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State-of-the-art survey of biomass measurement technologies in the bioenergy supply chain

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CLEEN Cluster for Energy and Environment   METLA   Metsäteho   FIBIC FINNISH BIOECONOMY CLUSTER

1. Contents

2. Foreword

Six Strategic Centres for Technology and Innovation have been established since 2008 in Finland [96]. Two of them, FIBIC – Finnish Bioeconomy Cluster [31] – and CLEEN – Cluster for Energy and Environment [17] – launched a large national research programme called Sustainable Bioenergy Solutions for Tomorrow – BEST in 2013. The programme aims at building a common understanding of future bioenergy business opportunities and the know-how and capabilities for seizing them. The 34 participants of this research programme are universities, research organizations, SMEs and large companies associated with forestry, bioenergy, technology and consultancy. The BEST programme has five work packages:

- WP 0 Management and international cooperation
- WP 1 Bioenergy scenarios and strategies in global and local scales
- WP 2 Radical improvement of bioenergy supply chains
- WP 3 Advanced integrated concepts and new markets
- WP 4 Enhanced business opportunities through securing sustainability

This report has been prepared as part of the BEST programme in subtask 2.2.5.1 *State-of-the-art survey of measurement technologies for biomass-to-bioenergy conversion and production processes*. The subtask is located under WP 2, task 2.2 *Technological solutions for supply chains* and subtask 2.2.5 *Measurement technologies.* Participating organizations in subtask 2.2.5.1 include Measurepolis Development Ltd as the author responsible for the report, and the Finnish Forest Research Institute (Metla) and Metsäteho Ltd as supporting authors providing text and information for the report. Additionally, the Technical Research Centre of Finland (VTT), and particularly their researcher Matti Virkkunen, provided images and information for the report.

The BEST project is funded by Finnish stakeholders, and thus the focus of this survey is fully on the Finnish bioenergy supply chain. Tekes, the Finnish Funding Agency for Innovation, is the major funder of the project. The research organizations mentioned in the report are predominantly Finnish, because the BEST programme supports the research and development of the future bioenergy supply chain in Finland, although foreign research organizations can act as research partners. Many foreign enterprises are, however, mentioned in subchapter 6.1 as the manufacturers of biomass measurement instruments, as many of their solutions are in use in Finland.

The main goal of this state-of-the-art study is to collate the measurement needs and knowledge of potential measurement technologies related to biomass in the bioenergy supply chain. The report provides information for decision-making and information on potential solutions for measurements carried out in a new terminal concept.

The report covers biomass measurement technologies in Finland from forest measurements to power plants. Chemical analyses and methods are delimited from this survey. The quality properties of energy wood defined by means of chemical analyses in power plant laboratories are mentioned briefly, because in future those properties could be measured by solutions based on new technology and even online.

Biomass is biological material derived from living or recently living organisms. It usually refers to plants or plant-based materials. The survey centres on the most typical Finnish, i.e. forest-based, biomasses (forest chips, logging residues, stumps, industrial chips, sawdust, bark, etc.), but in some cases agrobiomasses are also mentioned.

Some research organizations have researched biomass measurements in the Finnish bioenergy supply chain and provided reports. The VTT Technical Research Centre of Finland, the University of Jyväskylä and the University of Kuopio (now the University of Eastern Finland) prepared state-of-the-art reports on moisture measurement methods in 2007 [45][46]. Metsäteho Ltd published several documents on measurement vision, future supply chains, and moisture measurement technologies of wood material [37][52][66][80]. In 2010 Metsäteho updated the research and development programme of wood material measurements. In the most recent programme, the development of bioenergy measurement methods has a more important role than before [34][38]. The Finnish Forest Research Institute also published a review of measurement needs and developing trends of forest-based biomass [81]. Also in Sweden, the researchers of Mälardalen University published a review of the moisture measurement methods of wood chips that were meant for the power plants in 2004 [77].

The government has legislated for the measurement of wood material and energy wood measurement was included in the law from the beginning of the year 2014 [54][60]. Additionally, the Finnish Forest Research Institute has provided a regulation for the measurement of wood material [58][68][69]. The wood fuel quality instruction “Puupolttoaineiden laatuohje” was also updated in 2013 by VTT [4].

3. Current measurements in the forest-based biomass supply and processing chain

The supply chain for a forest-based biomass starts in the forest. First, the stand is cut by harvester or manual felling. After the cutting, the produced biomass is transported to the roadside storage by a forwarder. The supply chain continues with long-distance transportation by truck, train or even ferry. The biomass is transported either into the biomass terminals or directly into the end usage points such as power plants or biorefineries. The processing chain might change according to the used material. For example, the logging residues are chipped at the forest storage, at the terminal or at the usage point. Conversely, the stumps are mainly crushed at the terminal or at the usage point. Image 1 shows an example of the supply and processing of logging residues. After the cutting, the logging residues are forwarded next to the forest road where they are typically chipped and placed into the container of the transportation vehicle. The vehicle transports the chips to the power plant where they can be processed and burned. [99]

Image 1. *The supply chain for logging residues where chipping is done at the roadside storage. (Image source [3])*

Forest-based biomass can be measured in several locations within the forest-based biomass supply chain described above [57]. Measurements can be made:

- in forest
- at roadside or terminal storage
- during cutting, chipping or crushing of wood material
- within forest transportation or long-distance transportation and
- at the location of end usage.

3.1 Measured properties and quantities

Several properties of the forest-based biomass are measured during the biomass supply chain from forest to power plant. Mass and volume are typically the main measurement properties of the biomass. The moisture content of the biomass is, however, the most important property which can be estimated from the volume, mass and information of the species. Direct moisture measurements are done later in the supply chain. The moisture content is normally determined by sampling at the plant. At the power plant or biorefinery, quality properties such as particle size, foreign particles, ash content, etc. of the biomass are measured in more detail. [4]

3.1.1 Preliminary measurements of the forest stand

The measurement chain of the stand usually starts with the forest inventory and during the forest planning. Manual measurements are taken from the sample plots which are used to estimate the total volume of the trees on the stand by tree species and timber assortments (logwood, pulpwood, energy wood). The diameter and height measurements can be taken for example with electronic calipers [63] and Vertex ultrasound hypsometers [33]. A relasc[[ope is used to estimate the basal area of the stand per hectare. The manual measurements produce information about the volume of the trees and which species are available. The measurement information can be linked into the satellite tracking and map-based software used in forest planning [105].

The forest stand information can also be measured with aerial-based laser scanners (LIDAR), satellite and aerial images. LIDARs are used to estimate the volume of the forest biomass and detect the geographical detail of the stand [35] [51]. Satellite images are used to estimate the volume of the biomass and to determine the different species in the stand [36]. LIDAR measurements are mainly used for large-scale forest regions. In the manual and automatic inventory, information about the amount of the wood biomass can be estimated [57]. Therefore, the first commercial value of the stand can be determined by the forest planning and forest inventory.

3.1.2 Measurements during harvesting

The harvester (Image 2) measures length and diameters greater than 4 cm of each stem and calculates the volume of the produced stems for preliminary classification. Stems are classified as normal logs, small logs, and pulpwood and the rest of the material (i.e. logging residues) is mainly classed as energy wood. The harvester cannot measure the actual amount of logging residues which has to be estimated by harvester measurement data or models. The crown mass is usually estimated from the stand information and the number of stumps from the ratio of cut trees per area. The communication standard StanForD 2010 allows users to decide whether the logging residues are determined and saved for each log separately [83]. Usually small-diameter stems, stumps and remaining logging residues are used as energy wood. In some cases even large-diameter logs are used. In the case when the log is affected by rot fungus, the log usually goes for energy wood.

Image 2. *The cutting process on the stand (Image source: Jari Lindblad, Metla)*

After the felling of trees, the produced biomass is collected and transported to the roadside storage by the forwarder (Image 3) where it can be stored and processed before long-distance transportation. The forwarder uses a load scale to obtain the mass of the harvested timber and the rest of the logging residues. Today, the load scaling has displaced the previous manual road side pile measurements for the energy wood [49]. [65]

Image 3. *The forwarder piling the logging residues on the roadside storage (Image source: Jari Lindblad, Metla)*

3.1.3 Measurements at the roadside storage

For energy wood, the measurements at the roadside storage are currently very limited. The measurements are mainly done for small-sized stem piles from the thinning. The piles can be measured by the manual pile measurement method to obtain the frame volume of the pile. Pile measurement is slow and quite expensive, thus it has been replaced by the load scale measurement The solid volume of the biomass can be determined from the mass-based load scale measurements or from the frame volume of a pile or a container by means of transformation coefficients based on the regulations given by the Finnish Forest Research Institute [69]. There are different coefficients for different types of wood such as crown mass, stems, stumps, industrial chips and forest chips which can be selected, according to the regulations. When the chipping is done for the logging residues (Image 4) the amount of wood is determined from the frame volume of the container and a suitable transformation coefficient from the regulations [69].

