2. Wood as Energy Resource

2.1 Amount of Consumption and Resources

Wood is an important energy source all over the world. In Denmark energy wood is available in the form of forest chips, fuelwood, wood waste, wood pellets, and also it is produced to a very limited extent from willow crops in short rotation forestry. The major part of wood harvested on the forest area of approx. 460,000 ha ends up as energy wood directly or after having been applied for other purposes first. In the light of the Government's aim to increase the forest area by doubling it during a rotation, Denmark's total wood fuel resources will increase over the years.

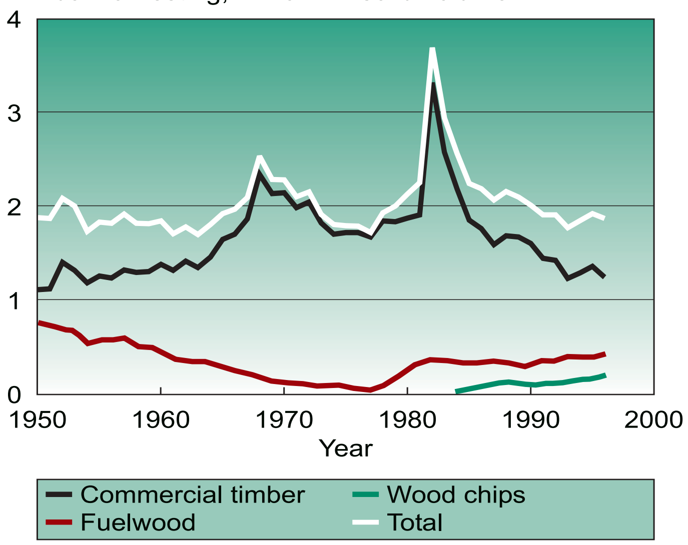

Figure 3: Wood Harvest 1950-1996 distributed on commercial timber, fuelwood, and wood chips. The wind breakages in 1967 and 1981, in particular, resulted in increased harvesting /ref. 8/.

Consumption of Energy Wood

According to the Danish Energy Agency's survey of the energy production in 1997, wood covers approx. 21,000 TJ which is equal to 28% of the total production of renewable energy and equal to approx. 500,000 tonnes of oil. Table 1 illustrates the distribution among the individual wood fuels.

Since 1950, Statistics Denmark has made detailed statistics classifying the wood harvest in Danish forests, and it amounts to approx. 2 million m^3 s. vol (solid volume) with fluctuations around the wind breakage disasters in 1967 and 1981. In 1996, an amount of approx. 620,000 m^3 s. vol, equal to approx. 108,000 tonnes of oil, was used for direct energy production, which is approx. 33% of the total harvest.

Fuel	Consumed 1997 (TJ)	Proportion (%)
Forest chips	2,703	13
Fuelwood	9,603	46
Wood waste	5,879	28
Wood pellets	2,828	13
Totalling	21,013	100

Table 1: Consumption of wood fuels. By way of comparison, it may be mentioned that the energy content of 1000 tonnes of oil is 42 TJ /ref. 7/.

Wood chips result from first and second thinnings in spruce stands, from harvesting overmature and partly dying pine plantations, from harvesting in climate- and insect damaged stands, from the harvesting of nurse trees (species that are planted at the same time of the primary tree species in order to protect them against e.g. frost and weeds), and from tops by clear-cutting (timber harvesting of the whole stand at the end of the rotation) in spruce stands. Wood chips have become a still more important fuel over the two most recent decades, and the production amounts to approx. 200,000 m^3 s. vol per year.

Fuelwood is obtained primarily in hardwood stands by thinning and by clear-cutting in the form of tops, branches and butt ends. Earlier, fuelwood was the most important product of the forest, but around the turn of the century, wood as a source of energy was substituted by coal and later by oil. The oil crisis in the 1970s and the increase in taxes imposed on oil and coal in the middle of the 1980s resulted in an increased interest in wood for the purpose of energy production.

According to statistics, forestry produces 420,000 m^3 s. vol of fuel, but the consumption of fuelwood from gardens, parks, hedges/fringes etc. is not registered. The total consumption is estimated at approx. 700,000 m^3 s. vol per year /ref. 9/.

