Radio frequency identification and composite container technology demonstration for transporting logistics of wood biomass

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RFID (Radio Frequency Identification) technology is widely used in industry but thus far has almost no applications for energy biomass logistics. A demonstration study was performed to build a real-time Web-based tracking system, denoted as RfIDER that uses RFID to manage energy biomass logistics. In the demonstration study, the functionality of this system was evaluated and further developed. The demonstration involved trucks carrying both composite and metal interchangeable containers with RFID tags mounted on them. Also, the productivity of all work phases in the transportation chain was examined and the readability of the RFID tags was evaluated. The demonstration study revealed that the RfIDER system enables following containers in real time through the supply chain and both storing and reading information on individual containers reliably, such as biomass owner, origin, destination, content, and quality. The RFID tags' readability was better with composite than metal containers. Potential benefits of the system demonstrated are real-time nature and accuracy of the data gathered and an opportunity to allocate and classify said data on the basis of customer needs. Possible logistical advantages include greater efficiency of unloading operations at the energy plant via use of existing information stored in the system. © *2014 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4862786]

I. INTRODUCTION

In 2012, 8.3×10^6 cubic metres of forest chips were used in Finland, accounting for 16.5 TWh, or over 4%, of the country's total energy use.[1] The new target, for the end of 2020, has been set at 13.5×10^6 cubic metres.[2] Most solid forest fuels are transported by trucks with a solid frame, either as chips or as uncomminuted material.[3] Some trials have been done with rail- and water-based transport options in recent years. Today's main solution for forest-chip supply is roadside chipping directly into trucks (79%), with less going via regional terminals (16%) or directly to end-use crushing stations (5%).[4]

There is imbalance between locations of demand and supply, which means longer transport distances from the supply areas to the largest demand sites in Finland. Regions with high demand but low supply volumes require other logistics solutions than conventional supply methods, since transport by truck is economical only for short transport distances.[5] This development will bring rail and waterway transport modes into supply logistics. Therefore, need has emerged to find efficient solutions for integrating the separate transport modes. Interchangeable containers have proved to be one promising option. The advantage of container logistics lies in possibilities for intermodal transport and efficient terminal operations. Operations involving containers and transportation fleets can be separated, to increase the efficiency of logistics, with short waiting time for transport and a fast operation cycle.

So far container trucks are seen marginal use (8%) in peat and wood-chip transport in Finland.[3] Three containers can be transported by a truck and ordinary trailer. The truck must

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feature a hook system to allow the transfer or unloading of the containers. Containers without doors need to be unloaded with a special turning machine. An innovative container made of composite material has been designed for intermodal truck and railway transportation.[6] The weight of the composite container is 1500 kg, half that of a traditional metal container. The composite container has been sized to allow a load of up to 20 tons. The container dimensions can be modified within the limits set by current road transport legislation (width 2.55 m, height 4.4 m, and length 25.25 m). To allow intermodal transportation, the container is designed to be suitable also for railway wagons. A watertight, thermally insulated structure prevents freezing-related problems in wintertime, which is a benefit in Nordic winter conditions.[7]

This study concentrates on Radio Frequency Identification (RFID) technology and its functionality as a part of composite-container biomass logistics. RFID is a remote identification method that uses radio frequencies. Its operation can be compared to that with barcodes, except that RFID tags can hold more data, can contain active electronics, and do not require line of sight—allowing an RFID tag to be embedded in the product if necessary. The tags are also generally more durable than barcode stickers.[8] A typical RFID system consists of a tag and reader, their antennas, and electronics controlling their operations. The reader device uses a magnetic or electromagnetic field to communicate with the tag, which is a small electronic device that consists of a small antenna, control electronics, and a small amount of memory. Commonly, the tags are passive, getting the energy required for communication from the reader device's magnetic- or electromagnetic field. Some tags, called active tags, contain an internal power source for continued operation and can, for example, monitor temperature or other environmental conditions. RFID technologies can be also grouped by the frequency ranges used: Near Field Communication (NFC), Low Frequency (LF), High Frequency (HF), and Ultra High Frequency (UHF). The principle of operation differs by frequency range: NFC, LF, and HF use magnetic fields in their communication, and UHF uses electromagnetic fields.

