Biomass fuel supply chains for solid biofuels

From small to large scale
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Efficient supply chains needed as use of biomass fuels increases

The proposal for a Renewable Energy Directive aims to establish an overall binding target of a 20% share of renewable energy sources in final energy consumption and a 10% binding minimum target for biofuels in transport to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20%. The role of biomass fuels in achieving these targets is significant. Among the “20%” scenarios, the highest biomass contribution anticipated is 230 Mtoe (2,675 TWh). This includes a maximum of 63 Mtoe (733 TWh) that would have to come from agricultural crops (if the entire biofuel contribution had to come from first-generation biofuels). On the conservative assumption that 15% of the biomass used is imported, the contribution that would have to come from the EU would be a maximum of 195 Mtoe (2,268 TWh).

This publication summarises the most commonly used biomass fuel supply chains. Wood fuels are the most common biomass fuels, and production chains have been developed and well-adopted in the market.

### Solid biomass fuel supply chain options according to end-user sector

<table>
<thead>
<tr>
<th>End-user and average annual fuel consumption</th>
<th>Biomass fuel</th>
<th>Quality requirements</th>
<th>Technology for energy conversion</th>
</tr>
</thead>
</table>
| Households (<50 kWh)                        | Wood pellets| Good mechanical durability
Low ash content                               | Pellet boilers
Pellet stoves                                 |
| Annual fuel consumption <30 MWh            | Wood briquettes| Low ash content, packaged | Stoves and fireplaces            |
|                                              | Wood chips  | Low moisture content, < 35 w-% | Stoker boiler                   |
|                                              | Log wood    | Low moisture content, 15-20 w-% | Stoves and fireplaces, boilers   |
| Farms, large buildings (<1 MWh)            | Wood chips from whole trees or delimbed trees | Low moisture content, less than 35 w-% | Stoker burners
Grate firing                                   |
| Annual fuel consumption < 3 GWh            | Straw bales | High quality bales, low moisture content (< 18 w-%) | Grate combustion, also whole bales |
|                                              | Wood pellets| Good mechanical durability
Low ash content                               | Pellet boilers
Stoker boilers                                |
| District heating plants (<5 MWth or power plants (<5 MWj) | Wood chips from forest residues or whole trees | Moisture content usually less than 40 w-% | Grate combustion Fluidised bed combustion Gasification |
| Annual fuel consumption <35 GWh (DH, CHP) or 85 GWh (power only) | Straw or energy grass bales | Moisture content, less 20 w-% | Cigar combustion
Crane combustion, also whole bales            |
| CHP and power plants (>5 MWj)               | Wood fuels from forest residues, stumps | Boiler and handling equipment based requirements | Usually cofiring with coal or peat Fluidised bed combustion Gasification |
| Annual fuel consumption from 85 GWh to several TWh | Wood or straw pellets | Boiler and handling equipment based requirements | Cofiring with coal Pulverised combustion |
|                                              | Herbaceous biomass (straw or energy grasses, like miscanthus and reed canary grass) | Big bales, moisture content less than 20 w-% | Cigar combustion
Grate combustion Fluidised bed combustion Cofiring with coal |
|                                              | Olive residues | Boiler and handling equipment based requirements | Grate firing
Cofiring with coal in fluidised bed boiler    |
Forest residues and the unutilised potential of biomass fuels

According to the EUBIONET II study for 20 EU countries, the estimated annual figure for the total techno-economical volume of solid biomass fuel resources is 143 Mtoe (1,663 TWh). About half of this potential is already exploited.

The greatest potential to increase the use of biomass in energy production seems to lie in forest residues and other biomass resources (agrobiomass and fruit biomass). The utilisation of forest residues is often connected with round wood harvesting, so the use of round wood by the forest industry impacts also the exploitation of the forest residue potential. Industrial byproducts and residues (bark, sawdust, cutter chips, grinding dust, etc.) are quite well exploited in energy production and pellet or briquette production.

The availability and cost of forest biomass varies considerably between countries and within countries. The most common biomass fuel is forest wood (wood chips, logs and hog fuel). In general, the availability of forest resources, the demand for forest fuels, and machine and labour costs are the defining factors behind prices. Usually, both the optimal harvesting technology and the availability of forest fuel must be studied on a local level for reliable results.

In the case of logging residues, the biological logging residue accumulation can be estimated by the total area of final fellings and stemwood biomass conversion tables.

The share of biomass components. Source: METLA

<table>
<thead>
<tr>
<th>Tree species group</th>
<th>Stem +stem bark (%)</th>
<th>Stem wood loss (%)</th>
<th>Branches (%)</th>
<th>Needles (%)</th>
<th>Tops (%)</th>
<th>TOTAL estimation (Nordic and Baltic countries)</th>
<th>Roots estimation (rest of Europe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce</td>
<td>55</td>
<td>8</td>
<td>24</td>
<td>11</td>
<td>2</td>
<td>100</td>
<td>22</td>
</tr>
<tr>
<td>Pine</td>
<td>68</td>
<td>8</td>
<td>18</td>
<td>4.6</td>
<td>2</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Broadleaved</td>
<td>78</td>
<td>8</td>
<td>12</td>
<td>1.7</td>
<td>1</td>
<td>100</td>
<td>22</td>
</tr>
</tbody>
</table>

To get a picture of the technical and economical potential, the following restrictions limiting the biological potential have to be taken into account:
- Soil quality, poor soils not available
- Tree species, spruce is the favoured species
- Harvesting yield, 65% of the residues are harvested
- Accumulation, should exceed 35 solid m³/ha
- Accumulation per stand, should exceed 50 solid m³ per stand
- Difficult terrain, topography, stoniness, bearing capacity
- Silvicultural recommendations, e.g. conservation of biological diversity
- Storage losses, deformation, needle and leaf drop-off
- Market availability, forest owner’s willingness to sell

Reduction of the theoretical forest fuel potential from 785 million m³ to the technically harvestable volume of 187 million m³ (36 Mtoe, 411 TWh). Source: METLA

1 m³ = 2.2 MWh or 7.9 GJ
Based on the restrictions in the area, the techno-economical logging residue potential can be estimated. When the potential data is combined with the price of the residues, transport distances and harvesting costs, the supply cost of forest fuel can be estimated. At this point it is also important to note that the potential available for one specified plant is limited further by the usage of other plants.

**Herbaceous biomass from energy crops and grasses – a challenge for the future**

The total arable land in the EU27 amounts to 108.9 million hectares, of which 7.2 million hectares represented set-aside land in 2005. AEBIOM has estimated that circa 30 million hectares of arable land could be available for energy production, while the total area under energy crops in the EU is around 2.5 million hectares. Energy crops include the cultivation of energy grass, miscanthus and short rotation coppice (willow, poplar). In the Nordic countries reed canary grass is cultivated for energy purposes, including around 20,000 hectares in Finland. In Central Europe miscanthus is cultivated on 16,000 of hectares and willow on 26,000 ha for energy purposes.

Straw is the most common herbaceous biomass used for energy purposes. The production of straw in Denmark is 5.5 million tons. The main grain types are wheat and barley. The energy use of straw and energy grasses is based on baling technology.
Biomass contributed 48.3 Mtoe (562 TWh) to the heating sector in EU, of which approximately 15.9 Mtoe (185 TWh) was traditional firewood. Since the 1990s the use of wood pellets in heat production has increased, and today almost 300,000 installations are in use by the market, most of them in households.

**Efficient production of log wood and trading via the internet**

In traditional firewood production and supply chains the entrepreneur fells trees in the forest, transports them to a storage place, cuts and splits them, and dries the processed firewood in simple outdoor storages. The entrepreneur takes care of marketing and delivering to customers, mostly in bulk. Because most firewood merchants are farmers and forest owners, it is natural that most of the raw material comes from the forests of the merchants. A typical trend is that the less a merchant produces firewood the more self-sufficient he is in supplying raw material for production.

In modern firewood production chains the firewood production may engage several entrepreneurs in different stages of the delivery chain. There may be a specialised entrepreneur for raw material procurement, a contractor for manufacturing (cutting, splitting, drying of firewood) and a specialised operator for marketing, delivery and invoicing.

In large scale firewood production (>100 m³/a) the raw material is usually bought as delimbed stems that have been harvested with modern cut-to-length harvesting machines and delivered to the firewood production site. The raw material consists mainly of pulpwood-sized stems of deciduous wood species, such as birch, beech, oak or alder. The wood species mix of the raw material is designed on the basis of the quality requirements of the produced firewood.

