2. Straw as Energy Resource

Straw is a by-product resulting from the growing of commercial crops, primarily cereal grain. Straw from rape and other seed-producing crops is also included in the total production. Agriculture's choice of crops - and thus also the amount of the production of straw - depends in the first instance on agronomy, i.e., the science of cultivation of land, soil management, and crop production, and on financial matters affecting the management of the entire agricultural area.

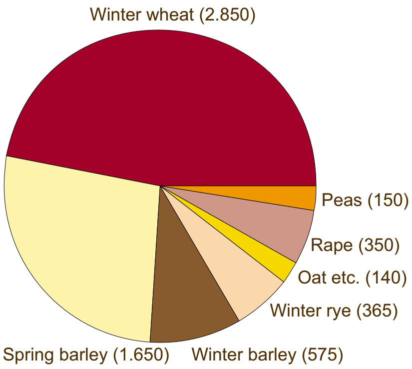

Figure 3: Straw harvest in 1996. Of the total of approx. 6 million tonnes of straw that can be gathered in, wheat and barley make out more than 80% /ref.30/. (Thousands of tonnes).

The annual straw production is influenced by the framework stipulated by the EU agricultural policies, including developments in cereal prices, the fallow of land etc. The straw quality and the amount of straw that can be gathered in, are also influenced by the weather during growing and harvest.

In 1996, the Danish area with cereal grain amounted to 1.55 million ha /ref. 25/. The cereal grain yield was 9.17 million tonnes of cereal grain, and the amount of straw was 6 million tonnes. The straw production in a year with average harvest is estimated at 6.3 million tonnes, but may vary up to 30% due to climatic conditions during the period of growing and gathering in.

Straw Applications

Of the total straw production, only a minor part is used for energy purposes. The major part is used in agriculture's own production, i.e., as bedding in livestock housing systems etc. Also a considerable amount of straw is used for heating, grain drying etc. in agriculture. In addition, an amount agreed upon according to crop delivery contract is sold to district heating plants and power plants for energy production. The straw left after deductions for these applications, is for the major part chaffed and ploughed back and is thereby used for soil amelioration. Thus this is a straw surplus which - with the annually weather-dependent variations - makes out a potential fuel reserve.

Of a total straw harvest of 6 million tonnes, an amount of approx. 15% was used for energy purposes in 1996. In 1997-98, it is estimated that the consumption of straw at power plants and CHP plants will rise to approx. 400,000 tonnes.

Based on the Biomass Agreement of June 14, 1993, the Electricity Utility Group ELSAM and ELKRAFT Power Company Ltd in co-operation with the Farmers' Union, specialists from relevant research institutes, and the Danish Energy Agency carried through an investigation of the existing and future amounts of straw /ref. 6/. The purpose of that was to establish an assessment of what amounts will be available in the future for a development of the straw-based electrical power and heat generation in Denmark. This investigation operates with three different scenarios including a range of possible developments in the theoretically accessible surplus that is possible to gather in as a consequence of a transformation of the agricultural production, larger livestock, change in environmental and agrarian political matters etc.

The investigation concludes that, in theory, sufficient amounts of straw will be available. However in years with extremely poor harvest, straw may be in short supply.

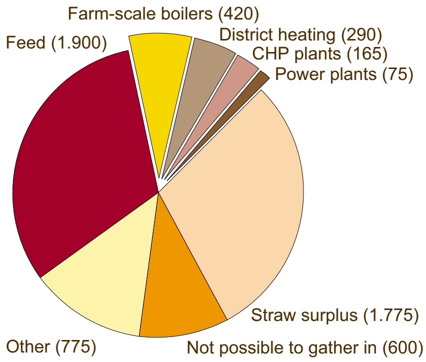

Figure 4: Of a total straw harvest of 6 million tonnes, an amount of approx. 15% was used for energy purposes in 1996 /ref. 25 and 29/. "Other" is bedding, clamps etc. (Thousands of tonnes).

photo: biopress/torben skøtt

Straw is a waste product from cereal grain production. The picture shows the combine harvester chaff cutter having chaffed the straw so that it can be ploughed back. The area behind the combine harvester is fallow land.

