.
- Net weight (kg)

Act as a stock management system: calculates energy balance in terminal
- Incoming energy
- Outgoing energy
- Net energy change of biomass in drying process

Figure 43. Quality control concept for dryers control.

In Fig. 43 the quality control concept for dryers control is shown. A weight of material feed in the dryer is determined by loader scale and moisture is measured by online moisture technology (e.g. Senfit BMx). The material weight after drying is determined by loader scale and the moisture is calculated from moisture content of the feed and used drying power. All information is used for managing the terminal processes and controlling the storages. The net energy change in drying process is used for calculating the terminal energy balance.

4. QUALITY AND VALUE – GOOD AND BAD STORAGE

4.1. COMBINING MEASUREMENTS AND OTHER QUANTITY AND QUALITY DATA AND STANDARDIZATION

Timo Melkas, Metsäteho Oy, Timo Saarentaus, Metsä Group & Jouni Tornberg, Kajaani University of Applied Sciences – Measurepolis

MAIN OUTCOME

Flow-charts were created for logging residues, small-sized stem wood and stumps (figures 44-47). They describe the measurement needs and the information flow in the energy wood supply chain and how the available information should be combined. Moisture content is one of the most important issues considering the quality of the raw material – especially when trying to optimise the end-use and the time of delivery. Also for this reason principles of the feedback system are described. A more specific description of an ERP-system based on these flow charts is done by Räsänen et al. in co-operation WP2 (chapter 5).

MOTIVATION

The objective of this study was to describe procedures to combine quantity and quality data measured during the supply chain to define the heat value and energy content of energy wood at different stages of the supply chain.

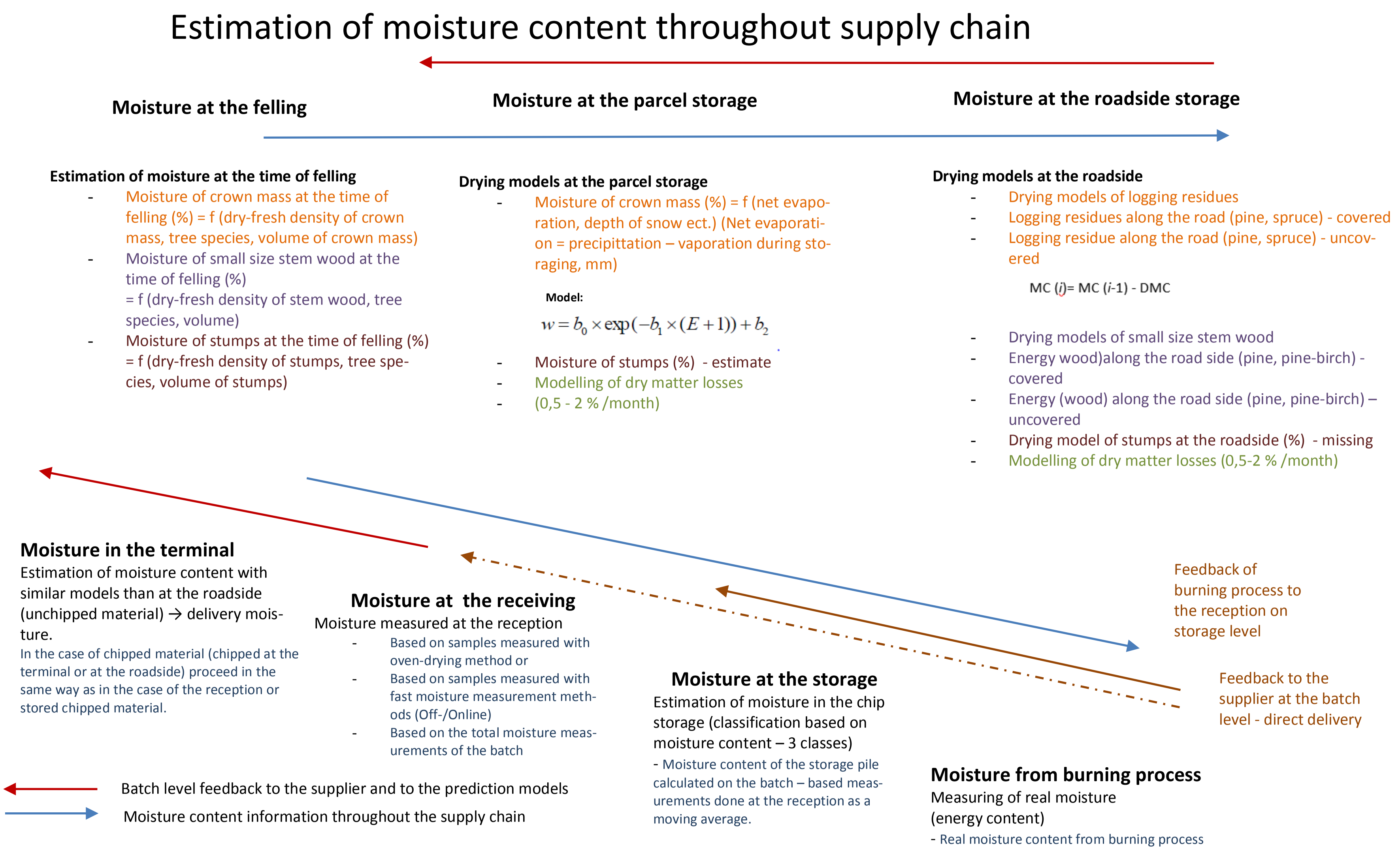
RESULTS AND CONCLUSIONS

Flow-charts were created for logging residues, small size stem wood and stumps (Fig. 44-47). Flow-charts describe at the common level the kind of measuring information and during which stage it is needed in the supply chain to calculate the heat value and energy content throughout the supply chain and how this information can be combined and stored. Moisture content is estimated on a daily basis for each storage from the parcel storage to roadside and always to the terminals based on the drying models. Measurements are done as part of the logistic supply chain by weighing the material during handling. At the biomass terminals and plant reception moisture content and foreign matter are measured based on samples or total measurement of the batch.

When considering the quality of the raw material, the batch-based feedback system is in a key role. Real-time feedback to the supplier and the principles, e.g. how the feedback information of the real energy content (moisture) is used, are very important from the end-user's and the entrepreneur's point of view. The feedback information of moisture content and foreign matter is needed to optimise and improve the quality of the raw material. In the future the feedback information can be also used to calibrate the self-learning drying models used at the logistic supply chain.

Measurement and feedback systems are site-specific and highly dependent on plant requirements and volumes. The most cost efficient and reliable measurement solutions are presented in this report. During the final months of the project different types of drying models will be evaluated by Luke and the best model will be selected for use in practice. The objective is to adopt new drying models for logging residues that take into consideration weather conditions and to implement it before the next harvesting season 2017.

In this study, flow-charts were created for logging residues (Fig. 45), small-size stem wood (Fig. 46) and stumps (Fig. 47), but in principle the same estimation and measuring methods and concepts can be applied also to other materials. A more specific description of the ERP-system has been done by Räsänen et al. (2016) in co-operation WP2.



Estimation of moisture content throughout supply chain

Moisture at the felling

Moisture at the parcel storage

Moisture at the roadside storage

Estimation of moisture at the time of felling

- Moisture of crown mass at the time of felling (%) = f (dry-fresh density of crown mass, tree species, volume of crown mass)
- Moisture of small size stem wood at the time of felling (%)
  = f (dry-fresh density of stem wood, tree species, volume)
- Moisture of stumps at the time of felling (%)
  = f (dry-fresh density of stumps, tree species, volume of stumps)

Drying models at the parcel storage

- Moisture of crown mass (%) = f (net evaporation, depth of snow ect.) (Net evaporation = precipittation – vaporation during storaging, mm)

Model:

$$w = b_0 \times \exp(-b_1 \times (E+1)) + b_2$$

- Moisture of stumps (%) - estimate
- Modelling of dry matter losses
- (0,5 - 2 % /month)

Drying models at the roadside

- Drying models of logging residues
- Logging residues along the road (pine, spruce) - covered
- Logging residue along the road (pine, spruce) - uncovered

MC (*i*)= MC (*i*-1) - DMC

- Drying models of small size stem wood
- Energy wood)along the road side (pine, pine-birch) - covered
- Energy (wood) along the road side (pine, pine-birch) – uncovered
- Drying model of stumps at the roadside (%) - missing
- Modelling of dry matter losses (0,5-2 % /month)

Moisture in the terminal

Estimation of moisture content with similar models than at the roadside (unchipped material) → delivery moisture.

In the case of chipped material (chipped at the terminal or at the roadside) proceed in the same way as in the case of the reception or stored chipped material.

Moisture at the receiving

Moisture measured at the reception

- Based on samples measured with oven-drying method or
- Based on samples measured with fast moisture measurement methods (Off-/Online)
- Based on the total moisture measurements of the batch

Moisture at the storage

Estimation of moisture in the chip storage (classification based on moisture content – 3 classes)

- Moisture content of the storage pile calculated on the batch – based measurements done at the reception as a moving average.

Moisture from burning process

Measuring of real moisture (energy content)

- Real moisture content from burning process

Feedback of burning process to the reception on storage level

Feedback to the supplier at the batch level - direct delivery

Batch level feedback to the supplier and to the prediction models

Moisture content information throughout the supply chain

Figure 44. Estimation of moisture content throughout supply chain.