**Raw material procurement – manual or mechanised**

The raw material for firewood can be harvested manually by chainsaw or mechanically by harvester. Manual cutting and piling is more economic in small-scale firewood production and in small stands and in forest clearings. Mechanical methods are better suited for large-scale operations. If pulpwood and firewood is harvested simultaneously in mechanised felling, firewood is picked out and stored in separate stacks. In both of these cases, whether the wood is harvested manually or mechanically, farm machines equipped for wood harvesting are used at least for forest haulage. Farmers usually have tractors equipped with various forest implements, e.g. loaders, trailers and felling heads for harvesting firewood material.

Moisture content is the most important factor influencing the quality of firewood.
The moisture content of fresh wood is around 50 w-%. Therefore, wood has to be dried before it can be used as firewood. The ideal moisture content of oven-ready firewood is 15 to 20 w-%. Stems for firewood are typically harvested in winter or early spring in the Nordic countries for maximising the length of the natural drying period and in summer in Central Europe. In the Nordic countries the duration of natural drying period is typically from April to August, depending on how rainy these months are. Because of the high costs of thermal drying firewood, the right methods and timing in felling and storage play a significant role in production. Bark effectively prevents the drying of wood; hence it is important to fell stems as soon as possible, i.e. in early spring. If the stems are stored in piles it is preferred to harvest trees with a harvester, as the feeding rollers of the felling head break bark effectively. Sometimes up to 50% of bark is peeled off. The moisture content of manually harvested stems is at least 10 %-units higher than the moisture content of stems handled with machines after one month of storing at a roadside.

In general, the quality of stems remains better the shorter time they are stored in stacks. Particularly in summer, a substantial deterioration takes place already after a few months of storage. Nevertheless, if it is necessary to store stems for a longer period of time, e.g. several months, stacks should be covered. The covering should be done in such a way that the air circulates freely through the stack in order to maintain the dryness and condition of the stems. Some logs should always be put under a stack to hold it up off the ground, thus keeping moisture from the ground away from the stems.

**Professional firewood production technology**

There are two basic methods for professional firewood production. Delimbed stems or pulpwood stems are chopped either with sawing or shearing machines. Different devices with various sizes and productivities are available for chopping and splitting, depending on the scale of firewood production. In general the quality of firewood made with sawing-splitting machines is higher. However, higher productivity can be reached with shearing machines, especially with small stem diameters.

The idea of mechanised firewood production is that stems are made directly into chopped firewood and dried in the same stacks, cages or sacks that firewood is packed in connection with the cutting and splitting operation. For example 1.3 bulk m³ packages made of plastic net can be used as a handling and trade unit. Packages are set on forklift platforms and thus are easily delivered to a customer. In all cases the stacks or the handling units are either covered with tarpaulins or moved into covered storage after the summer to prevent them from getting wet again. In professional firewood production the split firewood packages are artificially dried to the desired moisture content. Investing in drying machinery is inevitable for year-round firewood production.
The third – more traditional – firewood production method involves an intermediate phase of first making one-meter long logs, which are then split. These split billets are usually dried and stored outdoors in piles and chopped into smaller pieces when customers order firewood. This is a traditional method inherited from the period when most of the heating was done with firewood and split billets were burnt in large stoves. Compared to modern firewood production methods, the extra work phases needed for the additional cutting and splitting of billets decrease the productivity and increase the costs of this method. However, the advantage of first making split billets is that it provides flexibility to chopping, as these billet piles function as a ‘buffer’ storage and chopping can be done whenever it fits the merchant. If chopped firewood is made with this method, it is very important to ensure good drying and storing conditions for the split billets. Otherwise it will be difficult to produce first-class firewood without colour, moisture and mould defects.

Firewood production costs with modern mechanised production methods during the entire process from forest to customer can be divided in four parts: raw material procurement and transport (41%), splitting operations (11%), firewood distribution (36%) and marketing and overheads (7%). Production costs with modern firewood manufacturing systems vary between €31 and 50/€ loose m³ (VAT 0%), which corresponds to approximately €15 to 20/MWh.

**E-trading – a modern tool for efficient marketing**

Since the technological issues of firewood production are rather well answered, the main questions relate to efficient solutions for managing the production-delivery chain as a whole. The logistics of raw material procurement and end product handling must be seamlessly connected to marketing-sales and order-delivery processes.

E-trading is an efficient and upcoming web service connecting firewood producers and users. For producers e-trading services provide an easy channel for contacting customers and presenting prices and terms of delivery. For customers the channel facilitates access to information about firewood availability and makes comparing producers easy. There are several e-trading market places in Europe (see www.eufirewood.info).
Refined biomass - wood pellets for stoves and boilers

Approximately 6 million tons of wood pellets are produced in Europe. Wood pellets can be used in pellet stoves or pellet boilers or cofired with fossil fuels in utility boilers. Several pellet boilers in a range of size classes (15 to 500 kW) are available on the market. The use of wood pellets increased rapidly in the 1990s in Europe.

Wood pellets and refined biomass fuel briquettes are usually cylindrical compressed wood fuel products made from the residues and byproducts of the mechanical wood-processing industry. The raw material is dry or moist sawdust, grinding dust and cutter shavings. Pellets and briquettes can also be compressed from fresh biomass, bark and forest chips, but the raw material must be milled and dried before pelletising. Herbaceous and fruit biomass can also be used as a raw material.

Wood pellets are a fuel product compressed from milled wood. Pellets are cylindrical in shape with a diameter of 6 to 10 mm and a length of 5 to 40 mm. Sawdust and cutter shavings are available as byproducts of sawmills and planing mills. If sawdust is moist, it should be dried before pelletising. The optimum moisture content is 10 to 12w-% for raw material. The moisture content refers to the proportion of evaporable water to the total weight of the material. Coniferous wood is a slightly better raw material for wood pellets than deciduous wood due to its higher lignin content. Lignin is the natural binding material of wood fibres and thus acts as the binding material of the pellets. The production of one pellet ton (moisture 7 to 10w%) requires about 7 bulk m³ of sawdust (moisture content 50 to 55w-%), or about 10 bulk m³ of cutter shavings (moisture content 10 to 12w-%).

The process of pellet production comprises the following stages: milling, drying the raw material (for moist biomass), pelletising, cooling, fine separation and packaging/ storing. Drying is not required if the raw material consists of cutter shavings or dry sawdust. However, if moist sawdust is used, it should be dried after grinding.

In milling, the raw material is ground to a grain size equal to at least the diameter of the pellet. However, the ground wood dust should not be too fine, or there will no longer be fibres to help bind the pellet. Usually a hammer mill is used for grinding when homogeneous raw material is obtained for compression.

The milling and drying of raw material can be combined, if drying is required. In a miller-dryer, the crusher changes the particle size of sawdust, which is dried. Crushing makes the drying process considerably easier. The particles are of equal size (3 – 4 mm) and have about the same moisture content. As the moisture content of all particles is homogeneous, the pellets are more durable.

The pellets are compressed in a flat die or vertical mounted ring die. Although the die type and compression mechanism of pelletising equipment differ from each other, practically all systems comprise the following parts: feeder, die and roll part, main engine, reduction gear and chassis. The die is always chosen case by case, depending on the properties (hardness, moisture, composition) of the raw material being compressed.

No additives are normally used in the compression of wood pellets, but the pellets are bound by the cohesion of
inner surfaces, by fibrous parts of particles, and primarily by adhesion caused by lignin that is softened by the heat of compression. It is possible to use additives with binding, lubricating or moisture-protecting effects. However, additives are not often used in the manufacture of wood pellets, as the additives increase costs and are usually not needed. The additive should not hamper combustion or develop stinking or poisonous gases. It is also possible to use additives from agriculture or forestry such as starch, to improve mechanical durability of pellets. For agrobiomass pellets additives are often used to prevent slagging in the boilers.

Steam is often used in pelletisation. It should be dry or slightly superheated, as the aim is to heat the material, but not to moisten it in excess. Steam addition has been found to reduce the wear of the die and make the pellets stronger and tougher.

Cooling is a very important stage of the process. After compression the temperature of the pellets is high, usually about 90°C. The moisture released in the compression stage is removed with heat from the product. Cooling stabilises the pellets and hardens the lignin melt on the surfaces of the pellets, as a result of which the shape of pellets remains unchanged.

In screening, the raw material dust mixed among the pellets is separated and fed back into the pelletisation process. Screening is usually performed with a vibrating screen to secure a homogeneous product that does not cause problems in conveyors and combusting equipment. Finally, the pellets are conveyed to a storeroom or put into big or small bags for transport to consumers.