Wood waste consisting of bark, sawdust, shavings, demolition wood etc. is used primarily in the industry's own boiler furnaces. Approx. 640,000 m^3 s. vol is used per year of which part of it is used for the production of wood pellets and wood briquettes, a rather new production in Denmark. In addition to that, a huge amount of wood waste is imported for the purpose of this production. The consumption of wood pellets and wood briquettes amounts to approx. 200,000 tonnes and approx. 20,000 tonnes respectively per year.

Energy willow is grown in short rotations (3-4 years) on farmland, but the production is not yet so widespread in Denmark, where willow covers an area of only approx. 500 ha. The amount of fuel produced from willow is therefore not so important compared to other wood fuels.

Future Resources

The Danish Forest and Landscape Research Institute has calculated the amount of available wood fuel resources (fuelwood and wood chips) from Danish forests above 0.5 ha /ref. 10/. The resources have been calculated on the basis of information provided by the forest inventory in 1990 of tree species, age-class determination, and wood production of the individual forests. The calculations have been made in the form of annual averages from 1990-1999, 2000-2009, and 2010-2019 based on hypotheses that are deemed to be realistic under the prevail-

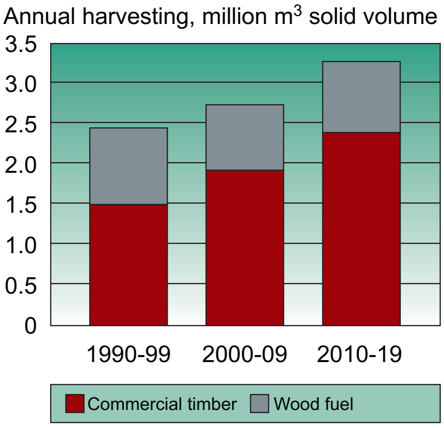

Figure 4: Forecast from 1994 of the potential annual harvesting of commercial timber and wood fuel in the periods 1990-99, 2000-09, and 2010-19. Harvesting is expected to rise in a good two decades /ref. 10/.

ing outlets for cellulose wood and other competing products for wood fuel.

Total annual harvesting is expected to increase in the next two decades to approx. 3.2 million m^3 s. vol due to, among other things, afforestation (Figure 4). Note that the total harvesting (Figure 3) according to Statistics Denmark is approx. 500,000 m^3 s. vol lower per year compared to the forecast for 1990-99. This apparent divergence is due to the fact that forestry does not have sufficient outlets for wood for energy. The annual commercial timber harvest is expected to increase in both periods after the year 2000, while the harvesting of fuelwood and wood chips is predicted to decrease from approx. 950,000 m^3 s. vol to approx. 800,000 m^3 s. vol, and then again increase to approx. 900,000 m^3 s. vol in the last period (Figure 4). The change in harvesting is due to an unequal age-class distribution of the spruce area, the finishing of mountain- and contorta pine wood stands, and an increase in the harvesting of wood fuel in hardwood stands /ref. 11/.

While the total potential annual harvesting can be forecast with great certainty, the distribution among fuel and other products will be subject to a range of outward circumstances. If the development of the most recent years continues, the fuel proportion will increase.

Based on the figures of the survey, the forests are capable of currently supplying the present chip-fired heating and CHP plants with wood chips and in addition supply the necessary amount of wood, i.e., 200,000 tonnes of wood chips per year, which is equal to approx. 250,000 m^3 s. vol, which the power plants according to the Biomass Agreement shall use as from the year 2004.

2.2 Afforestation and Wood for Energy

Afforestation includes the planting of new forests on agricultural land. The future supply of energy wood should be ensured partly through afforestation. Here, the energy wood production can be increased by increasing the number of plants compared to the number of plants in normal stands, and by using nurse trees.

The Energy Political Aim

It says in the preamble to the Danish Forestry Act that in addition to protect and preserve the Danish forests and improve the stability of forestry, ownership structure, and productivity, the aim is to"... contribute to increasing the forest area" /ref.12/. It is the aim of the Government to double the forest area over the next rotation (80-100 years). This aim is also in relation to the energy policy of political interest, and it should be seen in connection with the Biomass Agreement of 1993 and the Government's action plan, Energy 21, of which it appears that the use of biomass in the energy sector should be increased, including wood chips /ref. 2/. In the Danish strategy for sustainable forestry, it is clearly stated that this doubling of the forest area should be achieved by "... aiming at a regular planting intervals" /ref. 13/. This means that approx. 5,000 ha should be planted per year in order to achieve the aim, of this 2,000-2,500 ha by private forest owners. Since 1989, only approx. 50% of the plants has been planted.

