- *Willow short rotation coppice is difficult to store in large amounts, because dry matter losses due to fungi will be high*
- *Willow short rotation coppice whole shoots can be stored with success over a summer and will lose much water, making it a good fuel for small scale installations*
- *If the willow is harvested as chips, it should be delivered straight to the large scale consumer*
- *Fungi and bacteria can cause huge losses in dry matter, especially in small chips, up to 30 % over 9 months storage*

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Storage of short rotation coppice willow fuel

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Background

The area of short rotation coppice (SRC) willow in Ireland is slowly increasing to meet local renewable energy demands, with some additional use in cofiring of peat for electricity generation. Increased demand for willow biomass poses a problem: it can only be harvested when it is leaf-free, over the period from end of November-April, whereas cofiring and other applications generally need a year-round fuel supply. Potentially, cofiring and CHP will require very large volumes of wood fuel from forests and short rotation coppice, meaning that large volumes of fuel may have to be stored for prolonged periods of time, in some cases up to 8 months. Also, for small scale use, fuel has to be stored and probably also dried. Willow has a moisture content of 50-55% at harvest, but most small-scale boilers are only designed to combust fuel at maximum moisture content (MC) of 30%.

Another factor to consider is that the bark:wood ratio of willow SRC is much higher than forest-derived wood chips. Bark contains many plant nutrients, which together with its high moisture content, makes willow SRC an ideal growth medium for bacteria and fungi, especially when the material is harvested as chips.

As was pointed out in the COFORD Connects Note on harvesting SRC willow, shoots can be harvested as whole-shoots (3-8 m in length), as billets (10-20 cm) or as chips (2.5-5 cm). The smaller the size, the less natural ventilation will take place in the stacks and the better bacteria and fungi will flourish.

Guidance on how to deal with the range of issues pertaining to the storage of willow SRC fuels comes from an EU-funded project undertaken in 1996. For the purposes of the study it was assumed that large scale installations using SRC willow would be built in Denmark, Italy, and the UK. Denmark took the lead in the storage studies, where large scale trials were undertaken to determine the effect of particle size, covering and ventilation of SRC willow chip piles. Over a 2-year period some 18 SRC chip piles were assembled, each one at least 50 tonnes in size. Moisture content development, the amount of dry matter loss and the temperature inside the piles was monitored.

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Study details

Drying behaviour of the following willow SRC fuel sizes was examined:

- Whole-shoots
- 20 cm billets
- 10 cm billets
- 5 cm chip
- 2.8 cm chip

Piles were located:

- outdoors, uncovered (whole-shoots, billets, chips)
- outdoors, loosely covered with plastic (whole-shoots, billets, chips)
- outdoors, wrapped air tight (chips)
- indoors, unventilated (chips)
- Indoors, natural ventilation (chips)
- indoors, ventilated if and when relative humidity (RH) of the ambient air dropped below 65% (chips)
- indoors, ventilated with heated air less than 65% RH (chips)

Piles were built over the period December 1995-January 1996. Each pile was divided into two sections: one removed in May 1996; the other in September 1996. Each pile had four temperature sensors buried in the core of the pile, two in each section. The temperature was measured on an hourly basis for the duration of the trial and compared with the ambient temperature outside the pile.

Principles of cooling or artificial drying of wood chip piles

Removing moisture from wood chip piles depends on the relative humidity (RH) of the air outside the pile, the rate of air flow through the pile, the moisture content of the wood chip in the pile and the particle size.

Cool air is less able to hold moisture than warm air, so by heating the air, the RH drops and the air can accept more evaporated water from the chips. If the RH is above 65% the ability to remove water from the chips is limited. If the RH is very high one risks rewetting the chips, since wood is hygroscopic (readily takes up moisture from the air).

Particle size influences two aspects of drying: the smaller the particles, the easier the moisture can travel from the inside of the particle to the surface to be evaporated. On the other hand, piles with small particles show a higher pressure drop on ventilation. This means that to ventilate or dry a pile of fine wood chips, one needs a larger ventilator and more power to get the air through the chips, than in a pile of very coarse chip. Water in wood can be found in three phases: between the cells, which is easy to evaporate, in the cells, which needs to travel outside the cell to be evaporated and chemically-bound water in the woody material. By natural drying one can remove the moisture between the cells and reach a MC of around 18-20%. To evaporate the water in the cells one needs additional energy. This is typically done in sawmill kilns, and one can reach a moisture content of ca 8%, which is the natural equilibrium for indoor use of wood. Wood with a lower moisture content than 8% will reabsorb moisture from the surroundings.