Transportation is a fairly important factor regarding the economy of pellet industries. It is not feasible to transport cutter shavings and sawdust over long distances, but the pellet plant should be located close to raw material sources. The long transport distances of pellets also reduce cost-effectiveness. When planning logistics, return transports should be used as far as possible to improve the cost-effectiveness.
Wood pellets are sold either as bulk goods or in large or small bags. The size of small pellet bags ranges 15–25 kg, and they are packed on interchangeable pallets. The pallets are delivered to retailers, who deliver the pellets to final users. Small bags are meant for consumers, who use pellets in small scale in stoves or as additional fuel. The size of large bags ranges 1–1.5 m³, i.e. 500–1 000 kg. Transports of pellets in large bags are more economical, but a forklift lorry, a crane or a front loader is needed for unloading. Hence, this transport system is unpractical for small-scale consumers, who do not often have any hoisters for conveying large bags.

Large bags are especially used in farms, which have equipment to handle these bags.

Pellets can be transported in bulk by tractors or trucks under a tarpaulin. Bulk pellets are distributed by truck using pressurised air for blowing the pellets directly into the store of the end user. In this way the pellets are distributed like fuel oil. The truck may be designed especially for wood pellets, or trucks designed for animal fodder can be used.

The pellets should be stored in a dry space to prevent them from coming into contact with water or water drops. Rain or condense water, snow or moisture rising through the floor of the storeroom swell the wood pellets quickly and disintegrate them into sawdust. Moisture problems should also be considered when organising transports.

According to the EUBIONET II fact sheets, the production costs of wood pellets range from €75–101 per ton of pellets on average for moist raw material and €52–81 /per ton of pellets on average for dry raw material.
In heating systems (< 1 MWth) the quality of wood fuel has an important role. The general rule of thumb is that the smaller the system is the higher are the quality demands for the used fuel. The highest quality chips for small installations can be made from delimbed small wood stems from precommercial or commercial thinnings. Where lower quality chips can be fired, also whole tree chips from undelimbed small tree stems can be used.

**Biomass heating – business opportunities for rural areas**

Heat entrepreneurship is a form of rural enterprise where heat entrepreneurs supply heat produced with biomass fuels to the customers. The wood fuel used by heat entrepreneurs is mainly wood chips. The fuel is produced by the heat entrepreneur and comes from the entrepreneur’s own forests or is purchased standing from local state or private forests or bought from local wood processing industry or from farms.

The entrepreneur takes care of heating on municipal or private estates within the heating contract and carries out fuel procurement, plant operation and maintenance. The heat entrepreneur is paid according to the supplied heat. The price of the heat is usually bound to the price of other fuels, such as light fuel oil. The form of heat entrepreneur/enterprise may be a single entrepreneur, energy cooperative, a limited liability company or entrepreneur consortia.

Heat entrepreneurs are often forest-owning farmers who from their agricultural background own suitable machinery for wood fuel harvesting. The base machines of entrepreneurs wood procurement operations are farm tractors equipped with trailers and loaders and small wood felling heads.

Either manual or mechanized felling method can be used for harvesting small wood. Small wood is often harvested with chipping by the roadside using farm tractor machinery. In this method the felled trees are first stored at the stand (often over the growing season) then hauled to the roadside and chipped there directly to the long-distance transport unit. The storage of the material improves the quality of the chips and reduces unnecessary nutrient loss of the felling area due to leaf, needle and crown mass drop-off. After chipping the material is transported to the power plant by chip trucks or tractors depending on the transport distance.

The benefit of the farm tractor based harvesting chains is that, in addition to the many uses of the tractor in fuel harvesting, the tractor can be used for other purposes by the entrepreneur, for example on the farm. The disadvantages are short operating distance (<50 km) and limited capacity, for example in chipping.
Manual felling methods are used in seedling and young forest tending. Many different methods have been developed to improve the efficiency and to reduce the strain of the work. A chainsaw with felling frame is a suitable option for small wood felling and bunching.

Small wood is manually harvested by the orientated felling method. Orientated felling means that the worker’s aim is to fell as many trees to the same pile using the momentum of standing trees. This method reduces the strain of the work in felling and bunching because it allows the worker to operate in an upright position and bunching takes place simultaneously during the cutting of the trees. Trees in diameter of up to 15 cm are suitable for this work method. In productivity studies, the productivity of felling-bunching work with a tree size of 13 to 18 dm³ has been 3.6 to 5.1 m³ per effective work hour.

In order to reduce costs and increase the productivity of small wood harvesting, many different mechanised felling methods have been introduced. The general trend in small wood felling is that several trees are processed simultaneously by using accumulative felling heads. These felling heads are manufactured in many different sizes and therefore can be used with different base machines, including farm tractors, excavators and harvesters. A general rule of thumb is that the weight of the felling head for a farm tractor should not exceed 500 kg.

The size of the removed trees has a high impact on the productivity and costs of mechanised felling. With a machine cost of €50 per effective working hour and an average tree size of 17 dm³, the cost for felling is €20/m³ solid. If the average size of the trees is 10 dm³, the costs go up to €30/m³ solid. On the other hand, with a stem size of 50 dm³ the cost drops down to €9-10/m³ solid. An important factor favouring mechanised felling is that bigger stockpiles on the stand can be achieved. This has a great impact on the costs of the terrain haulage of the trees.

In the terrain haulage work phase the small wood is collected and transported from the stand with a farm tractor-trailer-loader unit and stored by the roadside landing in 4-5m high stockpiles, where the material dries during storage. Roadside landing areas are made accessible for long distance transport vehicles and chippers.
Storage of small wood at roadside landing

The productivity of terrain haulage varies according to the accumulation of the material at the stand, the hauling distance and the load capacity of the used machinery. If the accumulation of small wood is 60 m³/ha and the hauling distance 100 m, a productivity of 8 m³/h-15 can be achieved with farm tractor machinery (load size 4 m³). With a hauling distance of 250 m, the respective productivity is 7.6 m³/h-15. It is important to note that after manual felling the productivity of terrain haulage is generally 50% lower compared to mechanically cut stands. This is due to the fact that wood piles on manually cut stands are smaller and therefore also grapple loads tend to be smaller.

Terrain haulage of small wood with a farm tractor

The chipping of delimbed small wood stems or whole trees takes place by the roadside storage place. In connection with the chipping process the chips are blown directly into the containers of the long-distance transport vehicle. This makes chipping and transport dependent on each other and may cause delays and cut productivity. A practical productivity value of a tractor chipper is 60 bulk m³ per working hour. In theory, without delays and waiting times a productivity of 100 bulk m³ can be achieved.

The scale of forest chip procurement determines the technology used for the road transportation of the chips. With short transporting distances <25 km, 30 bulk m³ farm tractor-trailer units can operate cost efficiently. The transportation has to be well synchronised with chipping; for optimal chipping productivity an empty transport unit should always be available for loading. In other words, the transportation capacity should be fitted according to the chipper’s productivity and schedule.

Farm tractor with trailer for chip transportation

The core task in organising the fuel supply of a heating plant involves making contracts with the entrepreneurs supplying the fuel. Usually, the plant does not own or operate the harvesting machinery, and the fuel is purchased delivered at plant. According to the fuel demand the fuel supply volumes and delivery schedules are agreed with the suppliers.

The fuel suppliers are paid according to the energy content of the delivered fuel. The energy content of the fuel is determined by the volume, mass and moisture content of the fuel.
Costs of wood chips produced from small wood

In the case of wood chips produced from small-sized trees the fuel costs at plant consist of the standing price of the wood, the costs of the various work phases, and organisational costs. The thinning operations in young forests are subsidised by the state in some countries, including Finland. According to the EUBIONET II fact sheets, the production costs of forest chips produced from small wood are €16-21/MWh (€4.4-5.9/GJ).

For monitoring the quality of the fuel, samples are taken from each delivered fuel batch in order to determine the mean value of the moisture and bulk density of the chips. The moisture content of small wood chips usually varies between 18 and 40w-%. Usually a moisture content of 40w-% is the maximum for small-scale heating systems (<1 MW_t). The particle size of the chips is controlled during chipping; often the chips are sieved with a 40-mm sieve. The average energy content of a bulk cubic meter of wood chips with a moisture content of 31w-% is 0.74 MWh, and the fuel consumption with a boiler efficiency of 80-90% is at the level of 1.48 bulk m³ for MWh.