In the Danish Energy Agency's survey of 1996 on the wood chip amounts from Danish forests up to the year 2025, which is based on /ref. 10/, an increase of the forest area of 5,000 ha per year has been included. Energy wood production in the form of wood chips from afforestation is estimated at 4 PJ per year out of a total energy contribution of almost 10 PJ per year from wood chips. Thus afforestation is expected to contribute considerably to the total consumption of energy wood in future /ref. 14/.

Energy Wood from Future Afforestation

The energy wood production by future afforestation can be increased in proportion to the energy wood production in the existing forests by, e.g., increasing the number of plants in proportion to normal practice, and by using nurse trees. An increase in yield should not be at the expense of the all-round forestry where the production of quality wood, preservation of nature, protection of the cultural heritage, and recreation are given high priority.

A high stocking percentage results in a faster plant cover of the area and thus a larger production. Calculations show that the prospective spruce wood chip production can be increased by 30-50 % by increasing the number of plants from approx. 4,500 to 6,500 plants per ha. As the cost of planting increases with the larger number of plants, and the increased yield of wood chips does not cover the cost of more plants, the method of large numbers of plants will only be of interest if in addi-

photo: søren fodgaard

Afforestation on agricultural land. With the present planting program of 2,000-2,500 ha per year, it is necessary to increase the afforestation or increase the energy wood production from the existing forest areas in order to comply with the aim of the Danish Energy Agency.

tion to the increased yield of wood chips, the added benefit of improved wood quality, improved stand stability and reduced cost of weed control etc. can also be achieved.

Traditionally, nurse trees are planted at the same time of the primary tree species, which are normally more sensitive species, in order to protect against frost, weeds etc. As nurse trees are trees that are fast growing in their youth, the wood production increases resulting in larger quantities of wood chips produced from the thinnings in immature stands that are performed by harvesting the nurse trees row by row. Relevant nurse tree species are e.g. hybrid larch, alder, poplar, Scotch pine and birch. By using hybrid larch as nurse trees in a spruce stand, the yield of wood chips can be increased by approx. 35% with a number of plants of 6,400 per ha distributed on 4,200 spruce and 2,200 hybrid larch compared to an unmixed Norway spruce plantation (Figure 5) /ref. 15/.

Wood chips production, cubic metre loose volume per ha.

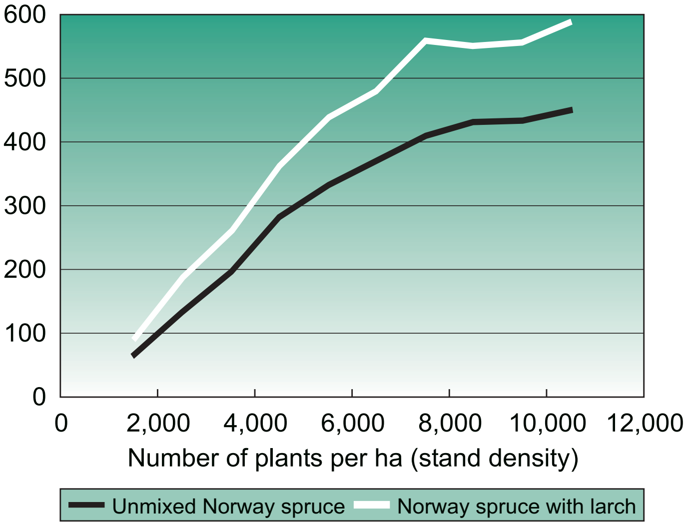

Figure 5: Production of wood chips in m^3 l. vol per ha for an unmixed Norway spruce stand and a stand consisting of Norway spruce with larch as nurse trees with variations in the number of plants in the Eastern part of Denmark. The wood chip production increases considerably by using nurse trees. /ref. 15/.

Normally, wood chips are only harvested in softwood stands, but by producing wood chips from hardwood, such as beech, the yield of wood chips can be greatly increased when using nurse trees. By planting hybrid larch also, the yield of wood chips could be tripled in proportion to a pure beech stand.

