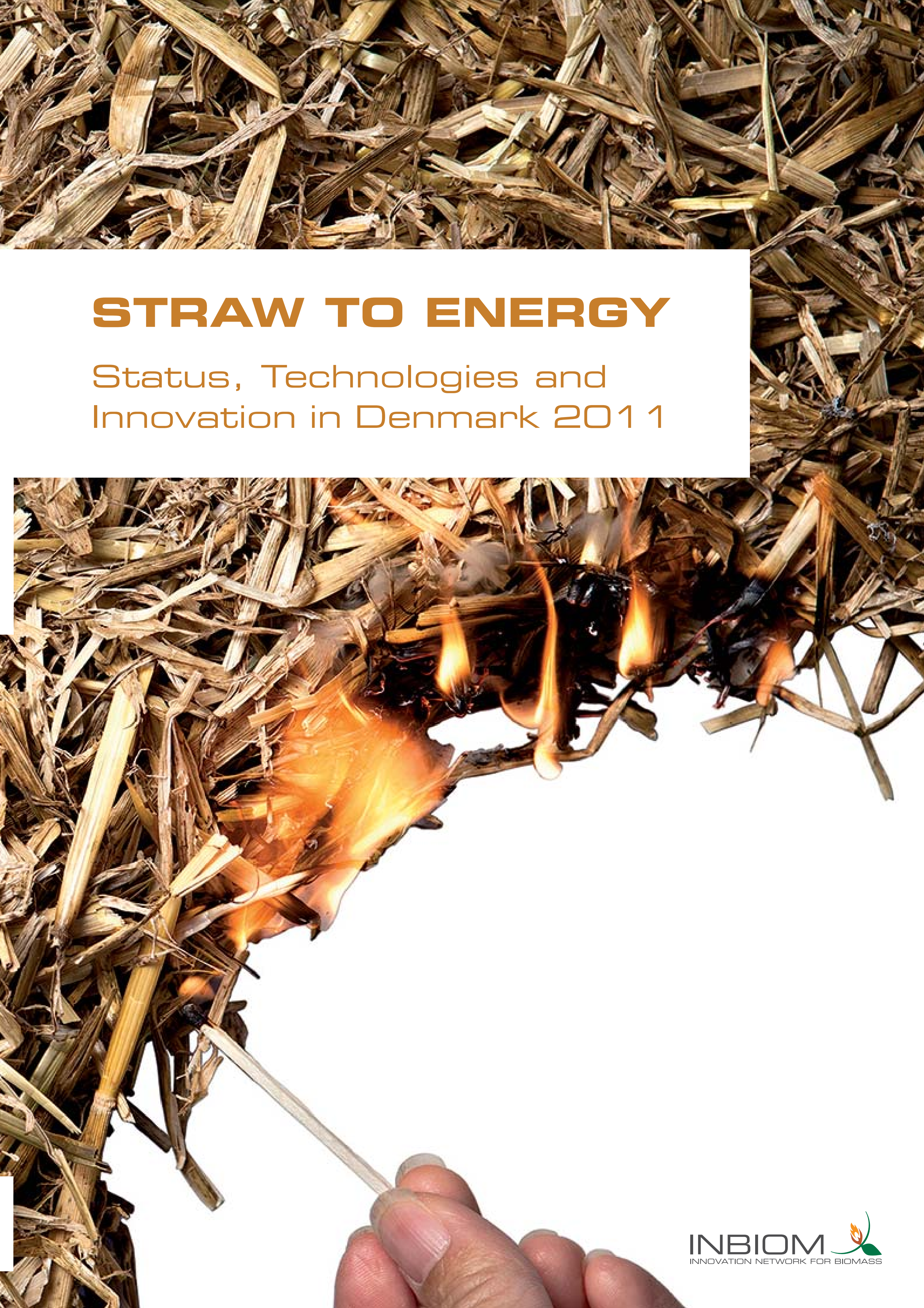
STRAW TO ENERGY

Status, Technologies and Innovation in Denmark 2011



INBIOM
INNOVATION NETWORK FOR BIOMASS

Straw to Energy

Status, Technologies and Innovation in Denmark 2011

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Danish Energy Policy

Since 1976, Denmark has had an active energy policy with a strong focus on renweable energy. The long-term goal is to become independent of fossil fuels and by 2020, Denmark should be among the top three countries in the world, in terms of renewable energy share.

In 1976 , Denmark got its first energy plan "Danish Energy Policy 1976", and since then has become known as a country with an active energy policy that emphasises effective energy use, energy savings and sustainable energy. Today, it is the government's vision that Denmark should become independent of fossil fuels. Denmark should be among the top three countries in the world, clearly targeting the 2020 aims that 30% of the energy supply is based on renewable energy.

The current Danish energy policy is based on a common agreement, settled between a large majority of the parliament's parties on the 21st February 2008. According to the agreement, energy consumption in 2011 must be reduced by 2% compared with 2006, and the overall share of renewable energy must be 20%. The agreement expires on the 1st January 2012 and, therefore, a new agreement must be settled during autumn 2011.

READJUSTMENT OF THE ENERGY SYSTEM

The Danish energy system, which in the 1970's was almost entirely based on imported oil and coal, is today characterised by a large diversification of different energy sources. There has been an ongoing expansion in relation to renewable energy, including particularly wind power, bio waste, biogas and straw. The steps that have promoted this development include energy price surcharges, political agreements supporting the establishment of certain kinds of sustainable energy, as well as tax exemption on biomass. Particularly the last mentioned policy has meant that a large number of households, farms and district heating plants up through the 1980's chose to exchange oil for biomass.

In 1993 a large parliamentary majority entered into a biomass agreement, which required the central power plants to take 1.4 million tons biomass per year, of which 1 million ton consisted of straw. Originally, the target should have been reached in 2000, but the agreement was revised several times and it was not until 2009 that the final elements were in place, with the opening on the Danish island of Funen of a new power plant for 170.000 tons straw per year.

Since the 1980's, there has been a decentralisation of Danish energy production, and production of electricity and heat is carried out over the whole country, rather than at just a few central plants. District heating based on excess heat has contributed to Denmark being one of the most energy efficient countries in the world. It has been possible to keep energy consumption largely constant, while there has been an economic growth of around 80% since 1980.

In 1990 the Danish parliament decided on the so-called Heating Supply Law, which provided the Minister for Energy with the far-reaching authority to regulate fuel choice in district heating plants and decentralised combined heat and power plants. As a result, a large number of coal and natural gas heated district heating plants were converted to combined heat and power plants, while a number of smaller district heating plants switched to bio fuels.

Photo: Torben Skøtt/BioPress

From 1993 central power plants were required to take 1.4 million tons biomass per year, of which at least 1 million tons should be straw.

Photo: Torben Skøtt/BioPress

Since the 1980's there has been a decentralisation of Danish energy production, and today electricity and heating is generated at many smaller plants.