Radio-frequency identification is a mature solution used in logistics, because of its suitability for fully automated product identification.[9] With appropriately placed reader antennas around warehouse gates, it is possible to identify a product without any user intervention or need for the driver of the vehicle to pass through a gate. It has been found[10] that many current logistics processes could be made more efficient through increased transparency of the process, with the keys to process improvement being tracking and tracing. This means that, instead of stock-level monitoring, individual items and transport units should be subject to tracking along the entire product chain. Cost pressure and structural modifications are "drivers" intensifying use of such telematic technologies. Telematic technologies cut costs substantially by minimising redundant data acquisition, the time spent in looking for or being guided to a site, inspection work, and the time of roundwood and biomass storage.[11] The basic idea of RFID in forestry and the timber industry is to use automatic identification to detect individual logs and support the information management in timber procurement. Therefore, each log is marked with an RFID tag. A unique number on every tag identifies that log in transit and makes the wood traceable throughout the forestry-wood production chain.[12]

Although RFID technology is widely used in industry, it is almost never applied in energy-biomass logistics. One reason might be the bulky form of reside biomass as compared to sawn timber or other commodities. In the study reported here, RFID technology was applied for energy-biomass logistics, wherein interchangeable-container logistics serves as an interesting target for such application since it is a suitable platform for RFID installation. The idea was to gather real-time information from truckloads of energy biomass, transaction logging, and reading sites. It was assumed that unloading actions speed up at power plants if truckload information has been stored in the information system earlier, in the loading stage. This might involve real-time measurement integrated into the information system.

The aim of this study was to create a real-time Web-based tracking system (the RfIDER container-logistics system) to manage biomass logistics. By means of this system, it was possible to follow containers moving along the supply chain via an Internet portal, with all tracking data stored on a virtual "cloud server." Both smartphones with NFC features and reader gates equipped with a wireless Internet connection were used for transfer of data to the RfIDER system. In the course of the demonstration study, the functionality of this system was evaluated and further developed. Also interchangeable-container logistics was examined via collection of load-size, container-durability, and productivity information during the demonstration.

II. MATERIAL AND METHODS

A. Containers

The online real-time, RFID-based tracking system RfIDER was developed to follow shipments of biomass along the logistics chain. The demonstration focused on long-distance transportation to the power plant after terminal chipping. Involved in the demonstration were a biofuel supplier (Hyötypaperi Oy) based in Valkeala, Finland, a power plant as fuel user (Etelä-Savon Energia Oy) located in Mikkeli, Finland, and a composite-container manufacturer (Fibrocom Oy) during 28.5–12.7.2012 (seven weeks in all). In total, 28 truckloads of fuel chips were transported, with 10 of them made from stumps (ST), 10 from logging residues (LR), and eight from small-diameter energy wood (SW). The frequency of transport between fuel supplier and user was four loads per week.

This study concentrates on interchangeable containers built through the use of composite materials, but metal containers too were followed. RFID tags were mounted on the channel-composite structure with which a container is manufactured in "one-shot" moulding, so the walls and floor are tied seamlessly and continuously together (the system is known as Supercont®). This means a lighter, temperature-isolated, and more durable structure and thereby a sustainable transport-carrier option, as earlier studies have demonstrated.[6,13]

In this study, that container weighed 1720 kg because of additional metal inserts (1500 kg commercial version available), was 6.058 m (20 ft) long, had a width of 2.55 m, and was 39.5 m^3 in volume. The full trailer-truck combination consisted of one composite container and two metal containers. The metal container was 3000 kg in weight, 6058 m (20 ft) long, and 37 m^3 in volume. This made the total volume of a full trailer-truck 113.5 m^3 and the tare weight 26 600 kg (including containers). Containers were loaded at the terminal via an open roof by means of wheel loaders with a dumping bucket whose volume is 8–10 m^3.