Image 4. *Chipping the logging residues at the roadside storage. (Image Source: Jari Lindblad, Metla)*

3.1.4 Measurements at the plant gate

The main measurement for biomass transportation is weighing, achieved via the weighting bridge. Transportation trucks with loads are weighted when they arrive at the gate. After scaling the energy wood is unloaded at the terminal or plant storage. Samples for the laboratory analyses are collected either by the driver or by automatic methods. The weight of the truck is also measured after the unloading to obtain the total weight of biomass.

The volume of the chips can also be measured from the container of the transportation truck. The volume is determined from the width and depth of the container and by measuring the height of the load. The solid volume of the load is estimated from the volume of the load and the common conversion factors given by the Finnish Forest Research Institute [69]. For example, the common conversion factor for forest chips is 0.40. Also, automatic laser scanner devices are used for measuring the volume of forest chips in the truck [111]. [46]

3.1.5 Laboratory measurements at the plant

Quality properties such as moisture content and other chemical analyses for the biomass are mainly determined from samples of the deliveries. The samples can be collected manually from the load with a shovel or can be taken automatically from the load, falling material or conveyor belts. A representative sample is hard to determine from chips or sawdust, because the moisture content can vary. The delivery could include various wood species and types, which makes the sampling even more problematic. The Scandinavian SCAN and European EN standards define the sampling and preprocessing for the industrial wood chips [86][92]. VTT has published a quality guide with instructions on how to take a representative energy wood sample correctly [4] and how to apply the related EN standards [44]. The quality of the biomass is typically high in a dry and homogeneous mass with a high heat of combustion and without nonflammable components such as soil. Thus, the quality of the forest chips made from the logging residues or stumps is usually poor compared with the chips which are made from the tree body. Green matter and alkaloids in the logging residues will affect the burning process and increase the erosion problem of the boilers. The reliable measurement of high-quality biomass properties is easier in comparison with low-quality biomass.

The main property of biomass is the moisture content. In the laboratory the moisture content is determined by the oven-drying method [4] defined e.g. in international ASTM standards [6][7], European CEN standards [15] and, for industrial wood chips, in Scandinavian SCAN standards [84]. The samples are weighted before and after drying to obtain the dry mass. From the dry mass the energy content can be determined by means of the reference table generated for different types of wood classes and species [4]. The moisture content determination is a relatively time-consuming process and the result for energy content may be obtained after the wood is burned or processed.

Biomass samples are collected and analysed according to the various EN and ASTM standards. The collection of the samples is defined by the EN standard [92]. The main properties are the moisture content [6][89], bulk density [8][93], particle size [94] and energy content [6][24]. Typical properties shown in chemical analyses are ash content [9][90], sulphur content [25], chlorine content [25] and nitrogen content [26]. Other heavy metal compounds are analysed by [27] and [28].

The chip and dust particle size is an important factor in the burning and refinery process. The particle size of industrial chips is normally determined by sieve series according to the SCAN standard [85]. The sieve series includes sieves with different sieve openings which are used to determine particle sizes. The larger openings are at the top of the screen and the sizes decrease with each level. The smallest particles go through all the sieves to the bottom of the sieve series [94]. The sieving process used for forest chip/wood fuel is described in the quality instructions of VTT [4]. Additionally, optical machine vision systems based on laser or camera technology for online chip size measurement above the conveyor are available on the market.

4. Measurement needs for future terminal concept in the biomass supply chain

A biomass terminal is part of the logistical chain ranging from a forest stand to a power plant. Different terminal types can be distinguished: raw material storage, storage for ready-made fuel and fuel production terminal. Stores of fuel raw material and ready-made fuel in terminals act as buffers and increase the security of supply during seasons challenging to forest operations as well as during peak load times. Other benefits of terminals include the optimal and manageable utilization rate of machinery, improvement of fuel quality during storage by reduction of the moisture content of the material. In a larger perspective terminal operations may also even work out the load fluctuations of machine operators, and the material can be processed and transported outside peak load season.

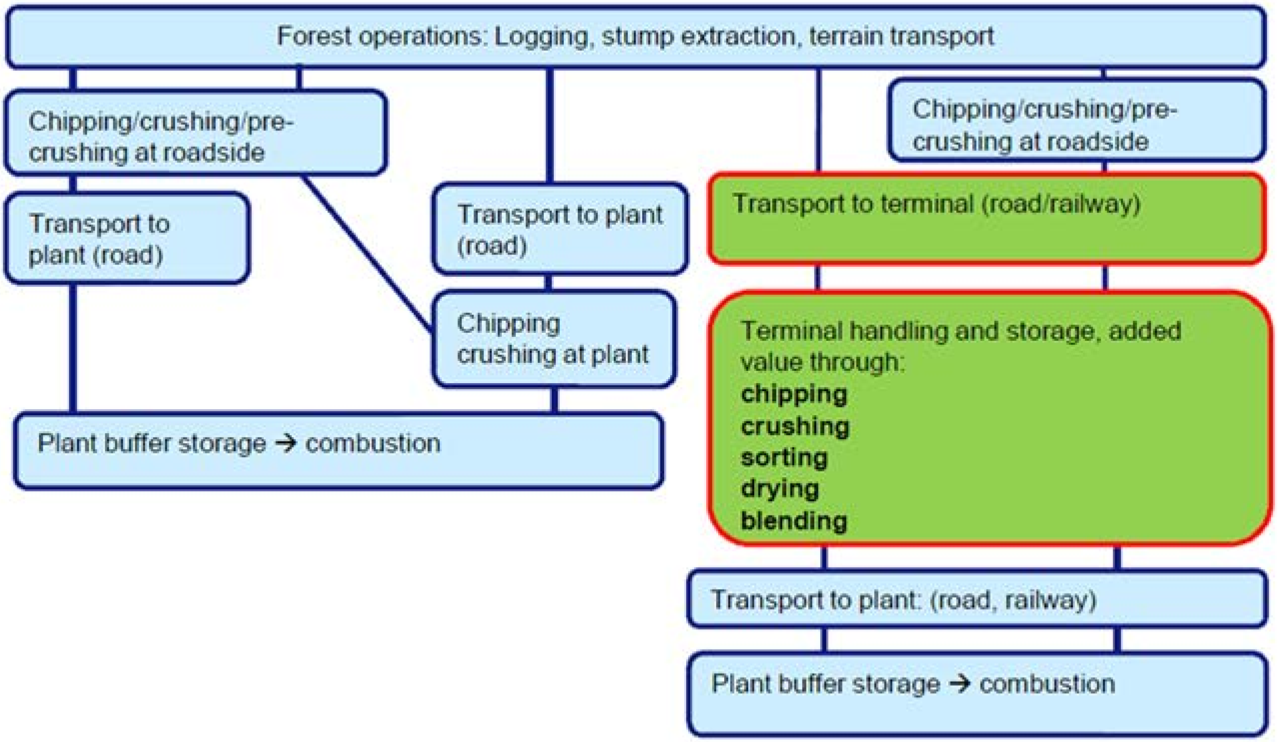

Image 5*. A flowchart presenting conventional biomass supply chain(s) on the left hand and future biomass supply chain(s) through the terminal concept.*

The new terminal concept study in the BEST programme will seek optimal solutions for the operations that take place within terminals. Whereas current terminals operate at levels of 10-200 GWh of produced fuel per year, the aim now is to study larger units up to 1000 GWh/year, depending on user requirements and regional biomass fuel availability. The best available purpose-built machinery will be studied for processing and handling the material.

Logistical benefits can be obtained when the terminal is located near highway crossings or junctions between transport modes (e.g. truck-railway or truck-barge/dry bulk ship). Truck transports dominate the current biomass transports, but there is huge potential in the increase of railway transportation of fuel raw material and ready-made fuels. As transport distances become longer, the benefits of economical railway transport should become more and more apparent. The terminals equipped with railroad connections will probably be combined terminals for industrial round wood and wood and agro biomass. Also, railway transport of biomasses and industrial round wood are likely to be combined. This poses a challenge in terms of space requirements, measurement of materials and storage management in the terminals.

The new terminal concept also creates new demands and requirements for the measurement of raw material. In the future, there will be a need to measure or estimate moisture content of biomass at every stage in the supply chain – at the roadside, at the terminal and at the plant. Nowadays, 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 optimized and the quality of the raw material of biofuel can be improved.

The moisture content is therefore one of the most important features of biomass throughout the bioenergy supply chain, but today moisture content is measured only in a few locations in the supply chain and typically measurements are taken from small samples in comparison with biomass load/storage. Therefore, novel measurement locations, methods and even technologies are still needed. Measurements should be taken as part of the logistics chain. Automatic measurements may increase the value of the biomass during the processing. If the raw material moisture content can be monitored and modelled online before the burning process, the quality of the incoming biomass can be improved. In addition, if the preliminary data such as weather information can be combined in the supply chain, this could increase the prediction possibilities for the moisture content and other quality properties. The preliminary information can be used for storage as well as usage planning and optimizing of deliveries. Some larger corporations already use the preliminary information on a small scale to predict the moisture content of the biomass pile.