The calculations of the yield of wood chips are based on existing research data on spruce, but new requirements for the forests in respect of increased diversity and flexible stands may mean that more mixed stands will be established in the future.

The effect of increased stand density is investigated by research.

Demo - Field Experiments

In co-operation with The National Forest and Nature Agency, the Danish Forest and Landscape Research Institute established in 1998-99 demo - field experiments on three afforestation areas in Denmark. The purpose of the experiments is, among other things, to investigate the energy wood production in mixed stands on various soil types. The experiments are aiming at demonstrating the additional expenditure involved in increasing the number of plants, prospective gains in the form of reduced need for weed control and replanting (replanting after dead plants), and in the long term an improvement of the wood quality.

The demo - field experiments include nine different planting models using the following mixture of species:

- Mixed softwoods (Sitka spruce/Norway spruce, and Douglas fir with or without larch as nurse trees).
- Pure hardwood stands and mixed hardwood stands (beech, oak, and oak with alder).
- Mixed hardwood- and softwood stands (beech with Douglas fir and beech with larch).

A standard number of plants is chosen, which is doubled either with the primary tree species (beech, Norway spruce/Sitka spruce, oak, Douglas fir) or by using nurse tree species (alder, larch).

The experiments are currently inspected and measurements are taken, and the actual energy wood yield figures will be available in connection with thinning in immature stands in approx. 15-20 years. The results form the basis of the planning of future afforestation.

Legislation and Subsidies

In connection with afforestation, the planting plans must be approved by the Directorate for Agricultural Development, and the afforestation must be shown to be in conformity with the counties' designations in their regional land use plans of plus and minus land for afforestation, i.e., the areas where afforestation is wanted or not.

photo: the danish land development service/bert wiklund

The Danish forest area will be doubled over the next 80-100 years. Many of the new forests will be hardwood forests with oak and beech being the primary species.

The public authorities try to encourage private forest owners to carry out afforestation via various subsidy schemes, but so far they have only succeeded partly. The major part of the afforestation takes place on the National Forest and Nature Agency's own areas or on privately owned properties without subsidies. At the turn of the year 1996-97, a new subsidy scheme under the Danish Forestry Act came into force which has intensified the interest in afforestation, e.g., due to income compensation and increased possibilities of being subsidised. This has resulted in applications exceeding the means available within the schemes.

The framework of afforestation and the possibilities of being granted subsidies are laid down in a range of acts and executive orders. A precondition for being granted subsidies is, that the area is designated as a forest reserve in order to secure the existence of the forest in future. In addition to that, there are certain requirements for the structural design and the size of the forest. The subsidy schemes include among other things subsidies for preparatory investigations like locality mapping (investigations of soil) and land plotting, planting, and care of stands, establishing of hedges and income compensation for a period of 20 years /ref. 16/. Further information can be obtained by contacting the State Forest Service.

photo: biopress/torben skøtt

The area has been carefully cleaned before planting the willow cuttings. The planting takes place by a two-furrow planting machine, and a tractor marking arm ensures quite parallel rows. The dual wheels of the tractor distribute the ground pressure so that the soil is not unnecessarily compressed.

2.3 Energy Plantation (Short Rotation Coppice)

Willow has been used as a cultivar for centuries for the purpose of tools, barrel hoops, basketry, and wattles. For the purpose of the production of wood chips for energy, willow has only been cultivated for a few years in Denmark, and at present willow wood chips are only used to a limited extent at heating plants in Denmark.

Energy Plantations in Denmark

The term energy plantations applies to hardwood plantations (generally willow) that are growing fast in their juvenile phase and capable of multiplication by cuttings and stump shooting. Through intensive cultivation, these properties are utilised for the production of biomass that can be used for energy production.

According to the Energy Action Plan of 1996 (Energi 21), it is the intention that the contribution of energy crops or other biomass, excluding straw, to the energy supply shall be increased from 0 in the year 2005 to approx. 45 PJ in the year 2030. If not supplemented with other biomass, this is equal to the yield of approx. 500,000 ha willow. However, the growing of energy crops will to a high extent depend on the EU agricultural policy and subsidy schemes. In order to estimate the potential of the energy crops, a demo and development programme has been implemented in order to analyse future use of energy crops.