B. The RFID system

The main goal for the system was to add in-depth traceability to the system and add ability to link product quality and volume measurements to each specific shipment. The issue of traceability can be a challenge in the biomass-logistics chain, because the material is often shredded or bulk material, and it is transported in bare containers and stored in piles in warehouses and outdoors. If the material is not tracked and measured at the time of transport, the opportunity to make measurements is often lost after the moment of delivery when the delivered material is mixed with the material that remains in storage.

Based on the design goals, the following feature requirements were set for the system:

- Gathering, collection, and displaying of real-time information
- Traceability of items and transport vehicles through the logistics chain
- Retaining of the cargo's traceability through the logistics chain, even after transportation has been completed and the cargo moved to storage
- Recording of the locations of storage-chain events as they occur
- Targeting of measurements (e.g., volume, weight, type of biomass, and moisture) at each item of cargo
- Having data-entry devices both at stationary logistics-chain nodes and in transport vehicles

To accommodate the distributed nature of a logistics chain, a cloud-based system was designed during this study, wherein automatic scanner gates and vehicle-driver-operated mobile devices feed in data to the central system. Such a system consists of three distinct parts: a cloud-server system that contains the logistics data and gathers information from each node of the logistics chain, a mobile reader device that can be used in the field, and stationary scanner gates that identify products going through them. While the server system is still centralised, using a cloud-based service has the advantages of scaling and fault-tolerance for redundancy. If one cloud server fails, the server provider removes it from use and ensures seamless fail over the servers. Similarly, if the capacity of one server is no longer sufficient for the system, more servers can be hired quickly from the cloud service provider. If the load varies regularly in line with a predictable pattern, the deployment of additional server capacity can be automated.

The individual parts of the logistics-tracking system communicate with the cloud server, using wireless Internet connections. The reader gate and its control computer can utilise the available wireless local area network (WLAN) access points and mobile networks. The mobile phone that accompanies transport vehicles and is operated by the transportation worker accesses a mobile-phone network. A logistics manager's or warehouse manager's computer can access the current logistics data or examine transportation history by means of any device that has Web access.

By utilising mobile connections to the central cloud server, the various nodes of the tracking system make status updates instantly available to other parts of the logistics chain. This allows the data on the current state of the cargo and the transportation vehicle's location to be updated in real time. The managers and others who rely on having current information about transportation status can also get real-time information because of its instant transmission. For example, a storage station can prepare for incoming cargo without anyone making phone calls to every possible delivery vehicle.

Each type of device has its own interface, tailored for its specific use scenarios. The transportation enterprise worker's smartphone has a phone application that can recognise the cargo by means of an NFC tag and has a simplified interface for entering new-cargo details and measurements. It also automatically sends location and time data to the central server after having recognised a cargo container. The automatic reader gate's control has a simple status-monitoring interface that can show status data quickly yet operates without user intervention and needs no actions on the part of the user for transmission of monitoring data. The Web-based interface, which can be accessed via any browser, is designed for information consumption, unlike the mobile interface, which is meant mainly for input. In addition to access to both current and past transport and cargo data, the Web interface supports administrative functions such as adding new containers, registering tags, and amending cargo measurements if some measurements need to be added or adjusted later.

In the demonstration work considered here, RFID tags were read both by smartphones (NFC) and by reader gates (UHF). NFC-tag type was Outdoor sticker—Trikker-UL CT50, round, diameter, 50 mm × 2 mm, HF 13.56 MHz, writeable user memory size 64/48 bytes, NXP Mifare Ultrlight chip with permanent write protection. UHF-tag type was Confidex Survivor^{TM}, encapsulated EPC Class1 Gen2 compliant passive tag, dimensions 224 × 24 × 8 mm, read range up to 11 m, memory size 240 bit EPC+user 512 bit. Normally, the expected lifetime is many years in normal operating conditions.

A tag was identified first at the terminal by a phone and finally at the plant by a gate-based identifier. The reader gate was at the weighing site of the power plant. Both reading methods had wireless-Internet-based connection to the RfIDER container-logistics system.

