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

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Demoreport 17 - JOINT DEMONSTRATION OF THE LARGE NINE AXLE CHIP TRUCK-TRAILER UNIT AND THE HYBRID CHIPPER– D4.5

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Joensuu, July 2015

Content

Preface

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

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

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

This report describes the performance of the nine axle truck-trailer unit constructed by Konepaja Antti Ranta Oy and Kesla C 860 H hybrid chipper in the supply systems based on chipping at the terminal or the roadside landing. The study defined the fuel consumption and productivity levels of the Kesla C 860 H hybrid chipper for processing large sized roundwood and logging residues as well as the payloads, unloading times and fuel consumptions of the nine axle truck-trailer unit for transporting fuel chips from the chipping place to the CHP plant. In addition, the quality and bulk density of the chips produced from roundwood and logging residues were analysed. In the follow up study were recorded the payloads and fuel consumption of the nine axle truck-trailer unit when transporting wood chips from plywood mill and sawmill to the BCTMP and sulphate pulp mill.

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Title	**PROTOTYPE OF HYBRID TECHNOLOGY CHIPPER– D4.5**
Author(s)	Juha Laitila, Jukka Antikainen, Antti Asikainen, Petri Kaksonen, Kari Kokko and Jussi Suutarinen.
Abstract	This report describes the performance of the nine axle truck-trailer unit constructed by Konepaja Antti Ranta Oy and Kesla C 860 H hybrid chipper in the supply systems based on chipping at the terminal or the roadside landing. The objectives of this study were to test the new hybrid technology chipper, Kesla C 860 H, with large sized roundwood and logging residues and define payloads, unloading times and fuel consumptions of the nine axle truck-trailer unit when transporting fuel chips from the chipping place to the CHP plant. Chipping productivity, fuel consumption, quality and bulk density of the produced chips was analysed. In the follow up study were recorded the payloads and fuel consumption of the nine axle truck-trailer unit when transporting wood chips from plywood and sawmill to the BCTMP and sulphate pulp mill. During the time studies, both the chipper and hybrid system were working well and truck mounted chipper was also capable of operating in constricted roadside landings. The large nine axle truck-trailer unit was at its best when transporting fuel chips from the terminal. The results of this study must be considered to be preliminary because the amount of chipped and transported wood assortments was rather small. The chipper and especially the hybrid system are under continuous development, and follow up-study is needed for the precise determination of the productivity, fuel consumption and operating costs. The bulk density of dry wood chips is rather low and thus the payload is usually limited by the frame volume rather than the mass capacity of the modern truck-trailer unit. The average chipping productivity of Kesla C 860 H hybrid chipper unit was 11 936 kg (dry mass) per effective hour (E_0h), when chipping roundwood. The average chipping productivity with logging residues was 11 830 kg E_0h^{-1}. Fuel consumption of Kesla C 860 H hybrid chipper was 2.7 litres per chipped 1000 kg (dry mass) when chipping roundwood and 3.1 litres for logging residues. Bulk density was 317−330 kg/loose-m^3 for logging residue chips and 255−271 kg/loose-m^3 for roundwood chips, when the moisture was 48−53 % and 33−44 % respectively. During the time studies the average fuel consumption of the truck-trailer unit was 52.7 litres per 100 km. According to follow up study, the average fuel consumption of the truck-trailer unit was 38.8 litres when driving with empty load and 54.5 litres with full load. Kesla C 860 H chipper has been introduced to the audience in first time at FinnMetko forest machinery exhibition on August 2014 in Central Finland, and second time in Hakevuori Forest Energy Day at Askola in Southern Finland in March 2015. The nine axle Lipe truck-trailer unit constructed by Konepaja Antti Ranta were introduced to the audience first time on 11– 13 June 2015 at Logistics - Transport 2015 fair in Helsinki.
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1 Introduction

1.1 Wood flows from forests

Truck-trailer units dominate the wood transportation of forest and energy industries in Finland (Karttunen et al. 2013, Strandström 2015b). The transport is unavoidable due to the distance between the resource and the end-users and truck transportation is used since there are no alternatives for the transport wood material from the forest landings (Wolfsmayr & Rauch 2014, Strandström 2015b). Railway or waterway based transportation modes are limited to long distance transports from terminals to the end-users (Wolfsmayr & Rauch 2014, Strandström 2015b). In last year 75% of the industrial roundwood transported was brought to the mill directly by road (Strandström 2015b). Railway transportation accounted for 22% of the industrial roundwood volume, and waterway transportation (by floating and barge combined) accounted for 3% (Strandström 2015b). In 2014 Finnish forest industries consumed 64.5 million m^3 of roundwood (Ylitalo 2015a). Moreover, 9.24 million m^3 of sawmill chips and dust, were utilized by the pulp and paper industries in the secondary wood consumption (Ylitalo 2015a).

Forest chips are transported by trucks to the power and heating plants and at the present time there are only a few large CHP installations that can even use railway or waterway transportation in Finland (Hakkila 2004, Tahvanainen & Anttila 2011, Karttunen et al. 2012a, Karttunen et al. 2013). A solid frame ordinary truck-trailer system is also the most commonly used vehicle for peat and forest industry by-product transport logistics (Hakkila2004, Karttunen et al. 2012b, Karttunen et al. 2013). Forest industry by-products consist of assortments such as bark, sawdust, shavings, cut off and recycled wood (Hakkila 2004, Kons et al. 2014, Ylitalo 2015b). The raw material of forest chips consist of logging residues, tree parts, non-merchantable roundwood and stumps from timber harvesting operations and pre-commercial thinnings (Hakkila 2004, Kons et al. 2014, Ylitalo 2015b).

1.2 Transport efficiency of wood biomass

Comminuting increases the density and homogeneity of forest residues (Eriksson et al. 2013), which justifies its application early in the supply chain (Björheden 2008). Transport efficiency is increased since each truck can carry more biomass as a result of higher solid content of volume which has positive impact in terms of cost, CO_2 emissions, need of manpower and traffic on the roads (Routa et al. 2012, Eriksson et al. 2014). Different wood biomass types have different characteristics that impact efficiency and economics of transporting logistics (Uusvaara 1978, Uusvaara & Verkasalo 1987, Talbot & Suadicani 2006, Ranta & Rinne 2006, Wolfsmayr & Rauch 2014, Cambero et al. 2015). For dry or loose material, the maximum load is limited by the volume of material, whereas the weight limits the maximum load for wet or artificially compacted chips (Talbot & Suadicani 2006, Ranta & Rinne 2006, Wolfsmayr & Rauch 2014).