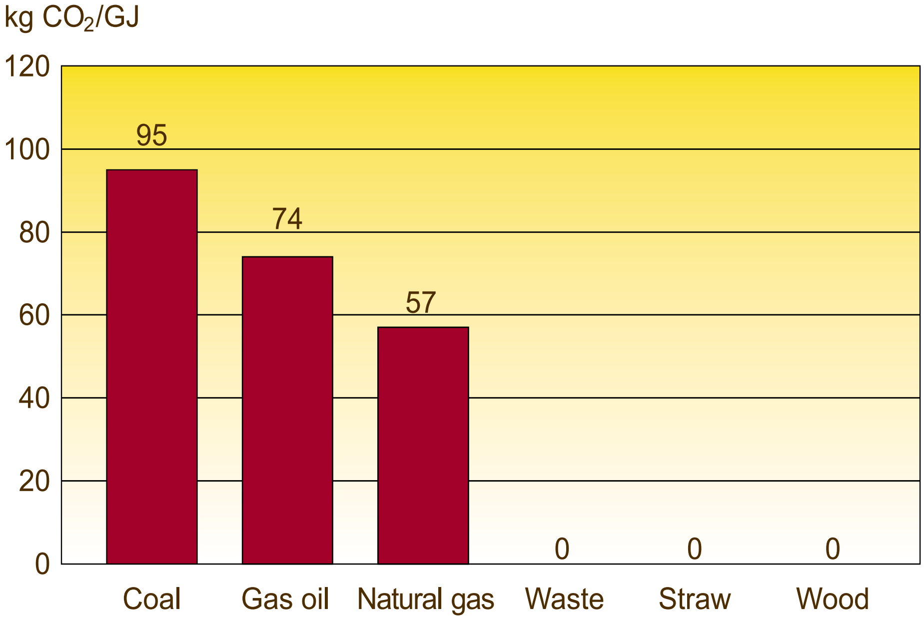

Figure 5: Fuel emissions. Burning coal emits, e.g., 95 kg CO_2 per GJ coal, while the biofuels are CO_2 neutral. The CO_2 values are average values for the fuel types mentioned /ref.58/.

Straw Market

Trading in straw for energy purposes among producers and the energy sector is in principle determined by crop delivery contracts for several years, concluded between the individual straw producer or an association of straw producers and the purchaser.

The purchasers are straw-fired district heating plants and CHP plants that by entering into long-term crop delivery contracts for straw make sure that they can perform their duty to supply heat and energy to the consumers. Not all straw is traded according to crop delivery contracts. By purchasing straw in the spot market, e.g., at machine pools, or at the places of other middlemen, the plants may often achieve an advantageous price for part of their annual consumption of straw.

The crop delivery contract for straw may include the following terms and conditions:

- Term of contract and notice of termination
- The amount of straw agreed upon, including provisions in the event of increase/decrease in the consumption of straw, non-delivery due to decrease in crop yield etc.
- Terms of delivery, including the type of bale, the dimensions and weight of bales, water content, and other grade determinations
- Basic price and the regulation of price in proportion to water content and time of delivery
- Provisions concerning the regulation of the basic price
- Provisions concerning arbitration

Plough Back of Straw

Land that has been cultivated for several years has a lower carbon content than has uncultivated land. Thus when cultivating land, carbon is removed from the soil in the form of CO_2 being released to the atmosphere. The carbon content is of importance to the fertility of the earth, a maintenance of this fertility requires a current application of crop remains or other organic matter. Though the optimal or critical levels for the carbon content of the earth is not known. Experiments carried out since 1920 at the Danish Institute of Agricultural Sciences Askov Experimental Station have shown that the carbon content of the earth has dropped no matter whether commercial fertiliser (NPK) or animal manure is applied.