In Denmark, willow is only grown on 500 ha agricultural land /ref. 15/, while it is estimated that willow is grown on approx. 17,000 ha land in Sweden. Willow is an agricultural crop, which means that it is possible to stop growing willow and change to another crop if so desired.

Willow Growing

Willow can be grown on various soil types. Soil types ensuring a good supply of water are suitable. Light soil types without irrigation will result in unstable yield. Willow roots may block drain systems. The area should be suitable for mechanical equipment including being capable of bearing machines during the winter months when harvesting takes place /ref. 17/.

When establishing energy plantations in Denmark, cloned withy cuttings have so far proven to have the best production potential. When planting, which takes place in spring, traditionally approx. 15,000-20,000 cuttings taken from one year old shoots are planted per ha. The cuttings are inserted in the ground by machine, and the 20 cm long cuttings are forced straight into the ground so that only a few cm stand up. By way of comparison, it may be mentioned that a new method has proven that the cost of planting can be reduced by 50% by horizontally spreading the material, cut in lengths of approx. 20 cm, and hence grooving it down into the ground /ref. 18/. The first winter after planting, the shoots can be cut off at a height of 5-8 cm in order to encourage more sprouting. Cutting down is considered advantageous in thin stands and where there are only 1-2 shoots per cutting /ref. 19/.

The worst enemy during the initial phase is weeds, particularly grasses, and the area should therefore be thoroughly cleaned before planting e.g. by subsoil ploughing. Weed control is easiest and best performed by means of herbicides combined with mechanical weeding. At the time of harvesting, which is done at a few years interval, everything is removed except leaves and roots, and that makes the application of fertiliser necessary in order to maintain the level of production.

Table 2 illustrates the application of fertiliser to a willow cultivation over the individual years.

The application of nutrients to energy willow with waste water, sewage sludge or liquid manure is an alternative to the application of fertiliser. The dense, deep striking willow root system is suitable for capturing the plant nutrients and heavy metal content of the sludge. Thus compared to wood chips, the fuel will contain relatively large quantities of nitrogen and cadmium. Under ideal combustion conditions, the major part of the nitrogen will be released in the form of N_2, and the heavy metals will remain in the ash. This is an important precondition for stating that using sludge for energy willow will be environmentally beneficial /ref. 20/.

Harvesting and Storage

The first harvesting on the area takes place 3-4 years after planting when the willow shoots are approx. 6 metres high. It is done in winter, and the following spring the plants start growing from the stumps, and after another 3-4 years, harvesting can take place again. It is expected that the willows can grow for at least 20 years without any reduction in the plant yield, and that means that harvesting can take place 4-5 times before new planting will be necessary.

Research has shown that long-time storage of willow chips is difficult to handle. This is due to the fact that the moisture content is approx. 55 - 58% of the total weight of green willow, and that young willow shoots contain a large proportion of bark and nutrients. In piles of willow chips, a fast temperature development typically takes place resulting in a considerable loss of dry matter. This development depends on the size of the chips. The larger the chips are, the lesser is the decomposition. Long-term storage is best if the willow has not been chipped but is stored in the form of whole shoots, which is expensive. A different method that has proven successful during experiments is airtight sealing of willow chips. Without oxygen, no decomposition takes place /ref. 21/. The difficult long-time storage means that willow wood chips are normally hauled directly to the heating plant.

	N	P	K
Planting year	-	0-30	80-130
1st prod. year	45-60	-	-
2nd prod. year	100-150	-	-
3rd prod. year	90-120	-	-
1st year after harv.	60-80	0-30	80-160
2nd year after harv.	90-110	-	-
3rd year after harv.	60-80	-	-

Table 2: Recommended application of fertiliser to energy willow before and after first harvesting (kg per ha). - means no fertiliser applied. The amount of fertiliser varies with the soil characteristic /ref. 19/.