The bulk density depends on the wood species basic density, particle size distribution, moisture content as well as the loading method and applied pressure when loaded (Uusvaara 1978, Uusvaara & Verkasalo 1987, Lindblad & Verkasalo 2001, Talbot & Suadicani 2006, Eriksson et al. 2013, Wolfsmayr & Rauch 2014). The solid volume to comminuted volume is affected by a number of factors which include the size and shape of comminuted material and the heterogeneity of the particle sizes, where larger heterogeneity will usually result in higher bulk density, as airspaces are less regular and filled by smaller particles (Uusvaara 1978, Uusvaara & Verkasalo 1987, Talbot & Suadicani 2006, Eriksson et al. 2013, Wolfsmayr & Rauch 2014). In many cases forest chips and forest industry by-products are rather light and volume demanding and could benefit of bigger load spaces when transported by road (Korpilahti 2015). Utilizing modern vehicle designs such as a moveable axle group or liftable axles or steering axles at the rear end of trailer, even a maximum dimensioned truck-trailer unit can be well maneuverable on forest roads and turnarounds (Korpilahti 2015).

Permissible payloads are governed by the legal gross mass and the allowable axle mass. Measures and weight limits for heavy vehicles were changed by the statute that came into force the 1st of October 2013 in Finland (Valtioneuvoston asetus 407/2013, Karttunen et al. 2013, Korpilahti 2015). New legislation enables higher gross weights as well as 20 cm higher vehicles which means bigger load spaces (Karttunen et al. 2013, Korpilahti 2015). The changes in legislation have been motivated by reductions in logistical costs and greenhouse gas emissions.

According to the new statute two new vehicle types such as 8-axle truck-trailer unit with maximum gross weight of 68 tonnes and 9-axle truck-trailer unit up to 76 tonnes are accepted (Valtioneuvoston asetus 407/2013, Korpilahti 2015). Prerequisite is that 65% of trailer axles having twin tyres, otherwise maximum weights are 64 and 69 tonnes (Valtioneuvoston asetus 407/2013, Korpilahti 2015). Current legislation on the physical dimensions of the truck-trailer combination limits total length to 25.25 m, width to 2.55 m and height to 4.4 m (Valtioneuvoston asetus 407/2013, Karttunen et al. 2013, Korpilahti 2015). Maximum load spaces are for truck about 60 m^3 and for a trailer 100 m^3 (Korpilahti 2015). Earlier the chip truck-trailer unit consists of a 3-axle truck and 4-axle trailer resulting in 60 tonne legal gross weight (Karttunen et al. 2012b, Karttunen et al. 2013). Typical frame capacities for conventional truck-trailer units range between 120 m^3 and 140 m^3 and tare weights between 20 and 25 tonnes (Karttunen et al. 2012b, Karttunen et al. 2013). Semitrailers are not common in Finland (Karttunen et al. 2012b).

1.3 Production of forest chips

Chipping is a central part of forest energy supply chain and it may take place on the logging site, at the road side landing, at a terminal, or at the plant. Machines operating at terminals, road side landings or logging sites are run using diesel engines while grinders and chippers operating at industrial sites can be powered with electric engines (Di Fulvio et al. 2015). A third option is to use hybrid systems, which store excess energy from the diesel engine during low periods of loading for use during peak loading times (Sun et al. 2010, Einola 2013, Eriksson et al. 2013, Di Fulvio et al. 2015). Fuel costs are 30-33% of total comminuting costs (Laitila et al. 2015a) and fuel prices have been rising remarkably (Einola 2013). Therefore more and more interest to novel solutions reducing the fuel consumption is brought to discussion and hybrid systems capable of evening out the power peaks of the work cycle are of great interest among machine manufactures.

In the year 2014, Finnish heating and power plants consumed 18.7 million m^3 solid wood fuels, of which 10.2 m^3 million were forest industry by-products and 7.6 million m^3 comprised forest chips (Ylitalo 2015b). About 49% of forest chips were made of small diameter thinning wood produced in the tending of young stands and 36% was produced from logging residues of final fellings (Ylitalo 2015b). The share of the stump and root wood was 11%, while 6% of forest chips were produced from large non-merchantable roundwood (Ylitalo 2015b). Majority of delivered forest chips were chipped at roadside landings (Strandström 2015a). About 29 % of the forest chips were produced at the terminals and 14 % were comminuted at the end-use-facilities (Strandström 2015a). Roadside chipping is the predominant supply system for logging residue and thinning wood chips (Strandström 2015a). Comminuting at the terminal is the leading method for producing fuel chips from stumps or non-merchantable roundwood (Strandström 2015a). Comminuting in the terrain is a seldom-used harvesting method in Finland (Kärhä 2011, Strandström 2015a).

1.4 Aim and implementation of the study

This report describes the performance of the large nine axle truck-trailer unit optimized for transportation of chips and other biomaterials between terminals and large end use facilities constructed by Konepaja Antti Ranta Oy and Kesla C 860 H hybrid chipper in the supply systems based on chipping at the terminal or the roadside landing. The study defined the fuel consumption and productivity levels of the Kesla C 860 H hybrid chipper for processing large sized roundwood and logging residues as well as the payloads, unloading times and fuel consumptions of the large truck-trailer unit for transporting fuel chips from the chipping place to the CHP plant. In the follow up study were recorded the payloads and fuel consumption of the nine axle truck-trailer unit when transporting wood chips from plywood mill and sawmills to the Joutseno BCTMP and sulphate pulp mill.

The quality and bulk density of the chips produced from roundwood and logging residues were analysed. The degree of filling is normally determined using a measurement stick or visual evaluation. In this study we tested a novel 3D-scanning device called Microsoft Kinect to obtain 3D-model of wood chip load from the truck container. In addition the fuel consumption and chipping productivity were compared to findings from previous study examining Kesla C 860 H hybrid chipper (Laitila et al. 2015b).

The field studies were conducted in cooperation with Kesla Oyj, Konepaja Antti Ranta Oy, Kuljetus Matti J. Salminen Oy, Konnekuljetus Oy, Vapo Oyj and Jyväskylän Energia Oy in June 2015 in the municipalities of Jyväskylä and Uurainen. The chipping study in Jyväskylä and Uurainen was hosted by Vapo Oyj. Kesla Oyj provided the chipper and Kuljetus Matti J. Salminen Oy an operator for chipping experiments. Konepaja Antti Ranta Oy provided the Lipe truck-trailer unit and Konnekuljetus Oy drivers for the chip transporting studies. Natural Resources Institute Finland was responsible for field studies and reporting of these. The produced chips of the chipping experiments were transported to the Keljonlahti power plant of Jyväskylän Energia Oy.