Example of production costs of wood chips delivered at plant (€/MWh)

Source: EUBIONET II fact sheets

<table>
<thead>
<tr>
<th></th>
<th>FINLAND</th>
<th>SWEDEN</th>
<th>AUSTRIA</th>
<th>PORTUGAL</th>
<th>FRANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stumpage price (paid to forest owners)</td>
<td>3.0</td>
<td>1.1 – 2.5</td>
<td>0</td>
<td>0</td>
<td>2.2</td>
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<tr>
<td>Cutting and piling</td>
<td>7.41 or 5.72</td>
<td>6.7</td>
<td>14.8</td>
<td>4.1</td>
<td>1.7</td>
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<tr>
<td>Forwarding</td>
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<td>4.0</td>
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<td>Long distance haulage</td>
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<td>1.8 – 4.3</td>
<td>3.7</td>
<td>5</td>
<td>1.4</td>
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<tr>
<td>Organization</td>
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<td>2.3</td>
<td>0.2</td>
<td>18.4</td>
<td>15.4</td>
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<tr>
<td>Total, €/MWh</td>
<td>21.16 pt or 15.9€</td>
<td>17.6 – 21.6</td>
<td>20.1</td>
<td>18.4</td>
<td>15.4</td>
</tr>
</tbody>
</table>

1Without subsidies (3.5 €/solid m³), 2 with subsidies (1.7 €/loose m³).
Chips made of delimbed small wood stems and whole tree chips are the forest fuel source for small installations. In bigger installations (>5 MWth) the variety of forest fuel sources is increased. Logging residues, stump wood and also straw and other herbaceous biomass fuels are applicable fuels for these installations. Depending on availability forest industry by-products such as bark, sawdust and cutter chips can also be used as a fuel.

In district heating and large-scale combined heat and power production plants (CHP) fuel deliveries must be reliable and on time. A clear fact is that the fuel supply can seldom be based on wood alone. To secure fuel availability, to reduce costs and to level out quality variations, large plants usually have multifuel boilers that use bark, sawdust, peat, etc. with forest chips, or the wood pellets are cofired with coal. Commonly wood fuels represent about a third of the plants' fuel flow.

The combined use of wood and other fuels creates special requirements for supply logistics and handling and blending the fuels at the plant. In addition to the feeding lines for chips, peat and coal, large plants often have separate receiving lines for uncomminuted fuel materials such as stumps, logging residues, logging residue bundles or energy grass bales. This material is crushed at the plant with a stationery crusher before feeding into the plant. Receiving stations must be fitted for multiple simultaneously operating machines, and the arrival of fuel trucks must be well scheduled.

Logging residues from regeneration cutting areas

Logging residue harvesting is generally done only on mechanically cut final felling areas. Manually cut areas and thinnings are left outside of the procurement chain due to the high costs of forwarding the material that is scattered throughout the felling area. Some of the logging sites are also out of question due to small size, long distances, difficult terrain or ecological restrictions, and in all cases it is recommended that at least 30% of logging residues are left at site. According to the common rule of thumb, the recovery of logging residue chips from regeneration areas of spruce is 0.5 MWh per solid m$^3$ of industrial stemwood removed.

Cutting of stem wood and piling of logging residues by one-grip harvester. Photo: John Deere
Stump wood is an increasingly important source of forest chips in the Nordic countries. Spruce is the best-suited tree species for stump harvesting due to its suitable stump-root system. The moisture content of stump wood fuel is lower than logging residue and small wood chips.

The harvestable dry mass of a stump-root system is 25-30% of the stem mass when sideroots thinner than 5 cm are not recovered. With a stump diameter of 40 cm the energy content of a spruce stump is 0.4 MWh. If 400 stumps can be harvested from a one-hectare felling area, the amount of harvestable energy is 160 MWh. At least one-third of the stump wood is left in the stand.

The production chain of logging residue chips is strongly attached to the work phase, where comminution (chipping or crushing) of the material takes place. Comminution can take place in the terrain, at the landing area, at the terminal or at the power plant. Therefore, the production chains are often named after the comminution location.

If the residues are to be recovered for energy, the harvesters should pile the residues along strip roads instead of directly in front of the machine. The residue will then accumulate in heaps alongside the strip road for easy recovery instead of being run over by forwarders on the strip road. Piling increases the productivity of terrain transport or chipping and reduces the contamination of logging residues.

The residues can be piled either to the one side or both sides of the strip road. The double-sided method has been found out to be more suitable at sites where large stems are felled. The piling of residues does not necessarily decrease the profitability of felling. However, the logging entrepreneur usually gains compensation from logging residue piling.

Chipping by the roadside

According to the chipping by the roadside method, the residue is transported to the roadside storage using a forwarder. The chipping takes place by the roadside, where the material is chipped and blown directly into the truck’s container.

The weakness of the roadside chipping method is that the chipper and the chip truck are dependent on each other. The close linkage of chipping and trucking can result in waiting and stoppages, thus reducing operational efficiency. A considerable part of the time consumption of a chipper or chip truck may be wasted in waiting. The smooth interaction of chipping and trucking is the most demanding phase of the system.

Terrain chipping is based on a single vehicle unit that is capable of performing several machine operation, such as chipping and forwarding. The chipper moves freely over the terrain after the final felling feeding the chipper. When the chip container is full, the terrain chipper returns to the landing and unloads chips into an interchangeable container. Chipping in terrain requires a highly mobile chipper suitable for operations at the felling area. Terrain chippers are equipped with a 15-20 m³ chip container that is emptied by tipping either to the side or backwards. With long terrain transport distances a chip shuttle forwarder can be used for transporting the chips from the chipper to the roadside landing.

Roadside chipping method is the most common method used.

Photo: LMH Hakkuri Oy
The chips are transported to the power plant by chip trucks equipped with 2 or 3 interchangeable chip containers that have a loose bulk volume of 35-45 m³. To avoid the interdependence of chipping and road transport, at least two sets of containers must be used: one set at the storage area and the other for transporting.

In the crushing at power plant method the terrain haulage is done with similar machinery as in the roadside chipping method. The residue trucks load themselves by the roadside and transport the material to the plant where it is comminuted. Chipping at a plant makes the chipper and chip truck independent of each other. The technical and operative availability of the equipment increases. Mobile chippers can be replaced by heavy stationary crushers, which are suitable for comminuting all kinds of biomass, including stump and root wood and recycled wood. The larger the fuel flow, the more obvious become the advantages. Since the investment cost is high, only large plants can afford a stationary crusher.

When chipping is performed at the plant, the truck transportation of residues takes place in the form of loose logging residues. The low bulk density of the residues is the weak link in the system. Loads have to be carefully compacted or load spaces have to be expanded. The transportation of loose residues is economic only on short transporting distances.

The bundling of residues method is a form of chipping at the plant procurement chain. In this method the ineffectiveness of transporting loose residue is avoided by compressing the residues into logging residue bales or logs. The residue is bundled in terrain with a forwarder based bundler. The bundle is three meters long and has a diameter of 60-70 cm. Depending on the quality of the residues (tree species, moisture) the energy content of each bundle is roughly 1 MWh (3.6 GJ).

The bundles are transported to the roadside using a standard forwarder. For road transport standard timber trucks can be used. In Nordic countries such as Sweden and Finland the 40-ton maximum loads can easily be achieved when transporting logging residue bundles.

The bundling method is a form of chipping at the plant procurement chain. In this method the ineffectiveness of transporting loose residue is avoided by compressing the residues into logging residue bales or logs. The residue is bundled in terrain with a forwarder based bundler. The bundle is three meters long and has a diameter of 60-70 cm. Depending on the quality of the residues (tree species, moisture) the energy content of each bundle is roughly 1 MWh (3.6 GJ).

The stumps are pulled out from the ground in final felling areas using excavators in connection with the scarification of the soil for forest regeneration. Stumps are then stored and dried at the stand over the summer season and then hauled and piled to the roadside storage for a year. During storage stumps are dried and cleaned from soil and stones. Sand and stones prevent comminution with sharp knives, so crushers are used instead of chippers.
Bundling of logging residues.
Photo: John Deere

Pulling of stumps.
Photo: Metla
**Procurement chains for logging residues**

**Piling**
The first stage of logging residue harvesting is piling the residues. To facilitate the collection the branches and tops of the trees are left in small piles with a height of 0.5-2 metres. The piles are formed while the single grip felling head of the harvester delims all the trees at certain points on the side of the strip road. The piling of the residues may decrease the productivity of harvesting. Normally the decrease is 5% or less.

**Forwarding**
The residues are hauled from the logging site to roadside storage with forwarders. Residue forwarders have grapples without plates between the forks to avoid the stones and soil to be lifted off with the residues. Since the bulk density of the material is low, the productivity of terrain transport can be improved by expanding load spaces. The load space can be expanded backwards with additional bolsters and sideways with widening bolsters. This has rather a dramatic effect on the load size: with conventional load spaces, the load sizes vary from 4-5 solid m$^3$, whereas with extensions load sizes of up to 8-14 solid m$^3$ can be achieved. The productivity of terrain haulage varies according to the accumulation of the material at the stand, the hauling distance and the load capacity of the used machinery. In normal conditions, with 9 m$^3$ of load space and with the typical 250 metres forwarding distance from the stand to the roadside storage, the productivity of forwarding is 10 solid m$^3$ per working hour.