With smartphone, it was possible to read tags and feed in load information via NFC technology at the loading location. NFC systems operating in the HF radio-frequency bands worked well with short reading distances. The antenna of the reading gate was fixed equipment installed at the weighbridge and connected to a laptop. The distance between antenna and container tag was approx. 1.2 m. The antenna was mounted at a vertical position adjusted to suit the height of the tags.

The reader-gate equipment included antenna, reader, and laptop (see Fig. 1). It was operated in UHF bands, with a reading distance of several metres. The waterproof tags were installed on the outer wall of the container for both smartphone and reader-gate recognition. For the Supercont® system, two NFC tags were installed for smartphone use and three UHF tags for reader gates: on one external side and two of each on the opposite side. For each metal container, one of each tag was attached to both sides.

FIG. 1. Reading hardware for a reader gate and RFID tags, oblong for reader gate and circular for smartphone.

C. Transport demonstration and time study

All stages in the transport demonstration were time-studied for assessment of productivity. Both driving and breaks during transportation were evaluated, for calculation of effective time consumption. Time consumption of transportation stages was based on RFID-measurements and was stored into RfIDER-system, whereas terminal operations and breaks were observed and stored by researcher. The demonstration began with loading of chipped material onto the container truck at the terminal (Hyötypaperi Oy, Valkeala). The truck was weighed both full and empty at the terminal and power plant, to yield the net load. The truck and trailer portion could be measured separately at the weighbridge.

The transporting cycle proceeded as follows:

- Weighing of the empty container truck
- Loading of containers by a front loader at the terminal
- Weighing of the full container truck and taking moisture-measurement samples—at the terminal
- NFC-based identification by a phone
- Long-distance transportation
- Weighing at the power plant as a full load
- RFID identification by a reader gate
- Unloading of composite containers by means of dumping from the back
- Weighing at the power plant as a empty load

After unloading at the power plant, back-hauling with a municipal recovered fuel (REF) load from local landfill back to supply terminal was performed. Thus, the demonstration represented a round trip as two-way transportation. The back-hauling was excluded from this study. Distances between Valkeala-terminal and power plant in Mikkeli were 100 km and between power plant and landfill 7 km. The whole round trip was 214 km.

Load information was fed in to the RfIDER system after tags' reading by smartphone. The information included load name, source and destination, supplier and end-user name, register number of truck, volume estimate, and measured weight. While the tag was being read, the system registered the time and also the geographical location with reference to Google's map base. Smartphone reading was done during the loading and gate reading during the load's weighing at the power plant (Etelä-Savon Energia Oy, Mikkeli), where the time study ended. As a whole, all time study data were first stored into RfIDER-system and afterwards moved into Excel and further analyzed. Also, the readability of tags of both types was evaluated with both types of container structures.

Each load was unloaded in the fuel-storage area at the power plant, where the truck driver took fuel samples for moisture measurement and carried them out to the fuel-analysis laboratory, next to the receiving station. In this study, also comparative samples were taken during loading and delivered to the supplier's laboratory. Composite samples were collected for all types of raw material, to allow analysis of the heating value of the dry matter and ash content at both laboratories.

TABLE I. Average load sizes and standard deviations for alternative raw-material sources in the transportation demonstration (ST = stumps, LR = logging residues, and EW = small-diameter energy wood).

	Loads as chipped material			
Raw material	Number	Volume (m^3)	Weight (tons)	Energy (MW h)
ST	10	102	34.7 ± 2.0	89 ± 10
LR	10	110	30.0 ± 2.5	95 ± 7
EW	8	113	25.7 ± 5.3	80 ± 6

III. RESULTS

A. Load information

Load sizes and properties of materials are presented in Tables I and II. Volumes in cubic metres were hard to estimate, because of the compression effect after pressing of the load by the bucket of a wheel loader. The volume estimates were based on the situation before compression; therefore, the actual loose volume could be higher than the measured frame volume. This could be seen especially with chipped material from small-diameter energy wood, owing to this having the lowest volume weight. However, the filling rate was good, at 90%–100%. This was estimated by measuring the undersize from the load frame. Loading in this way enabled utilisation of the full frame capacity. With pneumatic blowing or belt-conveyor systems, it would be harder to achieve such high filling rates.