THE KYOTO PROTOCOL

A few decades ago, energy policy was primarily considered a national affair, but today it is to a great extent international events which set the tone for Danish policy on this area. The development on the global energy markets, the liberalisation of the energy sector and our climate obligations in relation to the Kyoto protocol have a considerable effect on the Danish energy sector.

The objective of the Kyoto protocol is that during the period 2008-2012, industrialised countries must reduce their emission of greenhouse gasses by at least 5% compared with the level in 1990. The European Union should reduce its overall emissions by 8%, although there are considerable differences in the obligations of individual member states. Denmark and Germany have both agreed to reduce their emissions by 21%, while other countries such as Portugal, Spain and Greece are actually permitted to increase their emission levels.

Denmark is one of the few nations to have ratified article 3.4 of the Kyoto protocol, and this means that changes in the soil's carbon content must be included in the climate accounts. This can become important for the use of biomass, as the utilisation of straw for example reduces the soil's carbon pool, while perennial energy crops such as willow increase the amount of carbon in the soil. The lack of carbon storage by removing straw from farm land can be compensated however by growing autumn crops, while the CO_2 gain by using straw for energy purposes is significantly larger than the effect the lack of carbon storage causes.

Despite difficulties in finding international consensus on a follow-up on the Kyoto protocol after 2012, efforts will continue to reduce emission of greenhouse gases.

THE DANISH CLIMATE COMMISSION

In September 2010 the Danish Climate Commission published a report, which shows that Denmark can become independent of fossil fuels by 2050 and this can be done without affecting the economy. The analyses of the Danish Climate Commission show that it will cost about 0.5% of the GDP to make a complete change to a green energy system, or about the same as it will cost, if we continue to use coal, oil and gas. This is because our current energy system will become more expensive due to rising prices on fossil fuels and CO_2 quotas, and this will largely compensate for the investments in new energy technology, which will make it possible to become self-sufficient with renewable energy.

According to the Danish Climate Commission, the central elements in a green energy system will be:

- Energy savings
- Offshore wind turbines, which can deliver a great deal of the electricity, which will become the foundation of the future energy system
- Biomass, which will play an important role, partly as fuel in the transport sector, partly for production of electricity and heat, when there is a shortfall from wind turbines
- District heating and heat pumps for heating of houses
- Electricity and biofuels for the transport sector
- Intelligent use of electricity, where the consumption to a higher extent than today, is capable of following the production

As far as the Danish Climate Commission has been able to establish, Denmark is the first country in the world that is providing concrete suggestions for combined solving the problems of climate change and energy supply.

In 2011, based on the Danish Climate Commission's report, the Danish government will present their ideas for realising a fossil free energy system.

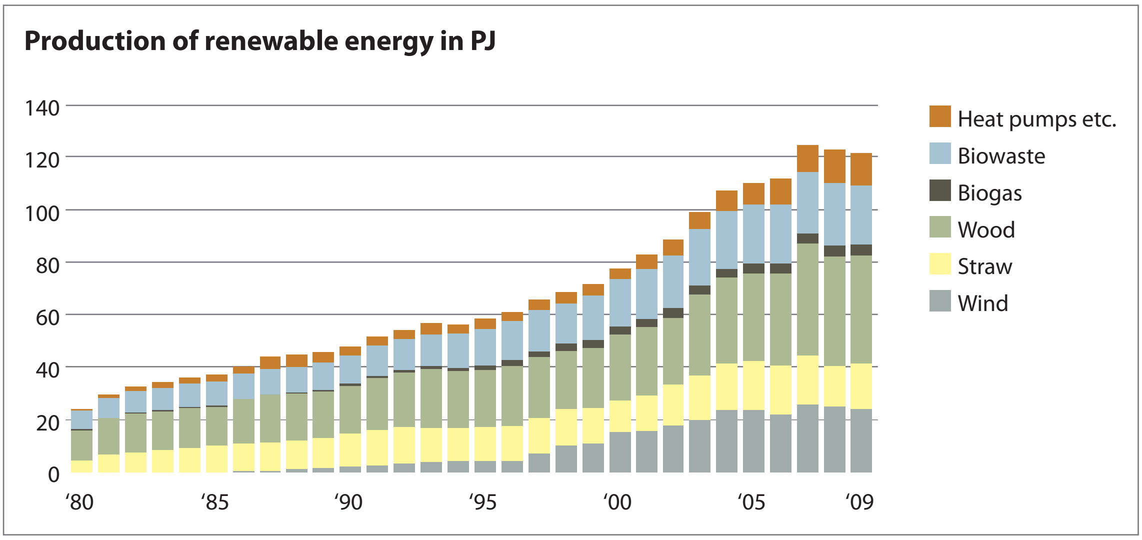


Figure 1. Production of renewable energy in the period 1980-2009. Source: Danish Energy Agency

Straw as a Source of Energy

Straw is a significant source of energy, but it is also a troublesome type of fuel, which can cause corrosion in power plant boilers. The use of straw for energy production has increased significantly since the 1980's, but there are still more than two million tons of surplus straw available, and if the right varieties are grown, the surplus can be even larger.

Only a few decades ago, straw was considered to be a problem waste product, which should be disposed of as quickly as possible. The part of the straw that could not be used for feed and bedding was typically burnt on the fields after harvest. However, in 1991, field burning became illegal, and since then there has been a greater focus on using straw for energy purposes.

The biggest advantage of using straw in the energy sector is that it is a CO_2 neutral fuel, which does not contribute to an increase of the atmosphere's content of greenhouse gasses. Today, straw is primarily used as fuel at individual farm plants, at district heating plants and in large power plants, but in the future, straw will probably also be used for production of gas and bioethanol. DONG Energy has spent a considerable amount of money on developing new technologies for energy production from straw, and has established a pilot plant for production of bioethanol, and is currently working on a plant for thermal gasification of straw. The advantage of converting straw to gas is that it provides better opportunities for utilising the fuel at existing coal boiler plants.

STRAW AS FUEL

Straw normally contains 14-20% water, which vaporises during combustion. The dry matter contains of about 50% Carbon, 6% Hydrogen, 42% Oxygen as well as small amounts of Nitrogen, Sulphur, Silicium, Alkali, Chloride and other.

When straw is used as fuel, the water content must not exceed 20%. If the water content is higher, there is a risk that the bales of straw become too hard and compact. Similarly, a high water content increases the risk of formation of condensation and corrosion.

The presence of Chlorine and Alkali in the flue gas can be a problem at combustion, leading to the development of Sodium Chloride and Potassium Chloride, which are highly aggressive and cause corrosion in boilers and pipes – particularly at high temperatures. The aim is to use straw with a low content of harmful matter, and here the weather plays a significant role. Straw, which has been exposed to a lot of rain after maturing - especially after harvest, and has turned grey, is far less aggressive than yellow straw, which only has been exposed to a limited amount of rain.