Particle size and foreign matter are also becoming increasingly significant. Especially in biofuel production the monitoring of the quality of the raw material is very important. The raw material should be uniform in terms of particle size and freshness. The most important development needs of the biofuels are related to controlling the process with various types of online measurement systems at the biorefinery – the moisture content before and after drying and the particle size of saw dust. Also, if it is possible to reduce the amount of foreign matter by processing material in terminals, we can save in transportation costs and also on the burning process. Therefore, it is important to develop online systems to measure the foreign matter in terminals and in power plants.

Especially for terminals of the future there is a need to develop cost-effective measuring methods for biomass and the most important measurable variables are weight, moisture content, volume and foreign matter. Nowadays almost all trucks are equipped with a loader scale – the volume derived from the weight is used as the basis for payment and the weight to avoid overloading. Also, in the new terminal concept the weighting will be the main method for controlling and measuring the incoming and outgoing material. The best-available purpose-built machinery should be equipped with scales and the moisture content must be determined for each lot online. Possibly the weight and the moisture content will be measured by scales and moisture sensors in a chipper loader.

Fast moisture measurement for the biomass at the roadside or smaller terminals is still lacking. Handheld moisture measurement devices with electric operating principles cannot measure high (more than 50%) moisture contents reliably, and the real moisture content may be higher. Therefore there is a need for device which makes it possible to measure the moisture content (30-75 %) of the raw material (chips and sawdust) all year around at the roadside and in terminals. Samples can be taken for example by a chain saw in a grapple or during chipping.

The goal should also be for laboratory measurements to be replaced with fast measurements during the process. This would make it possible to develop feedback systems so that the driver can get quality reports online and the quality of the raw material can be improved.

5. Measurement technologies in the biomass supply and processing chain and terminal concept

5.1 Measurement technologies

A large variety of technologies is used in the biomaterial supply chain from the forest to the end usage location. Subchapter 5.1 lists and describes the technologies used in measurement instruments for raw materials of biomasses. Operating principles of measurement instruments can be electric, i.e. based on resistance, impedance or capacitance of the material. Measurement can be based on electromagnetic radiation (Image 6) such as visible light, IR/NIR technology, microwaves, X-rays, laser technology, NMR technology or magnetics. Even acoustic methods have been applied in biomass measurements. All the previous technologies have been applied in commercial products. A neutron activation method has been researched for forest-based biomasses, but commercial products are currently available only for other types of materials. Terahertz radiation is the latest frequency range of electromagnetic spectra applied for industrial purposes. The typical terahertz applications are associated with security issues, but the technology has also researched moisture measurements. Applications for forest-based biomasses are not yet available, however.

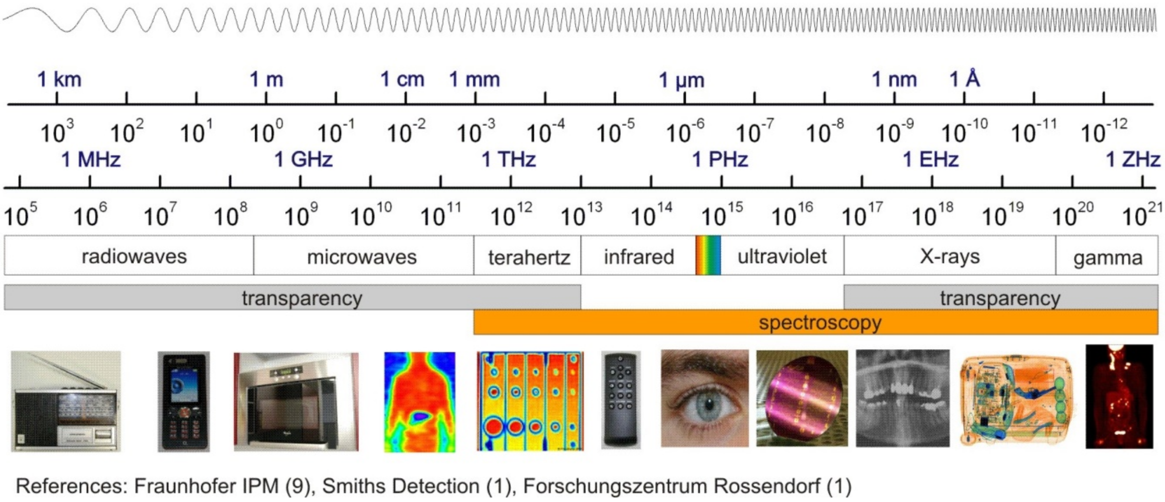

Image 6. *A diagram of the electromagnetic spectrum showing frequencies and wavelengths and some applications. (Image source [108].)*

The most important properties that need to be measured are the mass, volume and moisture content of the biomass unit in several locations within the bioenergy supply chain. If these properties are known with adequate accuracy, the heat of the combustion and thus the commercial value of the biomass unit can be estimated quite well. Additional properties that are typically measured further along the chain include foreign particles, particle size, colour or brightness and sometimes the bark content of biomass. The mass of the biomaterial is measured in several locations. The mass is obtained via the bridge scale, vehicle scale or loader scale in forwarders, trucks and wheel loaders. The mass loss is measured with laboratory scales during the oven drying. There is no subchapter on weighting measurements in Chapter 4, because the scales have several operating principles. Thus weighting measurements are categorized in subchapters 5.1.1 and 5.1.11.

5.1.1 Electric measurements

Electric measurements have been applied in wood assessment for decades [41]. Typically, these are resistance- or frequency-dependent impedance (affected by resistance, capacitance and inductance) measurements with two electrodes. Variation in impedance is interpreted as variation in wood material properties. The simplest electric measurement system for a wood sample uses the resistance of the sample. Because the resistivity of wood is highly correlated to the water content of the sample, resistivity measurement may serve as moisture measurement. According to James's review of electric moisture meters in 1988 [62], the first resistance-based moisture meters were tested as long ago as the 1920s. Today, capacitive sensors have overtaken resistance-based moisture meters as electric measurement instruments. Capacitive sensors generate an electric field between the sensor plates. The capacitance of the sensor changes according to the changes in the dielectric properties of the wood sample (e.g. because of moisture variation) located between the sensor plates. [41]

Many scales use an electric operating principle. A variety of electric scales is used to evaluate amount and moisture content of bioenergy quantity by mass measurement. Electric scales range from large truck scales to small laboratory scales used in the oven drying method. Typically electronic scales are based on strain gauges or piezoelectric crystals.

5.1.2 Measurements with VIS cameras

The wavelength of the visible light is between 380 and 780 nm in the electromagnetic radiation spectrum [11]. The invention and commercialization of digital cameras have boosted forest-based industry measurement applications and many other fields as well. Most of the visible light cameras used in industrial applications are line scan cameras located above a conveyor belt. Since the early 2000s colour cameras have been replacing grey scale cameras in many applications.

Machine vision cameras operating in the visible light range can measure a variety of forest-based biomass properties: foreign particles, volume flow of the biomass, lightness and particle size of wood chips. Camera-based measurements are surface measurements, and thus they can analyse properties visible to the naked eye. Even surface moisture of biomass flow can be evaluated with VIS cameras, although the IR-spectrum band works better thanks to high absorption peaks in NIR-band wavelengths [16]. Stereoimaging can be done with two or more visible range cameras and the system can measure 3D profiles and thus volumes of the object [20]. Self-evidently, the lighting must be good for machine vision applications.

5.1.3 Measurements based on IR cameras

Electromagnetic radiation with wavelength from 750 nm to 30 µm is called infrared radiation. The infrared band just above visible light from 750-2000 nm is called near infrared (NIR). All objects above the absolute zero temperature emit infrared radiation. Thermal imaging measures infrared radiation with a matrix sensor: a thermal image shows the temperature variations of the object. Water can effectively absorb specific IR wavelengths and is applied in moisture measurement devices [16]. Applications are available e.g. for forest-based biomasses in both laboratory and online devices. IR radiation cannot, however, penetrate deep inside the object/sample, so the moisture measurement produces the surface moisture content of the object/sample. The colour of the biomass may also affect the IR-moisture measurement.

5.1.4 Microwave technology-based measurements

In the electromagnetic spectrum microwave frequency is between the frequencies of terahertz waves and radio frequency waves, i.e. roughly between 1GHz and 100 GHz, or wavelengths between 3 mm and 1 m [1]. The borderline between microwaves, terahertz waves and radio waves has not been precisely defined, however.