The average moisture content of crushed material from stumps was 44% and chipped material from logging residues and small-diameter energy wood 34%. These measurements were done by the laboratory of the supplier commissioned for this study. The power plant's laboratory obtained the same values, except that the average moisture content for chipped material from small-diameter energy wood was approximately three percentage points lower. On the other hand, the supplier's laboratory found lower heating values for dry matter than the power plant did: the supplier found approx. 2 MW h lower load values for stump material and logging residues than the power plant did, while for small-diameter energy wood the supplier obtained approximately 2 MW h higher load values than the power plant. The difference in single-load energy content between supplier and power plant could have been as great as 20 MW h because of the sampling and measurement arrangements. The measurement of moisture content in this study differed: the supplier used a sample from each load, while the power plant took a composite sample representing several loads. The heating values of dry matter in this study were approximately 5% lower than the values of 19.32–19.36 MJ/kg reported in the literature.[14] Impurities such as soil material can cause such a difference.

In this study, the ash content of crushed material from stumps was 4.5%, chipped material from logging residues 3.9%, and small-diameter wood 0.6%. The ash content of the stumps was typical, because of the soil material mixed with the roots, but with logging residues it was higher than the normal range of 2%–2.5%.[15] If one uses the average moisture content, the volume weight of the crushed material from stumps was 339 kg/l-m^3, chipped material from logging residues 272 kg/l-m^3, and chipped material from small-diameter energy wood 227 kg/l-m^3.

TABLE II. Material characteristics with alternative raw material sources in the transportation demonstration.

Raw material	Calorific value (MJ/kg, dry)	Moisture content (%)	Ash (%)
ST	18.34	43.8 ± 5.9	4.5
LR	18.43	33.6 ± 4.2	3.9
EW	18.31	34.1 ± 11.5	0.55

TABLE III. Average time consumption of work stages during the transportation demonstration—the sites are a biomass supply terminal, Hyötypaperi Oy, Valkeala (HP); power plant, Etelä-Savon Energia Oy, Mikkeli (ESE); and municipal waste-material terminal, Metsä-Sairila Oy, Mikkeli (MS).

Stage	Site	Duration (h:mm)	Share (%)
Loading	HP	00:25	9
Transportation	HP-ESE	01:18	27
Breaks	HP-ESE	00:04	1
Unloading	ESE	00:34	12
Moving	ESE-MS	00:10	3
Loading	MS	00:37	13
Transportation	MS-HP	01:20	27
Breaks	MS-HP	00:22	8
Total		04:51	

B. Time studies

All work stages in the transport demonstration were time-studied to one-minute accuracy. Their actual time consumption and percentage of the total time used are presented in Table III.

One transport cycle lasted, on average, 4 h 51 min. Terminal operations at loading and unloading sites accounted for 34% of the total transport cycle. The share of transport was 66%, wherein breaks accounted for 9%. The transport distance between biomass-loading location (Hyötypaperi Oy, Valkeala) and unloading location (Etelä-Savon Energia Oy, Mikkeli) was 100 km and the average driving speed 77 km/h, thanks to a good highway-type connection between terminals. Return loads as municipal waste material were collected from Metsä-Sairila Oy, Mikkeli, near the power plant.

Unloading at the power plant took 34 min with use of a hook-based unloading system for back-dumping. Biomass flowed away from the doors when the container was cambered by the truck itself (see Fig. 2). Two other containers had to be transferred to truck from trailer before unloading, which meant additional manoeuvring in the unloading yard.

Unloading time could be decreased by means of RFID technology and a separate dumping system for closed containers with an open roof (see Fig. 2). In this case, there would not have been any need for weighing and sampling operations at the power plant if all information needed had been stored on RFID tags. The truck combination should only drive through reader gates for registration. Also, heavy forklift trucks, instead of a dumping system, could have been used for container handling.