Fuel Characteristics

Willow chips do not differ very much from other types of wood chips, but may contain more bark and more water. The lower calorific value of bone dry willow does not differ from that of other wood species, but is approx. 18 GJ per tonne of bone dry material. But compared to most other wood species, willow wood is relatively light. This means that one m^3 l. vol (loose volume) of willow chips contains less dry matter (approx. 120 kg/m^3 l. vol) than e.g. one m^3 l. vol of beech chips (approx. 225 kg/m^3 l. vol) This is of importance to the amounts by volume a heating plant must be capable of handling in order to achieve the same generation of heat. The high moisture content makes the wood chips particularly suitable at plants equipped with a flue gas condensation unit. If so, the evaporation heat is recovered.

photo: biopress/torben skøtt

By harvesting of whole shoots which takes place by specially designed machines during the winter, everything, except leaves and roots, is removed. The willow shoots are harvested close to the soil surface.

The Production of Willow Chips

In plantations, the entire cost of production should be paid by a low value product, i.e. willow chips. This makes the production of energy willow chips vulnerable compared to the production of straw or forest chips. By the production of straw for energy, the cereal production carries all the costs including combine harvesting, and the straw will only have to pay for the collection, transport and storage. Similarly, the production of sawmill timber pays for tree growth, while the wood chips pay for chipping, storage, and transport to heating plant. Willow growing is therefore financially risky and depends to a high extent on the harvesting yield.

Therefore, the calculation of the production level for willow plantations in Denmark has received much attention. Occasionally, high yield figures of 10-12 tonnes of dry matter per ha per year or more are recorded, but they have often been achieved in individual, small and very intensively cultivated willow stands and are thus not a realistic estimate for yields in commercial stands. Yield measurements, carried out in Danish cultivated willow stands from 1989 to 1994, show that the average yield is approx. 7.5 tonnes of dry matter per ha per year, which is not as much as previously estimated. The results of the yield measurements have not been able to unambiguously explain the influence of the stand factors on the production level, but this average yield has been achieved in willow stands with fertiliser being intensively applied and with half of the stands being irrigated. Measurements of the yield have been carried out on clones, that were common at the beginning of the 1990s /ref. 22/. Danish measurements on new clones form part of an EU project. Preliminary results indicate that the additional yield of the new clones is modest in comparison with the old clones.

Willow Growing in the Future

For the time being, there is good reason to follow the development of willow growing in Sweden, who has taken the lead. More and more information is obtained about cloning developments, harvesting yields, cost of harvesting, and soil types preferred by willow. It may be possible for agriculture to take up a niche production of willow on soils suitable for the growing of willow, but less suitable for cereals. Finally, willow may conquer a niche where it can contribute to solving some environmental problems in the form of waste water and soil purification.

2.4 Physical Characterisation of Wood Fuels

In Denmark, wood from forestry and from wood industry is used in the form of firewood, wood chips, bark, shavings, briquettes, pellets, and demolition wood for firing in, e.g., wood stoves, wood pellet-fired boilers, district heating plants, and CHP plants. The technologies used at these plants stipulate various requirements in respect of the physical properties of the wood i.e. size, size distribution, moisture content, ash content, and pollutants (stones, soil, and sand).

A physical characterisation of wood fuels is important when choosing fuels for various boiler systems and technologies. In addition, information on the physical properties of the wood fuels can be used when drafting contracts for future deliveries, specifying the fuel in relation to certain types of boiler systems, and the drafting of quality descriptions of the wood fuel. Knowledge of these properties in relation to various types of wood fuels thus contributes to a promotion of an environmentally and economically optimal application of the fuel /ref. 23/.

Fuelwood

Fuelwood is split, round or chopped wood from delimbed stems, cut-off root ends, and tops and branches of hardwood or softwood. Ready-to-use firewood is normally split to 15-35 cm. Chunks of 6-8 cm thickness are most suitable for the majority of wood stoves. Firewood consists of wood and bark.

The moisture content in green spruce is approx. 55-60% of the total weight and correspondingly approx. 45% for beech /ref. 24/. After drying during the summer season, the moisture content is reduced to approx. 15% of the total weight - depending on weather, stacking and covering - which is the recommended moisture content for use in wood stoves /ref. 25/. The ash content is often below 2% of the dry matter.

		Fraction unit (%)	
Name	**Screen tray**	**Fine**	**Coar.**
Overlarge	45 mm round holes	< 5	< 15
Overthick	8 mm slats	< 25	< 40
Accept	7 mm round holes	> 40	> 23
Pin chips	3 mm round holes	< 20	< 15
Fines		< 10	< 7
Hereof:			
Slivers 100-200*	100-200 mm length	< 2	< 12
Slivers > 200*	> 200 mm length	< 0,5	< 6

Table 3: Requirements for the size classification of fine and coarse fuel chips according to the old Standard No. 1 which is currently being revised /ref. 26/.