The ash content can vary between 2-10%, although the average is 4%. Straw from crops that have been cultivated on sandy soil normally has the lowest content of ash, while straw from lowland soils usually has the highest ash content. The heating value is highest with the lowest ash content, so it can be an advantage to use straw from sandy soil for heating purposes.

The ash from straw burning can become viscid already at 600 degrees, and this is important for the power plants, where a high steam temperature is envisaged in order to obtain high electricity efficiency. New boiler types and better steel alloys have reduced the problem over time, but power plants still consider straw as a more troublesome fuel than wood.

RESOURCES

There is some doubt about current and future availability of straw for heating. Agriculture not only delivers raw material to the energy sector, but also has to produce food and feed, show consideration for nature protection and nutrient leaching, and the soil's carbon pool. If the farmer chooses to plough the straw into the soil, then this will increase the soil's carbon content, which has an impact on the climate records as mentioned on the previous page.

Over the years, a number of analyses have been completed concerning the available straw resources in Denmark as well as abroad. Even though there can be great differences in the individual studies, the general consensus is that resources are far greater than current consumption.

However, handling and transport of straw can be very expensive, so even though resources are plentiful, there may not be an economical benefit from utilising the straw. While energy wood today has become an international commodity, straw is still primarily traded locally. In principle nothing prevents straw pellets from being sold across borders; it just has not happened yet.

Photo: Torben Skøtt/BioPress

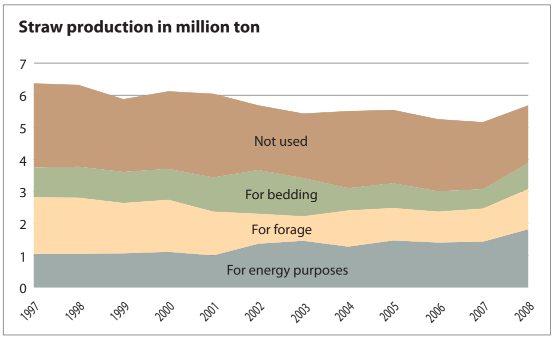


Figure 2. The annual straw production and the use of straw for different purposes in Denmark. Source: Statistics Denmark

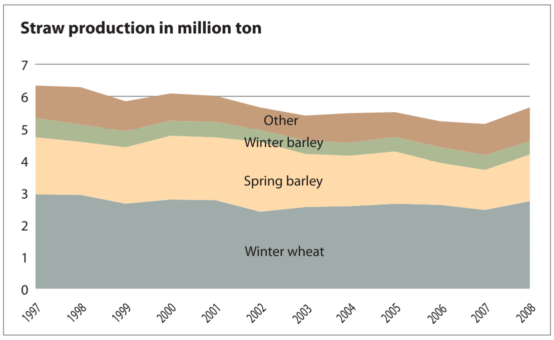


Figure 3. The annual straw production by crops. Other crops are e.g. rape seed and other cereals. Source: Statistics Denmark.

DANISH RESOURCES

A good indication of the amount of straw resources in Denmark can be found at Statistics Denmark, which each year assesses the total annual production of straw and its use for different purposes (see figure 2). From this it can be seen that there was a total straw production of 5.5 million ton per year between 2004-2008 on average, of which 3.4 million ton was used in agriculture and for energy purposes. As a result, there is an annual straw surplus of about 2.1 million tons.

The question however, is how accurately the straw surplus is estimated, and how much the surplus can vary from one year to another. The greater proportion of the straw that is needed, the more important it becomes that the predictions prove correct – with regards to security of supply.

The consumption of straw for feed and bedding can vary a great deal between each year, but looking at a longer period of time, there are no large variations. An increased tendency for straw to remain on the field, can reduce the supply of straw for energy purposes – especially, if initiatives to further ploughing down of straw are taken at political level.

The area given to cereals has proven to be relatively constant, although there can be significant variations on the yield from year to year. Annual variations are one of the largest sources of insecurity in supply of straw.

THE YIELD DEPENDS ON THE TYPE

Field trials with winter wheat in the harvest year 2008 have shown that the relationship between straw and grain mainly depends on the variety. From ten different varieties of winter wheat, there was a range of between 35-53 kg straw per 100 kg grain, so the choice of wheat variety can be one of factors to decide in order to obtain a larger straw surplus. Furthermore, fertiliser trials have shown that the share of straw in winter wheat is reduced as more fertiliser is used, but as the amount of fertiliser is set by official norms, this is not expected to have any great importance in practice.

In figure 3, total straw production for different crops is shown, based on figures from Statistics Denmark. However, only a small change in the relation between grain and straw is needed, before there is a significant variation in the production of straw. Each time the amount of wheat straw is

Parametres of importance for the fuel value of straw, wood chips and coal. Yellow straw is collected immediately after it has been harvested, while grey straw has been subjected to rain before collection.

	Yellow straw	Grey straw	Wood chips	Coal
Water content	10-20%	10-20%	40-50%	12%
Ash	4%	3%	1%	12%
Carbon	42%	43%	50%	59%
Hydrogen	5%	5%	6%	4%
Oxygen	37%	38%	38%	7%
Chloride	0.75%	0.20%	0.02%	0.08%
Nitrogen	0.35%	0.41%	0.30%	1.00%
Sulphur	0.16%	0.13%	0.05%	0.80%
Heating value	14.4 MJ/kg	15.0 MJ/kg	10.4 MJ/kg	25.0 MJ/kg

Photo: Torben Skøtt/BioPress

The relation between straw and grain depends to a great extent on the variety. If the most straw-rich winter wheat is selected for example, it is possible in theory to increase the total straw amount by 800.000 tons per year.

changed by 1 kg per 100 kg grain, total wheat straw production in Denmark changes by 47,000 tons.

As the straw yield from winter wheat as mentioned earlier can vary between 35 and 53 kg straw per 100 kg grain , it will theoretically be possible to change the total amount of straw by 800.000 tons per year. In practice, there are many varieties of corn being grown, and the figures illustrate the potential for increasing the total amount of corn by choosing types with a high straw yield.

FOREIGN RESOURCES

At EU level, Eurostat produces statistics on the use of bio energy in the individual member states. Unfortunately, it is not possible to sub classify bio energy in into wood, straw and manure for example.

The European Environmental Agency (EEA) has published a couple of reports, where they have estimated the potential bio mass resources in the EU. Assuming that a continuing food production and nature conservation must be maintained, the EEA has assessed that future bio energy potential will be close to 300 million tons oil equivalents, or nearly three times as much as the total consumption in 2008.

In Holland, Professor André Faaij from Utrecht University has assessed that in theory it will be possible to cover the whole world's energy use with biomass by 2050. The precondition is a far more effective agriculture than the one we have today. The biggest gains in production of bioenergy are expected to be Eastern Europe, Africa and South America, although there are also good opportunities for optimising production in the western world.