According to preliminary tests at the plant yard, the unloading time was 4 min per container. With this speed, the productivity would be 593 loose m^3/h for a container size of 39.5 m^3. The entire full trailer-truck would need approx. 12 min for unloading and 5 min for auxiliary

FIG. 2. Back-dumping of biomass containers (left) and unloading of containers with an open roof by the dumping system (right).

operations such as internal movement and container handling. This would halve the unloading time from that for traditional handling of containers by the truck itself.

C. Productivity analysis

Both loading and unloading productivity of forest chips were measured on the basis of effective time without any delays for all raw-material sources (see Table IV). Half of the chipped material was loaded by a wheel loader at the terminal yard with a bucket size of 8 m^3 and half with 10 m^3. For each load, the number of buckets needed was measured, and average values were tabulated. Moving from biomass piles to the truck combination varied within the range of 10–20 m.

Productivity in terms of energy content (MW h/h) or mass content (ton/h) depended on moisture content, whereas productivity with respect to volume content (loose m^3/h) was independent of moisture. Also, driver expertise and the volumetric efficiency of the buckets explained the productivity.

Unloading of the load at the yard of the power plant was measured for a full-trailer combination carrying three containers. Unloading was done by handling of each container one by one with the hook system of the truck. Unloading started with disconnection of the trailer and ended when all three containers were emptied and the trailer connected again. The average unloading productivity values were 231 MW h/h, 282 loose m^3/h, and 79 ton/h. Because of the above-mentioned additional manoeuvres performed by truck, productivity was lower in unloading in comparison to loading. It was found that chipped material ran out earlier from Supercont® because its surface material, using glass fibre, is smoother than that of the metal container.

D. Container durability

Supercont was designed to withstand loads of up to 20 ton. During the demonstration, load weights varied in the range of 6.7–14 ton. The container wall bulged out approximately 7 cm in the middle because of pressing of the load by a bucket. Wire rope connected to the mounting frame at the upper part of the container would have prevented this. On the other hand, this could have become broken during loading and pressing of the load. The same phenomenon was seen with metal containers, but the return to the original shape was not as complete.

Three weeks into the demonstration, the upper frame was strengthened and a work platform on the outer pull side was installed.

Some scratches appeared on the inner wall and floor of the Supercont container, due to bucket pressing and load-material characteristics. The container was used also for municipal waste-material transportation outside this study; it is this that caused this damage. Also some lightening of the outer resin was found at the corners, but it should not indicate any effect on the durability of the container, merely aesthetic harm.

E. The RfIDER system

The RfIDER system was developed to enable automatic monitoring of containers in the supply chain: to identify containers and assign the necessary load information. Automatic

TABLE IV. Loading productivity (effective time) for chipped material from alternative raw-material sources (ST, LR, and SW).

	Productivity			
Raw material	MW h/h	l-m^3/h	ton/h	Number of buckets
ST	410	472	160	11.6
LR	336	390	91	14.6
SW	370	524	119	13.9

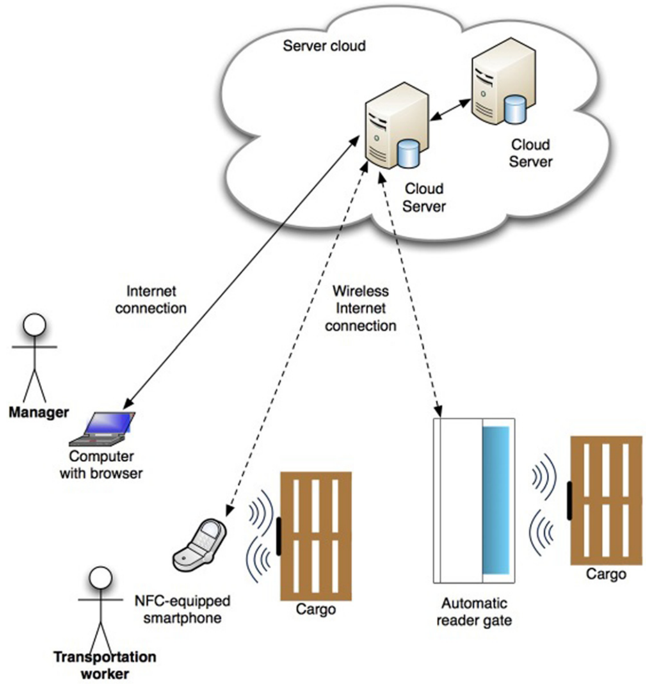

FIG. 3. Data transfer between the RfIDER system and outdoor devices.