As is the case with liquid manure, sludge and other crop remains, ploughed back straw may contribute to increasing the carbon content of cultivated land on a long view as is the case also with grass after grain crops. The gain by removing straw from the field for energy purposes is that it substitutes fossil fuels. Most of the carbon in the ploughed back straw is released in the form of CO_2, and altogether less CO_2 is emitted to the atmosphere if straw is removed for the purpose of substituting fossil fuels.

Straw as a Fuel

The most important argument for using straw for energy purposes is that this fuel is CO_2 neutral and therefore does not contribute to increasing the CO_2 content of the atmosphere, thereby resulting in an aggravation of the greenhouse effect.

Straw used for fuel purposes usually contains 14-20% water that vaporises during burning. The dry

	Unit	Yellow straw	Grey straw	Wood chips	Coal	Natural gas
Water content	%	10-20	10-20	40	12	0
Volatile components	%	> 70	> 70	> 70	25	100
Ash	%	4	3	0.6-1.5	12	0
Carbon	%	42	43	50	59	75
Hydrogen	%	5	5.2	6	3.5	24
Oxygen	%	37	38	43	7.3	0.9
Chloride	%	0.75	0.2	0,02	0.08	-
Nitrogen	%	0.35	0.41	0.3	1	0.9
Sulphur	%	0.16	0.13	0.05	0.8	0
Calorific Value, Water/Ash-Free	MJ/kg	18.2	18.7	19.4	32	48
Calorific value, actual	MJ/kg	14.4	15	10.4	25	48
Ash softening temperature	ºC	800 - 1000	950 - 1100	1000 - 1400	1100 - 1400	

Table 1: Fuel data at a typically occurring water content/ref. 11 and 32/. In /ref. 33/, leaching experiment on barley straw has been carried out. The result showed that after 150 mm rain, the chloride content had dropped from 0.49% to below 0.05%, and for potassium from 1.18% to 0.22%. At the same time, the straw had turned grey. Straw may turn grey (colonies of funguses) due to night dew and hot weather without leaching taking place.

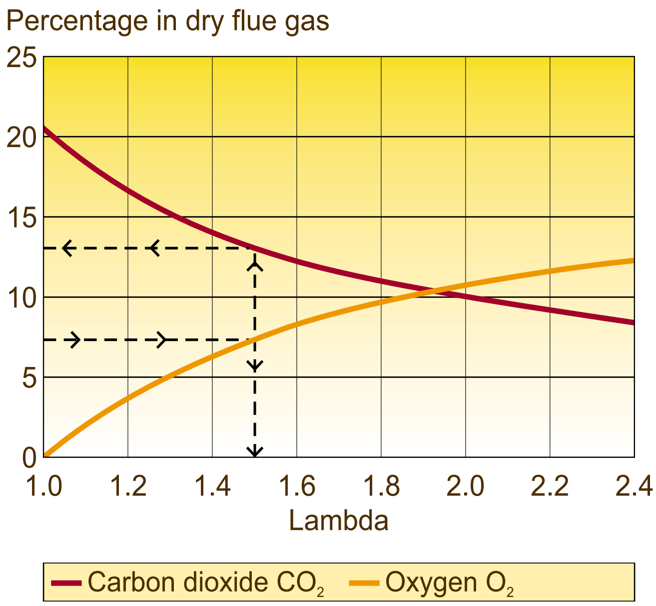

Figure 6: Ideal combustion of straw is performed by excess air of between 1.4 and 1.6. As an example, 7.5% oxygen is measured in the flue gas. The curve illustrates the presence of approx. 13% carbon dioxide with excess air being 1.5% .