Logging residues

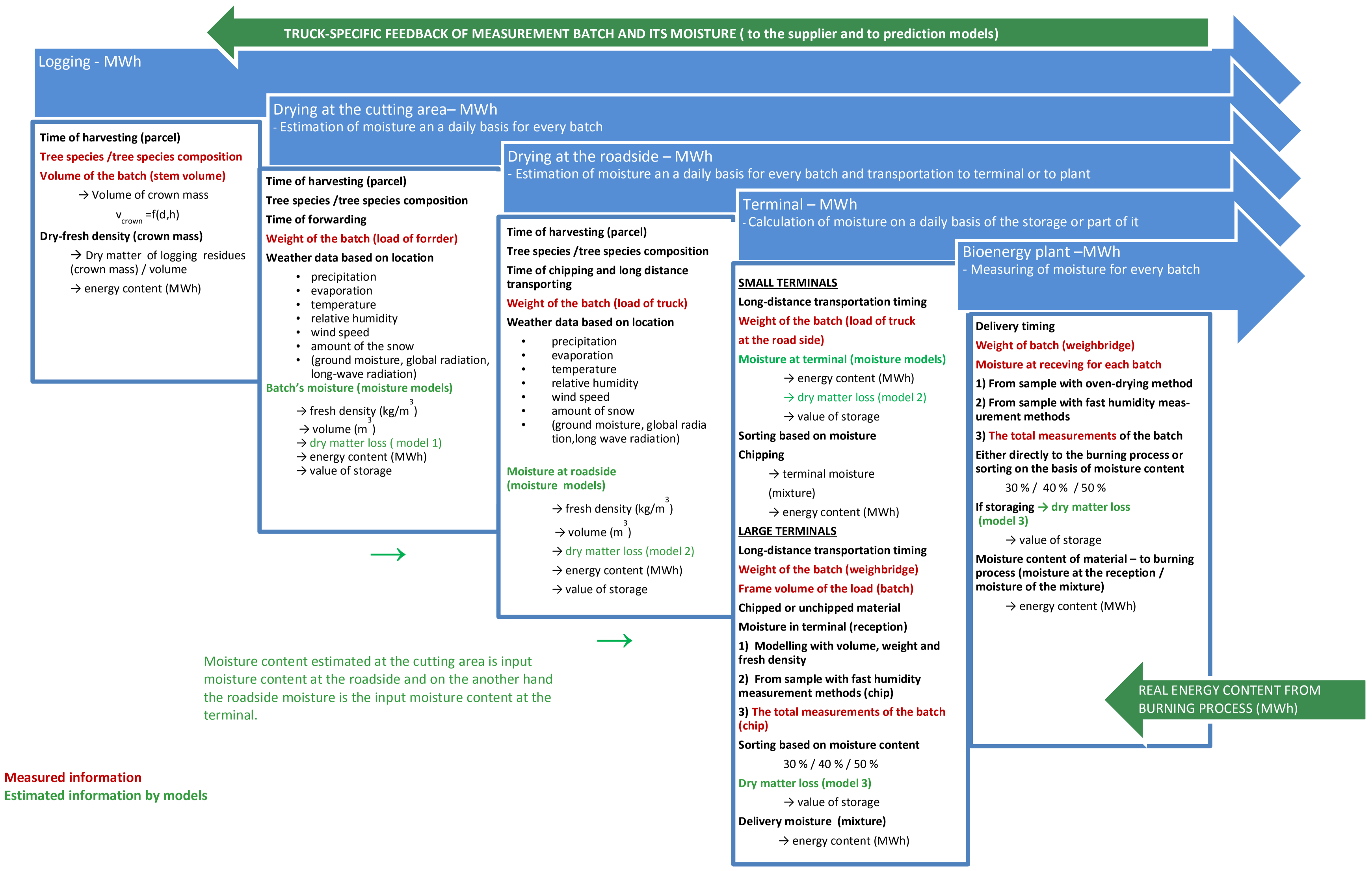


Figure 45. Flow -chart of logging residues. Flow-charts describe at the common level the what kind of measuring information and which stage during the supply chain it is needed to calculate the heat value and energy content throughout the supply chain.

Small size stem wood

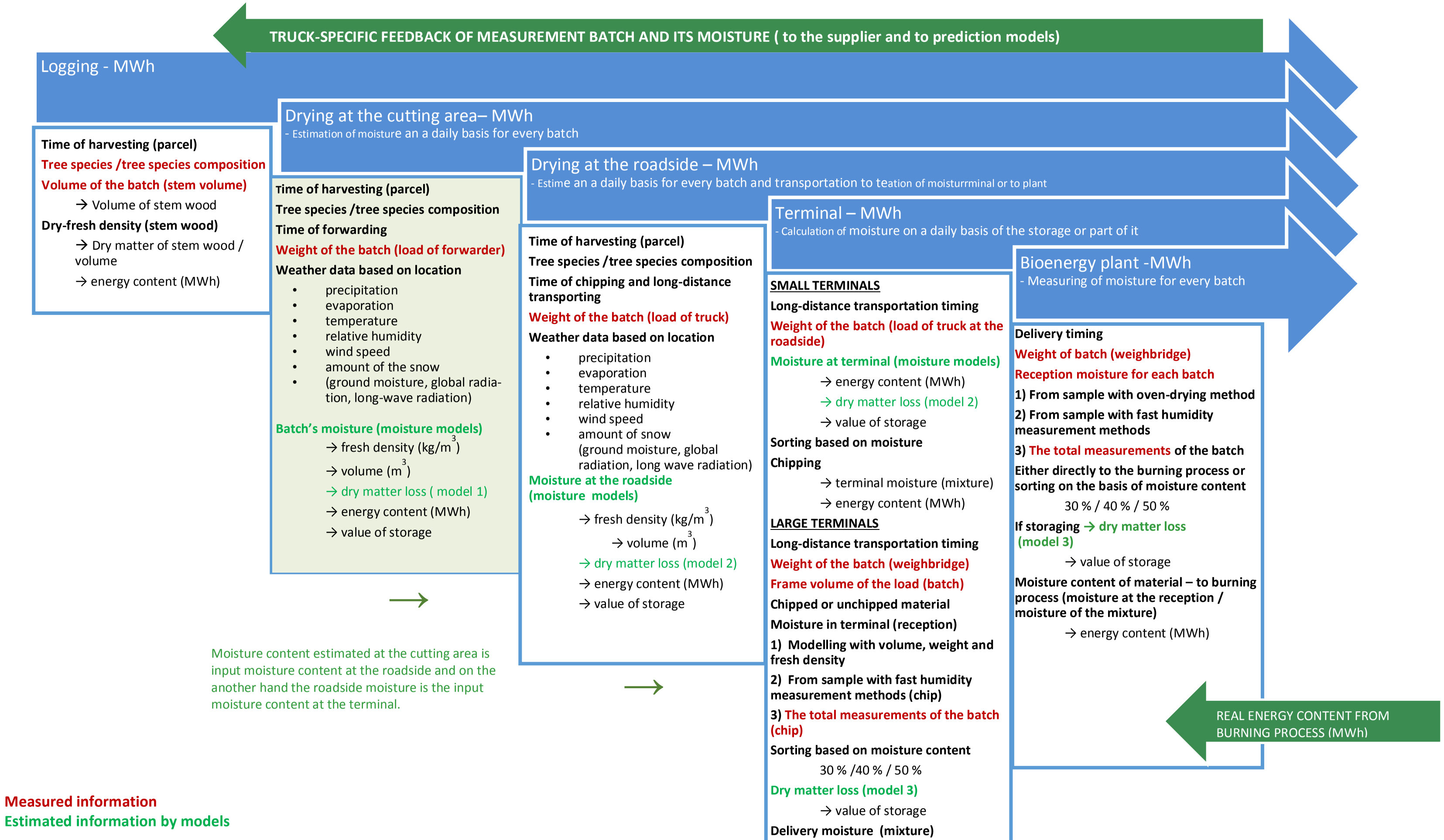


Figure 46. Flow-chart of small size stem wood.