monitoring was executed by means of reader gates, which could be installed on sites where container handling is part of the supply chain. In addition to time and location, measurement information was incorporated into the container design. One example is weight information from automatic scales, which could be sent to the RfIDER system.

Information gathered by smartphones and reader gates were sent to a cloud server via an Internet connection, where the data were compiled and stored (see Fig. 3). Via the Internet, it was possible to monitor containers' movements in the supply chain.

During the transport demonstration, the pilot of the RFID system operated as expected and proved it possible to monitor containers automatically through the aid of attached RFID tags. All containers were identified successfully, apart from one exception from among the full set of 28 transport-demonstration runs. The degree of success was in this case 96%. More of the tags attached to the composite container were continually identified than those mounted on the metal containers.

With the aid of this system, location and load information could be collected from the containers during movements in the supply chain, and further information added for the load. Accurate gathering of information and automatic recording of data made it possible to compile load statistics afterward. The statistics could include information on load- or supplier-specific amounts of energy delivered for a specified period.

IV. CONCLUSION AND DISCUSSION

In the study, concentrating on container logistics, both composite and metal containers were compared and the RFID system demonstrated. The aim was to develop the real-time logistics management system RfIDER, which made it possible to register and monitor container loads between supplier and end user. During the demonstration-based study, the usability of the RFID system was evaluated and further developed. Also, time consumption, productivity data for container handling, and information on container durability (Supercont) were gathered during the demonstration.

In total, 28 chipped and crushed loads from stumps, logging residues, and small-diameter energy wood were transported by the full-trailer combination with three containers holding a volume of 113.5 m^3. Because of the high volume weight of the crushed stump material (339 kg/m^3), the load should be reduced by approximately 10 m^3 whereas chipped material from logging residues (272 kg/m^3) caused no problems and chipped material from small-diameter energy wood (227 kg/m^3) did not utilise the full truck weight capacity. The maximum weight limit for road transport (60 ton) for full loads with the container truck would be the limiting factor for moist materials or materials with a high volume weight (>295 kg/m^3). In contrast, for materials with a low moisture content and low volume weight the frame volume would be the constraint as found in this study for chipped material from logging residues or small-diameter energy wood. Therefore, these loads were pressed more by the bucket of the wheel loader for compression. On the other hand, the return load of municipal waste (264 kg/m^3) needed even heavier pressing than chipped biomass material.

With the highest moisture content for stump material, the weight limit for a load, 33 ton, was reached. If all containers were made from composite material, allowing a 3200 kg greater load, the limit would not have been reached. Actually, the moisture content was lower than the annual average values with chipped material made from logging residues and small-diameter energy wood, because of the summer period and good natural drying conditions. There was greater variation in moisture content with small-diameter energy wood than with other raw materials. The reason for this was two originally separate storage sites in the forest, with different drying circumstances before the terminal-storage phase. The stumps' moisture was higher than normally over the study period, because they were lifted in spring and the drying time was shorter than is the usual practice (i.e., at least one whole summer season for drying).

Time consumption in terminal operations for loading and unloading accounted for 34% of the total transport cycle. In particular, the unloading time could be halved through the use of RFID technology and special dumping devices instead of trucks' own unloading devices. For dumping, the closed containers with open roof proved to be a viable option, according to the pilot tests. Unloading productivity (effective time) with such a dumping device (593 loose m^3/h) would be over 300 loose m^3/h higher than with a traditional method using the trucks' own hook system. Such a model of operations would decrease truck queues during fuel-consumption peaks. A separate effective unloading system integrated with automatic identification would make it possible to outsource weighing and sampling operation outside the power-plant area.