Microwaves excite vibrations in polarized molecules, such as water molecules. The rate of microwave power absorption in most materials is proportional to the water content of the material. This property is familiar from microwave ovens. Thus microwave devices have been applied in moisture measurement and also in forest-based biomass moisture measurement. In addition to moisture content, the other properties of the material to be measured (e.g. particle size, density, temperature) affect the microwave propagation, so measurement instruments typically require a calibration sample set for each material. Some enterprises offer microwave-based moisture measurements in both laboratory instruments and online instruments at the conveyor belt. [10][19][97]

5.1.5 X-ray and gamma ray technology-based measurements

X-rays are electromagnetic radiation with high energy, high frequency and short wavelength. In the electromagnetic spectrum X-rays are located between ultraviolet (UV) and gamma rays, i.e. between wavelengths from 10 nm to 0.01 pm. Gamma radiation is the radiation with the highest frequency and energy and the shortest wavelength (below 10 pm). X-ray imaging was first applied in medicine in the 1890s. An X-ray (or gamma ray) source emits the radiation through an object to detectors. The radiation is attenuated depending on the internal characteristics of the object. Thus a transmittance image reflecting these characteristics of the object is generated. X-rays are applied to biomasses to detect foreign particles and used in volume flow and moisture measurements in both online processes and laboratory environments. X-rays can also evaluate the homogeneity of the biomass. Gamma rays can be used like X-rays and measurement instruments based on gamma radiation are in use in industrial applications. Gamma radiation-based measurement applications for biomasses were not used during the survey, however. Both gamma rays and X-ray systems need effective shielding because of ionizing radiation which is harmful to people. Because X-ray (and gamma ray) systems are based on mass absorption, a thin biomass layer and the deviation of biomass density cause problems in moisture measurement. [5]

5.1.6 NMR-based measurements

Under the influence of a static external magnetic field, magnetic moments in nuclei with an odd number of protons and/or neutrons are aligned with the external magnetic field instead of being randomly ordered in the absence of the field. This alignment is tilted with an RF pulse. After switching off of the RF pulse, the nuclei with a specific resonance frequency (Larmor frequency) precess into the alignment with the external magnetic field inducing a signal that is detected. This phenomenon is called nuclear magnetic resonance (NMR) and it creates the basis for example for magnetic resonance imaging (MRI), a highly sensitive method in medical imaging and diagnostics. The Larmor frequency is chemical element-dependent gyromagnetic ratio. NMR technology is applied for biomasses only in laboratory moisture measurement devices. The technology is quite new in the bioenergy sector: the first NMR product for the moisture measurement of biomasses came onto the market in 2013. Ferromagnetic objects in measurement samples may decrease the quality of the NMR device measurement results. [56]

5.1.7 Measurements based on magnetism

Actual measurement instruments based on magnetism are not in use in the biomaterial supply chain, but the devices are rather like on-off-type detectors producing information about the presence of ferromagnetic particles in the biomass flow. Magnets have been used for a long time in sawmills to detect unknown metallic particles in logs before sawing. Similar systems are applied in conveyors transporting bioenergy raw material before e.g. storing at the power plant or before further processing, e.g. crushing of wood-based material. The simplest systems only collect small ferromagnetic particles from the biomass flow without providing any information and the particles must be removed from the magnet by hand now and then. Obviously, these devices are not very reliable in terms of recognizing foreign particles and materials, because they cannot detect non-ferromagnetic metals and other foreign particles such as stones.

5.1.8 Measurements based on laser technology

At present laser illumination is one of the most common measurement techniques for machine vision applications in industrial measurements. The two main approaches are passive and active lasers. Passive laser measurement requires a device that projects a straight laser line of high accuracy and intensity on the object. The laser line is photographed and the shape of the object surface is obtained from the shape of the laser line. When the object moves under the laser, a 3D model of the object can be constructed from the individual profiles. Typically, at least two laser-camera combinations located on different sides of the object are required to cover the object. Such multiple laser-camera solutions have been applied in several industrial applications. One camera-laser pair can be enough for material flows such as chip wood on a conveyor belt and such solutions are available in the market. The system works well in dark environments, where laser light lines are clearly visible to cameras.

The active laser-based methods measure the distance to an object. The measurement is usually based on the time of flight of a laser pulse, but it can also be based on the phase shift between the emitted and the reflected laser pulse. If the laser distance measurement is swept along a line across the object, the laser device provides the 2D profile of the object. The 3D profile is generated with distance measurement by sweeping the laser above a moving object, for instance above a conveyor belt. It is possible to create a 3D profile by sweeping the laser in two directions, x and y, if the object stands still. Active laser-based solutions are applied in measurement of bulk mass volume (e.g. wood chips and coal) and roundwood volume in the truck load, for stockpile volume measurements and also for mass flow measurement above the conveyor.

5.1.9 Measurements based on acoustics

Even acoustics have been utilized in the quality analysis of forest-based biomasses. Typically acoustic forestry and wood measurement applications evaluate strength and firmness of standing trees or sawn planks and boards using acoustic sensors. Strength and firmness are not important properties of forest-based bioenergy, however. The only bioenergy measurement based on acoustics carried out during the survey detects foreign particles in biomaterial flow. Wood chip flow is dropped on an acoustic detector plate, and foreign particles such as stones, metallic particles and ice blocks are detected because the sound is different from normal.

5.1.10 Measurements based on neutron activation

Neutron radiation has been applied in industrial moisture measurement. Radiometric moisture measurement is based on interaction between neutrons and the hydrogen atoms of water in the material to be measured. In industrial applications neutrons are generated typically by a small particle accelerator or radioactive isotopes. The interaction decreases the energy of neutrons, i.e. changes the hot neutrons to cold, thermal neutrons. The thermal neutrons are detected with a detector sensitive to them. The neutrons are absorbed, if the neutron energy decreases sufficiently. The absorbed neutrons typically produce a gamma radiation quantum that can be detected. Thus the amount of the thermal neutrons and the amount of the absorbed neutrons (emitted gamma quanta) reveal the inner properties of the material. In the PGNAA (prompt-gamma neutron activation analysis) only the gamma radiation quantums are detected. [21][78][79]

The neutron activation method has been researched for moisture measurement and the PGNAA method even for wood-based biomasses [78]. A US company, the Acrowood Corporation, even had a commercial industrial online application based on neutron activation called Drywood on the market a few years ago [45], but the information cannot be found any more. Apparently, the appliance of the technology is challenging, because wood and biomaterials are mostly hydrocarbons with a lot of hydrogen atoms. [110] [12]

5.1.11 Mechanical measurements

Some biomass properties are still evaluated by means of mechanical measurements. A typical instrument in the bioenergy supply chain is scale. The operating principle of e.g. bridge scales can be mechanical, although electronic truck-scale instruments are also available (see section 5.1.1). Mechanical scales can be implemented by means of springs or counterweights. Hydraulic or pneumatic scales are also classified as mechanical measurement instruments. [113]

5.1.12 Measurements based on terahertz waves

Terahertz (THz) radiation is part of the electromagnetic spectrum located between microwave and infrared radiation. Terahertz waves cover wavelengths between 30 µm and 3 mm. Research on terahertz waves is quite a new area. The properties and industrial possibilities of terahertz waves are only now being researched. Currently, terahertz radiation is applied in security instruments at airports and in medical imaging devices. Communication between satellites and aircraft with terahertz waves is under study. Additionally, terahertz waves have been researched for moisture measurement of different materials, inter alia for hardwood leaves [76]. Wood materials and other wood-based biomasses were not tested, however. [108]

5.2 Biomass measurement technologies in the future

New methods for determination of the moisture content of biomass have become commercially available in recent years. Some of the most promising methods are NMR and microwave-based measurement instruments which could even displace the oven drying method in the future. NMR technology has been reported to be fast and the devices perform well compared with oven drying [43]. In addition to moisture content, the NMR method could one day be used for detecting other chemical compounds as well.

Novel laser scanners can produce more information for aerial imaging than earlier versions. Older laser scanners sent a laser pulse and received a single response from the object and this was the distance information. Today the device can receive several response pulses from different distances for a single laser pulse sent. Thus this information can produce information of the forest type. The same property can also reveal the compactness of the object, e.g. forest residues in field storage or in a truck load.

Measurements during storage and transportation could be a future application. The moisture content of the unprocessed or chipped wood material could be measured or estimated by multiple burnable moisture sensors attached inside the biomass pile at the roadside storage or in a truck. The sensors could form a network and adjust the moisture determination. VTT has developed such wireless sensor networks for temperature monitoring inside the bulk mass pile. Even the temperature measurement inside the biomass pile can reveal the quality reduction of the biomass unit in storage.

The moisture content and foreign particles could also be detected during the chipping process. The biomass flow caused by the chipper or crusher could be analysed by optical and acoustic methods during the truck loading. For example, NIR-based methods could be used to detect the moisture content of the passing biomass in the blower of the chipper and acoustic methods could be used to detect foreign particles such as rocks before chipping.