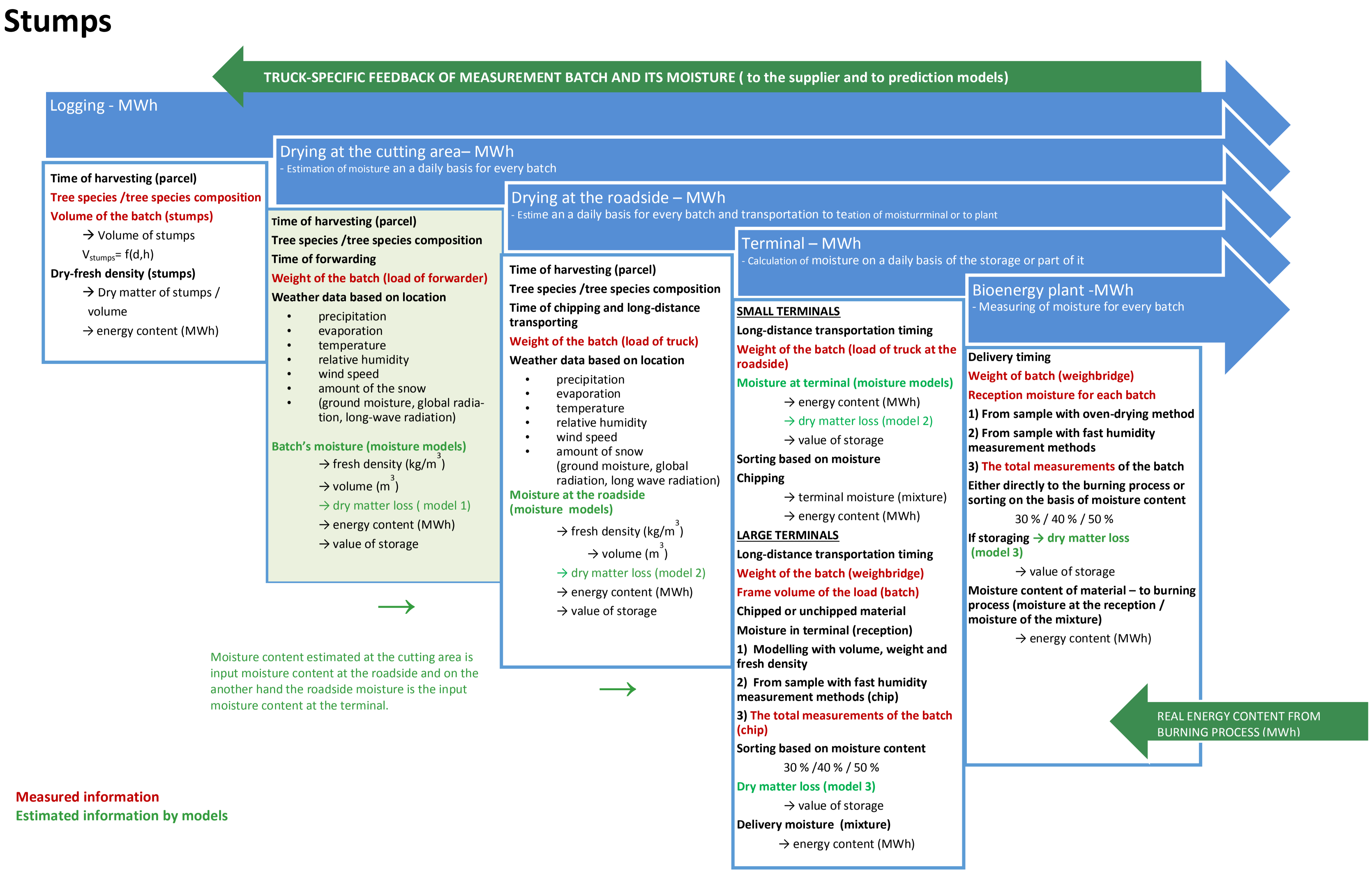


Figure 47. Flow-chart of stumps.

4.2. MOISTURE MODELS

Johanna Routa and Lauri Sikanen, Natural Resources Institute Finland, Luke, Marja Kolström, University of Eastern Finland & Jyrki Raitila, VTT Technical Research Centre of Finland

MAIN OUTCOME

The natural changes in moisture content of energy wood stockpiles can now be forecasted by models, which are using weather statistics, material characteristics, time and location as an input. Models help energy wood supply companies to manage their material flow and improve the efficiency of their deliveries. Models are done for logging residues and for delimbed energy wood. Some companies have implemented models already and experiences are very positive.

MOTIVATION

Storages and storing are important and necessary parts of energy wood procurement. Storages are used for balancing the supply and the demand, but most of all; storages are used to decrease the moisture content of the wood material. Drying is strongly weather dependent, but also timing and material characteristics play an important role. Traditionally, storing periods are long and the decision of chipping and transportation is based on average estimates and everyday experience. This too often leads to the fluctuation of moisture content and poor quality of wood fuels.

THE IDEA OF THE MODELS

Moisture models were developed to help estimate changes in the average moisture content of uncomminuted energy wood piles. They are based on daily cumulative evaporation and precipitation. Moisture models can be connected with the weather grid of the national meteorological institute (FMI) which enables the working of the model in every location based on local weather data (Fig. 48). Models can work automatically as a part of the enterprise resource planning applications.

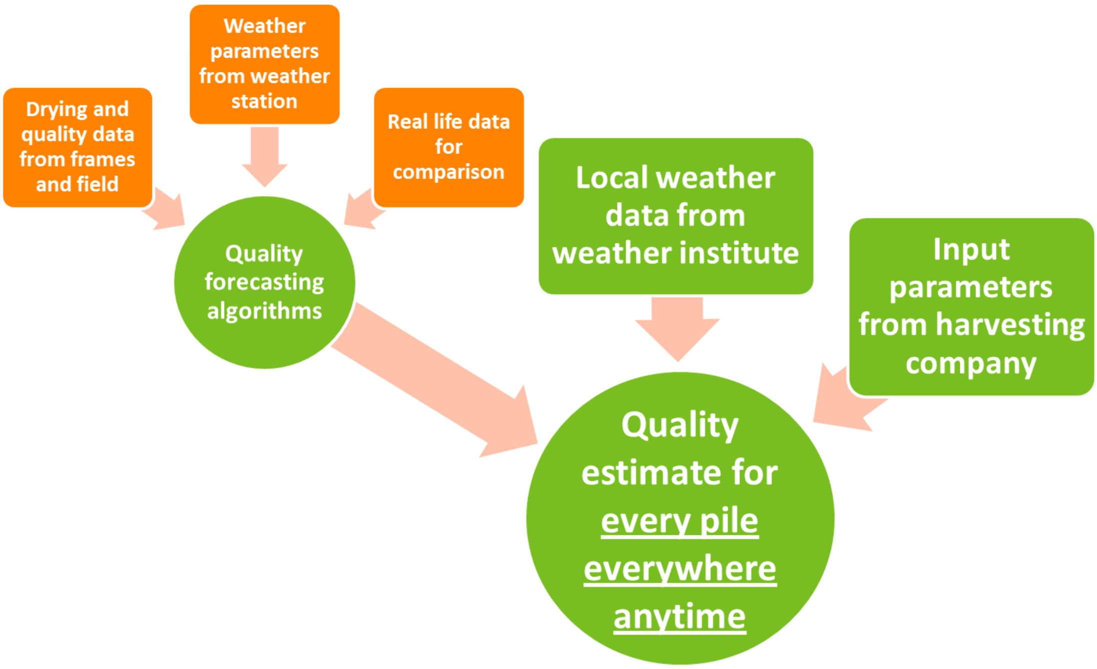


Figure 48. Moisture models enable quality estimates for the piles of the harvesting company to support scheduling of piles for chipping, transportation and combustion.

MODELS

The models presented below are public and ready to be used (Routa et al. 2015 a; Routa et al. 2016). Nevertheless, companies need to adapt models into their systems to ensure effective use. Exceptional conditions and unusual storage locations may cause bias for model outcomes. The models are as follows:

Delimbed energy wood stems in roadside pile, pine birch mix, covered **(R^2=0.70, SE 0.2)**

$MC(i) = MC(i-1) - DMC$

$DMC = 0.062 \times (\text{evaporation} - \text{precipitation}) + 0.051$ (11, 12)

Delimbed energy wood stems in roadside pile, pine birch mix, uncovered **(R^2=0.64, SE 0.2)**

$MC(i) = MC(i-1) - DMC$

$DMC = 0.062 \times (\text{evaporation} - \text{precipitation}) + 0.039$ (13, 14)

Logging residues in roadside pile, spruce, covered **(R^2=0.44, SE 0.36)**

$MC(i) = MC(i-1) - DMC$

$DMC = 0.105 \times (\text{evaporation} - \text{precipitation}) - 0.072$ (15, 16)

Logging residues in roadside pile, spruce, uncovered **(R^2=0.64, SE 0.57)**

$MC(i) = MC(i-1) - DMC$

$DMC = 0.17 \times (\text{evaporation} - \text{precipitation}) - 0.076,$ (17, 18)

where *MC (i)* = moisture content
DMC = daily moisture change

Use of the models starts with determining the moisture content of fresh wood. For that reason, average moisture of fresh logging residues and small-diameter stem wood, depending of the cutting month, are presented in Table 6.

Table 6. Moisture content of fresh logging residues depending on the cutting month in Finland.

	Moisture content of fresh logging residues, monthly, %											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pine	55	55	55	54	54	54	54	53	54	54	55	54
Spruce	52	52	51	51	51	50	51	51	51	50	51	52
	Moisture content of fresh stem wood, monthly %											
Pine	57	57	57	56	56	55	55	57	57	57	57	57
Spruce	57	57	57	56	56	55	55	57	57	57	57	57
Birch	45	45	45	46	48	42	42	42	42	44	45	45

Use of this application is recommended from March to October in Finland, depending on the weather data. Calculation begins when the surface layer starts to dry, typically drying starts between March and May in Finland and drying ends in October or November, depending on location and seasonal variation in weather. Using the models requires applying some restrictions, since the moisture content should not exceed 60 % and it should not be under 25 %, because it is not realistic. If logging residues have been logged during winter, the moisture content of logging residues starts at 60% in the beginning of the drying season, regardless of harvesting month.

VALIDITY

The accuracy of the models has been tested with independent data. Nevertheless, the best validity check has been done by companies, which have reported acceptable accuracy and usability of models, but also encouraged further development especially for autumn period accuracy.

CONCLUDING REMARKS

Weather data is nowadays available easily for different kinds of applications helping and supporting forest work and biomass supply. Drying models for energy wood can be used now successfully for management and control, but very soon also for measurements and quantifying transactions. These “big data” applications challenge us to develop further innovations.