matter left consists of less than 50% carbon, 6% hydrogen, 42% oxygen, and small amounts of nitrogen, sulphur, silicon and other minerals, e.g., alkali (sodium and potassium) and chloride. Combustion takes places in 4 phases. During phase 1, the free water vaporises. In phase 2, the pyrolysis (gasification) occurs, during which combustible gases are produced depending on the temperature. There will always be a certain content of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), and other hydrocarbons. Phase 3 is the combustion of gases. If sufficient oxygen is supplied, a complete combustion occurs where the residual products are carbon dioxide (CO_2) and water. Where the oxygen supply is insufficient, carbon monoxide, soot (finely divided carbon), tar, and unburnt hydrocarbons are produced. During phase 4, the charcoal burns. By complete combustion, carbon dioxide is produced. By reduced supply of oxygen, monoxide is produced. Finally, there is only ash that consists of incombustible inorganic matter. By incomplete combustion, the ash may also contain unburnt straw residues.

The air that is supplied in excess of that theoretically required for complete combustion is called excess air. A certain amount of excess air is necessary in order to secure sufficient air all over the area where the gases are to burn although the gas/air mixture is never quite uniform. The ratio between the air supplied and that theoretically required is called the excess air ratio (lambda).

$$= \frac{\text{air supplied}}{\text{air required}}$$

Through boiler walls and fire tubes, the major proportion of the combustion heat is absorbed by the water in the boiler, while the remainder disappears through the chimney as a mixture of carbon dioxide, vapour, and small amounts of carbon monoxide and other gases, e.g., tar and compounds of chlorine. In addition, the flue gas contains small particles of ash and alkaline salts.

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 in respect of the steel of boiler and tubes, particularly at high temperatures.

The ash is not without problems either, since its softening temperature is relatively low in proportion to other fuels, beginning at 800-850°C. However, it has even been demonstrated that the ash may become viscid already at 600°C /ref. 31/. This is of importance, in particular, at power plants where a high steam temperature is desired in order to achieve a great efficiency. This requires a high superheater temperature, thereby risking extensive deposits on the superheater tubes.

Where a combination of straw and coal is used as a fuel, the presence of alkaline matter in the ash indicates that - contrary to pure carbon ash - it cannot be used as a filler in building materials, but must be dumped at controlled disposal site.

Straw Pellets

Experiments have been carried out on the use of straw pellets, i.e., comminuted straw that has been pressed into pellets of a diameter of 8 or 10 mm/ref. 13/. The experiments showed that straw pellets can be used as a fuel in large boilers, whereas ash and particularly slagging problems make straw pellets less suitable for use in small boiler plants. Straw pellets can be pressed with molasses as a binding agent thereby admixing an anti-slagging agent, e.g., kaolin, in order to make them more stable during transport and in order to counteract the

photo: lars nikolaisen

Straw pellets of a diameter of 10 mm mixed with molasses and kaolin and the resulting ash content of 8-10%. Kaolin prevents the ash from forming clinker. Molasses makes the pellets stable during transport tendency of the ash to become viscid and form clinker. The calorific value of the pellets is 16.3 MJ/kg at 8% water, and the volume weight is 4 times larger than that of straw baled into big bales, i.e., approx. 550 kg/m^3.

Washing of Straw

It has been known for a long time that straw that has been lying in the field and has been exposed to rain has a reduced content of the corrosive matter, chlorine and potassium. Contrary to “yellow” straw, this “grey” straw is more lenient to the boiler, since part of the matter that corrodes boiler wall and tubes has been removed. Grey straw also has a somewhat higher calorific value than yellow straw.

In order to reduce the corrosive effect of straw upon the boiler plant, the ELSAM - Electricity Utility Group of Jutland-Funen implemented in the spring of 1996 experiments on the removal of the unwanted components by boiling the straw at 160°C. Later it was demonstrated that chlorine and potassium can also be washed out at lower temperatures. At present, it is considered most economical to wash the straw at 50-60°C. So far, straw washing has only been tested at small plants. According to ELSAM, a plant that can treat 125-150,000 tonnes of straw per annum will most probably cost about DKK 200 million/ref. 26/.