6. Measurement technology actors in the biomass supply and processing chain

Chapter 6 lists the most notable actors who provide research and development services as well as commercial instruments related to measurement technologies for biomasses. Subchapter 6.1 lists the enterprises with biomass measurement instruments on the market. Subchapter 6.2 describes the most important research units from the Finnish perspective.

6.1 Enterprises

The most notable companies which offer measurement instruments for biomasses are listed in subchapter 6.1. The subchapter is divided into four sections according to the use of the moisture measurement instruments: handheld devices, laboratory instruments, online solutions and plant field measurements such as truckload measurements. The fifth section lists the companies which deal with measurement of biomasses.

6.1.1 Enterprises providing handheld devices

The Finnish company Farmcomp Oy offers a variety of handheld moisture measurement devices for wood and agrobiomasses. All products are listed under the brand name Wile and moisture measurement is based on capacitive measurement technology. One of the Farmcomp solutions for wood material moisture measurements is Wile Bio Moisture, which can be used for wood chips and logging residues. The moisture measurement range for the chip wood material is 12-40% and for logging residues 30-70% respectively. Another solution for wood material is Wile Bio Wood, which measures the moisture content of sawdust and wood pellets in range of 15 to 65% and 4 to 23% respectively. [30]

An Austrian company, Schaller GmBH, markets a number of moisture measurement devices for several industrial or environmental purposes under the brand name Humimeter. Moisture measurement applications with Humimeter devices can be used for climate or environmental purposes, and in food, bioenergy, material, building and paper measurement. Schaller offers handheld and online measurement solutions and also laboratory instruments. As regards forest-based biomasses, Schaller offers several laboratory and handheld moisture measurement devices for wood chips, wood shavings, pellets and round timber. Online solutions for wood chip moisture measurements are also available. Schaller does not mention the operating principle of its devices in its webpage and brochures, but that of some Humimeter models can be found e.g. on retailers' webpages. Operating principles for five Humimeter measuring instruments for a field of bioenergy were found. In all five cases the instruments were electric. The operating principle of instruments for wood chips and similar material was capacitive. For solid woods and standing trees they used resistance/conductance-based devices [87]. A German company, ACO - Feuchtemesssysteme und Industriekomponenten, offers similar handheld moisture measurement instruments [1]. ACO is assumed to be the manufacturer of the instruments and Schaller an additional dealer operating under the brand name Humimeter.

6.1.2 Enterprises providing laboratory devices

Measurement devices based on IR radiation

The US company MoistTech has manufactured both online and laboratory moisture measurement instruments based on near infrared (NIR) technology. The company offers NIR-based moisture measurement instruments for several application areas: food, chemicals, minerals, tobacco, renewable energy, paper, textiles, cotton, wood, wool, leather, etc. It must be remembered, however, that NIR-based measurements detect the moisture on the surface of the object and it is not always equal to the inner moisture content. MoistTech's laboratory instrument, 868 Laboratory NIR Moisture Analyzer (e.g. for wood chip measurement) in *Image 7*, can be adjusted in moisture content range of 0 to 90%. [75]

Image 7. IR technology-based laboratory device MoistTech 868 Biomass Moisture Transmitter for surface moisture measurement of wood chips. (Image source: MoistTech Corp.)

Measurement devices based on microwaves

The Finnish company Senfit Ltd provides both online and laboratory-level material moisture measurement instruments based on microwave technology. Senfit offers BMA, a desktop moisture analyser for biomass moisture measurement *(Image 8).* The moisture measurement range of the device is 0 to 70% and the sample of 400 grams must be taken by hand. The temperature of the sample should be between 10 and 30 C° and measurement time is less than a minute. The particle size should be under 31 mm x 31 mm, but the company offers a crusher to decrease the particle size of the sample. The Senfit BMA desktop moisture analyser is calibrated for different material types using oven-dried calibration samples. [88]

Image 8. Senfit BMA desktop moisture analyser based on microwave technology. (Image source [88].)

Measurement devices based on NMR technology

The Finnish company Metso presented the first material moisture measurement device based on nuclear magnetic resonance (NMR) technology in 2013. The laboratory moisture measurement instrument Metso MR moisture uses a sample size of 0.8 litres and it measures moisture content between 10 and 90 % with accuracy of ±1% *(Image 9).* Moisture measurement of the biomaterial sample takes about two minutes. The calibration of the MR moisture is rapid and simple. It uses empty and water-filled containers. [71]

Image 9. Calibration of Metso MR bulk material moisture measurement instrument.

Measurement devices based on X-ray technology

The Swedish company Mantex Ltd produces both laboratory and online devices for different biomaterial measurements based on X-ray technology. The core of the technology is dual-energy X-ray absorptiometry. The laboratory X-ray instrument Mantex DesktopScanner *(Image 10)* is marketed as suitable for moisture measurement of wood chips, bark, pulp, recycled wood and paper, coal, waste and sludge. The moisture measurement range of the instrument is not mentioned on the company’s website, but accuracy is said to be better than 2% and precision higher than 0,7%. [62]

Image 10. The X-ray technology-based laboratory instrument Mantex Desktop Scanner. (Image source: [62].)

6.1.3 Enterprises providing automated measurement devices

Measurement devices based on capacitive sensors

In addition to handheld moisture measurement devices, the German company ACO manufactures capacitive material moisture measurement sensors for online applications. ACO MMS-1 and MMS-2 can be attached in the wall of a container or pipe and capacitive sensors provide the moisture information. Measurement range is freely adjustable and the accuracy of the moisture measurement is 0.1% in comparison with the laboratory measurements. The diameter of particle size of the material is required to be below 12 mm. [1]

Measurement devices based on VIS cameras

The Finnish company Teknosavo Ltd has produced a number of online solutions for forest biomass measurements with the emphasis on machine vision and camera-based instruments. The RGB camera-based ChipSmart^{TM} measures online the lightness of wood chips, bark content, surface moisture, particle size distribution and volume flow of wood chips above the conveyor belt. [102]

Measurement devices based on NIR technology

In addition to laboratory instruments, the aforementioned MoistTech enterprise offers online solutions for material moisture measurements as well. A typical model for the online moisture measurement of fuel wood is MoistTech Online IR 3000 *(Image 11)*. MoistTech's websites state that the typical measurement range for such NIR-based online devices is 0 to 20% moisture content with 0.1% accuracy. [75]

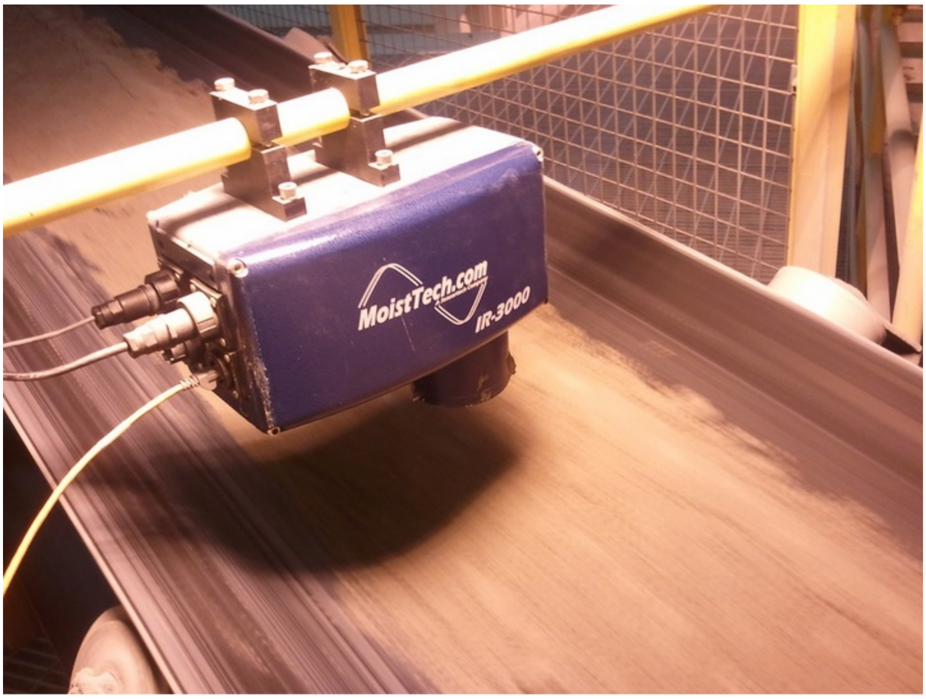

Image 11. The MoistTech IR-3000 near infrared sensor measuring online moisture content of wooden material. (Image source [75].)