Straw Handling

Straw for the energy sector is almost always delivered as big bales, sometimes known as Hesston bales. In one place, however, they have chosen to convert the bales into pellets, prior to delivery to the power plant. While this raises the costs, it also facilitates handling and reduces stock volumes significantly.

Photo: Torben Skøtt/BioPress

The handling of straw has developed into an independent discipline within agriculture, with heavy duty machinery primarily used by large farms and agricultural contractors. Since the 1980's when the big balers came on the market, agriculture has invested considerable amounts of money in baling machines, wagons and stores in order to be able to deliver straw to the energy sector.

After harvesting, straw lies in long rows at the ground, ready to be baled. Most farmers want the straw removed as quickly as possible, so they can start planting next year's crops. However, it can be beneficial to let the straw lie on the ground for a couple of days or weeks. If the straw is exposed to a rain shower or two and is allowed to dry again, it becomes so called "grey straw", which is a better fuel, as many problematic substances such as Chlorine and Alkaline have been washed out. In practice, few farmers or agricultural contractors make use of this method, as heating and power plants do not have a differentiated price for straw, and pay based on weight and water content.

The straw yield is typically about three tons per hectare, but it depends of course on the crop, the yield level and the weather.

TYPE OF BALES

Today, power plants and district heating plants almost entirely use big bales, also known as Hesston bales. Small bales, round bales and mini big bales are primarily used for farm plants and for the farms that use straw for fodder and bedding.

Big bales measure about 125 x 240 cm, and the weight is typically slightly over half a ton. The length of the bales can however be regulated from 110 to 275 cm, but for the sake of highway transport a length of 240 cm is the most suitable.

For a short period of time, experiments were carried out with cut straw, which was stored in haystacks in the fields in order to reduce the costs of straw handling. The first tests suggested that the price could be reduced by 50%, but there were too many practical problems and the concept was dropped in the middle of the 1990's.

Big bales have in many ways proven to be a well-functioning system for the handling of straw, although they do not of course utilise capacity of transport effectively. There can only be 24 big bales on a lorry load, equalling about 12 ton of straw, which is less than half of what a lorry can carry. The

Photo: Torben Skøtt/BioPress

When using a telescope loader the bales can be stacked significantly higher than with a fork lift truck and a front loader.

poor utilisation of capacity not only leads to higher transportation costs, but also leads to extra expenses for the handling of straw bales and poor utilisation of the storage capacity.

Over the years there have been many attempts to increase the weight of big bales, but this has never really functioned in practice. New cranes are however able to handle a bale weight of about a ton, so presumably it is only a matter of time, before big bales with a weight of up to a ton become a common sight in straw plants.

Another solution is the so-called medi-bales, which have been developed by Nexø straw heating plant and the agricultural contractor Præstegården. By cutting 30 cm off the height of the big bales, they can load 36 bales with a total weight of 15 tons on each lorry load. The system only requires small adjustments of cranes and straw bales, reducing the need for new investment.

HANDLING

When loading straw, a front loader, excavator, tractor shovel, telescope loader or a mini loader is used. In principle, there is a not a big difference between the first three types, which are all based on a front installed loading system.

Telescope loaders, on the other hand, have a greater lifting capacity and can reach further so that the bales of straw can be stacked high, which reduces storage costs. Telescope loaders are therefore becoming more and more widespread. The mini-loader is not quite as common, but is very flexible and can be used in tight locations.

As seen in figure 4, the work load is biggest when loading with a front loader and smallest when using a tractor shovel and telescope loader, as they are always able to load two bales at a time. Converted into tons, it appears that there is a difference of 2.5 minutes per ton between loading with a tractor shovel and loading with a front loader. While this may not sound much, when loading one million tons, which is the annual delivery made to power plants, it results in an extra work effort of about 41,000 hours.

At larger plants, unloading normally takes place with a portable crane that grips an entire layer, on the fore-carriage and trailer at the same time. This means that the crane loads 12 bales at a time, corresponding to two lifts to unload a lorry load. While the bales are hanging in the crane, they are weighed and the water content is analysed. After this, the bales are transported to the storeroom, where they can be placed by the same crane, on the conveyor, which leads to the combustion plant.

In smaller heating plants, forklift trucks are mostly used, which unload 1-2 bales at a time. In connection with unloading, the whole load is weighed and tests are made to check water content of the straw.

Photo: Torben Skøtt/BioPress

Big bales are taken to the straw cutter at Køge Bio Pellet Factory.

As shown in figure 4, it almost takes the same time to unload with a crane, as with a forklift truck, however, in relation to the latter, time must be ascribed to weighing and analysis of the water content, which makes the total time consumption about 50% higher. In addition, extra time must be spent if the storage room is going to be completely filled.

STRAW PELLETS

Another possibility is to convert the straw into bales, which is later made into pellets, before delivery to a plant. The production of pellets increases the costs, but in return, transport costs can be reduced – especially if the straw is going to be transported a long distance. Handling at the plant can also be simplified, and stocks can be reduced significantly. The large straw storerooms, cranes, transportation systems and straw cutters can be replaced by tall silos, filled at the top with blowers and automatic unloading from the bottom. This will lead to cost savings, while at the same time the problems of dust and straw can be completely or partly eliminated.

Amager Power Station in Copenhagen, which is owned by Vattenfall, has been stoking since 2003, with pellets at Køge Bio Pellet Factory, about 50 km south of Copenhagen. The transport of straw pellets is by water, in order to avoid heavy lorry transport through Copenhagen.

The pellet factory in Køge has a capacity for 130,000 tons straw pellets per year, but during the last years only 60-70,000 tons pellets have been produced annually. The straw is delivered as big bales from farmers in Zealand and Lolland-Falster, and the handling at the plant is identical with the systems that are present on a common power plant.

The compression of the pellets is carried out by steam from a nearby combined heat and power plant, and the energy consumption comprises only a few per cent of the pellets heating value.