4.3. DRY MATTER LOSSES

Jyrki Raitila, VTT Technical Research Centre of Finland & Lauri Sikanen, Natural Resources Institute Finland, Luke

MAIN OUTCOME

Dry matter losses can be a remarkable cost factor and emission source in biomass supply for energy and biorefining. Roundwood is not sensitive for dry matter losses and that is why storing along a supply chain and in terminals should be focused on roundwood, if possible. Within logging residues and comminuted material, dry matter loss of 1% per month is an appropriate figure to be used in inventory calculations. In worst cases, dry matter losses can be close to 3% per month. The measurement of dry matter losses is challenging and despite of serious efforts, the predicting of losses and their biological and physical processes are not known well enough.

MOTIVATION

Biomaterials are always affected by biological processes. Feedstock from forests and fields has a naturally high moisture content and host many different microbes. Biological processes proceed in piles and stacks if conditions are favourable. These processes cause losses of the heating value of the material and at the same time, they generate greenhouse gas emissions (GHG). Storing can be the biggest single source of GHG in the supply chain and monetary losses can be significant as well. The scale and reasons for dry matter losses need to be known and controlled to improve the sustainability and efficiency of the supply chain.

WHY DO DRY MATTER LOSSES OCCUR?

The quantity of biomass available for energy and bio-products produced in biorefineries is ultimately affected by the dry matter loss that takes place during storage. Dry matter loss in biomass feedstocks can occur through living cell respiration, biological degradation, chemical reactions and material handling (Krigstin 2016).

Fungal growth and chemical oxidative reactions cause the major of wood degradation when environmental conditions are favourable. These conditions include a suitable temperature (15–60 °C), a moisture level above the fibre saturation point (MC usually above 25%), and appropriate oxygen and carbon dioxide concentrations. Temperature is reported to be the most important factor in determining the number and type of microorganisms inhabiting in wood chip piles (Farrell 1997). Higher mass losses have been observed when the temperature was between 20 to 30 °C which is optimal for fungal growth. Almost no degradation occurred when the temperature was lower than 15 °C or higher than 65 °C (Ernstson et al. 1991). Frozen woody biomass stored over winter does not experience any dry matter loss (White et al. 1986). Moisture levels of 30–35%-w in biomass are ideal for fungal growth, but if the air humidity is high, they can grow in lower moisture contents as well (Thörnqvist 1982).

Measuring changes of dry mass is quite challenging for several reasons. Monitoring periods are long, feedstock piles are usually quite heterogeneous and they are located in natural conditions where monitoring is based on sampling.

Despite difficulties in measuring changes in dry matter of biomass feedstock piles, several studies have attempted to monitor dry matter losses during storage in various parts of the world. For example Assarson et al. (1970) reported that losses in roundwood storage were about 1.1% for one summer and 1.7% over two drying seasons for pine. Correspondingly, Erber et al. (2014b) reported 2% dry matter losses per year for Norway spruce. In the studies of Nurmi (2013) the decrease in density of whole pine trees was 6% at the greatest during 15–17 months of storage. Correspondingly, the highest loss in stem wood was 4.2% during seven months of storage. In logging residue and logging residue chip piles, in particular, dry matter losses have been found to be significantly larger. Thörnvist (1985) recorded a loss of 0.1% per month during nine months of storage when logging residues were stored at a landing on the roadside. With regard to stem wood chips Jirjis (1995) reported 8.7% dry weight losses for birch from May to December.

DRY MATTER STUDIES IN BEST

Dry matter losses were studied in three different setups. In Onkamo pile trial, 1 454 m^3 of logging residue chips were piled and wired by thermocouples, which monitored temperature changes in the pile. Temperatures rised quickly and severe dry matter losses were expected. Effective heating up generated occasionally also effective drying and dry matter losses were not rising to remarkable level. Eight months of storage generated 2.7% dry matter loss. Another loss value, 10.7% was obtained by using moisture observations of the heating plant. The trial revealed two things, definition of the dry matter loss reliably is extremely challenging and self-heating could be utilised also for the drying of chips in terminals.

In Mikkeli, three about 5000 m^3 loose wood chip windrows were stored at the biofuel terminal for 4-8 months. The windrows were made from stem woods chips and two of them were covered with tarpaulin. Every truck load that was delivered to terminal was weighted and moisture content of the samples was measured. Same measurements and heat value analyses were done when fuel was taken from storage to usage (the method is identical to conventional methods at power plant reception). From these measurements dry matter mass change during storage was calculated. Results are presented in Table 7.

Table 7. Results of the Mikkeli pile trial.

	Windrow 1	Windrow 2	Uncovered Windrow 3
MC_a [%]	41.3	41.4	41.6
m_a [kg]	1 190 830	1 212 950	1 202 640
m_{a_dry} [kg]	698 660	711 031	702 582
E_a [MWh]	3 276	3 333	3 291
MC_d [%]	43.1	43.5	45.9
m_d [kg]	1 109 400	1 136 950	1 127 650
m_{d_dry} [kg]	631 249	642 377	610 059
E_d [MWh]	2 951	3 000	2 834
Δm_{dry} [kg]	-67 411	-68 655	-92 524
ΔE [MWh]	-325	-333	-457
Δm_{dry} [%]	9	10	13

At Mekrijärvi drying park, dry matter loss was observed in the most of the studied piles of logging residues and small size stems. Small size stems lost their dry matter about 1 % per month during the storage time. If the storing time is long, the dry matter loss could be high. Logging residues are more variable material. Dry matter loss could vary between 0-3 % per month in the roadside storage (Routa et al. 2015 b). If logging residues are dry enough when piling to the roadside storage, they don’t lose their weight. But in contrary situation the dry matter loss could be high and total loss of matter can reach over 40% during storage time.

Based on the previous presented figures in the Fast Track study, 1%, 2% and 3% monthly dry matter losses were used as calculation parameters.

4.4. CAPITAL COSTS OF STORAGES

Lauri Sikanen, Natural Resources Institute Finland, Luke

MAIN OUTCOME
Capital costs are results of money and costs generated when harvesting the material and establishing the storage. The cost level is dependent on the interest rate used in calculation. In normal supply chain, capital cost for one year of storing is 0.5–5% of the mill gate price of the feedstock.

MOTIVATION

Energy wood is often stored for a long time at the roadside storages and terminals before entering the combustion process. Minimising or optimising the size of storages has been one of the mainstreams in ordinary roundwood procurement for two decades. Due to this, the capital costs of energy wood storages were taken as the focus in the BEST programme as a part of storage cost research.

ACCUMULATION OF COSTS

In order to be able to calculate the total capital costs of storages, we must know how much capital is tied in them. This can be done by simply summing up costs, which have been created until the material is in the storage. For example, roadside storage of logging residues includes stumpage costs (paid to the forest owner), harvesting costs and forwarding costs paid to the harvesting company and a minimum 7% for overhead. There can also be other costs, like covering costs or rent of storage areas.

Costs are dependent on the assortment; costs tied to small roundwood storage at the roadside are higher because of higher stumpage and harvesting costs. Tied-up capital can be investigated and compared, for example, by supply chain cost studies, as presented in Fig. 49.

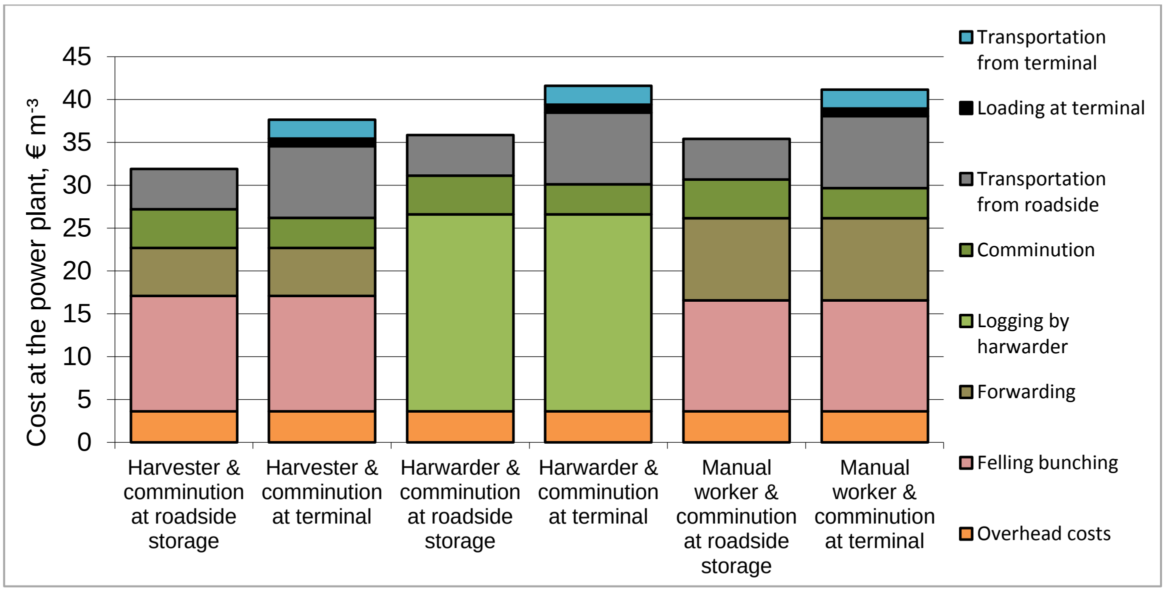


Figure 49. Costs of whole tree chips by main work stages at the power plant, €/m^3 (Laitila 2008).