The Swedish company Bestwood Ltd offers an NIR-based online moisture measurement instrument called BAS-600 for bulk materials. The system is quite similar to the MoistTech Online IR 3000 presented above and is used in boiler control. The BAS-600 instrument is attached above the conveyor belt and can be used for a wide number of solid fuels such as forest residue, household waste and coal. [13]

Measurement devices based on microwave technology

In addition to the laboratory instruments, the previously mentioned Finnish company Senfit Ltd offers online moisture measurement solutions based on microwave technology. The Senfit BMA Online moisture measurement instrument takes a small continuous sidestream of bioenergy flow from a conveyor belt or container with a screw conveyor and measures the moisture content of biomaterial with a microwave sensor *(Image 12)*. In commercial advertisements the measurement range of BMA Online is reported to be 20 to 65 % and the moisture measurement resolution is 0.1%

in, but some real applications can measure moisture content of 10% and in other applications measured moisture content can be up to 80% [50]. Another online moisture sensor, Senfit OMS, can be mounted above a continuous bioenergy flow and wall mounting is also possible. The given measurement range is 0 to 50%. [88]

Image 12. Senfit BMA Online measuring moisture content of wood-based biomass on the conveyor belt. (Image source [88].)

A German company, Döscher & Döscher Ltd, offers the microwave technology-based sensor MoistureScan for online moisture measurement of bulk materials. The sensor is typically mounted in the wall of the pipeline so it measures the moisture of passing material inside the pipe. The measurement depth is reported to be 5 cm from the sensor surface. Measurement range is not reported on the company's webpage because it depends on the sample material and sensor type. [22]

Intelscan Ltd, an Icelandic company, has manufactured microwave technology-based moisture measurement instruments called iScan. They have applied iScan online sensors for wood pellet moisture measurement. The instrument is designed for rather dry materials, so the given measurement range is 5 to 15% with accuracy of ±0.5%. [40]

A large Australian company, Callidan Instruments, part of RealTime Group Ltd, manufactures microwave-based moisture measurement instruments for several different industrial purposes: e.g.

for mining, agriculture, food and energy production. The instrument applied for online biomass moisture measurements is called Moistscan MA500HD and has a C-frame configuration *(Image 13).* The measurement instrument is mounted around a conveyor belt and it measures 100% of the material running below the sensor. The measurement range of the instrument is reported to be between 0 and 90% depending on the material [73]. In an example of a US pulp mill the moisture measurement range for chip wood with the same instrument is, however, between 48 and 54% only [74].

Image 13. Left: Moistscan MA500HD, the moisture measurement instrument based on microwave technology. Right: The instrument measuring wood chips in a pulp mill.

As an international enterprise with German roots, Berthold Technologies produces solutions for process control, bioanalytics and radiation protection. The solutions for process control include moisture, volume flow, level and density measurement instruments. The operating principles of the moisture measurement instruments are microwave technology and neutron activation, although the latter is not well suited for forest-based material applications. The only instrument mentioned for forest biomasses, the LB 567/568 MicroPolar, is a microwave technology-based online moisture measurement instrument applied for wood fuel as well *(Image 14).* Typical accuracy of material moisture measurement is ±1%. Some measurement instruments for bulk materials, such as volume /mass flow measurement instruments, may be applied for biomasses as well, although that is not mentioned separately on the webpage or in brochures. [12]

Image 14. Berthold LB 567/568 Micropolar microwave technology-based instrument measuring chip wood moisture online above the conveyor belt. (Image source [12].)

Measurements based on X-ray technology

Inray Fuel, the X-ray based online measurement solution of Finnish company Inray Ltd, measures several properties of incoming biomass using a combination of the X-ray radiation source above the conveyor belt and a detector under the belt. The solution measures all the material on the conveyor belt and produces moisture and quality information on the biomass. The X-raying of material flow reveals foreign particles such as stones. In addition, the X-ray based technology allows the automatic recognition of fuel type and the evaluation of the composition of the fuel material. The company has experience of moisture measurements in the range of 15 to 70%, but there are several variables affecting the reliable results such as the typical moisture range and homogeneity of the material and the thickness of the material layer on the conveyor. [39]

Image 15. The radiation source unit and the detector unit of the X-ray based Inray Fuel mounted in a conveyor of a power plant.

Swedish Mantex Ltd also sells X-ray based online measurement instruments for biomass analyses. The system called the Mantex Flow Scanner is very similar to the Inray Fuel, measuring all incoming material with X-ray radiation sources above the conveyor belt and below the detector. The instrument measures the moisture content with accuracy of 2%, but the measurement range is not mentioned. A flow scanner measures the dry mass flow and detects foreign particles as well. Mantex states that frozen material and ice are included in FlowScanner measurements (the website does not tell us, however, if ice is included in moisture measurement values or material flow detection only). [62]

Measurement devices based on lasers

The large international (originating in Germany) enterprise SICK produces a variety of measurement instruments for hundreds of industrial purposes. The most famous products are probably active laser measurement instruments, based on flight of time or phase shift of laser pulse, and these technologies are typically seen in laser scanners. For online measurement of biomasses SICK offers a solution named Bulkscan® LMS511. The laser scanner-based instrument can be attached above a conveyor belt and it measures volume flow of bulk material: e.g. wood chips going onto the conveyor. [95]

Measurements based on acoustics

The only acoustic sensor for bio material measurements found during the survey was Teknosavo Ltd's SoundSmart. SoundSmart offers an unusual solution for the detection of stones, metallic particles and ice blocks. The incoming wood chip or bark flow is dropped on a metallic sensor. Large objects produce a different sound in comparison with normal wood chips, and foreign particles can be removed by means of a pneumatic gate controlled by the acoustic sensor. The product advertisement [103] does not mention the technology applied in the solution, but SoundSmart is an acoustic measurement according to a Swedish master's thesis [48]. The name of the product refers also to the acoustic operating principle.

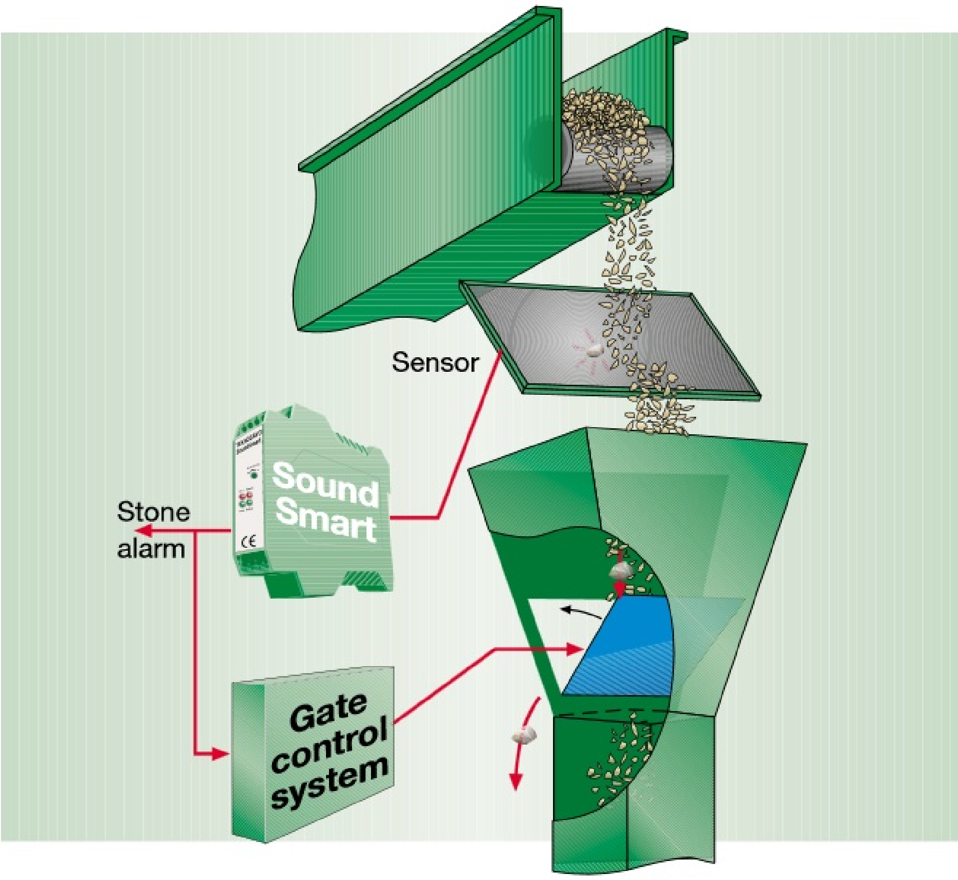

Image 16. The operating principle of Teknosavo SoundSmart. (Image source **[***103]*)

6.1.4 Enterprises providing measurement devices for plant field

Measurement devices based on VIS cameras

The Danish company Dralle Ltd has manufactured a measurement system for roundwood pile measurement based on stereo imaging. The system consists of two cameras mounted on a roof-rack at a fixed distance from each other. The vehicle drives by the pile and collects image data. Unless the pile cannot be driven around (e.g. at the road side storage), the backside of the pile cannot be measured . In the case, the average depth of the pile must be given to the software and thus it calculates the volume of the wood material in the roundwood pile. Additionally, the software counts the logs in the pile. [23]