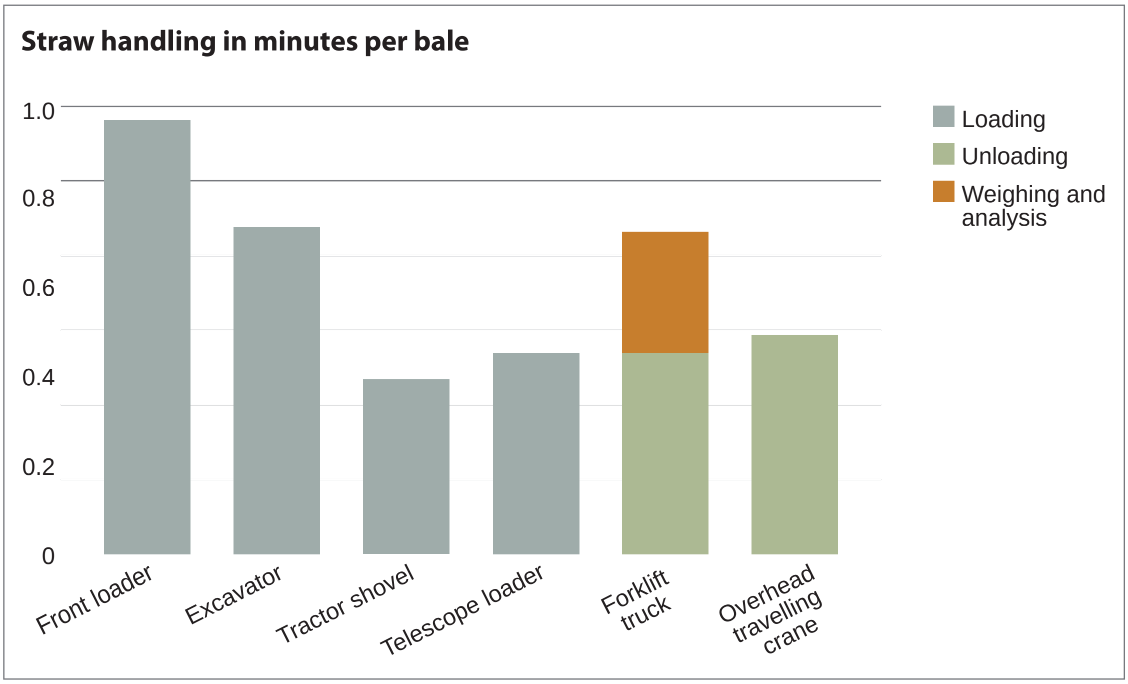
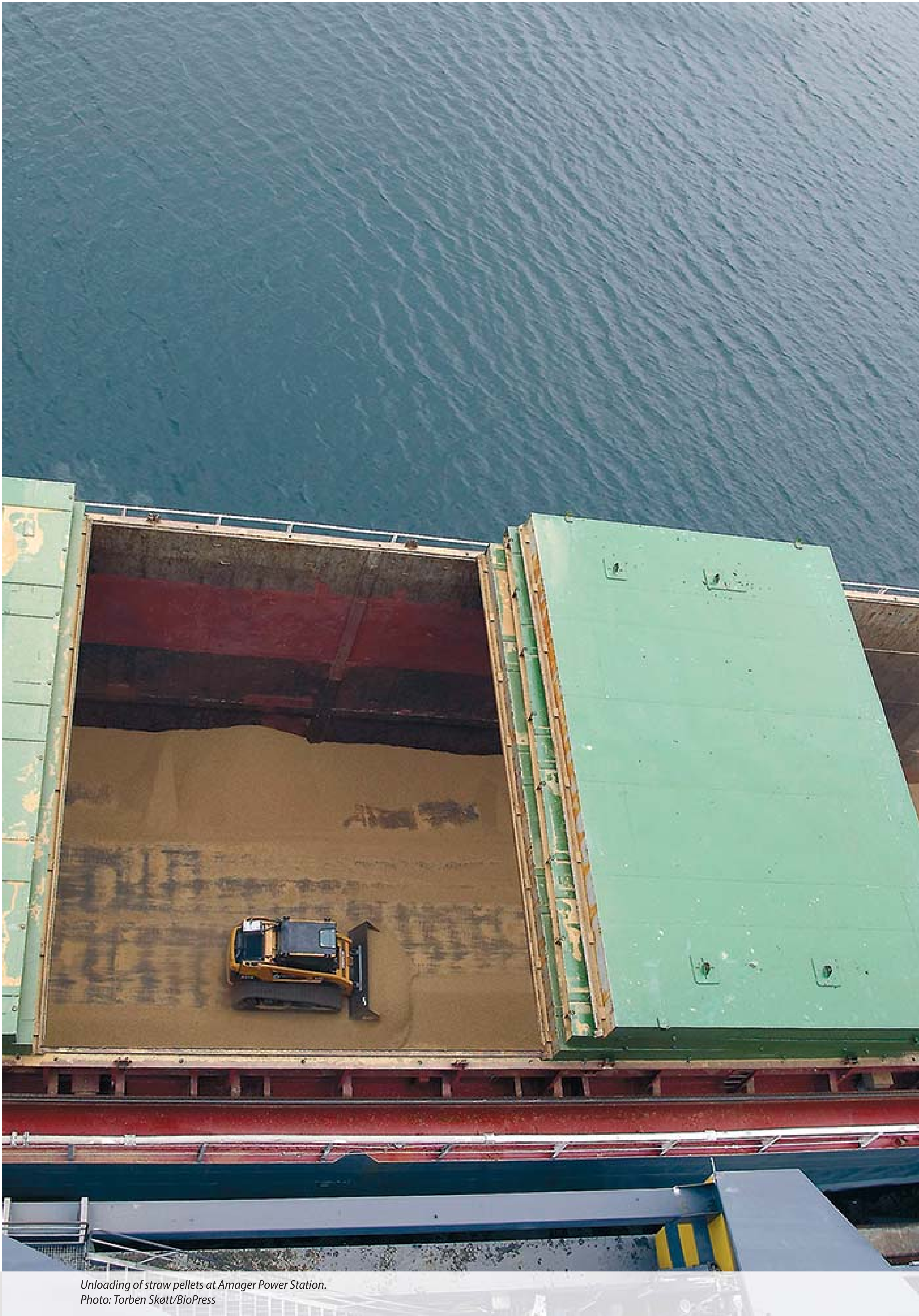


Figure 4. Time consumption for loading and unloading straw. When unloading with a forklift, extra time must be spent on weighing and analysing the water content in the straw. Additionally, time must be spent on moving the bales if the stockroom is going to be completely filled. Source: Centre for Biomass Technology.



Unloading of straw pellets at Amager Power Station.
Photo: Torben Skøtt/BioPress

Straw for the farm and neighbours

Individual straw fired boilers have gone through a rapid development since the first plants appeared on the market at the end of the 1970's. Efficiency has doubled, while the emission of harmful substances has been reduced significantly. Today, more and more farmers choose to invest in slightly larger boilers, so that their neighbours can get cheap and environmentally friendly heating through the district heating network.

Following the first energy crisis in 1973, many people started to look for a cheaper and more reliable heat source than oil, and for farmers it was natural to turn their attention towards the large amounts of straw, which were burnt off on the fields each year. Up through the 1970's, several machinery manufacturers started to produce simple straw fired boilers, which were designed for small bales. Later on, straw fired boilers for round bales and big bales were also produced, and automatic heating plants were developed, which only demanded minimal attention.

In general, there are two types of straw boilers: manually heated plants, also known as portion plants, and automatic heated plants.