YEAR OF STORAGE FOR ENERGY WOOD STEMS COSTS OVER 1 EURO PER MWH

Storage time varies a lot between companies. It is still typical that energywood is stored more than half of the year in the forest and almost two year storage times are not unusual either.

The typical Finnish roadside storage of energy wood is a pile of small-diameter stems harvested either as whole trees or as delimbed stems. The stumpage of such a material is close to 2 €/m^3 and harvesting cost is 22 €/m^3 (felling 15 €/m^3 and forwarding 7 €/m^3). Overheads are usually at least 7% which equals 1.68 €/m^3. Per MWh the capital is about 14 €.

The interest rate is an important factor in storage cost calculation. The rate is company dependent and the best way to define this is to look at the objectives of the company. Some companies have clear aims for the interest of invested capital. In the BEST programme, storage cost calculations were made for the interest rates of 3%, 8% and 12%. Based on the figures above, one year of storage for small-sized energy wood costs 1.12 €/MWh as capital cost if 8% is used as an interest rate. For 3% and 12% interests costs are correspondingly 0.42 and 1.68 €/MWh. This cost does not include any dry matter losses or other value or matter decreases.

CONCLUDING REMARKS

The very typical one year of energy wood stem storage at the roadside generates costs representing about 6 % of the total supply cost. Storing can also increase the final value of energy wood by drying or defoliation, but part of the benefit can be lost, if storing is not controlled properly and if storing times are not carefully planned. Capital costs of storing need to be monitored together with benefits, dry matter losses and timing of payments.

4.5. FAST-TRACK APPROACH

Lauri Sikanen, Natural Resources Institute Finland, Luke & Jyrki-Pekko Kinnunen, University of Helsinki

MAIN OUTCOME

Fast-Track supply is the approach of the harvesting and transportation of logging residues, in which the easily decaying material is supplied directly to the user without storing. Scaling and timing of fast-track is done according the limitations of operational environment. Cost savings were 8–13% in the case analysed.

MOTIVATION

Typically energy wood has been stored for relatively long times at the roadside to decrease the moisture content and to balance supply. The main interest has been in quality improvement gained by drying. Costs and losses have not been studied carefully and, especially, they have not been monitored in a wider context. In the BEST programme, dry matter losses and capital costs during storage periods were studied and their remarkable economic effect was identified. Finally, the calculation model was developed for the alternative supply method, where part of the logging residues were chipped and transported as fresh material instead of keeping them in storage for months. This approach was referred to as *Fast-Track*.

HOW FAST-TRACK WORKS

In Fig. 50 the problematic features of storage have been described. The idea is to optimise the supply so that negative effects are kept as small as possible and positive aspects are promoted in order to fulfil the demand of good-quality material.

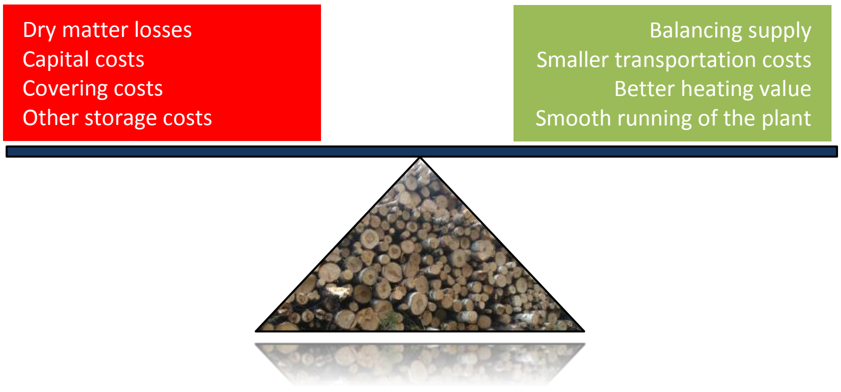


Figure 50. Problematic features of storage, i.e.storage dilemma.

The Fast-Track approach is based on the year clock of energy wood supply and timing of operations in different seasons (Fig. 51). The most effective drying season is in the spring, where quality improvement happens, if it happens. All other periods are either neutral or decrease the value of the material by capital costs and dry matter losses. The maximal output of the system is needed in winter, and therefore the best fuel is used at that time. This material is dried during the previous drying season and it is produced from material harvested just before the season, in order to minimise storage time.

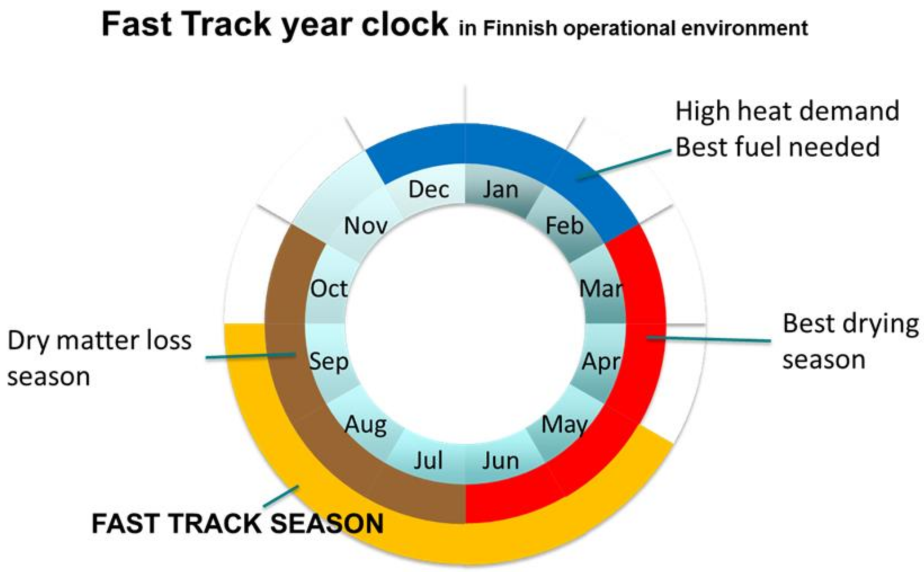


Figure 51. Year clock of energy wood harvesting.

In the study, 146 000 m^3 of logging residues were allocated to the use by traditional methods, when average storing was 12 months, and by the Fast-Track approach, when 47 000 m^3 of the feedstock was directly chipped and transported to the plant.

FAST-TRACK SAVES MONEY IN SUPPLY

The cost saving potential of the fast-track supply is dependent on the rate of dry matter loss. Comparisons in the study were made with 1%, 2% and 3% dry matter loss per month. In the Fig. 52, differences are presented with different dry matter loss rates and with 8% interest rate for capital costs. The Fast-Track approach can decrease the cost level from 8% to 13% depending on the dry matter loss level.

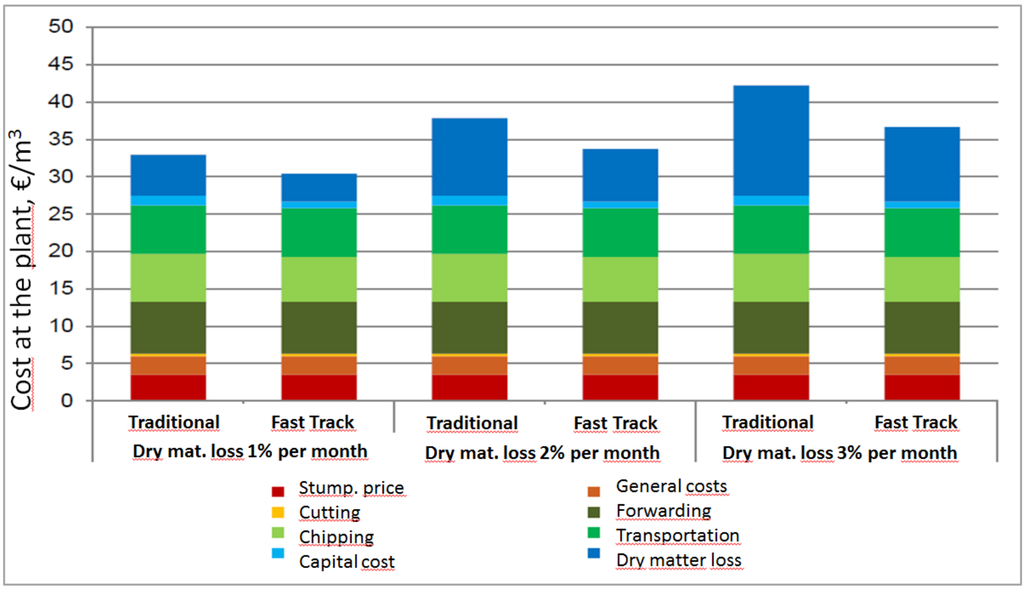


Figure 52. Cost levels of traditional supply and Fast-Track approach with different dry matter loss levels.

The calculations made in the study are case-dependent. We must plan a Fast-Track approach concerning the structure of feedstock and annual demand levels. Boilers using Fast-Track chips must be big enough to tolerate moist and green chips.

CONCLUDING REMARKS

Fast-Track chips are not the same as traditional chips in quality. When the moisture is higher, the pricing of chips can be different and that would lead to a different cost-benefit situation.