2 Material and Methods

2.1 Kesla C 860 hybrid chipper

The Kesla C 860 H hybrid chipper is mounted on a three-axle Volvo FM 440 truck chassis (Figure 1) and the raw material are fed into the chippers feeding table with Kesla 2112T timber loader. The width and height of intake opening are 800 mm x 600 mm. There are eight angled blades in a novel rotor that are positioned in a two rows of drum and a square mesh sieve is placed beneath the drum to avoid that oversized chips leave the drum casing. During the time study, the hybrid chipper was equipped with a 100 mm x 100 mm sieve. The Kesla C860 hybrid chipper weighs 8200 kg.

Figure 1 – Chipping non-merchantable roundwood (top) and logging residues (down) with the Kesla C 860 H hybrid chipper during time studies (Photos: Petri Kaksonen/Kesla).

The Kesla C 860 H hybrid chipper is powered by an inline four-cylinder Volvo Penta TAD572VE diesel engine powers in a hybrid arrangement with an electric motor. The engine provides 160 kW at 2300 r/min and a maximum torque of 910 Nm. It has a bore and stroke of 110 x 135 mm and displacement of 5.1 litres. The wet weight of the engine is 583 kg. The diesel engine only powers a generator providing electricity for the electric drivetrain (Figure 2). The electric generator and motors are from Visedo's PowerDRUM XSe and XXS frames. Visedo also provides the PowerMASTER M-frame inverter for the generator and motor control.

The electric drivetrain powers not only the wood chipper but all equipment needed for the chipping operation, including the Kesla 2112T crane used for feeding the wood into the chipper (Figure 2). The needed energy is generated by the diesel engine with the support of super capacitor energy storage (Figure 2). The motors driving the chipper and hydraulic pumps are permanent-magnet motors, and the total system minimizes loss of energy and provides high energy efficiency. There is no mechanical connection between diesel engine and chipper. In future there is an option to connect the hybrid chipper to the power network, which enables it to run on electricity alone (Figure 2)

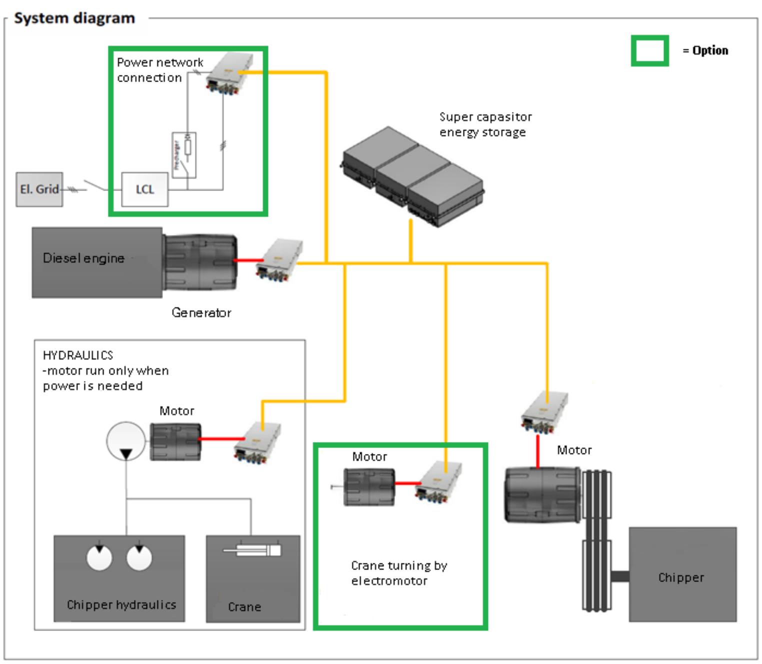

Figure 2 – The system diagram of the the Kesla C 860 H hybrid chipper (Source: Petri Kaksonen/Kesla Oyj).

2.2 The nine axle Lipe truck-trailer unit

The studied nine axle truck-trailer unit, which brand name is Lipe, was constructed by Konepaja Antti Ranta Oy (Figure 3). The tractor of the Lipe truck-trailer unit was completely new Volvo FH16 HP 8*4 Rigid Tag Tridem having an engine power of 552 kW. The vehicle consisted of a 4-axle truck and 5-axle trailer. The truck-trailer unit was designed especially for transporting by-products of forest industries and wood chips from terminals, because the long wheelbase between the front and rear axles of novel vehicle concept require wider turning areas than traditional trucks. The detailed dimensions and turning radius are presented in the Figures 4 and 5.

The weight of the truck-trailer unit was 24 500 kg and the legal gross weight were 69 000 kg (for the truck 35 000 kg and for the trailer 34 000 kg). Total number of tyres were 22 (for the truck 12 tyres and for the trailer 10 tyres). The load space of the truck was 57.4 m^3 and the trailer 100 m^3. The floor and wall of the load spaces were thermo insulated and unloading was based on hydraulic side-tipping. In addition the load space was equipped with hydraulically opening and locking waterproof covers (Figure 3) and hydraulically raising sidewalls. The unloading and cover functions were controlled with the electric control system from the truck cabin. The versatile load space can be easily customized for use in different transportation tasks, which enables e.g. backhauling of baled pulp or sawn timber and thus minimizes vehicles driving distances with empty load.

Figure 3 – The nine axle Lipe truck-trailer unit at the Tikkakoski roundwood terminal during the chipping/loading experiment (Photos: Petri Kaksonen/Kesla).

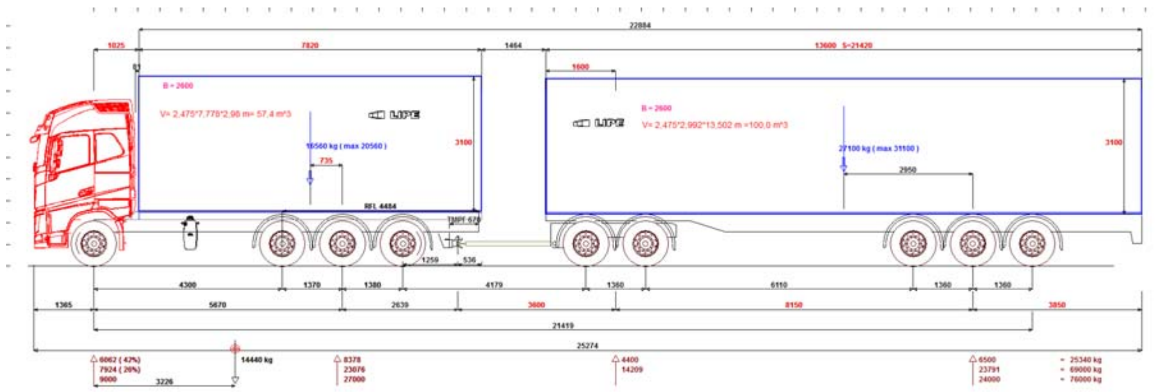

Figure 4 – Dimensions of the nine axle Lipe truck-trailer unit constructed by Konepaja Antti Ranta Oy (Source: Janne Immonen/Konepaja Antti Ranta Oy).