The portion plant is the most simple type of plant (see figure 5), where whole bales of straw are put in the boiler manually. In the case of a plant for small bales, this is usually done by hand, while a front loader is typically used if it is a plant for round bales or big bales. A portion plant boiler is relatively cheap and operating costs are minimal. However, a great deal

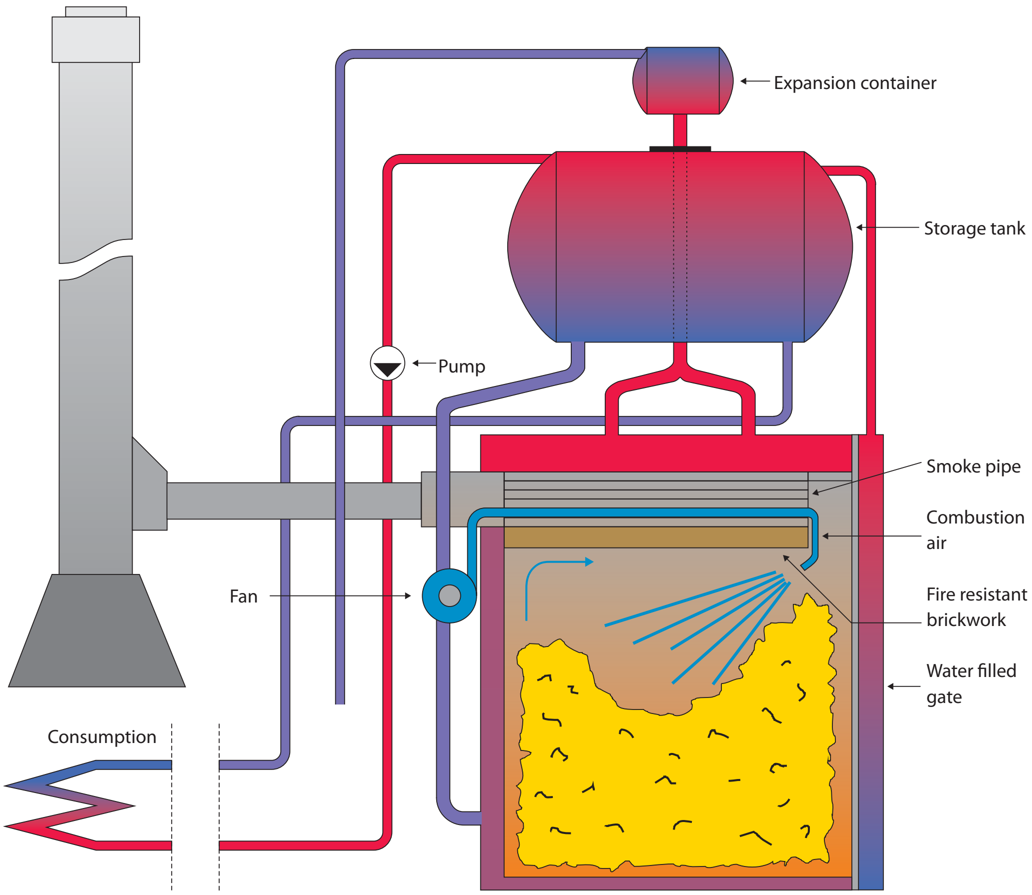


Figure 5. A portions plant straw fired boiler with a storage tank.

Photo: Torben Skøtt/BioPress

Portion plants for big bales.

Photo: Torben Skøtt/BioPress

Automatic heated plants for cut straw.

of time must be spent on removing ash and supplying new fuel.

Automatic heating plants consist of a straw boiler and a supply system, which consists of a conveyor – a so-called straw lane and a collector, which grinds the straw before it is led into the boiler by means of a screw conveyor or blower.

The plants are generally more expensive than the manually heated plants, and the operating costs are higher, but in return the need for attention is minimal.

EFFICIENCY AND THE ENVIRONMENT

The efficiency of the first straw boilers was only about 30-40%, and it was not always pleasant to be a neighbour when the farmer fired up. However, in 1976, the Danish Agricultural Research Institute, began testing straw boilers and helping the manufacturers with product development. Furthermore, in order to speed up development, the Danish Energy Agency implemented a subsidy scheme in 1995, where the size of the subsidy depended on how effective the boiler was. This led to significant improvements of the straw boilers, and the efficiency increased from the original 30-40% to over 80% (see figure 6).

Meanwhile, as boilers became more efficient, the emission of carbon monoxide dropped significantly (see figure 7). Carbon monoxide per se is not harmful for the surroundings in small doses, but can be used as evidence for how much the boilers pollute. If there is a lot of carbon monoxide in the smoke, there will also be a number of other harmful substances emitted. This includes for example soot and tar, the latter of which consists of various organic acids and the so-called PAH's, which are carcinogenic.

The presence of these substances is evidence of an incomplete combustion, and the most sensible way to remove these, is to improve the combustion so that the substances are burned off, while at the same time the heat is better utilised.

This can be done by ensuring a high temperature in the combustion chamber. Straw and other types of biomass create gasses, which do not ignite until the temperature has reached around 800-900 degrees. If the temperature falls too low, the gasses will not be combusted before they are emitted through the smokestack, which leads to a bad heating economy and a poor environment.

Older straw boilers typically consist of a water-cooled chamber, with the smokestack at one end, while the combustion air is injected into the opposite end. Based on this simple design, there will be a tendency for the smoke to be emitted through the smokestack without being combusted. Fortunately this can be remedied, and many the new boilers are designed, so the gasses are forced to pass in front of the air nozzles, which ensure a far greater probability of ignition and conversion into heat, instead of polluting the surroundings.

Figure 7 shows the content of carbon monoxide in the smoke from manually and automatically fired straw boilers in the period 1980-1998. As can be seen from the figure, there is a great difference in the emission from the individual boilers, but the tendency is clear: Straw boilers have become significantly more environmentally friendly over the years, and the automatically fired plants are generally better than the manually fired plants.

BUY A SMALL BOILER

Many people are tempted to buy a straw boiler that is larger than needed. This is not a good idea, however, and often leads to a poor heating economy and bad environmental impact. The right choice is a boiler, which is slightly too small to cover the heating needs on the very coldest days. A straw boiler is most efficient with a full load, and therefore, the larger the boiler is, the greater is the risk that it will operate with partial loads for most of the year.

The optimal boiler size will typically be about 75% of the need on the coldest day. In the few periods of the year, where the straw boiler cannot cover the consumption, an oil-fired boiler or electric heating can supplement it.