Also chlorine content of feedstock can be different and corrosion risks can rise. Corrosion processes in boilers are still under research, although the basic phenomena of combusting various types of wood are already well known. The highest chlorine and alkali metal concentration is in needles and bark. Storing logging residues first on the harvesting site and then at the roadside landing is an effective way to reduce the amount of needles in wood chips. It is inevitable that the Fast-Track method would increase the amount of needles in logging residue chips. However, it has not yet been studied if there is any real risk for increased corrosion with Fast-Track chips.

Demand of the plant defines how big of a percentage of annual chips can be Fast-Tracked. Nevertheless, savings can be remarkable; it is not easy to find other phases of biomass supply where we can increase the efficiency of the supply chain with 10% or more. We must also consider if we can skip the whole storing of logging residues. Since trucks can take bigger payloads and boilers can use more wet fuels, water content of the feedstock is no longer a critical factor.

5. ENTERPRISE RESOURCE PLANNING - ERP

Tapio Räsänen, Metsäteho Oy, Lauri Sikanen, Natural Resources Institute Finland, Luke, Timo Melkas, Metsäteho Oy, Timo Saarentaus, Metsä Group, Olli-Jussi Korpinen, Lappeenranta University of Technology & Jouni Tornberg, Kajaani University of Applied Sciences – Measurepolis

MAIN OUTCOME

Process and data flow descriptions were constructed for logging residues delivered as chipped to power plant, for stump biomass delivered uncomminuted to power plant and for small size stem wood delivered via terminal to power plant. The results enable the building of ERP as a separate system or as integrated into existing systems.

MOTIVATION

Energy wood supply is an essential part of forestry nowadays and especially in the future bioeconomy. Leaping forward in the efficiency and sustainability of supply chains, enterprise resource planning (ERP) must be in the focus. Increasing volumes are challenging to control effectively. Cost effective operations with low emissions and appropriate chain-of-custody can be challenging especially, when also value chains are developing more diverse. Traditional energy production from biomass is accompanied with other kinds of biorefining.

PROCESS AND DATA FLOW DESCRIPTIONS

Process and data flow descriptions were done by selecting first the supply chains that were to be defined. The descriptions were done for three different types of supply chains that cover all types of biomasses and most common ways of delivering the energy biomass to power plants. They were done in close co-operation with the descriptions of the measurement needs and the information flows in the energy wood supply chain (chapter 4.1). The described supply chains were:

1) Logging residues delivered chipped to power plant;
2) Stump biomass delivered uncomminuted to power plant and
3) Small size stem wood delivered via terminal to power plant.

The descriptions were put together by identifying the parties involved in the supply chains, main level operational processes from harvesting to combustion at power plant and the background processes and by specifying data flows between the supply chain processes. ERP system was conceptually divided into two subsystems: 1) control and management of energy biomass (ERP core system) and 2) management system of delivery operations (Fig. 53). The latter one can be regarded either as a part of the forest company information system or it can be a combination of the forest company system and a transport and resource planning service for contractors, like LogForceTM service is in Finland. In this work, energy biomass trade, ordering and operational management of transportations were not in focus, so the description of those was left open. Also the forest company backend systems and mobile applications were not defined any further. A messaging service is defined as a separate system between ERP and other IT systems. Such a service does not exist yet even for the roundwood logistics, but the requirements for the common service have been specified and setting it up is already close to happen. The aim is that the messaging service would be used as a connector between different parties also in bioenergy logistics where we today lack of standardized ways of data and message communication.

DATA MANAGEMENT

An essential part of ERP system is the data warehouse (database) in which the data concerning the different storages and the biomass stored in them is saved and managed for calculation purposes. The database consists of objects (e.g. biomass batches or storage piles) and all the data attributes of the objects. In BEST concept of a “virtual biomass terminal” was raised in order to provide an access to the data for all parties involved in the supply chains of biomasses. In a way ERP data warehouse can be considered that kind of application supposed that the business model of it will be further defined and the use principles and use rights agreed. Another important part of ERP system is the calculation module of biomass quality. In the descriptions it is considered as a black box including all the models needed to calculate moisture, energy content, dry matter loss and other potential quality parameters as well as the value of the biomass. The quality calculation module can be considered as a brain of the system and it is closely connected to the data warehouse but also to external data sources, especially the open weather data (Fig. 54).

STANDARDISED CONTENTS

Main outcome of the descriptions are the data flows between the supply chain processes and the definitions about how the data is communicated and managed in ERP system and IT systems of the parties. Inbound and outbound data flows were specified including the sources of data, i.e. measurement systems or company background processes. Data flow specifications were based on the existing data transfer arrangements and the data standards that are applied already today in roundwood and bioenergy logistics. Data flows are specified as messages between sending and receiving systems containing the payload data. Most of the messages are based papiNet standard and those related to harvesting are based on StanForD 2010 files. papiNet and StanForD 2010 are XML-based data communication standards that are commonly used in Finland and also elsewhere in wood supply. Therefore no other options for data interfaces were considered. Data entities were defined preliminarily and they were mapped to the data elements or attributes of the papiNet messages or StanForD 2010 files. The standards on their behalf specify further the data structures and data types and possibly partly also enumerations and permitted values of data. Based on these process and data flow descriptions a common BEST data model has been built up in WP2. The objective of the common data model is to generalize the data definitions in order to apply them in the planning of IT systems and applications targeted to manage different types of biomass-based fuel supply chains.

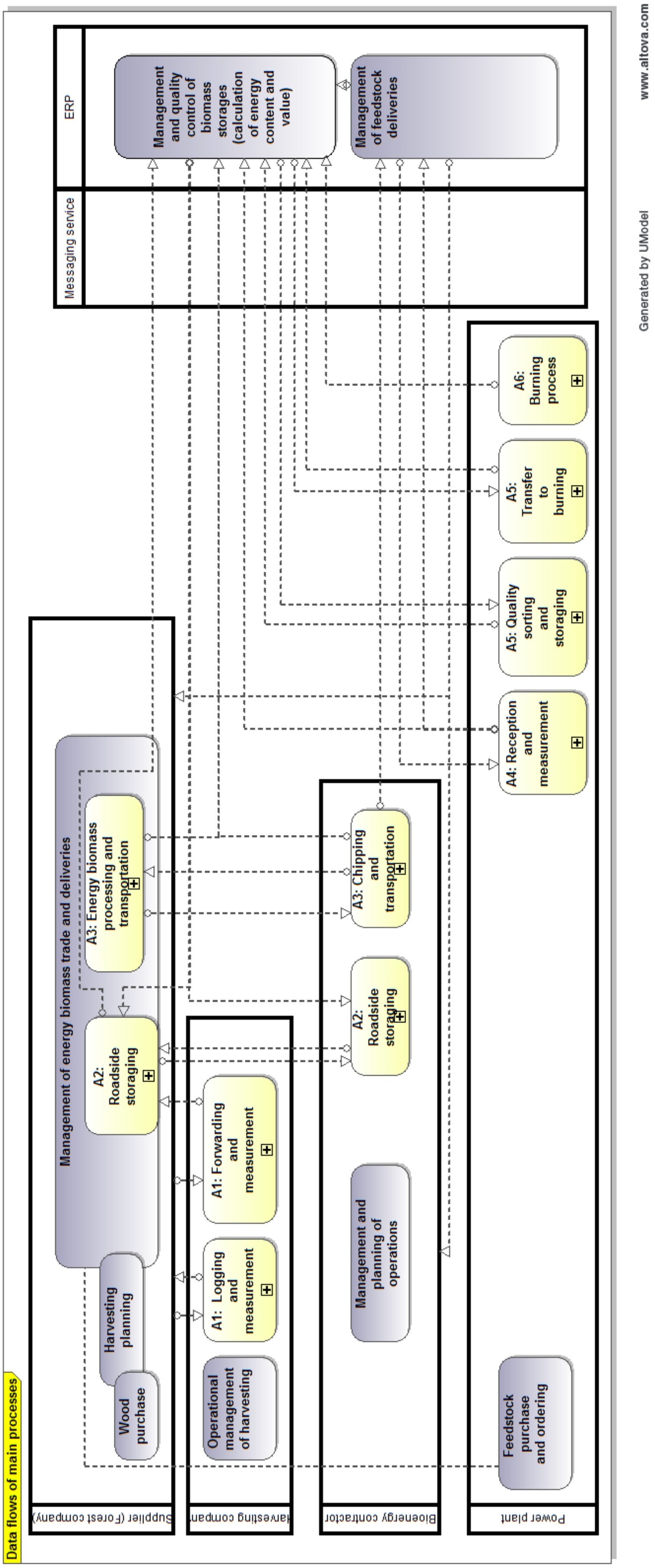


Figure 53. Data flows of main processes.