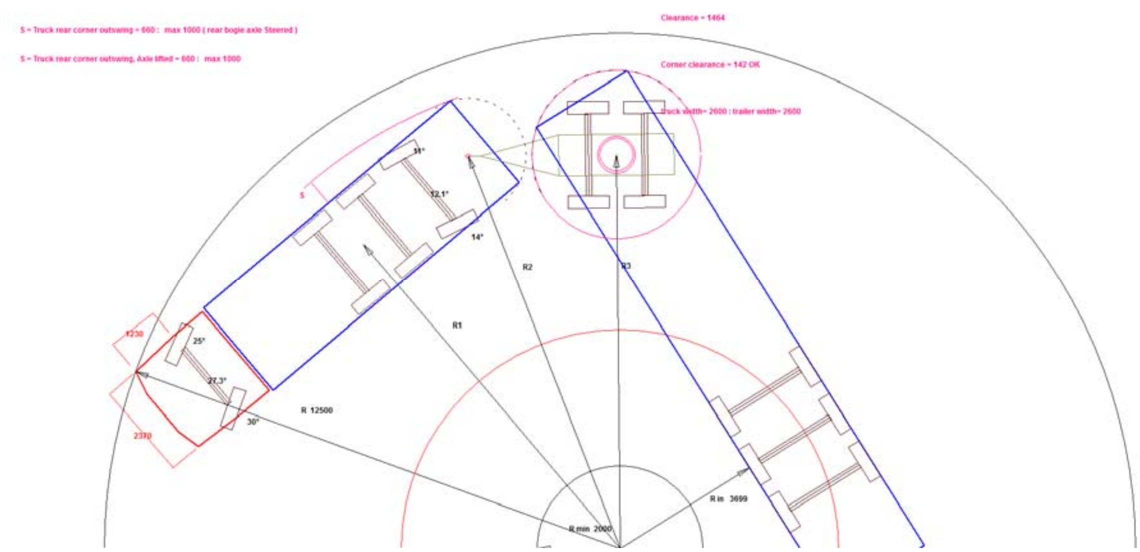

Figure 5 – Outer and inner turning radius for the nine axle Lipe truck-trailer unit (Source: Janne Immonen/Konepaja Antti Ranta Oy).

The truck and the trailer were equipped with air-suspension which is rarely used in low level road network and on forest roads in Finland. For drivers, driving the vehicle is much smoother with air-suspension compared to conventional steel leaf springs. The other advantage of the air-suspension system is embedded weight scaling solution: the driver can monitor the weight of the load in real time. This ensures the possibility to maximize the load size during the chipping/loading operation and which reduces the transportation costs. The driver can observe the individual axle loads of the vehicle and the trailer by using the separate monitoring device (Figure 6).

Figure 6 – The axle mass monitoring device (Photo: Antti Asikainen/Luke).

2.3 Time study of chipping

The chipping study of non-merchantable roundwood was carried out in 15th June 2015 at wood terminal in Tikkakoski, Central Finland. Logging residues were chipped in 16th June 2015 at roadside landing in Uurainen, Central Finland. Both the experiments were carried out under natural light during the daytime (8:00–19:00), with the same experienced chipper operator. The temperature was +10–16 °C during the study. The chipped material were non-merchantable Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and Downy birch (*Betula pubescens*) roundwood from thinnings and final fellings (Figure 7), and Norway spruce (*Picea abies*) dominant logging residues (tops and branches) from final felling (Figure 7). The storing times of both materials were about one year.

Figure 7 – Chipping non-merchantable roundwood with the Kesla C 860 H hybrid chipper at the wood terminal in Tikkakoski (top) and logging residues (down) at the roadside landing in Uurainen (Photos: Petri Kaksonen/Kesla).

The length of roundwood logs was 3 m and they had a minimum top diameter of 6 cm and the diameters of the butt ends ranged from 10 to 60 cm. The observation unit for roundwood chips was the Lipe truck-trailer unit with a 157.4 m^3 gross cargo volumes. Due to restrictions of the road network, the observation unit for logging residue chips was a Lipe truck container unit with a 57.4 m^3 gross cargo volumes. Each load was measured with a certified weight scale at the plant, and both filled and empty weights of the containers/trucks were recorded. The effective hourly productivity (E_0h) of the chipping operation was presented per dry mass (kg) of the forest chips. The chipping machinery was positioned parallel to pile and during chipping, the chips were blown directly into container either from the side or from the rear (Figure 7). During the study 49.5 odt (80.4 green tonnes) of roundwood and 18.2 odt (36.9 green tonnes) of logging residues were chipped with Kesla C 860 H chipper.

The fuel consumption of the chipper units was measured at a local fuel station after chipping trial. Chipper units were parked in exactly same place in the beginning and at the end of the shift and tank were refilled to full. The accuracy of the fuel pump was 0.1 litres and the fuel consumption was presented per dry mass (1000 kg) of the produced forest chips.

The working time was recorded through the application of a continuous timing method wherein a clock ran continuously and the times for different elements were separated from each other under distinct numeric codes (e.g. Harstela 1991, Magagnotti et al. 2013). During the experiment the researcher observed the work performance outside the risk zone so that he was not disturbing the work of the operator (Figure 7). The operation time of the studied chippers was recorded manually with a Rufco-900 field computer, and working time was divided into work elements in order of priority:

Boom out: Boom movement from the chipper to the piled material

Grip: Gripping of material

Boom in: Boom movement from the pile to the feeding table

Feeding: Placing the material into the feed orifice and release of the grapple load

Adjustment: Possible adjustments of the material on the feeding table

Chipping: Chipping while the timber loader is idle

Moving and preparation: Repositioning of the chipper to next pile and preparing the chipper ready for chipping work

Delays: Time not related to chipping work, but for which the reason for the interruption was recorded.

The data analysis was conducted for direct chipping time only (E_0h), in order to avoid the confounding effect of delay and preparation time, which is typically erratic (e.g. Spinelli and Visser 2009, Eliasson et al. 2012, Holzleitner et al. 2013). The studies were also too short to record representative delay times. To the effective working time (E_0h) included the work phases of boom out, grip, boom in, feeding, adjustment and chipping. The number of grapple loads for each truck load was counted, in order to calculate the average weight of the grapple load in feeding.

The chip samples were taken directly from the arriving truck loads as part of the normal delivery process at the Keljonlahti power plant, after unloading chipped wood to the ground (Uusvaara 1978, Uusvaara and Verkasalo 1987). Samples were taken to define the moisture content, basic density, particle size distribution, ash content, and net calorific value of chipped wood, and samples were analysed in the laboratory of the Natural Resources Institute Finland according to the following standards: EN 14780, EN 14774-1, EN 14774-2, EN 14774-3, SCAN-CM 43:95, EN 15149-1, EN 14775, EN 14918.