During the demonstration, the load weight varied in the range of 6.7–14 ton with Supercont because of moisture variation of biomass material and the effect of compressing of the load. Because of the lack of wire ropes to stiffen the upper structure of the composite container, the walls bulged out, as with metal containers, after loading. After unloading, they would recover except with the distorted metal profile of the upper edge. This could be amended by means of better construction. However, the composite container lasted well regardless of the heavy operations during the loading stage.

The low tare weight of the composite container and the container-truck combination would favour loading sites where the load-bearing capacity of forest roads is the limiting factor for access to the storage sites or high volume weight material, such as pellets or coal. However, the maximum weight limits for the truck combination would prevent full loads with heavy materials. The Finnish Government decided to increase the maximum truck-combination weight from the current 60 ton (seven-axle) to 68 ton (eight-axle) or 76 ton (nine-axle) in Finland in 2013. The larger loads permitted by higher weight limits could also allow loading of denser materials.

RFID technology is well suited to composite containers because of the good accuracy of reading of RFID tags with reader gates. Data can be collected in real time for a centralised information system, to which all users in the supply chain could have access alongside an interface tailored to each special need. The benefits of such an information system include the possibilities for real-time, accurate, and well-allocated information on the containers and their content.

When compared to other parts of the logistics industry, biomass supply chains show increased challenges in transportation, inventory management, and time-sensitivity.[16] The use of RFID in biomass logistics has been examined in other studies, which have found that the use of RFID benefits the logistics chain.[11,12] Areas of benefits cited were identifying, tracking, and locating logistics assets and establishing the chain of custody. The results of this study support these findings.

Interest groups participating in this study and benefiting from RFID-system use are container manufacturers and services providers, logistics and transport operators, and end users (e.g., power plants). The container manufacturer could keep a container-service diary, the logistics operator could evaluate the degree of container-capacity utilisation as a basis for setting of service prices, and the end user could maintain traceability of transported biomass and in real time track the quantity and quality of biomass for each supplier by tagging the weight and moisture information before the reception process at the plant.

One of the ideas of identification could be applied to a large-scale supply chain for biomass logistics. A container with a special tag is a recognisable unit, which allows for use of an external operator to transport containers full of biomass owned by various companies. An operator could be used as a link in a large-scale supply chain especially when the number of containers is massive and other modes of transport, with intermodality, are used. The identification could be done at power plant level simultaneously with weight and moisture measurements. After measurement for each individual container, the verified owner of the biomass can be paid.

The substitution of biomass for fossil fuels in energy consumption is a measure to decrease the emission of greenhouse gases and mitigate global warming.[17] From this perspective, the use of forest biomass for energy is generally acknowledged as being in agreement with the principles of sustainable development. Tracking of biomass loads is important not only for effectiveness control but also for sustainability control. Sustainability criteria for forest-based biomass are topical for proving its climate-change and competitiveness effects in comparison to fossil fuels. The European Commission is preparing a draft directive on the sustainability criteria for solid biomass used in energy production. The greatest threat might be that forest biomass is classified as a fossil source for purposes of emissions trading.[18] Each power plant using forest biomass would be compelled to report the sustainability of each lot of forest chips for the whole life cycle, from the forest to the power plant, along with the decrease in emissions in comparison to fossil fuels. However, Finland tries to avoid certifying systems wherein sustainability criteria should be checked for each lot of forest chips leaving the forest. The existing rules and systems for roundwood should be used also for energy biomass to the fullest extent possible.

In conclusion, added value from RFID technology can be gained as part of complex logistics involving many suppliers, terminals, and modes of transport. The supply chain for composite containers utilising RFID technology could be employed not only for automatic identification to improve cost-efficiency of transportation but also for tracking of each biomass load and to certify sustainable production of forest-based biomass. Still there is further research need to evaluate how this system works in forest conditions, i.e., roadside chipping at forest road, and how in this case the tags should be installed to the residue piles and vehicles and is there need to modify the tag construction.

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