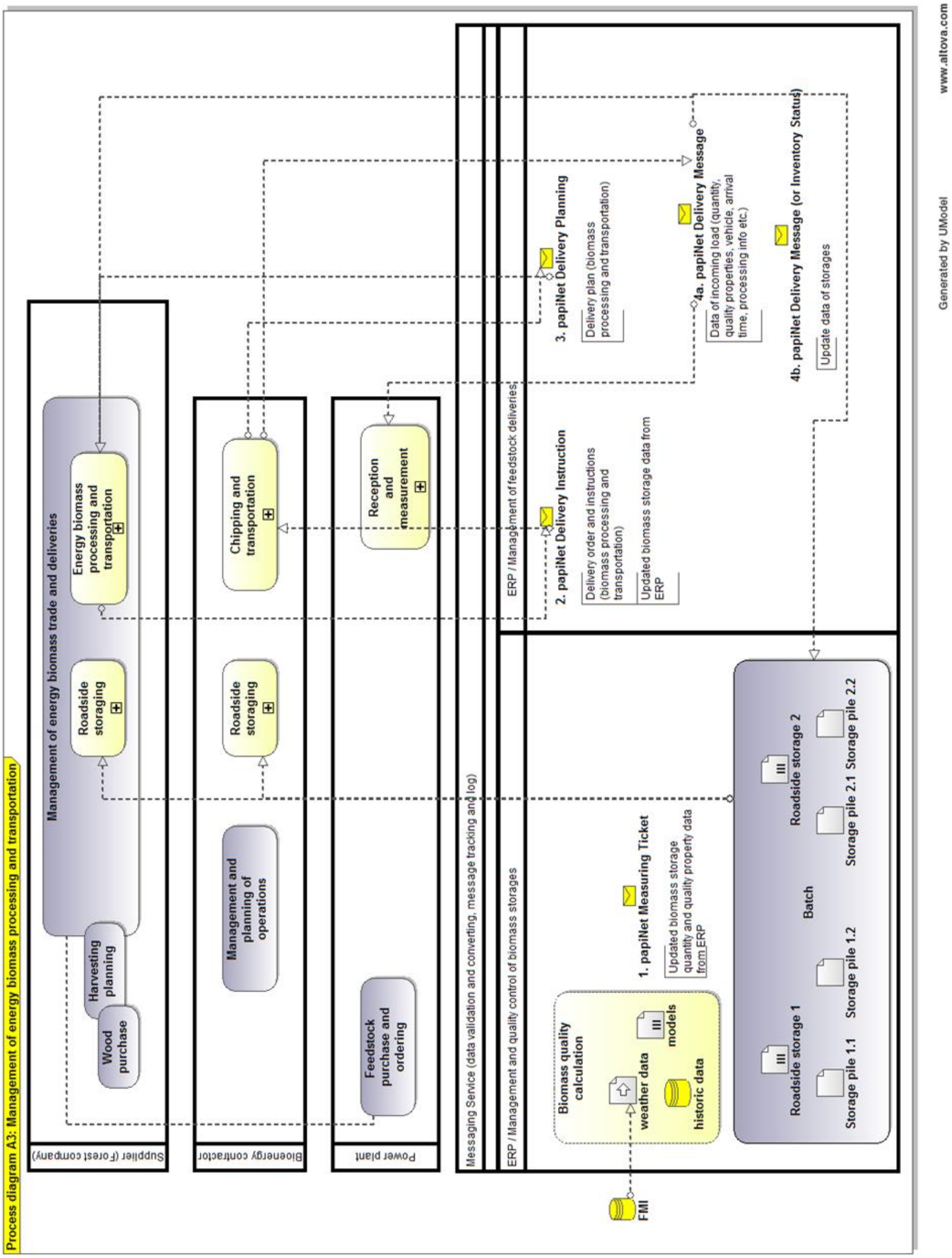


Figure 54. Process diagram. Management of energy biomass processing and transportation.

CONCLUDING REMARKS

The work done in BEST enables management and control of energy wood supply according to the same precision and quality as done already for roundwood. Connection to the weather data and quality forecasting algorithms are new features, which could be implemented also in the roundwood supply in the future.

6. CONCLUDING REMARKS

Effective and sustainable feedstock supply for energy and biorefining requires careful planning, management and control. Control requires information about quantities, qualities and locations as inputs. Management requires knowledge about demand and supply, capacities and limitations of machines, terminals and other stakeholders of the value network. When all pieces of the puzzle are in hand, the big picture can be constructed comprehensively. Of course, the picture is dynamic; the next quarter of a year requires different pieces than the former. The production of the information needed must be effective and clear. We cannot afford the collection of useless data or double measurements.

The MWh roadmap critically monitored the supply chain and defined the phases and processes, where heating values (energy contents), together with other measurements, should be optimally done. New technological development based on X-rays, NIR, NMR and wireless sensor technologies as well as the soft-sensor method were successfully tested for moisture and purity analysis. The usability and preferences between technologies must be evaluated in the context of the whole process of the company. New approaches of 3D-modelling opened interesting and cost-efficient opportunities for bulk volume measurements in terminals and reception yards. These new 3D-technologies will most probably be developed for real solutions and products in the near future together with soft-sensor approaches. The ultimate goal should be to be able to gather quality and quantity information in a quick and inexpensive way as early as possible, and be able to transfer it to all operators continuously.

The power of simulations was once again proven in the analysis of terminals as a part of the supply system. Location, technology and sizing are critical factors for terminals. They will be studied in the future with a wider perspective, for example by sharing expertise between Finland and Sweden, where terminals are currently very common and widely used. The biomass supply through terminals can be very cost-competitive compared to traditional supply routes directly from the forest to the plant. However, effective terminals have to be large enough in order to pay back investments in infrastructure and machines. Prompt matching of processing and storing capacities with biomass flows is very important, and advanced information management systems are helpful in accomplishing that. The investment in simulations in the planning and design stage of the terminal is marginal when compared to the cost effect of unsuccessful terminal investment.

Intelligent calculus can be used as a common nominator for the approach, where the quality and value changes of the feedstock are estimated and forecasted dynamically based on material characteristics, location, weather, time and seasons. Moisture forecasting models were developed in BEST for the phase, where they can be implemented and they surely can provide valuable information for supply management. The BEST Fast-Track approach challenges the traditional storing of logging residues and encourages direct supply of green residues in summer and autumn, if a plant can tolerate it. Also, traditional rules of thumb addressing the corrosion risk during combustion with green feedstock were challenged with success.

Leaping forward in the efficiency and sustainability of supply chains, enterprise resource planning (ERP) must be in focus. In BEST, definitions, data flows and process mapping of ERP systems were built especially for the control and management of energy biomass supply. The information needed comes partly from existing systems of traditional industrial roundwood supply. A remarkable amount of information comes from specific energy wood supply operations, including measurements, quality control and improved harvesting and transportation practices. The data definitions and characteristics were done in BEST with the accuracy enabling the implementation of the high-end energy biomass ERP as a separate solution or as a part of existing ERPs, such as those used already in roundwood procurement.

References

Andersen, M.R., Jensen, T., Lisouski, P., Mortensen, A.K., Hansen, M.K., Gregersen, T. and Ahrendt, P. 2012. Kinect Depth Sensor Evaluation for Computer Vision Applications, Department of Engineering, Aarhus University. Denmark. 37 pp. - Technical report ECE-TR-6

Anon. 1992. http://www.finlex.fi/fi/laki/ajantasa/1992/19921257. In Finnish.

Anon. 2013 a. http://www.finlex.fi/fi/viranomaiset/normi/404001/41503. In Finnish.

Anon. 2013 b. http://finlex.fi/data/normit/41198-13012fi.pdf. In Finnish.

Assarson, A., Croon, I., & Frisk, E. 1970. Outside chip storage (OCS). Sven Papperstidning 73(16):493–501.

Balenovic, Ivan et al. 2015. Estimation of the mean tree height of forest stands by photogrammetric measurement using digital aerial images of high spatial resolution. Annals of Forest Research, [S.l.], p. 125-143.

CEN-TS 15414-1. 2008. Solid recovered fuels. Determination of moisture content using the ovendry method. Part 1; Determination of total moisture by a reference method.

Enström, J., Athanassiadis, D., Grönlund, Ö. & Öhman, M. 2013. Framgångsfaktorer för större skogsbränsleterminaler [Success factors for larger forest fuel terminals]. Working paper 813–2013. Uppsala: Skogforsk. In Swedish.

Erber, G., Routa, J., Kolström, M., Kanzian, C., Sikanen, L. & Stampfer, K. 2014. Comparing two different approaches in modeling small diameter energy wood drying in logwood piles. Croatian J For Eng 35(1):15–22.

Ernstson, M-L., Jirjis, R. & Rasmuson, A. 1991. Experimental determination of the degradation of 845 some forest residue fuel components at different temperatures and oxygen concentrations. Scan J For Res; 6:271-287.

Farrell, R. L., Hata, K. & Wall, M. B. 1997. Solving pitch problems in pulp and paper processes by the use of enzymes or fungi. Advances in Biochemical Engineering/Biotechnology 57:198-212.

Fridh, L. 2014.Evaluation of the METSO MR Moisture Analyser. Arbetsrapport Från Skogforsk nr. 839–2014.

Jirjis, R.1995. Storage and drying of fuelwood. Biomass Bioenergy 9(1):181–190.

Järvinen T. 1998. Näytteenotto, näytekäsittely ja analyysit kiinteillä polttoaineilla. Loppuraportti, tutkimusselostus ENE23/T0207/98. Jyväskylä. In Finnish.

Järvinen, T. 2012. Kiinteiden biopolttoaineiden CEN – näytteenottostandardin soveltaminen Suomen oloihin, VTT:n Tutkimusraportti, Jyväskylä, 55. http://www.energia.fi/sites/default/files/censov_tutkimusraportti_240412.pdf

Kons, K., Bergström, D., Eriksson, U., Athanassiadis, D. & Nordfjell, T. 2014. Characteristics of Swedish forest biomass terminals for energy. Int J For Eng. 25(03): 238-246.

Kons, K. 2015. Forest biomass terminal properties and activities. Licentiate Thesis. Umeå: Swedish University of Agricultural Sciences, Department of Forest Biomaterials and Technology.