**Storage**
Logging residue storages are located by the roadside. Ten meters of roadside should be reserved for every 100 m$^3$ of residues if the pile is approximately 5 m high and wide. There also many other requirements for the landing site due to large machinery operating by the roadside landing. The road has to be well-bearing because the fully loaded vehicles may weigh up to 60 tons. The landing area also has to be spacious for turning and passing because the length of the vehicles may be up to 20 metres and their width 2.6 metres.

For the best results in terms of operational efficiency and the quality of the residues, the piles should be as large as possible. Small piles get wet easily over extended storing periods and require extra machinery movements during chipping and loading. The residues should be piled with the butts of the trees facing the road and the rear edge of the pile no more than 5-6 metres from the road. For easy processing, crosswise piling should be avoided. Dry residue piles should be covered with tarred paper in the autumn before rain and snowfall. Fresh residues should not be covered.

**Chipping and crushing**
Chipping can take place at the roadside storage place, at a terminal storage or at the end-use facility. When chipping is done by the roadside, the chips are usually blown directly into the containers of the long-distance transport vehicle. The capacity of mobile chippers varies according to the size and power of the model. Due to their mobility and the good quality of the chips, drum chippers built on truck chassis dominate in large-scale roadside chipping. The capacity of this type of chippers is around 35-40 m$^3$ solid per effective working hour.

When crushing is done at the terminal, bigger machine units are used due to the higher material amounts. Large mobile crushers weigh around 30 tonnes and have a capacity of 50-60 m$^3$/h in good conditions. Since the size and weight of this machinery makes transportation difficult, this machinery is better for larger worksites such as fuel terminals. Since crushers tolerate impurities such as rock and metal better than chippers, more challenging materials such as stump wood can be processed with crushers.
In the terminal harvesting chains, the different work phases of the harvesting chains are not dependent on each other due to the storage periods of the material. The use of terminals may reduce the demand for storage area at the end-use facility and increase logistical possibilities for optimised energy wood deliveries – the most suitable material can be delivered to the place where it is most needed, exactly at the right time.

With the changing demand for chips, the terminal also acts as a buffer storage, thus improving the reliability of deliveries. Large stationer crushers are used for crushing material at the plant.

A stationary crusher is capable of comminuting all kinds of biomass delivered to the plant: loose and baled logging residues, undelimbed tree-sections, recycled wood, and stump and root wood. Since the cost of the investment is 1-2 million, stationery crushers are a feasible option only for large plants. With an annual chip production of 150,000 m³ (300 GWh), the cost of using a stationery crusher is approximately 1.3/MWh. The share of capital costs in the crusher's operating costs is very high, so changes in the utilisation rate have a high effect on the costs per crushed fuel unit.

Transportation – chip truck
Transporting chips by road involves full-trailer trucks with a load space volume of 110-130 loose-m³, 50 loose cubic metres of which are on the truck and 77 on the trailer. The trucks have closed chip containers made of metal or isolated containers with a glassfibre-styrofoam-plywood construction for reduced freezing problems in winter use. In Finland the maximum permitted total weight of the truck-trailer combination is 60 tonnes.

The weight of the unloaded truck is usually 20-24 tonnes, which allows 36-40 tonnes of chips to be transported per load. The general maximum permitted total weight of the trucks in Europe is 40 tonnes, and thus the load size is decreased to 20 tonnes, depending on the unloaded weight of the truck. The chip trucks are usually loaded by the chippers at the roadside landing. For a load of 110-130 loose m³ this chipping-loading operation usually takes 1.5 hours. For unloading the load spaces are equipped with bottom scrape conveyors.

Transportation – residue-stump truck
The challenge of transporting uncomminuted forest fuel lies in the low bulk density of the material. Large 150 m³ truck-and-trailer vehicles have been built to transport loose logging residues, residue bales, undelimbed tree sections and stump and root wood to the plant. The bottom and the sides of the load space must be closed, as with chip transports. For achieving maximal load sizes, the load space has to be built according to the maximum allowed dimensions. Variable load space – e.g. an extendable trailer – is a good option for reaching the optimal load size with different densities of transported material. The trucks are equipped with cranes for loading and unloading the material. Fingered grapples are more suitable than normal timber grapples for loading uncomminuted forest fuel. The load can also be compacted with the crane.

In the case of bundled logging residue, regular timber trucks can be used. The load space of a regular truck-trailer combination fits 60-70 logging residue logs. Transporting loads consisting of commercial timber and residue logs is also possible – for example, the truck may be loaded with pulpwood and the trailer with residue logs. In many cases this possibility facilitates many advantages in terms of the maximal utilisation of loading capacity and backhauling. The loading and unloading of residue logs is done with similar equipment than used with commercial timber. In the optimal case the truck unloads the residue logs directly to the feeding table of the stationary crusher at the plant.
Efficient procurement by networking operators

A network model is usually applied in the fuel procurement of a district heating plant or CHP. When selling fuel to heating plants and power plants, the network model is able to operate efficiently and satisfy customers’ criteria in terms of price, quality, flexibility and availability.

Normally the fuel supply is integrated with round wood procurement. Large forest companies operate nationwide and perform their wood procurement through special forest departments. The fuel supplier has a purchasing contract with forest companies. Forest companies have further contracts for both timber and forest chip procurement with independent entrepreneurs. These independent entrepreneurs take care of forest haulage and on-road transportation. Forest companies also contract with forest owners. The fuel supplier can arrange fuel transportation to the energy production plants either with his own logistics or by using contracts with transportation companies.

For performing the cost analyses for different harvesting chains, every machine (work phase represented by the machine) is first studied with detailed cost calculations. The main cost factors of the hourly cost calculation are labour, capital and operating costs. They can be further divided into fixed and variable costs. Fixed costs are not dependent on the level of activity but on time considerations. Variable costs are dependent on the scale of the activity, i.e. how much the machine is utilised over a certain time period.

Planning phases of the forest wood supply chain. Drawing: VTT

Due to variations in the availability of logging residues, stand characteristics, legal restrictions and labour and machine costs, for example, there are no general values for the harvesting costs of forest fuels and no general order of superiority between different harvesting chains. For optimal forest fuel procurement solutions from the perspective of a single plant or entrepreneur, careful planning is required.

The production costs are €12-22/MWh (€3.3-6.1/GJ) and they are dependent on the production chain. In Central Europe logging residues are harvested separately.

Trading of biomass fuels based on energy content or tons

In the Nordic countries fuel suppliers are paid according to the energy content of the delivered chips. For measuring the energy content of the delivered chips each truckload is weighed at the plant, and samples are taken for defining the moisture content. Based on the weight of the load, the moisture content, and the net calorific value of the chips, the energy content of each delivered load can be calculated. In Central Europe the fuel price is determined according to tons delivered.

Usually 4 to 6 samples must be taken from each arriving truck-trailer load. In the Nordic countries the truck driver usually takes care of this while unloading at the plant. Single samples are combined daily for determining a moisture content profile for each supplier. The net calorific value is determined less frequently, for example on a monthly basis. Particle size is determined in connection with the introduction of new fuel suppliers, new machinery or new raw materials.

Wood and straw pellets for cofiring

Pellets are the most traded biomass fuel. This is natural, as pellets are the most compact form of solid biofuels, so the transport costs per energy unit is the lowest. Wood pellets are also imported into Europe from North America for cofiring in power plants.

Estimated harvesting costs of logging residue chips with different harvesting chains in Northern European conditions.

Source: VTT

<table>
<thead>
<tr>
<th>Harvesting chain Work phase</th>
<th>Roadside chipping Cost, €/MWh</th>
<th>Terrain chipping Cost, €/MWh</th>
<th>Crushing at plant Cost, €/MWh</th>
<th>Bundled residues Cost, €/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquiring harvesting rights</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
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<tr>
<td>Piling of the logging residues (harvesting delay)</td>
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<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
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<tr>
<td>Bundling of the residues</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.55</td>
</tr>
<tr>
<td>Terrain transport of the residues/residue bales (200 m)</td>
<td>2.60</td>
<td>-</td>
<td>2.60</td>
<td>2.40</td>
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<tr>
<td>Terrain chipping</td>
<td>-</td>
<td>6.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chipping at roadside</td>
<td>3.90</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Road transport (50 km), 60 tons maximum weight</td>
<td>3.11</td>
<td>4.10</td>
<td>4.80</td>
<td>3.60</td>
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<tr>
<td>Crushing at plant (feeding of the crusher included)</td>
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<td>Organising the supply</td>
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<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Total</td>
<td>11.28</td>
<td>11.88</td>
<td>11.47</td>
<td>12.17</td>
</tr>
</tbody>
</table>
When cofiring pellets in large coal-fired power plants, the pellets are typically added to the coal prior to milling and are milled together with the coal in the coal mills. The produced wood dust is pneumatically transported to the power plant together with the coal dust and cocombusted in the same burners as the coal dust. However, grinding at the coal mills does require a minimum hardness for the pellets, which can be deducted from the density. Density should be higher than approximately 600 kg/m³. Cofiring without burner adjustment is possible up to 20–30% on energy basis. Cofiring in standard coal-fired power plants requires investments of €120/kWfuel for fuel handling and intermediate storage and requires operation and management costs of €12/MWhe. The mill gate prices for pellets in Canada are approximately €80 per ton, and production costs are estimated at €50 to 60 per ton, which is lower than in Europe. Transportation to export ports and ship loading amounts to €35 per ton, and sea shipping by bulk carrier from Canada to Europe will cost approximately €25 per tonne, bringing the total CIF price to approximately €140 per ton.