In both cooling and drying, air from outside the pile is blown through the pile from beneath. Either the drying floor is equipped with air ducts below the ground, or pipes or tunnels are placed on the floor before the wood chips are loaded on a flatbed drier.

There is a difference between cooling a pile and active drying. In cooling, the temperature is kept below ambient temperature + or - 10 degrees, and only a relatively small amount of electricity is needed for the cooling fan. By cooling the pile, the more aggressive thermophile fungi do not develop and this reduces dry matter losses.

In drying a pile, the purpose is to reduce the MC by removing water from the pile. This can only be done where the ambient air has a RH below 65%, or by heating the air so that the RH falls below 65%. In this case the fan has to run much of the time and uses far more energy than if only cooling.

Results

Table 1: Impact of storage duration and drying conditions on the moisture content of a range of SRC willow fuel sizes.

Fuel size/storage conditions		May completion			September completion		
	Starting MC	MC	Dry matter loss	Heating value loss	MC	Dry matter loss %	Heating value change
				%			
Outdoors							
Whole shoot, open	52.1	36.7	7.5	-0.6	16.6	2.8	0.9
Whole shoot, covered	52.1	34.8	2.9	5.0	17.4	6.0	6.1
20 cm billets, open	51.3	37.8	9.1	-3.6	18.7	17.1	-7.2
20 cm billets, covered	51.3	43.4	12.3	-8.6	19.9	13.2	-3.0
10 cm billets, covered	51.2	49.4	11.3	-10.3	43.1	19.4	-15.3
5 cm chips, oven	50.2	51.3	17.5	-18.0	10.9	28.8	-25.5
5 cm chips, covered	50.3	52.4	19.1	-20.1	50.8	19.8	-20.1
5 cm chips, airtight	48.5	53.3	9.4	-12.0	-	-	-
2.8 cm chips open	51.4	50.1	23.1	-22.4	47.6	30.0	-28.5
2.8 cm chips, covered	54.8	53.5	16.5	-15.7	53.9	27.7	-27.2
2.8 cm chips airtight	60.5	-	-	-	62.1	8.6	-10.1
Indoors, cooling experiment							
5 cm chips indoors, unventilated	49.8	36.3	17.4	-12.4	28.9	17.0	-6.6
5 cm chips indoors, ventilated	49.9	35.7	10.4	-4.7	24.2	12.9	-4.4
2.8 cm chip indoors, unventilated	51.7	40.8	13.6	-8.8	36.7	12.8	-6.5
2.8 cm chip indoors, ventilated	51.2	39.7	12.1	-7.1	32.6	15.6	-8.6
Indoors, drying experiment							
5 cm chips indoors, unventilated	54.8	44.9	17.0	-12.1	-	-	-
5 cm chips indoors, natural ventilation	54.3	45.3	19.1	-14.8	-	-	-
5 cm chips, indoors, intermittent ventilation	53.9	35.4	10.9	-2.7	-	-	-
5 cm chips indoors, continuous ventilation	55.5	19.1	4.2	10.3	-	-	-

The results show that the longer the size of the fuel the better it dries. Over a period of 9-10 months whole-shoots and 20 cm billets dried very well, from the initial MC of ca 50% at harvest to around 18% by the end of the longer drying period, but even after 4-5 months the moisture content had dropped to around 35-37%.

The smaller fuel sizes which were piled outdoors did not really dry, whether they were covered or not.

Bringing material indoors had a positive effect on drying, most piles lost 10-15% MC over the first five months, and 25% in 9-10 months, especially when piles were cooled to keep the temperature in check.