Five samples were taken for each truck load, and wood samples were stored in plastic bags, which were carefully closed and marked. Moisture samples were packed in double bags in order to minimise the risk of bag outbreak or evaporation. The dimensions of the plastic bags were 35 x 35 cm (volume 8 litres), and the raw material, date, and time were written on the label. In addition, plastic bags were wrapped in a plastic sack, and each load was packed in a corrugated paperboard box of its own.

2.4 Time and follow up study of transporting

The transporting research was carried out as a combination of time study and follow-up study. The time study was integrated with the chipping experiments and during that were transported two truck-trailer loads of roundwood chips and two pure truckloads (truck without trailer) of logging residue chips to the Keljonlahti power plant via forest, asphalt and unpaved gravel roads. Due restrictions of the turn-around place, the logging residue chips were transported without trailer.

Two professional truck drivers participated to the time study and the time study analyst observed the transportation work while sitting in the truck's cabin. The unloading times of the truck-trailer unit at the Keljonlahti power plant were recorded manually with a Rufco-900 field computer. Driving distances were measured using the truck's odometer, with an accuracy of 100 m. The fuel consumptions loaded and unloaded were recorded with the on board computer of Volvo truck. Each load was measured with a certified weight scale at the plant, and both filled and empty weights of the containers/trucks were recorded.

To the follow-up study participated three professional truck drivers. Drivers were asked to independently complete a form, on which they recorded information about the driving distances loaded and unloaded, payloads and fuel consumption with empty and full load. The truck drivers worked in three-shift system and the follow up study took the time five days. The follow up study data compromised 13 full truck-trailer loads of wood chips transported via asphalted highway from Central Finland to Joutseno BCTMP and sulphate pulp mill located in South-East Finland.

2.5 Measuring degree of filling

The degree of filling (Figure 8) is normally determined using a measurement stick or visual evaluation. In this study we tested a novel 3D-scanning device called Microsoft Kinect (Figures 9 & 10) to obtain 3D-model of wood chip load from the truck container. The main goal was to determine the degree of filling more efficiently and accurately than with current methods. The Microsoft Kinect sensor (Figure 9) was originally developed for the gaming industry but when the Microsoft published the software developer packages (SDK) for the device the usage has rapidly expanded for different industrial fields as well.

Figure 8 – The loads were completely filled at the chipping place (Photo: Petri Kaksonen/Kesla).

The sensor includes several different components which are used at the measurement process (Figure 9). The most important parts are the IR emitter and IR depth sensor which are used in the depth map measurements. The depth map is calculated from known speckle pattern which is formed using a diffractive element and an infrared laser (IR Emitter). The laser beam is scattered to dense point cloud which is projected on the surface of the target.

The used laser is on an infrared region so it cannot be detected by an eye; therefore the projected image is captured using an infrared camera (IR Depth Sensor). The resolution of the IR depth sensor is 640 x 480 pixels with 11 bits dynamics which defines the scanning accuracy of the sensor. The final 3D object can be formed by registration of different depth maps using the iterative closest point (ICP) method.

The sensor was developed for indoors use and the power of the laser is relatively low which may cause a problem when the sensor is used outdoors. The intensity level of the direct sun light is much higher than the laser can produce which will saturate the measurements. Cloudy weather or some external shade will improve the measurement usability and accuracy.

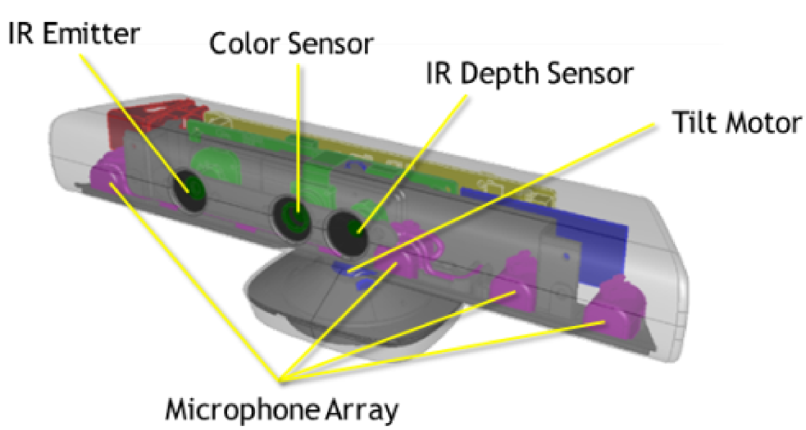

Figure 9 – The structure of the Microsoft Kinect sensor (Source: Microsoft)

The measurements were planned to do at the terminal site using a long rod. The sensor was installed at the end of the rod and it was moved manually over the container. However, the measurements were hard to complete because of handling problems of the long rod, but the most crucial limitations came from the weather conditions. The direct sunlight (measurements were saturated) and occasional rain (laptop wasn't a weather proof) disturbed the measurements. Therefore the measurement location was changed into the power plant where the rod can be adjusted more easily over the container (Figure 10). The measurements were done from 5 meter high stairs where the top of the container was easily seen and measured (Figure 11).

Figure 10 – The Microsoft Kinect sensor was installed at the end of the rod and it was moved manually over the container (Photo: Antti Asikainen/Luke).

Figure 11 – The 3D-scanning were done from 5 meter high stairs at the power plant (Photo: Antti Asikainen/Luke)

3 Study results

3.1 The chipping experiments

The average chipping productivity of Kesla C 860 H hybrid chipper unit was 11 936 kg (dry mass) per effective hour (E_0h) and standard deviation (SD) was 772 kg E_0h^{-1}, when chipping roundwood (Figure 12). The average chipping productivity with logging residues was 11 830 kg E_0h^{-1} (SD 989). The average chipping productivity (dry mass, kg) per maximum engine power (kW) was 75 kg kW^{-1} when chipping roundwood and 74 kg kW^{-1} with logging residues. The average weight of the grapple load was 150 kg (SD 9) for roundwood (dry mass) and 81 kg (SD 16) for logging residues (Figure 12). Compared to previous experiment (Laitila et al. 2015b), the productivity were at the same level (Figure 12).