Amer power plant in the Netherlands cofires wood pellets with coal. Photo: SenterNovem

Straw pellet storage in Danish pellet plant. Photo: DTI

Reed canary grass is harvested for energy in Northern Europe. Photo: Vapo Oy.

Cultivating reed canary grass in Northern Europe

Reed canary grass (Phalaris arundinacea L.) is a wild, perennial grass that grows in Scandinavia, including Lapland. Reed canary grass thrives on wet soils and can tolerate occasional flooding. In the later stages of growth, it also manages in dry conditions. Cultivated reed canary grass suits all soil types, but the best yields have been obtained on humus rich soils. In good conditions, the dry-matter yield may be nearly ten tonnes per hectare. In practice, however, the average yield is approximately 5 tons. Reed canary grass is harvested in spring, when the moisture content of dead grass is 10-20w-%. The fuel properties of spring-harvested reed canary grass are clearly better than those of autumn-harvested grass. Nutrients move to the rhizomes in the ripening stage. This improves the combustion properties of the straw mass and also stores nutrients for the following growing season. One reed canary grass stand can be harvested annually for more than ten years. Harvesting losses and logistics still pose challenges to the production and use of reed canary grass. The cultivation and use of reed canary grass has been developed since the beginning.
of the 1990s. Reed canary grass has been grown on peatlands and cut-away peatlands since 1995.

The first yield is harvested in April, two years after sowing. Harvesting can be started when the moisture content of the grass is 10-15w-% and the field is firm enough to carry harvesting machinery. The harvesting season lasts a few weeks in spring. If the new growth is more than 25 cm, mowing should not be performed, as increased moisture weakens the quality of the crop. Annual fertilisation is performed after harvesting.

Harvesting is a challenging stage. In unfavourable conditions, up to half of the biomass may be lost. The normal harvesting stages are as follows: mowing, windrowing, and baling or chopping. Mowing can be performed with a mower-chopper or a disc mower. As there is a direct correlation between stubble height and harvesting losses, it is important to mow as close to the ground as possible. Plant stands that have been flattened by snow may be difficult to mow if the mower is driven in the direction of the lodged plants.

Baling can be performed with a round baler or a square baler. The best results are achieved on large, even sites using modern heavy-duty square balers. Baling can also be performed by using fixed-chamber and variable-chamber round balers. For storing and transportation, large square bales are the best. The density of square bales is more than 200 kg/m³, whereas the density of round bales is 120-160 kg/m³. Square bales can also be packed more tightly on trucks, which mean more efficient transportation. Round bales do not fill the truck space as well. Baled reed canary grass is chopped into lengths of 5-10 cm before blending it with other fuels. Chopping can be performed at fuel terminals or at power plants. In locations near energy peat production sites, harvesting can be performed by chopping the grass at site. Different types of chopping balers are available on the market. Loose chopped material can be blended with peat and delivered to power plants as a fuel blend. The most effective handling chain is one in which reed canary grass is delivered to the power plant in large square bales.

Straw bales – biomass fuel for district heating plants and for cofiring

Large-scale straw handling for energy purposes has developed into an independent discipline in agriculture in which particularly large farms and machine pools make investments. The big bale (width 120 cm, height 130 cm and length 240 cm) is the main type used by district heating plants. The weight is around 500 kg, and new balers can make bales up to 700 kg. In recent years a midi bale has been introduced with the following dimensions: width 120 cm, height 90 cm and length 240 cm. The resulting weight is 425-500 kg. The advantage is that the bale density (140-185 kg/m³) is slightly higher, and the tractor/truck can carry 3 layers of midi bales instead of 2 layers of big bales. The handling capacity by loading is also increased. The disadvantage is that the straw crane in the plant has to be modified.

Most farmers with straw contracts produce some hundred tons of straw annually. A few large farms and machine pools have developed large-scale handling of 10,000-30,000 tons of straw annually.

Production costs of reed canary grass bales and straw bales (€/MWh). Source: VTT & DTI

<table>
<thead>
<tr>
<th></th>
<th>REED CANARY GRASS</th>
<th>STRAW</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bales, mobile cruiser</td>
<td>Bales, stationary cruiser at plant</td>
<td>Loose material</td>
<td>Value of straw in the field</td>
</tr>
<tr>
<td>Land value</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Cultivation</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Annual fertilization</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Harvesting including baling</td>
<td>6.1</td>
<td>6.1</td>
<td>5.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Chopping of bales</td>
<td>4.4</td>
<td>2.6</td>
<td>0.0</td>
<td>1.3 – 1.5</td>
</tr>
<tr>
<td>Long distance transport</td>
<td>3.7</td>
<td>3.7</td>
<td>6.3</td>
<td>1.7 – 10.4</td>
</tr>
<tr>
<td><strong>Total production costs, €/MWh</strong></td>
<td><strong>27.9</strong></td>
<td><strong>26.1</strong></td>
<td><strong>25.6</strong></td>
<td><strong>13.0 – 22.6</strong></td>
</tr>
</tbody>
</table>

The yield for read canary grass in calculations is 6 tons dry matter/ha and transportation distance 70 km.
Main conditions for straw bale production:

- Bale size: big bale – height 1.3 m, width 2 meter, and length between 2.0 and 2.4 meters; midi bale – height 1.2 m, width 0.9 meter, and length between 2.0 and 2.4 meters
- Bale weight: big bale – between 400 and 600 kg; midi bale – 425-500 kg
- Moisture content: 15–16w-%, maximum 20 w-%
- Bales should be placed in a special way on the trailer at delivery for easy unloading
- The farmer must take ash in return related to the amount of straw delivered.
- The farmer has to deliver straw throughout the year. The plant specifies the timetable for delivery.

- Straw from wheat, rye, barley, oats, triticale and rape can be delivered.
- No visible mould on bales by delivery.

The quality control of the bales at the plant includes visual monitoring for mould, weighing and measuring the moisture content. The weighing takes place by unloading. To determine the moisture content, a measuring instrument equipped with a spear for insertion into the bales is used. According to the typical procedure involving a single load of 16-24 bales, the spear is inserted in at least 4 bales in different positions of the bale. If the average moisture content is over 18w-%, the load is reduced by 5% for each % that the moisture content exceeds 18w-%. As a result the price for the load is reduced, as the payment is based on tons. If the average is over 20w-%, the whole load or some bales will be rejected. If the average of the moisture content is under 16w-%, the load is increased by 5w-% for each % that the moisture content is less than 16w-%, but only to 11w-%.

Like most energy grasses straw consists of small amounts of nitrogen, sulphur, alkali (sodium, potassium) and chloride. The presence of chlorine and alkali in the flue gas is problematic, since these matters undergo chemical reactions into sodium chloride and potassium chloride that are extremely corrosive for the steel of the boiler, particularly at high temperatures.
Olive residues – a Southern European biomass resource

Since 1980 the area on which olives are grown has more than doubled. With more than 4.5 million hectares under cultivation, it is the second-most important agro-food sector in Europe. The production residues of olive and olive oil production are utilised as solid biomass fuel. The estimated amount of residues is about 1.5 million tons, including stones and exhausted olive cake (olive marc). The international trade in olive marc is growing, and in recent years approximately 400,000 tons of olive marc has been exported from Andalusia to Europe.

The raw material is olive cake (“orujo” in Spanish), also called olive pomace. The olive cake is a byproduct of the olive oil production process and constitutes a mixture of olive stone, olive pulp and the water added in the olive mills. The moisture content is approximately 55-70w-%. The amount of raw material depends on climate conditions, which determine the annual production period (8 to 9 months/year).