NIR-based solutions

The Swedish company Bestwood has a unique system for measuring the moisture content of bulk material in a vehicle load. The Bestwood BAS-700A is a crane-based probe with an NIR sensor. The crane puts the moisture measurement sensor inside the load and evaluates the moisture content in several locations. The automatic instrument works e.g. with sawdust, wood chips and forest residues. [13]

Image 17. Bestwood BAS-700A, a crane-based NIR-probe measuring moisture of a truck load. (Image source: [29])

Laser-based solutions

Biomasses are also measured in outdoor environments outside power plants. One measurement of biomass properties (typically mass or volume) takes place in the transportation vehicle (e.g. in trucks or train cars). The Chilean company WoodTech produces laser scanner-based applications for volume measurements of both roundwood (Logmeter 4000) and biomasses (Chipmeter 4000). The Chipmeter 4000 consists of a laser scanner mounted on a measurement bridge. Logmeter has three scanners: two scanners for load side profiles and one scanner for the top profile of the load. The scanner detects the profile of a truck load during the drive under the measurement bridge with laser sensors and evaluates the volume of the load. The system can also determine the average density of the load in co-operation with the bridge scale. Obviously, the measurement works better for biomasses such as sawdust and wood chips than for rootstock load or pruning residues. The volume measurement based on the surface profile gives more accurate results for dense materials. [114]

Finnish Visisystems has a similar instrument to WoodTech Chipmeter 4000 for the measurement of truck load volume. The solution, called Taljari, has a similar measurement bridge with a laser scanner and vehicles drive above the bridge. The surface profiles of the vehicle load are measured and compared with empty truck load data. Thus the load volume can be estimated using the empty container and the loaded container profile data. [111]

The Finnish company Codator Ltd has mounted measurement solutions similar to Logmeter 4000 in the paper/pulp mill field. The system, called Modus 2000, consists of a measurement bridge with three laser scanners mounted on it. Additional laser distance meters detect the velocity of the vehicle and the volume of the truck load is calculated from laser data. This solution is suitable only for roundwood bioenergy. [18]

The Swedish company Mabema Ltd has quite a similar system to Logmeter 4000 and Modus 2000 for volume measurement of roundwood in a truck load. The measurement principle of Mabema GPV is based on passive laser technology, however (laser line is photographed), whereas Logmeter 4000 and Modus 2000 are based on active lasers (flight time of the scanned laser pulse). Mabema GPV also has heavier infrastructure, as the laser devices and cameras are mounted inside the measurement building and the truck drives through the building. This system is suitable only for roundwood bioenergy loads. [61]

The solutions for stockpiling volume measurements of biomasses are mainly based on laser technology. There are several methods of measuring pile volume, including airborne LIDARs (3D laser scanners), conventional aerial (stereo) imaging and GPS (global positioning system) surveys. Ground-based 3D laser scanning probably provides the most accurate volume measurement for the cost. [39]

Outdoor scales

Typical outdoor measurements in the bioenergy supply chain are made by weighing instruments. Obviously, the weighing is a general measurement, so scales suitable only for biomaterial measurements are not designed. The conventional weighing instrument used inter alia for outdoor biomass measurements is bridge scale and can be used for trucks as well as for train cars. Several manufacturers can be found, but the Finnish Lahti Precisions Ltd particularly offers bridge scales for vehicles [53]. The bridge scale is a notable investment, because the cost may be 150 000 euros with related infrastructure. Thus in some cases portable and much more inexpensive vehicle axle load measurement devices can be used.

Another and newer scale type for trucks and forwarders is a load scale. It weighs biomass load quite accurately during loading. The crane scales require, however, that the movement during the loading is smooth. The Finnish Tamtron Ltd is one notable producer of load scales for biomass [101]. Finnish Mecanil Ltd [64] also manufactures wireless load scales and all the major harvester manufacturers, i.e. Ponsse, John Deere and Komatsu, manufacture load scales for their vehicles.

6.1.5 Enterprises providing solutions related to energy wood measurements

Kareliatech Oy is a Finnish company producing additional instruments for forest machines. Their main product is the single grip stump harvester for collecting stumps and rootstocks for bioenergy developed by Sakari Mononen [47]. Tekno-Tuote S. Mononen has developed the sampling device for moisture measurement of fuel wood. The device is based on a chain saw in the grab and it collects sawdust for moisture measurement during forwarding [37].

The Finnish company Prometec Oy is an expert in bioenergy measurement technology, although the company does not manufacture measurement instruments itself. The services of Prometec include the design of measurement technology solutions, measurement expertise for process development and testing and measurement services using several measurement instruments. [82]

6.1.6 Table of enterprises

The biomass measurement instruments described earlier in this chapter are listed in tables 1 and 2. The applied technology, the operating principle (handheld, automatic, for vehicles), the properties to be measured and the moisture measurement range (if available) are noted. First, Finnish enterprises are listed in table 1 and then foreign enterprises in table 2. The moisture measurement range values were selected from the company websites or commercial flyers. One has to be careful, even suspicious, when reading the moisture measurement range table, however. Most devices have to be calibrated for different materials and thus the measurement range depends on the application and the material to be measured. Thus, the measurement range for a single material is typically considerably smaller than the given measurement range for the instrument. Consequently some enterprises do not give the moisture measurement ranges at all. At the same time several enterprises give the moisture measurement range of all possible measurement set-ups together, even though the whole range cannot be used in the same setting. For instance, according to the product brochure the moisture measurement range of MoistScan MA500HD is mentioned as being between 0 and 90% [74], but Callidan Instruments Inc. advise that the moisture measurement range for wood chips in a pulp mill application is 48 to 54% only [73]. The moisture measurement range in a certain application may be tightened, however, to obtain higher accuracy for moisture measurement values. The moisture range values have been rounded to a resolution of 5% in tables 1 and 2.

Table 1. Finnish enterprises providing measurement instruments for bioenergy supply chain.

Company/product	Microwaves	X-ray	NMR	Electric(Capacitance/Cnductance)	NIR	Acoustic	Laser	VIS	Mechanical	Online device	Laboratory device	Handheld device	In vehicle	In plant field	Foreign particles	Chip size	Mass	Volume / Volume flow	Surface brightness	Surface moisture	Inner moisture	Measurin range in moisture-% (0 – 50 – 100)
CODATOR Oy																						
Modus 2000							x							x				x				
FARMCOMP Oy																						
Wile Bio Moisture (for chips)				x								x									x	
Wile Bio Moisture (for logging residues)				x								x									x	
Wile Bio Wood (saw dust)				x								x									x	
Wile Bio Wood (pellets)																						
INRAY Oy																						
Fuel		x								x					x						x	not available
LAHTI PRECISION Ltd																						
Autovaaka				x										x			x					
MECANIL																						
XW 50BS									?				x				x					
METSO AUTOMATION Oy																						
MR Moisture			x								x										x	
SENFIT Oy																						
BMA -Desktop Analyzer	x										x										x	
BMA On-Line	x									x											x	
OMS Moisture sensor	x									x											x	
TAMTRON																						
Timber									x				x				x					
TEKNOSAVO Oy																						
ChipSmart								x		x					x	x		x	x	x		not available
SoundSmart						x				x					x							no moisture measurement
VISISYSTEMS Oy																						
Taljari							x							x				x				no moisture measurement

Table 2. Foreign enterprises providing measurement instruments for bioenergy supply chain

.