The energy losses caused by washing, drying and the leaching of organic matter make out approx. 8% of the calorific value of the straw. This cost is offset though by the prolonged life of the boilers, because corrosion problems are avoided. Washing of straw is also expected to give advantages in respect of the subsequent application of the fly ash, since straw ash that does not contain alkaline salts and other impurities can be used as a filler in building materials.

Straw Price

The market price of straw for energy purposes is still being intensely negotiated among suppliers and purchasers. With demands by the large electrical power producers steadily increasing over the recent year due to the Biomass Agreement, the market has been characterised by a certain increase in prices. Thus the cost price is not only an expression of the cost of producing the straw and the profit, but it is also part of the parties’ strategy in respect of performing the Biomass Agreement. Consequently, price fluctuations in the range of DKK 360 to DKK 500 per tonne are seen. In 1997, the “span in price“ between the producers of straw and the power plants’ purchasers of straw was above DKK 80 per tonne, i.e. DKK 466 and DKK 380, respectively. Tenders for straw were invited by district heating plants east of the Great Belt in 1997 and 1998 with a tender result of DKK 350-400/tonne delivered to the plant.

West of the Great Belt, the straw price according to the most recent crop delivery contracts for straw has been in the range of DKK 320-370/tonne, also delivered to the plant.

The producer’s straw price includes in addition to return on investment and depreciation on the machinery used in connection with the gathering in of straw and a range of other elements, e.g., wages and cost of fuel in connection with turning, baling, gathering in, and costs of storage and transport to heating plant. In addition to that, lost fertiliser value, insurance, and the producer’s risk covering, i.e., due to shrinkage caused by bad weather conditions during the period of harvest and shrinkage during storage.

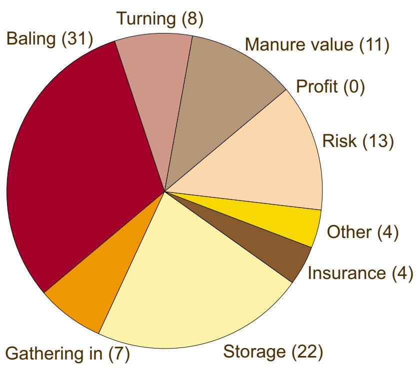

Figure 7: In April 1997, The National Department of Farm Buildings and Machinery calculated the cost price of straw for energy purposes at DKK 466.00 per tonne. Add to this the costs of transport to plant /ref.27/. (In p.s.).

A term that is now and then used is the “socio-economic straw price”. That is a price that is cleaned for direct and indirect taxes so that it reflects the actual cost of producing it. The socio-economic price is used, e.g., for a comparison between prices of various domestic and imported fuels and is more a planning tool than a price calculation for use in the day-to-day trading. This price is fixed by the Danish Energy Agency and was reported in 1994 to be DKK 240/tonne delivered on the plant. Of this amount, DKK 43/tonne accounted for the cost of transport and DKK 197/tonne accounted for other cost of production.

Transport Energy

Admittedly, the great number of trucks transporting straw to plants or transport over great distances emit CO_2 to the atmosphere caused by the engines of the trucks.

A truck travels 2-3 km on one litre of diesel oil, thereby emitting 2.7 kg CO_2. Therefore, the CO_2 emission can be estimated at approx. 1 kg per km travelled. A truck load of straw with a calorific value of 14.5 GJ/tonne weighs 11-12 tonnes and represents an amount of energy of approx. 170 GJ. Since the CO_2 emission from coal is approx. 100 kg/GJ, then the straw corresponds to a CO_2 emission of approx. 17 tonnes subject to coal being burnt instead of straw.

That means that the truck should travel 17,000 km with a load of straw in order to emit the same amount of CO_2 that is saved by using the truck load of straw as a fuel instead of coal. It can also be expressed by saying that the CO_2 saving is reduced by approx. 0.6% per 100 km transport distance travelled.