Usually olive cake is purchased from a maximum distance of 70 km. The stone can be separated from the olive cake previous to the extraction process in order to sell it as a biofuel, but the extraction becomes more complicated. On the other hand, the separation of the stone from the pulp in many installations makes the extraction operation difficult, since the percolation is altered, which means it would be necessary to compact the pulp.

Only a minimum quantity is separated to allow drying and extraction in optimal conditions. The quantity of stones represents about 1% of the total moist olive cake.

The process is based on solid-liquid extraction where the fats are separated (extracted) with a solvent (hexane). Once this operation has been carried out, the oil from the mixture with hexane is separated through distillation. This process can be modified in situations where the separation of pulp and stone is produced.

The productive process of the extractor begins with the delivery of fatty olive pomace from oil mills. The trucks from the oil mills unload the raw material in the storage yard.

The two components of the olive pomace (the pulp and the stone) are separated, for extracting only the first of the two components. This is because the pulp contains a major part of the oil from the olive pomace, while the stone, which presents an important percentage of the solid, contains so little oil that its recovery is not interesting. In this way, the capacity of the extraction area could be increased and more quantities of raw material could be processed.

However, it is necessary to consider other factors, such as the mechanical resistance of the set of particles to percolation, the formation of powder, the difficulty of distribution from the extractors, when carrying out the previous operation. This limits the size in the remixing to a determined thickness. For this reason the remixing operation is not a typical mixing, but rather it is done by moving the product with energy for its separation.

The stone has very good properties as a fuel for heating, even for domestic installations. Currently, due to the high price of stone, it is separated in many installations and even in the same oil mills. The olive pomace, particularly when produced from classic oil mills, must be remixed for separating it before being dried. With this operation the drying is made easier, because the surface contact increases between the olive pomace and hot air. For the same reason, the subsequent phase of percolation is favourable.

High quality fuel from olive residues – olive marc. The moisture content of the fuel is less than 10w-%. Photos: VTT
To avoid the acidification of the oil, and for favouring the extraction phase, the olive pomace is submitted to a drying process until the moisture content is suitable for reaching the above-mentioned ends. The moisture of the olive pomace is such that its transport should be made like that of a sticky waste, using a transport base that consists of an endless fan (bucket type).

The system used for the drying process is a rotating cylinder heated internally by hot gases fed from a combustor or burner situated in the front part of the cylinder.

There is direct contact between the gases and the product since there are no pollution problems from the solid. After the re-drying of the solid a cyclone is used to remove particles from the gases, which allows the recovery of the grains by a sucking motion of the drying gases. This also maintains the emissions within the legal limits and recovers a valueless part of the olive pomace. The final moisture content after the drying is less than 10w%.

The redried olive pomace is submitted to a solvent action. Hexane is most commonly used by practically all olive pomace extractors that extract the oil hidden in the solid mass. The liquid mixture of oil and solvent is called “miscela”, and the degreased residual pomace is called “orujillo” (olive marc, exhausted olive cake).

Hexane is not an ideal solvent due to its inflammability, which make it dangerous to handle. If the extractor is situated in an inhabited area, trichloroethylene, which is not inflammable, can be used as an alternative. However, this solvent presents, apart from its toxicity and corrosiveness, lesser selectivity than hexane.

In this plant, the extraction process is carried out in discontinuous form. The oil is prepared by sets or batches, making it necessary to have an important discreet time so that the operations described above are carried out well.

The discontinuous extractor bases its operations on the filling of each one of the extractors. Once the operation is finalised, it proceeds to the opening (manual or automatic) of the extractors.

Emptying or dumping the extractors can be performed from below or from the side. Emptying is done hydraulically, so workers are needed.

This mixture is filtered in order to eliminate the solid particles in suspension that the “miscela” can carry. It is absolutely essential that the solid organic substances in suspension do not arrive at the distillation, because these, under the heat action, give the oil many impurities (waxes, lignin, colouring matters, etc.) that harm the subsequent refining action.

The filtered “miscela” (liquid mixture of oil and solvent) that results from the operation of lixiviation must be separated in its components. Also, the oil from the olive pomace, the heaviest component, remains at the bottom of the apparatus while the solvent leaves as a gas form through the head of the separation column.

Prior to the separation of these two components, the change of both components from the vapor phase to the liquid phase must be produced. The condensers use a huge amount of water for cooling purposes. Water costs are getting more and more expensive, and the installation of cooling towers that use water in a closed circuit are being imposed. Therefore, the losses of the installation are much smaller. The blend of solvent and water originating from the distillation phase of the liquid mixture (miscela) and disolventisation phase of the solid is separated for recovering both components and recircuiting them to the process. The separation, given the difference in densities between both, is made by simple decantation in which the hexane, the most volatile, remains in the upper part of the tank.

The degreased olive pomace that is left after the extraction stage is submitted to a sucking process for recovering the hexane retained in the solid. At the same time the olive marc stays in conditions for being discharged from the apparatus, making it ready for storage and later use.

A recovery system is used for the incondensed hexane coming from the extractors and distillers by means of absorbents of natural acid base.

Production costs are typically €16.3/ton of raw material, which is about €8.9/MWh (€2.2/GJ).
Units and conversion factors

Volume
1 m³ solid or 1 m³  unit referring to wood as solid cubic meter, ≈ 7.2–7.9 GJ, ≈ 2.5 m³ loose
1 m³ loose  unit referring to wood as loose cubic meter, ≈ 2.5–3.2 GJ
1 m³ solid (log wood) 2.0–2.5 m³ loose and 1.2–1.5 stacked m³

Conversion of units

<table>
<thead>
<tr>
<th></th>
<th>toe</th>
<th>MWh</th>
<th>GJ</th>
<th>Gcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>toe</td>
<td>1</td>
<td>11.63</td>
<td>40.868</td>
<td>10.0</td>
</tr>
<tr>
<td>MWh</td>
<td>0.08598</td>
<td>1</td>
<td>3.600</td>
<td>0.8598</td>
</tr>
<tr>
<td>GJ</td>
<td>0.02388</td>
<td>0.2778</td>
<td>1</td>
<td>0.2388</td>
</tr>
<tr>
<td>Gcal</td>
<td>0.1</td>
<td>1.1630</td>
<td>4.1868</td>
<td>1</td>
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</table>

Prefix

<table>
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<th></th>
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<th>10⁻⁶</th>
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<td>1 000</td>
</tr>
<tr>
<td>M</td>
<td>mega</td>
<td>10⁶</td>
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<tr>
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</tr>
<tr>
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<td>tera</td>
<td>10¹²</td>
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<tr>
<td>P</td>
<td>peta</td>
<td>10¹⁵</td>
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<tr>
<td>E</td>
<td>eksa</td>
<td>10¹⁸</td>
<td>1 000 000 000 000 000 000</td>
</tr>
</tbody>
</table>

Examples:
1 toe = 11.63 MWh
1 Mtoe = 11.63 TWh = 40.868
1 kWh = 3 600 kJ = 3.6 MJ
1 MWh = 3.6 GJ
1 TJ = 1 000 GJ
1 PJ = 1 000 TJ
1 TWh = 1 000 GWh