Company/product	Microwaves	X-ray	NMR	Electric(Capacitance/Cnductance)	NIR	Acoustic	Laser	VIS	Mechanical	Online device	Laboratory device	Handheld device	In vehicle	In plant field	Foreign particles	Chip size	Mass	Volume / Volume flow	Surface brightness	Surface moisture	Inner moisture	Measurin range in moisture-% (0 – 50 – 100)
ACO																						
MMS-1 and MMS -2				x						x											x	free adjustable
BERTHOLD Technologies GmbH																						
LB 567/568 MicroPolar	x									x											x	not available
BESTWOOD																						
BAS-600					x					x										x		not available
BAS-700A					x									x							x	not available
CALLIDAN INSTRUMENTS (MOISTSCAN)																						
MA500HD (overall)	x									x											x	
MA500HD (biomaterial application example)	x									x											x	
DÖSCHER & DÖSCHER																						
MoistureScan	x									x											x	not available
DRALLE																						
sScale								x						x				x				
INTELSCAN																						
iScan online	x									x											x	
MANTEX Ab																						
DesktopScanner		x								x					x						x	not available
FlowScanner		x									x				x			x			x	not available
MOISTTECH																						
868 Laboratory NIR Moisture Analyzer					x						x									x		
IR-3000 Online Moisture Transmitter					x					x												
MABEMA																						
GPV							x							x				x				
SCHALLER GMBH																						
Humimeter BMA				?							x										x	
Humimeter BM1				x							x										x	
Humimeter BM2				x							x										x	
Humimeter BLL				x								x									x	
FS-200 HT				x								x									x	
FS-180 HT				?								x									x	
Humimeter WLW				?								x									x	
Humimeter BLW				x								x									x	
Humimeter BL2				?								x									x	
Humimeter BLO				?						x											x	
Wood Chips moisture transmitter				?						x											x	
SICK																						
Bulkscan® LMS511							x											x				no moisture measurement
WOODTECH																						
Chipmeter4000							x							x				x				no moisture measurement

6.2 Research organizations

6.2.1 Finnish research organizations

The Finnish Forest Research Institute (Metla) is a specialist research organization which develops solutions to the challenges and questions posed by the care, utilization, products, services and intangible value of forests. Metla was established in 1917, and the current network of research units covers the whole country. Metla is the main forest research institution in Finland and one of the biggest forest research institutes in the whole of Europe. Metla's operations are scientifically and socially influential, promote the competitive edge of business activity based on forests, and support regional development. Metla's products and services, and its data and know-how, are utilized both nationally and internationally in the advancement of bioeconomy. Metla's biomass measurement specialists are Professor Erkki Verkasalo and researcher Jari Lindblad. [67]

Metsäteho Ltd is a research and development company owned by Finnish forestry and wood processing companies, certain forestry organizations and Metsähallitus (a state forest enterprise and administrator of state-owned land and water areas). Metsäteho's research focus areas are related to wood resources, resource management and wood procurement logistics including raw material measurement. They have researched and compared e.g. commercial moisture measurement methods and tested prototypes for forest-based biomasses. Metsäteho contacts in biomass measurement issues are researchers Timo Melkas and Antti Korpilahti. [70]

The VTT Technical Research Centre of Finland is the largest multidisciplinary research organization in Northern Europe. It provides high-end technology solutions and innovation services. VTT is a non-profit research organization. VTT has researched the majority of the measurement technologies mentioned in chapter 5 and continuously looks for solutions for the bioenergy sector as well. The experts on the bioenergy supply chain can be found at the VTT unit located in the city of Jyväskylä (researcher Matti Virkkunen). VTT measurement technology specialists work at VTT Kuopio (researcher Kimmo Solehmainen), VTT Oulu (researcher Janne Suhonen), VTT Tampere (Research Professor Jouko Viitanen), VTT Espoo (Professor Arto Usenius) and VTT Kajaani (site manager Timo Lehikoinen). [112]

The University of Eastern Finland (UEF) has undertaken research on biomass measurement technologies. The Department of Applied Physics at Kuopio campus has expertise on the use of acoustics and electromagnetic radiation for wood-based material measurements. They have researched e.g. ultrasonic methods and electric impedance spectroscopy for biomass moisture measurement. Experts in these technologies are researcher Markku Tiitta and Professor Reijo Lappalainen.[104][106]

At Joensuu campus, the University of Eastern Finland has researched the effect of climate and seasonal change on biomass quality in roadside storage in co-operation with the Finnish Forest Research Institute. The research provides data for modelling e.g. the moisture content of the biomaterial during storing. Contacts for the project are Professor Lauri Sikanen and researcher Marja Kolström. [32]

The University of Jyväskylä has researched radiometric measurement methods for wood materials for some years. The neutron activation method mentioned in subchapter 3.1.10 has been tested for forest-based biomasses at the Department of Physics, but a breakthrough in terms of commercial solutions is still awaited. The contact at the University of Jyväskylä is research director Ari Virtanen. [107]

The University of Oulu has researched biomass moisture and energy content using soft sensors. Soft sensor methods utilize several measurements in the bioenergy supply chain and interaction of the signals is used to calculate new features. Soft sensor specialists at the University of Oulu are researcher Ari Isokangas and Professor Kauko Leiviskä. [109]

CEMIS, the Centre for Measurement and Information Systems, is a contract-based joint centre of the Universities of Oulu and Jyväskylä, Kajaani University of Applied Sciences, the Centre for Metrology and Accreditation (MIKES), and VTT Technical Research Centre of Finland. CEMIS is located in the city of Kajaani and it specializes in research and training in the field of measurement and information systems. CEMIS has had several research projects related to the forest industry measurements. Within the CEMIS consortium, the University of Oulu is currently researching the performance of novel biomass moisture measurement technologies. The contact person for this topic is senior researcher Petri Österberg. [14]

Fiber Laboratory, a research unit of Mikkeli University of Applied Sciences located in Savonlinna, develops solutions for fibre and process technologies and produces information for industrial utilization of forest-based biomasses. The unit is expert at building low-cost NMR instruments.

More information about the technologies can be sought from the research director Yrjö Hiltunen. [72]

Lappeenranta University of Technology (LUT) has a regional unit, LUT Savo Sustainable Technologies, at three cities in the Savonia region. The unit has a research group looking at new measurement technologies located in Varkaus. The unit researches measurement technologies with wireless and optic methods for biomass combustion boilers. [55]

In addition to the research organizations listed above, several Finnish universities have substantial expertise in measurement technologies, though they have not applied it to the bioenergy sector. For instance, the University of Oulu (Professor Jari Hannuksela), Tampere University of Technology (pProfessor Risto Ritala), Lappeenranta University of Technology (Professor Heikki Kälviäinen) and Aalto University (Professor Henrik Haggren) run research groups developing image analysis (stereo image analysis is the latest) and camera-based measurements and they have experience of their application in the forest sector. The University of Eastern Finland at Joensuu is renowned for optic measurements based on spectrum analysis (Professor Markku Hauta-Kasari) and Aalto University has applied laser-based systems in forestry measurements (Professor Arto Visala). NMR technology expertise can be found at the University of Eastern Finland in Kuopio (Professor Olli Gröhn) and the University of Oulu (Docent Ville-Veikko Telkki). CEMIS-Oulu, the measurement technology unit of the University of Oulu located in Kajaani, has researched e.g. microwave technology and optical measurements for solid wood materials (Professor Anssi Mäkynen).

6.2.2 Foreign research organizations important from the Finnish perspective

In 2013 the Swedish University of Agricultural Sciences (SLU) founded the Department of Forest Biomaterials and Technology from the former units of Biomass Technology and Chemistry and including forest technology and forest ecology & management researchers. The department will be the leading research unit for the development of the bioenergy sector in Sweden. Of course it includes related technology solutions as. [100]

The Division of Wood Science and Technology at Luleå University of Technology in Sweden is internationally known for its wood technology research within the fields of wood technology, wood physics and wood product engineering. The wood technology research group located in Skellefteå has worked with novel measurement technologies for forest industry. LTU's research emphasizes mostly solid wood-related technology rather than forest-based biomasses, however. [59]

The National Research Institute of Sweden, Skogforsk, has been involved in research and development of measurement technology in the wood supply chain. Skogforsk has researched handheld moisture measurement devices and the accuracy of loader scales. Skogsforsk was the responsible stakeholder in the development of the Stadford 2010 standard for harvester measurement data. [98]

7. Conclusion

The most important reason to measure forest-based biomass properties is the value evaluation. The value of the biomass quantity is revealed, if we know its energy content. The energy content of the biomass can be ascertained by observing the energy produced at the power plant. The reality is seldom so easy, however. Only the power plants with a single raw material supplier at a time can define the value of acquired biomass loads according to the produced energy. In the typical case the large power plants have several bioenergy suppliers all the time. Thus the fuel burned in the boiler is a mix of bioenergy fractions of tens of suppliers. So, the value of the bioenergy has to be defined in a different way: typically according to the quality and quantity of the biomaterial loads acquired. The moisture of the supplied fuel load is predominant property in parallel with the volume. Thus, most of the bioenergy measurement instruments on the market are designed for moisture or/and volume measurement. The measurement of other properties is mostly marginal, but may still be important.

The variety of available technologies is high and some new technologies such as NMR, microwaves and X-rays have broken into the market in the last few years. Additionally, more technologies are in the research phase.

The cost variation of the measurement instruments is high. The most inexpensive handheld moisture measurement instruments cost typically below 1000 euros. The price of laboratory instruments is some tens of thousands of euros and online devices within the conveyor belt are typically several tens of thousands, even hundreds of thousands, of euros depending on installation and additional acquisitions.

Industrial stakeholders have a lot of interest in changing the bioenergy supply chain radically. Large biomass terminals for the forest masses and agrobiomasses are under research. Supposedly the transportations of biomass loads through large biomaterial terminals serving power plants as well as sawmills, pulp mills, etc. could replace the majority of straight transportations from forests to plants. This will happen if costs are reduced. The new biomass terminal concept requires that the measurement technologies along the biomass supply chain have to be updated as well. We hope this state-of-the-art report could create the basis for that work.

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