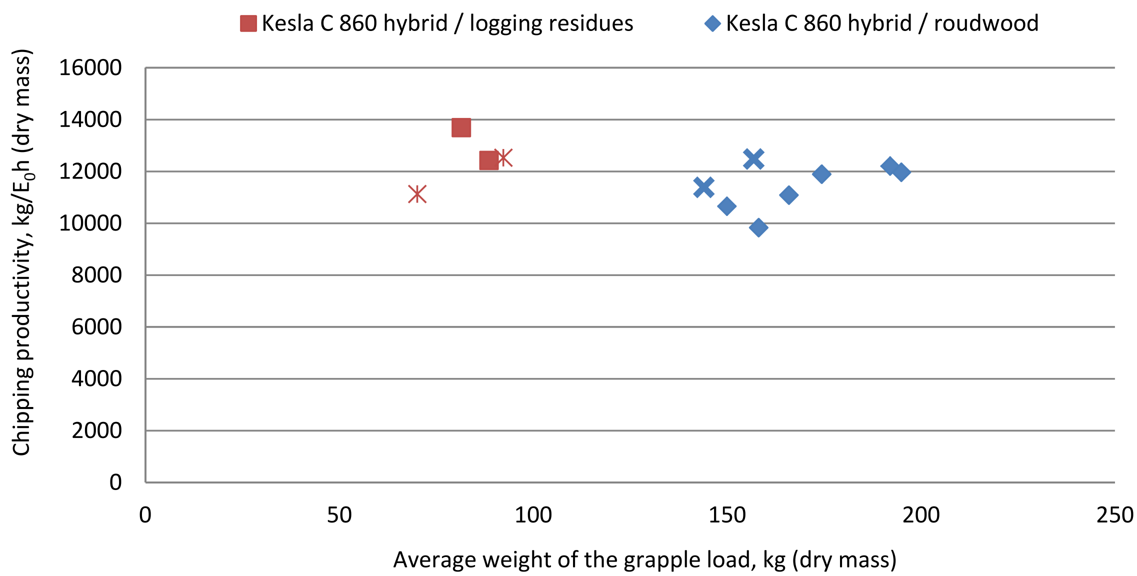

Figure 12 – Chipping productivity of Kesla C 860 H hybrid chipper with logging residues and roundwood. The results of the present study are marked with cross.

The average chipping time per 1000 kg (dry mass) was 304 seconds for roundwood and 301 seconds for logging residues (Figure 13). The study confirms that chipping time consumption is inversely proportional to engine power when chipping roundwood. Chipping, while the timber loader was idled, took 8–79 % of the effective working time. Loading (boom out, grip and boom in) accounted for 15–38 % and feeding (feeding and adjustment) 6–53 % of the effective working time when chipping roundwood and logging residues with Kesla C 860 H hybrid chipper (Figure 13). The fuel consumption of Kesla C 860 H hybrid chipper was 2.7 litres per chipped 1000 kg (dry mass) when chipping roundwood and 3.1 litres for logging residues. In the previous study, the fuel consumption of Kesla C 860 H hybrid chipper was 3.1 litres per chipped 1000 kg (dry mass) when chipping pulpwood and 2.9 litres for logging residues (Laitila et al. 2015b).

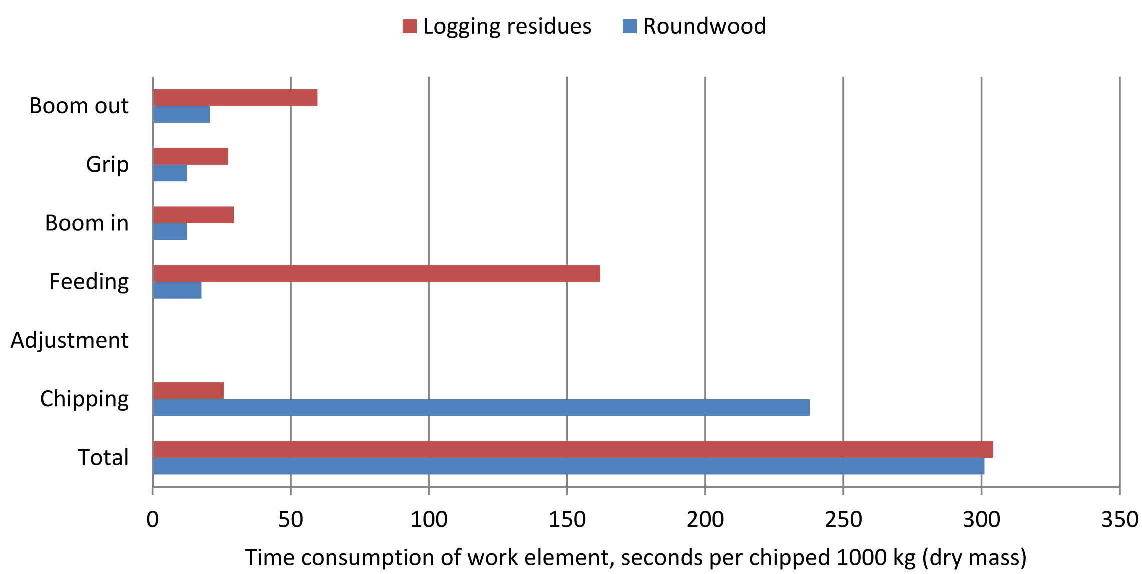

Figure 13 – Time consumption of work elements per chipped 1000 kg (dry mass) with Kesla C 860 H hybrid chipper when chipping roundwood and logging residues.

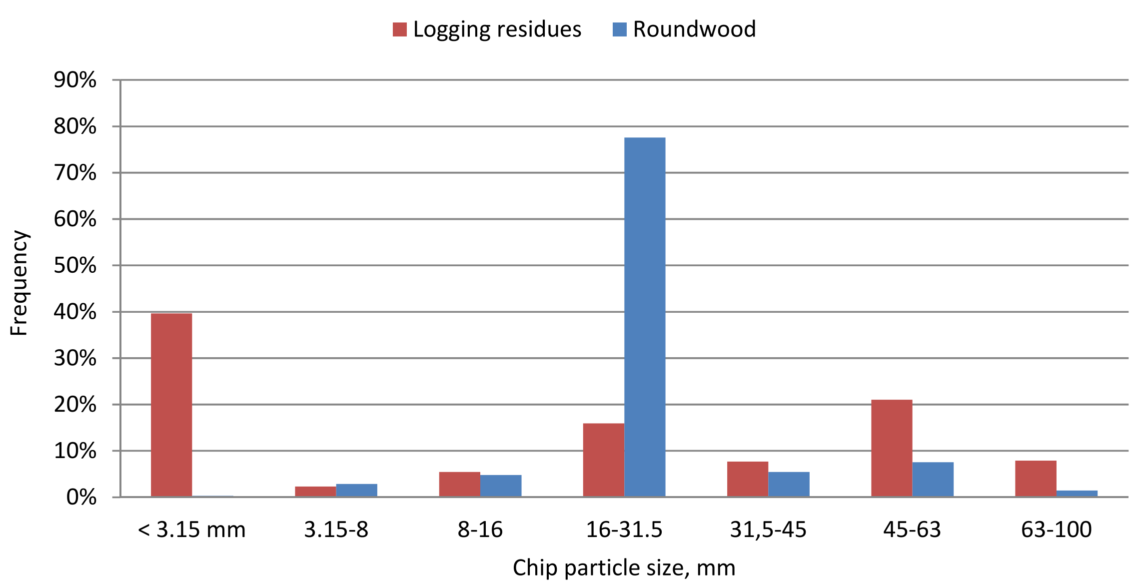

Figure 14 – Particle size distribution for logging residue and roundwood chips produced by the Kesla C 860 H hybrid chipper.