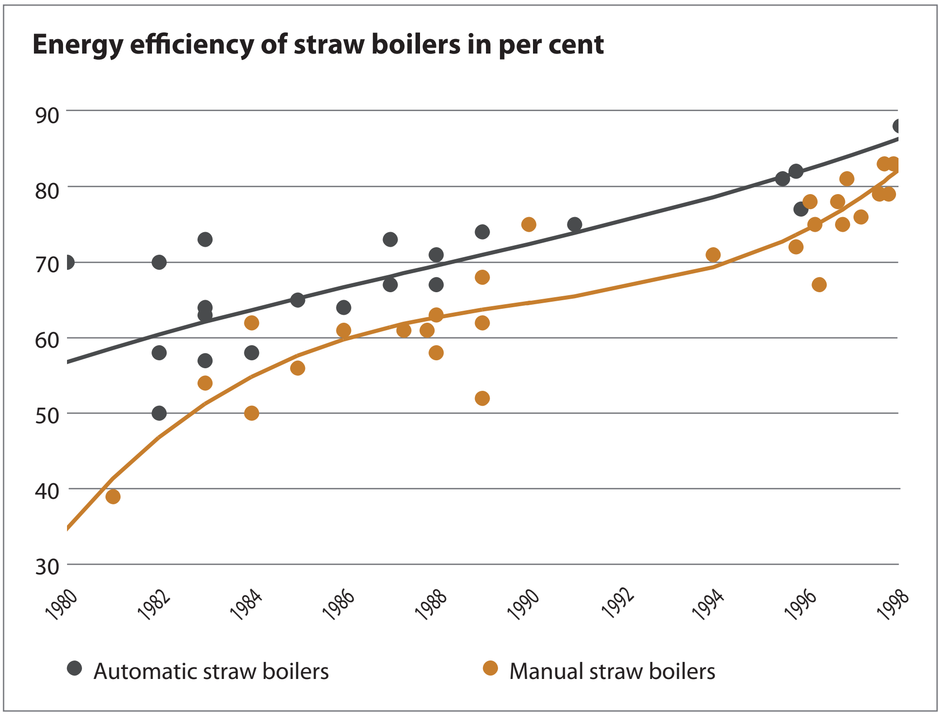


Figure 6. Efficiency for manual and automatic fired straw boilers in the period 1980-1998, where regular tests were conducted by Danish Agricultural Research Centre, Bygholm. Source: Danish Agricultural Research Centre.

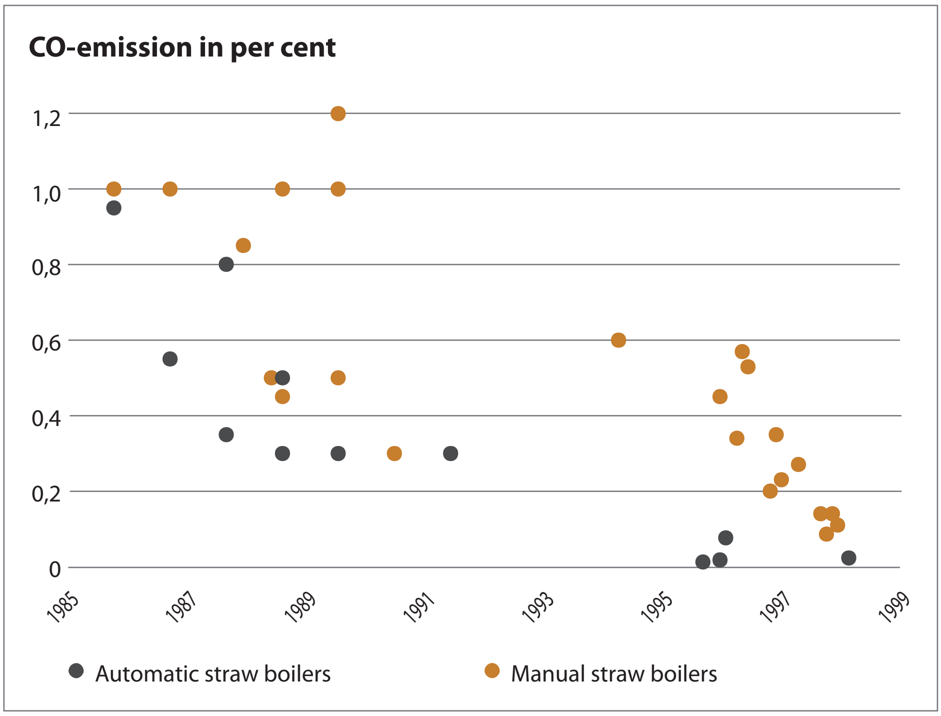


Figure 7. The emission of carbon monoxide for manual and automatic fired straw boilers in the period 1980-1998 when regular tests were conducted by Danish Agricultural Research Institute, Bygholm. If there is a lot of carbon monoxide in the smoke, then there are almost certainly other harmful substances, which can bother residents and the closest neighbours.

Manually fired plants should always be equipped with a storage tank, so that the heat does not necessarily have to be used at the same speed as it is produced. Especially in summer, where heat consumption is low, a storage tank can help to secure a sensible combustion. The storage tank is often a separate tank, which is placed on top of the boiler, but it can also be a complete unit with a boiler and storage tank. The tank normally ought to contain 60-80 litres of water for each kg straw the boiler room can contain.

Many of the automatic plants will also be able to achieve a better combustion if they are connected to a storage tank. The heating needs of a whole day can be produced in around 6-8 hours, and can reduce much of the starting and closing of the system, which often bothers neighbours.

NEIGHBOURHOOD HEATING

60% of all Danish households are today supplied with district heating, but the market for traditional district heating plants is more or less fully saturated. It can be difficult to make a profit with a district heating plant for small towns, and a new term has evolved called neighbourhood heating. In principle, it can be any household, which supplies their neighbours with heat, but is in practice often enterprising farmers, who chose to invest in a larger straw boiler than necessary, in order to deliver heat to their neighbours.

Just like farm plants, the straw boiler should be dimensioned, so it can deliver 70-80% of the needs on the coldest day. In this way, the best possible heating economy is achieved both in the winter period and during summer, where the consumption is minimal. During the cold winter period, an oil-fired boiler can be used as a supplement, and is usually constructed, so it can handle the entire consumption, if the straw boiler gets a stoppage.

In order for neighbourhood heating to be a success, there are some fundamental conditions that one must be aware of:

- The buildings should normally be as close as in normal urban areas, in order to avoid too much loss from piping.
- Large-scale consumers such as schools, care homes and companies can be crucial for the project's economy.
- Consumers should be able to achieve a financial saving by replacing oil-fired boilers with neighbourhood heating.
- Consumers should be guaranteed stable and cheap heating prices for at least 10 years.

The neighbourhood heating plants that are established in Denmark, vary from a few houses, up to 70-80 homes. The vast majority are established by farmers, who have considerable amounts of straw at their disposal, and are able to deliver cheap heating to their neighbours as a result.

The experiences with neighbourhood heating are generally very positive. For the farmers there will typically be an economic gain, consumers are happy to receive cheap heating, and the fact that there is cheap heating might make the smell from the nearby farm less bad.