** Diameter > 10 mm.*

Wood Chips

Wood chips are comminuted wood in lengths of 5-50 mm in the fibre direction, longer twigs (slivers), and a fine fraction (fines). Whole-tree chips are chipped from whole trees including branches in the first thinning of spruce stands or in connection with converting old mountain pine and contorta pine plantations. Wood chips are also produced from top ends and other residues in clear-cuttings. Sawmill wood chips are a by-product of the sawing of logs. Furthermore willow wood chips are produced from short rotation coppice grown on agricultural land.

The required type of wood chips depends on the type of heating system. A new system for the quality description of wood chips based on size classification is currently underway because the old standard from 1987 no longer covers the kind of wood chips produced and used today. The old standard divided wood chips into fine and coarse wood chips (Table 3).

The wood chips delivered to the heating plants are coarser than coarse wood chips. The new quality description is therefore based on five types of wood chips, i.e., fine, coarse, extra coarse, air spout and gassifier. Note that the names refer to the size-grading only and not to the quality.

Concurrently with the preparation of a new Danish quality description, a European standardisation work in respect of solid biofuels has been implemented. The purpose of this work is to standardise measuring methods and to arrive at common quality descriptions.

Screen analyses indicate the weight distribution among various size categories of wood chips. In the old standard, these size categories were based on a shaking screen that is also used for cellulose- and chipboard chips. The new quality description is based on a new rotating screen unit that is more capable of size-grading the wood chips.

The five types of wood chips are aimed at different types of consumers.

Fine chips are suitable for small domestic boilers where the chips are transported from the silo to the boiler with a screw conveyor. The screws are of a smaller dimension and very sensitive to large particles and slivers.

Coarse chips are suitable for larger boilers that are able to handle a coarser chip.

Extra coarse chips with a limited amount of fine material are suitable for heating plants with grates where the chips normally are forced into the boiler.

Air spout chips are suitable for installations throwing the chips into the combustion chamber. These installations need a certain amount of “dust” and are sensitive to slivers.

Gassifier chip is an extra coarse type of chips with a very limited amount of "dust" and other fine particles. This type of chip is particularly suitable for smaller gassifiers.

A detailed description of the various quality classes can be found in Table 4. All size-distributions are measured with a rotating screen that is developed with support from the Danish Energy Agency. The screen sorts out the so-called overlong particles before the remaining particles are distributed into the six classes by means of five screens with round holes of 3.15, 8, 16, 45 and 63 mm diameter respectively.

These holes are in accordance with the ISO Standard 3310/2. Particles larger than 63 mm and smaller than 100 mm are discharged from the end of the sieve. The overlong particles are sorted by hand into two classes: 100 to 200 mm length and over 200 mm length.

According to the old standard, slivers were defined as particles longer than 10 cm and at the same time thicker than 1 cm. These particles can be very troublesome in screw conveyors. In the new quality description, the term overlong covers all particles longer than 10 cm, irrespective of diameter. These particles are problematic during feed stock handling. The proportion of particles above 10 cm length is of great importance to the wood chip bridging propensity.

The moisture content in whole-tree chips depends on the production method. The moisture content of wood chips produced from green trees is approx. 50-60% of total weight, but after summer drying of the trees for 3-6 months, the moisture content is reduced to approx. 35-45% of the total weight. Chip-fired boilers with stoker for detached houses etc. can manage wood chips with a moisture content between 20 and 50% of the total weight, while district heating plants normally accept wood chips with a moisture content of 30-55%. District heating plants with flue gas condensation normally want wood chips with a high moisture content in order to utilise the condensation heat.