Bulk density was estimated to be 317–330 kg/loose-m^3 for logging residue chips and 255–271 kg/loose-m^3 for roundwood chips at the chipping place. Particle size class (Figure 14) was P31 for roundwood chips and P63 for logging residue chips (Alakangas and Impola 2014). The average basic density of roundwood and logging residues were 402 kg m^{-3} (SD 1.3) and 430 kg m^{-3} (SD 14.3). The average moisture content of roundwood chips was 39.6% (SD 8.0) and for logging residues the average moisture content was 50.8% (SD 2.8). The average of net calorific value of roundwood chips was 20.1 MJ kg^{-1} (SD 0.11) and 20.9 MJ kg^{-1} (SD 0.02) for logging residue chips. The average ash content was 0.7 % (SD 0.11) for roundwood chips and 4.2% (SD 0.89) for logging residue chips.

3.2 The truck transporting experiments

During the time study the fuel consumption of the truck-trailer unit was 66.2 litres per 100 km with full load and 39.2 litres per 100 km with empty load. The driving distance was 37 km and the payload of roundwood chips were 40 000 kg. Total weight of the truck-trailer unit was 65 600 kg. The fuel consumption of the pure truck loads (truck without trailer) was 41.5 litres per 100 km and 37.4 litres per 100 km with empty load. The average payload of logging residue chips were 18 450 kg and the total weight of the truck was 33 720 kg on average.

The average unloading time of the truck-trailer unit was 4.4 minutes with the hydraulic side-tipping, when the roundwood chips were directly unloaded to the asphalted yard of the Keljonlahti power plant.

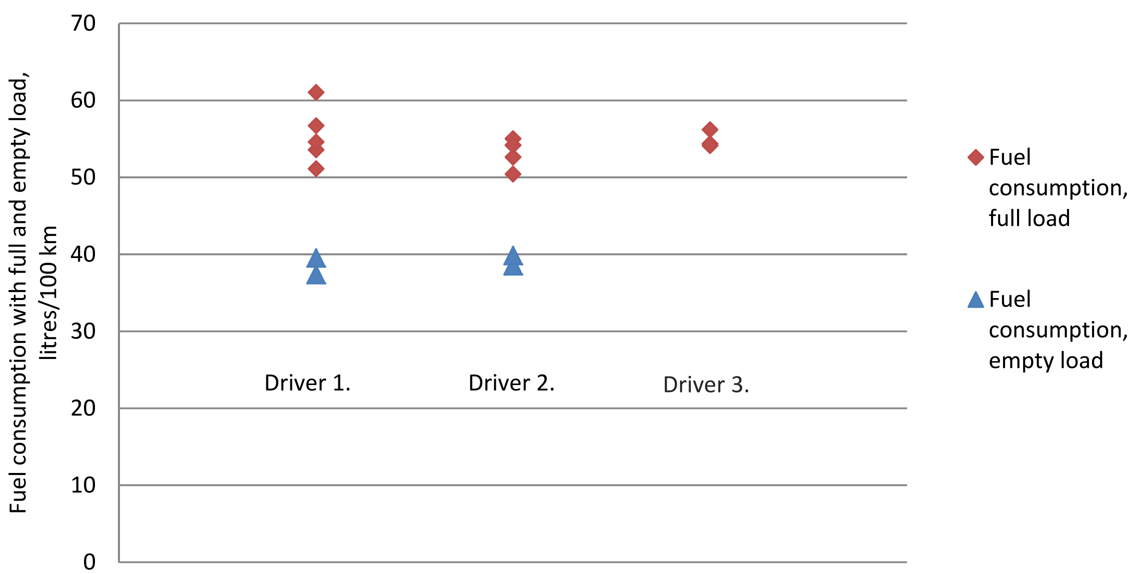

Figure 15 – Fuel consumption of the Lipe nine axle truck-trailer unit when transporting wood chips from plywood mill and sawmill to the BCTMP or sulphate pulp mill.

The average transporting distances in the follow-up study were 129 km (SD 32) with empty load and 265 km (SD 46) with full load. During the follow up study the average fuel consumption of the truck-trailer unit was 54.5 litres per 100 km (SD 1.1) with full load and 39.2 litres per 100 km (SD 1.1) with empty load (Figure 15). To the follow-up study participated three professional truck drivers. The driver 1 had the average fuel consumption with full load 55.4 litres per 100 km (SD 3.7). Correspondingly the driver 2 and the driver 3 had the fuel consumption 53.3 (SD

1.8) and 54.9 (SD 1.1) litres per 100 km (Figure 15). The payloads were in range of 31 700 – 48 154 kg (Figure 16) and the average payload were 39 774 kg (SD 5333). The two of the heaviest payloads (Figure 16) were recorded when transporting wood chips origin from sawmills. Fuel consumption of the nine axle truck-trailer unit increased slightly when the payload increased (Figure 16).

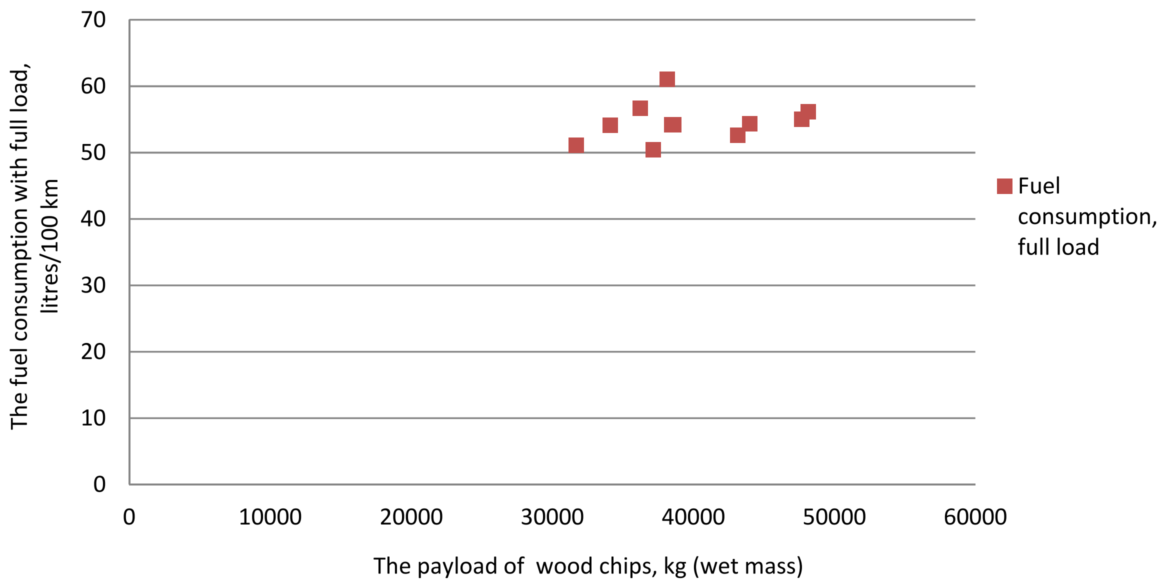

Figure 16 – Fuel consumption of the nine axle truck-trailer unit as a function of the payload when driving loaded.