In the drying trial, the more the piles were ventilated the better the drying. In the pile dried with warm air, the moisture content fell to 19% after just six weeks. It must be pointed out that during this process the bottom layer dries first, and the moisture which is released moves upwards through the pile. Often the moisture condenses near the top of the pile creating a very wet layer. However, once the drying zone reaches the top of the pile, the drying is complete and the chips will be at ca 18% MC. It is clear therefore that drying cannot achieve uniform MC levels above 18%, as the pile will consist of a dryer bottom layer and wetter top layer. If the dry layer is mixed with the wet layer, an average 30% MC may be achievable, but the fuel will have a heterogeneous MC and will burn unevenly.

As well as drying in storage, wood fuels, due to bacterial and fungal growth, will lose some dry matter. The smaller the average particle size, the higher the surface area and the better bacteria and fungi can utilise the cellulose in wood and convert it to carbon dioxide, water and heat. Table 1 shows that the smaller particles can lose substantial amounts of dry matter, up to 30% over 9 months storage, while losses in whole-shoots and billets tend to be more modest.

Looking at losses in heating value, the impact of storage conditions is further differentiated. If a lot of moisture is lost and little dry matter, the stack can in fact gain in net heating value. Piles which gained in heating value are shown in Table 1 with a positive value and vice versa for negative values, where the drying of the fuel did not compensate for losses in dry matter.

A unique feature of the trial was storing chips under airtight conditions, similar to ensiling of grass. The purpose was to investigate ways to minimise dry matter losses following winter harvest and storage over the summer months when willow cannot be harvested because of the presence of foliage. A sheet of plastic was laid out on which chips were placed. The plastic was folded up and a second layer was placed over the whole pile and weighed down with soil. During storage, any holes that appeared in the plastic covering were sealed to prevent air from entering the pile. This resulted in conditions in the pile turning from aerobic to anaerobic, meaning that wood decaying fungi and bacteria could not thrive. Instead a fermentation process took place (as happens with grass silage), resulting in the generation of alcohol and lactic acid. Once the pile turns sufficiently acid, the process stops. As a result of wrapping the piles airtight, dry matter losses decreased, while the moisture content increased slightly. Even after 9 months of storage, the material was still very fresh, and willow segments sprouted shoots within days of being removed from the pile.

There are considerable costs associated with the long term storage of wood fuel. If the wood is stored in a pile anywhere, there are costs of piling the chips into a regular pile and for covering it with plastic to keep off the rain. Also, reloading the chips after the storage is a cost. On the full harvesting costs one has to pay wages, depreciation and overheads, and payment will be deferred until the chips are delivered.

By reducing MC the value of chips increases per tonne, but the actual number of tonnes to be sold decreases. If we assume a price of €6 per GJ, then willow chips at 55% moisture content will fetch a price of ca €46.50 per tonne at the gate of the plant. For 40% moisture content the price will increase to €65 per tonne. One ha of 2-year-old willow will yield ca 53 green tonnes of wood chips, which will fetch a total of €2650. However by lowering the moisture content to 40% we have only 39.75 tonne left and this will fetch a price in total of €2584, so slightly less than for the very wet material and that without the extra storage expenses taken into account. The conclusion must be that it is best to deliver SRC willow wood chips straight to the plant unless one can get a considerable higher price per unit of energy (GJ or MWh).

Conclusions

SRC willow is a difficult material to store in large amounts, especially when it has been harvested with the cut-and-chip method (see SRC willow harvesting COFORD Connects Note). The small particle size results in a high surface:volume ratio, and with the high moisture and nutrient content of the chips, it leads to rapid growth of fungi and bacteria, increasing the temperature in storage piles and the loss of significant amounts of dry matter.

In small amounts the material can be stored as whole-shoots, but harvesting costs and subsequent re chipping make this method expensive in large-scale supply chains. Billets will dry just as well, but generally need to be converted to chips before they can be used, which is a large additional cost.

Forced ventilation drying of willow chips can be done, but is costly and additional energy may be needed for drying if the ambient RH is higher than 65%. It also requires extra handling. It may be a solution if a cheap source of waste heat can be found. If it is used a flow drier is preferable to a bed drier - for the reasons pointed out earlier in relation to moisture movement in the storage pile.

Drying is not a viable solution for large quantities of fuel, particularly for large-scale applications. Willow chips, harvested with a cut-and-chip method should be supplied to a large-scale use as fast and with as little handling as possible; it is a low value bulky product, which cannot bear the cost of high levels of handling.