Wood chips may be polluted with stones, soil, and sand which increase the ash content. The ash content in whole trees depends on the wood species and the quantity of needles, branches, and stemwood. The natural ash content in

Name	Hole size	Fine	Medium	Coarse	Air spout	Gassifier
Dust	3.15 mm	<10 %	<8 %	<8 %	>2 %	<4 %
Small	3.15< 8 mm	<35 %	<30 %	<20 %	>5 %	<8 %
Medium	8< 16 mm	*	*	*	>60 %**	<25 %
Large	16< 45 mm	<60 %	*	*	>60 %**	>60 %***
Extra Large	45< 63 mm	<2.5 %	<6 %	*	<15 %	>60 %***
Overlarge	>63 mm	<0.25 %	<0.6 %	<3 %	<3 %	>60 %***
Overlong 10	100-200 mm	<1.5 %	<3 %	<6 %	<4.5 %	<6 %
Overlong 20	>200 mm****	0 %	<0.5 %	<1.5 %	<0.8 %	<1.5 %

* *No demands*
** *These two classes shall make up for minimum 60 %*
*** *These three classes shall make up for minimum 60 %*
**** *Particles with the following dimensions are not allowed*
- longer than 500 mm with a diameter >10 mm
- larger than 30 × 50 × 200 mm

Table 4. The new quality description includes five types of chips. The table states the demands for size distribution in percentages of the total weight.

needles may exceed 5% of the dry matter weight, in branches and bark approx. 3%, and in stemwood approx. 0.6% /ref. 27/. Wood fuel for small boilers and district heating plants has an ash content of 1-2% of the dry matter weight.

Bark

Bark for energy production is produced by peeling of bark at softwood sawmills and by the cutting of slabs at hardwood sawmills. Strictly speaking, comminuted bark cannot be regarded as wood chips, but size analyses of bark - based on wood chip standard - show that bark has a very heterogeneous size distribution with a large proportion of fines /ref. 28/. Bark is very moist, approx. 55-60 % of the total weight, and single firing with bark normally takes place in special boilers because of problems with the high moisture content. Bark is the outermost layer of the tree, where pollutants are often found in the form of soil, sand, and to a certain extent lead from cartriges.

photo: finn jensen

The prototype of a new rotating classifier. Wood chips are filled into the hopper from the top, lengthwise orientated on a shaking table, and passed to the funnel tube (on the left), where the chips fall into the rotating drum. The round holes in the drum increase in size from left to right. The content of the drawers is weighed. From left: Overlong, fines, small, medium, large, extra large and overlarge.

Sawdust and Shavings

Sawdust and shavings that are produced by planing, milling etc. are a by-product or residue from wood industries. Sawdust and shavings are between 1 and 5 mm in diameter and length. The moisture content in sawdust varies with the material that has been sawed, originating from wood industries that manufacture rafters and windows etc., and may have a moisture content of 6-10% of the dry matter weight, but 45-65% of the total weight if the wood was green, recently harvested.

Shavings are very dry with a moisture content between 5 and 15% of the total weight. Therefore, they are normally used for the production of wood pellets and wood briquettes. They contain few pollutants, since it is normally stemwood that is used, and the ash content is therefore less than 0.5% of dry weight.

photo: the danish forest and landscape research institute/flemming rune

Forest chips, sawdust, and fresh bark from spruce, and wood pellets.

Wood Briquettes and Wood Pellets

Wood briquettes are square or cylindrical fuels in lengths of 10-30 cm and a diameter/width of 6-12 cm. Wood pellets are cylindrical in lengths of 5-40 mm and a diameter of 8-12 mm.

Briquettes and pellets consist of dry, comminuted wood, primarily consisting of shavings and sawdust compressed at high pressure. The size distribution is very uniform which makes the fuel easy to handle. Pellets from the same consignment will be of the same diameter. Moreover the moisture content is low, approx. 8-10 % of the total weight /ref. 29/. Slagging problems are very limited when burning briquettes and pellets, and the amount of ash is low, approx. 0.5-1% of the dry matter weight /ref. 30/.

Wood Waste

Wood waste is wood that has been used for other purposes e.g. constructions, residues from new buildings or reconstructed buildings before being used as fuelwood. Other types of recycling wood include disposable pallets and wood containers. The wood that is comminuted before burning varies very much in size. Demolition wood is often relatively dry with a moisture content of approx. 10-20% of the total weight. The burning of demolition wood and other industrial wood waste may be problematic, since the wood may be polluted with residues from paint, glue, wood preservatives, metal, rubber, and plastic material depending on the previous use. If the wood waste contains glue (more than 1% of the dry matter weight), paint etc., a waste tax should be paid, and the wood waste cannot be burnt in conventional boilers /ref. 31/.