3.3 The degree of filling experiment

Due the lack of the computation power of the used laptop machine the measurements were done in small pieces. These separate pieces were merged to one model (Figure 17) afterwards using the Meshlab and the volume analysis is done using the netfabb Studio software. Measurement experiments were done both for roundwood and logging residue chips. Degree of filling was determined by measuring the volume of the wood chip bed and compared that to total volume of the truck container. For wood chips made from roundwood the degree of filling was 82 % and for the logging residues 78 %.

It should be noticed that the determined degree of filling was obtained after the 30-40 km transportation so the wood chip level is compressed. In addition, the whole surface area of the wood chip load was not measured and evaluated because of the limited measurement conditions. Therefore, the surface area included into the analysis was only 60 – 80 % from the truck container area.

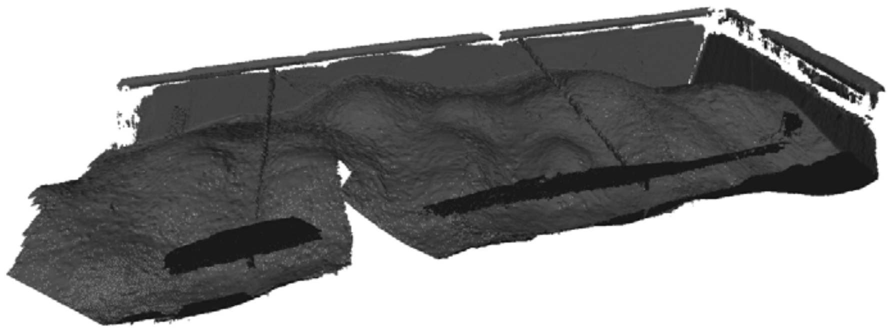

Figure 17 – Reconstructed model from the wood chip load. The model is formed from five separate scans.

The experiment shows that the measurement method works well for the determination of filling degree. However there are some limitations such as direct sunlight which will affect to the measurements. Method will work better if the ambient illumination can be limited which can be done by selecting the measurement location more carefully for example under covered hovel or similar.

4 General evaluation

During the time studies, the truck-trailer unit, the chipper and the hybrid system were working well. The truck mounted chipper was capable of operating in a constricted roadside landings and the large nine axle truck-trailer unit was at its best when transporting fuel chips from the terminal. The productivity results of the chipping experiment must be considered to be preliminary because the amount of chipped wood and assortments were rather small. The chipper and especially the hybrid system are under continuous development, and follow up-study is needed for a more accurate determination of long term productivity, fuel consumption and operating costs.

The versatile load space which enables e.eg. backhauling, is a clear benefit on long transporting distances, because larger procurement areas, increasing prices of transporting fuel and higher consumption of time of the transportation will increase the costs of the wood chips. The large monthly variation of energy wood demand poses a challenge for the transport economy: In winter demand of fuels and their transport is peaking and in early autumn, spring and summer there is much less transport work available (Windisch et al 2015). For instance, Jyväskylän Energia receives 190 loads/day of fuel in January and only 14 loads/day in August (Ryymin 2015). Versatility of transportation equipment represents also one way of achieving year-round employment and ensuring the availability and stability of a professional workforce. Unloading based on side-tipping is an efficient method, compared to methods based on walking floor or chain unloading, if chip delivery systems are designed compatible also for side-tippers.

Increased payload is a key economic factor in reducing transporting costs. The potential for artificial load densification is set by the initial bulk density of the chips and the volume capacity and legal payload of the truck-trailer units. The bulk density of dry wood chips is rather low and thus the payload is usually limited by the frame volume rather than the mass capacity of the modern large truck-trailer unit. Therefore the large nine axle truck-trailer unit having a 69 tonnes maximum gross weight is a smart choice optimizing the load space and weight ratio when transporting e.g. ground stumps or roundwood chips from terminals or veneer chips from plywood mills. With more heavy or wet materials (e.g. logging residues), the 76 tonnes nine axle truck-trailer unit equipped with twin tyres is the right choice.

The long wheelbase between the front and rear axles of newest concepts require wider turning areas than the traditional trucks (Figure 18). The tight turn with heavy load is possible but not recommended. The heavy load will strain the rear axles with massive forces and therefore the risk for axle or wheel breakdowns increases and the total life span of the trailer decreases. Utilizing modern vehicle designs such as a moveable axle group or liftable or steering axles at the rear end of a trailer this size vehicle can be well manoeuvrable also on forest roads and turnarounds.

Figure 18 – Benefits by using bigger trucks depend very much on the transported material and restrictions of the road network in its operation region (Photo: Petri Kaksonen/Kesla).

5 Demo results

The world first full hybrid wood chipper Kesla C 860 H were presented first time at the FinnMetko forest machinery exhibition on August 28–30th 2014 in Central Finland. The exhibition had over 32 000 visitors. In spring 2015 Kesla`s hybrid chipper was introduced to the audience, including high level policy makers and forest and energy professionals in Hakevuori Forest Energy Day at Askola (Figure 19). In total around 1000 people participated the demonstration at 19.3.2015 in Askola in South Finland.

The demonstrated nine axle Lipe truck-trailer unit constructed by Konepaja Antti Ranta were introduced to the audience first time on 11– 13 June 2015 at Logistics - Transport 2015 fair in Helsinki (Figure 20). The event had approximately 12 500 visitors and it is the biggest event for logistics and transport in Nordic countries.

To the joint demonstration of the nine axle chip truck-trailer unit and hybrid chipper in Tikkakoski and Uurainen participated total three people from Finland and Sweden.

Figure 19 – Kesla C 860 hybrid chipper demonstration in Hakevuori Forest Energy Day in South Finland (Photo: Kari Kokko/Kesla).

Figure 20 – Lipe truck-trailer unit demonstration at Logistics - Transport 2015 fair in Helsinki (Photo: Janne Jokela/ Metsäalan Ammattilehti).

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