Space requirement for fuel consumption of 10 MWh (36 GJ)
Net calorific value, moisture content and energy density for different biomass fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Net calorific value, dry content kWh/kg (moisture content 0%)</th>
<th>Moisture content (Mₚ,net,d) w-%</th>
<th>Net calorific value, as received = actual value kWh/kg</th>
<th>Bulk density (BD) kg/loose m³</th>
<th>Energy density ( Eₚ ) (MWh/loose m³)</th>
<th>Ash content, (A) dry, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawdust</td>
<td>5.28 – 5.33</td>
<td>45 – 60</td>
<td>0.60 – 2.77</td>
<td>250 – 350</td>
<td>0.45 – 0.70</td>
<td>0.4 – 0.5</td>
</tr>
<tr>
<td>Bark</td>
<td>5.83 – 6.39</td>
<td>45 – 55</td>
<td>2.22 – 3.06</td>
<td>300 – 400</td>
<td>0.60 – 0.90</td>
<td>1.0 – 3.0</td>
</tr>
<tr>
<td>Bark, coniferous</td>
<td>5.14 – 5.56</td>
<td>50 – 65</td>
<td>1.38 – 2.50</td>
<td>250 – 350</td>
<td>0.50 – 0.70</td>
<td>1.0 – 3.0</td>
</tr>
<tr>
<td>Plywood chips</td>
<td>5.28 – 5.33</td>
<td>5 – 15</td>
<td>4.44 – 5.00</td>
<td>200 – 300</td>
<td>0.9 – 1.1</td>
<td>0.4 – 0.8</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>5.26 – 5.42</td>
<td>7 – 8</td>
<td>4.60 – 4.90</td>
<td>550 – 650</td>
<td>2.6 – 3.3</td>
<td>0.2 – 0.5</td>
</tr>
<tr>
<td>Stem wood chips</td>
<td>5.14 – 5.56</td>
<td>40 – 55</td>
<td>1.94 – 3.06</td>
<td>250 – 350</td>
<td>0.7 – 0.9</td>
<td>0.5 – 2.0</td>
</tr>
<tr>
<td>Log wood (oven-ready)</td>
<td>5.14 – 5.28</td>
<td>20 – 25</td>
<td>3.72 – 4.03</td>
<td>240 – 320</td>
<td>1.35 – 1.95</td>
<td></td>
</tr>
<tr>
<td>Logging residue chips</td>
<td>5.14 – 5.56</td>
<td>50 – 60</td>
<td>1.67 – 2.50</td>
<td>250 – 400</td>
<td>0.7 – 0.9</td>
<td>1.0 – 3.0</td>
</tr>
<tr>
<td>Whole tree chips</td>
<td>5.14 – 5.56</td>
<td>45 – 55</td>
<td>1.94 – 2.78</td>
<td>250 – 350</td>
<td>0.7 – 0.9</td>
<td>1.0 – 2.0</td>
</tr>
<tr>
<td>Reed canary grass, (spring harvested)</td>
<td>4.75 – 5.17</td>
<td>8 – 20</td>
<td>3.70 – 4.70</td>
<td>70</td>
<td>0.3 – 0.4</td>
<td>1.0 – 10.0</td>
</tr>
<tr>
<td>Reed canary grass, (autumn harvested)</td>
<td>4.64 – 4.92</td>
<td>20 – 30</td>
<td>3.06 – 3.81</td>
<td>80</td>
<td>0.2 – 0.3</td>
<td>5.1 – 7.1</td>
</tr>
<tr>
<td>Grain</td>
<td>4.8</td>
<td>11</td>
<td>4.30</td>
<td>600</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Straw, chopped</td>
<td>4.83</td>
<td>12 – 20</td>
<td>3.80 – 4.20</td>
<td>80</td>
<td>0.3 – 0.4</td>
<td></td>
</tr>
<tr>
<td>Miscanthus, chopped</td>
<td>5.0</td>
<td>8 – 20</td>
<td>3.86 – 4.06</td>
<td>110-140</td>
<td>1.72 – 2.19</td>
<td>2.0 – 3.5</td>
</tr>
<tr>
<td>Straw pellets</td>
<td>4.83</td>
<td>8 – 10</td>
<td>4.30 – 4.40</td>
<td>550 – 650</td>
<td>2.4 – 2.8</td>
<td></td>
</tr>
<tr>
<td>Olive cake (olive pomace)</td>
<td>4.9 – 5.3</td>
<td>55 – 70</td>
<td>1.00 – 3.10</td>
<td>800 – 900</td>
<td>1.46 – 1.64</td>
<td>2 – 7</td>
</tr>
<tr>
<td>Olive cake (olive marc)</td>
<td>4.9 – 5.3</td>
<td>&lt; 10</td>
<td>4.30 – 4.70</td>
<td>600-650</td>
<td>2.6 – 2.9</td>
<td></td>
</tr>
</tbody>
</table>

1 kWh/kg = 1 MWh/ton = 3.6 GJ/ton

Calculation of net calorific value as received (CEN/TS 15234)

The net calorific value (at constant pressure) as received (net calorific value of the moist biomass fuel) is calculated according to equation:

\[
q_{p,\text{net, ar}} = q_{p,\text{net, d}} \times \left( \frac{100 - M_{ar}}{100} - 0.02443 \times M_{ar} \right)
\]

where

- \( q_{p,\text{net, ar}} \) is the net calorific value (at constant pressure) as received [MJ/kg]
- \( q_{p,\text{net, d}} \) is the net calorific value (at constant pressure) in dry matter [MJ/kg] (net calorific value of the dry fuel
- \( M_{ar} \) is the moisture content as received [w-%, wet basis]
- 0.02443 is the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25 °C [MJ/kg per 1 w-% of moisture]

Chemical composition of different biomass fuels, % of dry matter

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Carbon, C</th>
<th>Hydrogen, H₂</th>
<th>Sulphur, S</th>
<th>Nitrogen, N</th>
<th>Chlorine, Cl</th>
<th>Sodium, Na</th>
<th>Potassium, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawdust</td>
<td>48 – 52</td>
<td>6.2 – 6.4</td>
<td>&lt;0.05</td>
<td>0.3 – 0.4</td>
<td>0.01 – 0.03</td>
<td>0.001 – 0.005</td>
<td>0.02 – 0.15</td>
</tr>
<tr>
<td>Bark</td>
<td>48 – 52</td>
<td>6.2 – 6.8</td>
<td>&lt;0.05</td>
<td>0.3 – 0.5</td>
<td>0.01 – 0.05</td>
<td>0.007 – 0.020</td>
<td>0.1 – 0.5</td>
</tr>
<tr>
<td>Plywood chips</td>
<td>48 – 52</td>
<td>6.2 – 6.4</td>
<td>&lt;0.05</td>
<td>0.1 – 0.5</td>
<td>&lt; 0.05</td>
<td>0.25 – 0.50</td>
<td>0.7</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>49 – 50</td>
<td>6.0 – 6.1</td>
<td>&lt;0.007</td>
<td>&lt; 0.16</td>
<td>0.01 – 0.03</td>
<td>0.001 – 0.002</td>
<td>0.2 – 0.15</td>
</tr>
<tr>
<td>Log wood</td>
<td>48 – 52</td>
<td>6.0 – 6.5</td>
<td>&lt;0.05</td>
<td>0.3 – 0.5</td>
<td>0.01 – 0.03</td>
<td>0.001 – 0.002</td>
<td>0.2 – 0.15</td>
</tr>
<tr>
<td>Stem wood chips</td>
<td>48 – 52</td>
<td>5.4 – 6.0</td>
<td>&lt;0.06</td>
<td>0.3 – 0.5</td>
<td>0.01 – 0.03</td>
<td>0.001 – 0.002</td>
<td>0.2 – 0.15</td>
</tr>
<tr>
<td>Logging residue chips</td>
<td>48 – 52</td>
<td>6.0 – 6.2</td>
<td>&lt;0.05</td>
<td>0.3 – 0.5</td>
<td>0.01 – 0.04</td>
<td>0.075 – 0.030</td>
<td>0.1 – 0.4</td>
</tr>
<tr>
<td>Whole tree chips</td>
<td>48 – 52</td>
<td>5.4 – 6.0</td>
<td>&lt;0.05</td>
<td>0.3 – 0.5</td>
<td>0.01 – 0.03</td>
<td>0.001 – 0.002</td>
<td>0.2 – 0.15</td>
</tr>
<tr>
<td>Reed canary grass, (spring harvested)</td>
<td>45 – 49</td>
<td>5.3 – 5.8</td>
<td>0.04 – 0.13</td>
<td>0.65 – 1.10</td>
<td>0.04 – 0.09</td>
<td>&lt;0.03</td>
<td>0.3 – 0.5</td>
</tr>
<tr>
<td>Reed canary grass, (autumn harvested)</td>
<td>44.6 – 46.7</td>
<td>5.6 – 5.9</td>
<td>0.06 – 0.25</td>
<td>0.7 – 1.1</td>
<td>0.4</td>
<td>&lt;0.001</td>
<td>1.2 – 2.3</td>
</tr>
<tr>
<td>Grain</td>
<td>45</td>
<td>6.5</td>
<td>0.14</td>
<td>2.0</td>
<td>0.04</td>
<td>0.002 – 0.005</td>
<td>0.4 – 1.0</td>
</tr>
<tr>
<td>Straw, chopped</td>
<td>45 – 47</td>
<td>5.8 – 6.0</td>
<td>0.10 – 0.20</td>
<td>0.4 – 0.6</td>
<td>0.14 – 0.97</td>
<td>0.01 – 0.6</td>
<td>0.69 – 1.30</td>
</tr>
<tr>
<td>Straw, pellets</td>
<td>45 – 47</td>
<td>5.8 – 6.0</td>
<td>0.10 – 0.20</td>
<td>0.4 – 0.6</td>
<td>0.14 – 0.97</td>
<td>0.01 – 0.6</td>
<td>0.69 – 1.30</td>
</tr>
<tr>
<td>Miscanthus, chopped</td>
<td>46</td>
<td>5.5</td>
<td>0.05</td>
<td>0.46</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olive cake</td>
<td>48 – 50</td>
<td>5.5 – 6.5</td>
<td>0.07 – 0.17</td>
<td>0.5 – 1.5</td>
<td>0.1 (in ash)</td>
<td>0 (in ash)</td>
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</table>