Korhonen, M., Fisk, V., Laakkonen, P. and Melkas, T. 2016. BMA Online biomass moisture analyzer's measuring accuracy and its feasibility for different energy wood materials. Metsätehon tuloskalvosarja. 8b/2016.

Korpilahti, A. 2015. Bigger vehicles to improve forest energy transport. Metsätehon tuloskalvosarja 2/2015.

Krigstin, S. & Wetzel, S. 2016. A review of mechanisms responsible for changes to stored biomass fuels. Fuel 175 (2016):75–86.

Laitila, J. 2008. Harvesting technology and the cost of fuel chips from early thinnings. Silva Fennica 42(2): 267–283.

Luke. 2016. Luke tilastotietokanta. Available at: http://statdb.luke.fi/PXWeb/pxweb/fi/LUKE/LUKE__04%20Metsa__04%20Talous__04%20Energiapuun%20kauppa/03_Energiapuun_hinta_v.px/?rxid=001bc7da-70f4-47c4-a6c2-c9100d8b50db

Ministry of Employment and the Economy. 2013. National Energy and Climate Strategy - Government Report to Parliament on 20 March 2013. https://www.tem.fi/files/ 36292/ Energia-_ja_ilmastostrategia_nettijulkaisu_ENGLANNINKIELINEN.pdf

Melkas, T. & Tornberg, J. 2015. MWh RoadMap. Metsätehon tuloskalvosarja. 5/2015.

Melkas, T. & Tornberg, J. 2015. Measurements at the Bioterminal based on MWh- Roadmap. Metsätehon tuloskalvosarja. 4b/2015.

Nurmi, J. 2013. Changes in volumetric energy densities during storage of whole-tree feedstocks from silvicultural thinnings. Biomass and Bioenergy 61:114-120.

Ovaskainen, H. & Lundberg, H. 2016. Optimal biomass truck load size and work models for loading of loose biomasses. Metsätehon tuloskalvosarja 3b/2016. 48 p.

Routa, J., Kolström, M., Ruotsalainen, J. & Sikanen, L. 2015 a. Validation of Prediction Models for Estimating the Moisture Content of Small Diameter Stem Wood. Croatian Journal of Forest Engineering 36(2015)2.

Routa, J., Kolström, M., Ruotsalainen J. & Sikanen L. 2015 b. Precision measurement of forest harvesting residue moisture change and dry matter losses by constant weight monitoring, International Journal of Forest Engineering, 26:1, 71-83

Routa, J., Kolström, M., Ruotsalainen J. & Sikanen, L. 2016. Validation of prediction models for estimating the moisture content of logging residues during storage. Biomass & Bioenergy. 94 (2016) 85-93.

SCAN-CM 39:94. 1994. Wood chips for pulp production: Dry matter content.

SCAN-CM 41:94. 1994. SCAN-CM 41:94. Wood chips for pulp production: Sampling.

Schenk, T., 2005, Introduction to Photogrammetry, Lecture notes, Department of Civil and Environmental Engineering and Geodetic Science.

Strandström, M. 2016. Metsähakkeen tuotantoketjut Suomessa vuonna 2015. Metsätehon tuloskalvosarja 7/2016. In Finnish.

The Swedish Forest Agency. Skogliga konsekvensanalyser 2008. [Forest sector consequential analyses 2008]. Report 2008:25. In Swedish.

Thörnqvist, T. & Lundström, H. 1982. Health Hazards caused by fungi in stored wood chips. Forest Prod J 32: 29-32.

Thörnqvist, T. 1985. Drying and storage of forest residues for energy production. Biomass 7:125–134.

Tornberg, J. & Melkas, T. 2015. Wireless sensors for moisture and temperature estimation of storages and chip piles. Metsätehon tuloskalvosarja. 6b/2015.

White, M. S., Argent, R. M. & Sarles, R.L. 1986. Effects of outside storage on the energy potential of hardwood particulate fuels: Part III. Specific gravity, ash content, and pH of water solubles. For Prod J 36(4):69-73.

Venäläinen P. & Poikela A. Scenarios of Energy Wood Transport Fleet and Back-Haulage. Metsätehon tuloskalvosarja 2b/2016. http://www.metsateho.fi/wp-content/uploads/Tuloskalvosarja_2016_02b_Scenarios_of_Energy_Wood_Transport_Fleet_and_Back-Haulage.pdf

Virkkunen, M., Kari, M., Hankalin, V. & Nummelin, J. 2015. Solid biomass fuel terminal concepts and a cost analysis of a satellite terminal concept. VTT Technology 211. Espoo: VTT Technical research centre of Finland.

Virkkunen, M. 2016. Terminaalikartoitukset. Biomassaterminaalit-esiselvityshankkeen työpaja. Helsinki. 14.03.2016. In Finnish.

Virkkunen, M. & Raitila, J. 2016. Forest Fuel Supply Through the Terminal Network in Finland and Sweden. Conference paper. 24th European Biomass Conference and Exhibition. 6-9 June, 2016 Amsterdam. Proceedings: 17 – 22. DOI: 10.5071/24thEUBCE2016-1AO.1.5.

Väätäinen, K., Prinz, R., Malinen, J., Laitila, J. & Sikanen, L. 2017. Alternative operation models for using a feed-in terminal as a part of the fuel supply system for a CHP plant. Manuscript. Submitted to GCB Bioenergy Journal.

Zhang, Z., 2012. Microsoft Kinect Sensor and Its Effect, in IEEE MultiMedia, vol. 19, no. 2, pp. 4-10.

Österberg P., Antikainen J. & Melkas T. 2014. State-of-the-art survey of biomass measurement technologies in the bioenergy supply chain. BEST project report.

Österberg, P., Heinonen, M., Ojanen-Saloranta, M. & Mäkynen, A. 2016. Comparison of an NMR-based Bioenergy Moisture Measurement Instrument against the Loss-on-Drying Method. ISEMA2016. May 23-27, 2016. Florence, Italy. Proceedings.

Appendix I. Source data of simulation studies 1, 2 and 3.

Truck properties

Biomass type	Delimbed stems (DS)	Logging residues (LR)	Chips
Payload, t	41.4	24 / 30	45
Bulk density in truckload, kg/m³		150 / 187.5	300

Biomass properties

Biomass type	Delimbed stems (DS)	Logging residues (LR)	Chips
Calorimetric heating value, MJ/kg	19	19	19
Moisture content	35 %	50 %	35% (DS) 50% (LR)

Terminal properties

Max. number of vehicles allowed	Waiting before (1) and after (3) weighing	Waiting before unloading to season storage (2)	Unloading to season storage	Waiting before unloading to stationary chipper(2)	Unloading to stationary chipper
Inbound traffic	5	2	4	4	1
Outbound traffic	5	-	-	-	-

Machine productivity, t/h

Wheel loader	108
Mobile chipper	43.2
Stationary chipper	64.8

Truck unloading speed, t/h

Timber truck (delimbed stems)	99.4
Energy-wood truck (LR)	48 / 60

Routing features

Inbound deliveries	Season storage (DS)		Direct feed to stationary chipper (DS & LR)	
	distance, m	speed, km/h	distance, m	speed, km/h
Gate >> Waiting place (1)	50	20	50	20
Waiting place (1) >> Weighing	25	8	25	8
Weighing >> Waiting place (2)	290	20	130	20
Waiting place (2) >> Unloading	35	10	35	10
Unloading >> Waiting place (3)	430	30	100	30
Waiting place (3) >> Weighing	20	5	20	5
Weighing >> Gate	75	15	75	15

Outbound deliveries	distance, m	speed, km/h
Gate >> Waiting place (3)	365	20
Loading >>Gate	480	27
Gate >> Plant	5 000	60
Plant >> Gate	5 000	60

Layout-independent parameters of trucks

Weighing time (inbound traffic), min	1.0
Weighing time (outbound traffic), min	0.5
Chip truck visit at plant, min	25

Scenario-specific properties

Number of chip trucks/ mobile chippers/ workshifts	Steady	Basic/Mobile, Harvest Intensity	Peak	Stationary	Combined	LRT	LRT + ST (300)	LRT + ST (500)
July	2/2/2	2/1/1	0/0/0	0/0/0	0/0/0	-	-	-
August	2/2/2	2/2/2	0/0/0	0/0/0	0/0/0	-	-	-
September	2/2/2	2/2/2	0/0/0	2/0/*	2/1/*	-	-	-
October	2/2/2	2/2/2	0/0/0	2/0/*	2/1/*	-	-	-
November	2/2/2	2/2/2	0/0/0	2/0/*	2/1/*	-	-	-
December	2/2/2	2/2/2	4/2/2	2/0/*	2/1/*	-	-	-
January	2/2/2	2/2/2	5/2/2	2/0/*	2/1/*	1/0/**	2/0/**	2/0/**
February	2/2/2	2/2/2	6/2/2	3/0/*	3/1/*	-	-	-
March	2/2/2	2/2/2	6/2/2	3/0/*	3/1/*	-	-	-
April	2/2/2	3/2/2	0/0/0	3/0/*	3/1/*	-	-	-
May	2/2/2	3/2/2	2/1/2	3/0/*	3/1/*	-	-	-
June	2/2/2	1/1/2	0/0/0	2/0/*	2/1/*	-	-	-

*) 2 shifts or all-time open terminal depending on the sub-scenario, **)all-time open terminal

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