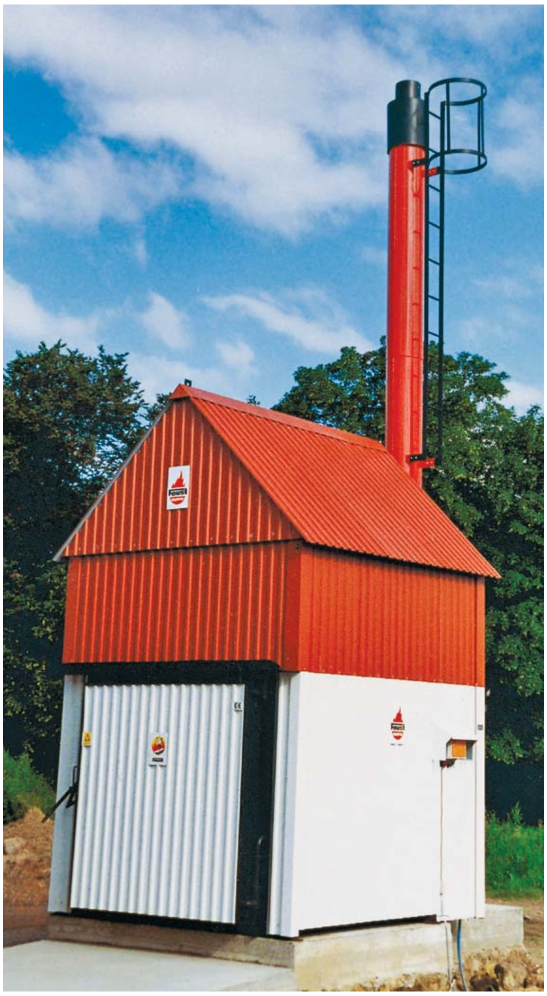


Photo: Maskinfabrikken Faust

Portion plants are often installed in a separate building in order to reduce risk of fire to the farm's other buildings.

Straw for district heating

Straw heated district heating plants can be a cheap and environmentally friendly alternative to other kinds of heating – especially if the plant is placed in an area with a large straw surplus. Some years ago, there was a tendency that the district heating plants favoured wood chips as fuel. Today however, there is not a big difference in the economics of using straw or wood chip.

Photo: Torben Skøtt/BioPress

Straw heated heating plants have been built in Denmark since 1980, and today, there are about 55 plants in operation. Several of the plants have been built in close co-operation with local farmers and in some places, it has been the farmers that have been responsible for the construction, as well as the operation of the plant. The effect of the plants varies from around 500 kW up to 12 MW, and the technical designs cover a wide field, although there of course are elements, which are generally used at all plants.

When a heating plant is going to invest in a new boiler for biofuels, they are faced with a fundamental choice: Is it going to be a plant for dry fuel, such as straw, or wet fuel, such as woodchips. This is because it is not technically possible to use the same boiler for wet and dry fuels, although the framework is quite wide in relation to what fuels the boiler can handle. The main problem is having the right systems for handling and feeding of the fuel.

At one point, there were 61 straw heating plants in Denmark, but around the year 2000, several plants chose to replace the straw boilers with new for wood chips. This was connected to the fall in wood chip prices, due to a considerable import of wood from the Baltics. Furthermore, several plants had poor experiences with the original contracts that had been agreed on with straw suppliers. Many of the first straw plants had chosen to enter into long-term, indexed contracts with farmers, and this had been expensive for several of them. Today, straw is primarily traded on the free market via competitive bidding, which has made straw more competitive, and resulted in the expansion of straw heated heating plants again.

The question about whether a straw or a wood chip plant is the most beneficial has a lot to do with the local circumstances. Straw is primarily traded at regional level, while wood chips have become an international commodity. If the plant is placed in an area with a large straw surplus, it can provide low heating prices and increased revenues to the local farmers. Straw is generally a cheaper fuel than wood chips (see figure 8), although the plant investments are slightly more expensive, and the operating costs are slightly higher.

As in the case of farm plants, it is a prudent practice to dimension the plant, so the straw boiler covers around 70% of the maximum consumption needs (see figure 9). Based on this, the boiler will perform at about 25% of the maximum effect in summer, which increases the chances of a good utilisation effect.

If the straw boiler is too big, the plant will run with partial load for much of the year, which means lower efficiency and a negative environmental impact. A heat accumulation tank can be used to even out the variations during the year and in the few periods in winter time, where the straw boiler cannot cover the requirements, it can be supplemented by an oil-fired boiler.

STRAW HANDLING AT THE PLANT

Today, all straw fired district heating plants use either big bales or medi-bales, which are 30 cm lower than big bales. It is normally the farmer or an agricultural contractor, who takes care of the delivery of straw to the heating plant, although in some places it is the heating plant that has the responsibility for transport and storage of the many tons of straw. Transport is usually by tractor, if the supplier lives close to the heating plant and by truck over longer distances.

Unloading at the plant typically takes place with a telescope loader or with a forklift, which normally can load two bales at a time. Several new forklifts are now equipped with special "grabbing arms", which take hold of the bales which are furthest away. In this way, a whole lorry load can be emptied from the one side of the lorry.

The straw is paid according to weight and water content. The weighing of the straw load takes place either on a weighbridge, or a so-called platform scale. The weighbridge is the fastest one to work with, as it must be used only twice, while the platform scale requires that the forklift drives up on the scale with each load. A weighbridge is, however, 2-3 times more expensive than a platform scale, so it is a balancing between time consumption and investment that should determine, which solution is the most suitable for the individual plant.

Before the unloading takes place the water content is measured with a device that is mounted with a pointed spike, which can be inserted into the individual straw bales. A water content of 14-15% is optimal. With a water content of 18-20%, some plants will reduce the price, and most plants will reject the straw completely if the water content is 25% or higher. Green and wet straw will normally also be rejected.

A straw storage room requires a lot of space, and as a result, most plants only have room for about a week's consumption at full load. There are typically four bales piled on top of each other in marked areas, so the crane can automatically place the bales on a conveyor belt – a so-called straw lane, from where the bales are transported to a shredder or directly into the boiler. A few smaller plants do not have a crane, and bales must be placed manually on the straw lane.

THE DESIGN OF THE BOILER

A straw boiler is of course designed for straw, but the majority of the plants will also be able to handle other kinds of biomass, as long as it concerns dry fuel. Several plants have good experiences with supplementing with corn husks, cherry stones, and dry and clean wood waste.

Straw boilers can have different designs, but generally speaking all plants are equipped with a vibration grate at the bottom, where the combustion takes place. The grate is divided into several combustion zones and can be moved backwards and forwards, so the burning straw is transported towards the ash removal point. The combustion can be directed towards each zone by providing it with more or less air.

Most of the straw's energy content consists of volatile gasses, which are burnt in the boiler chamber above the grate. Both

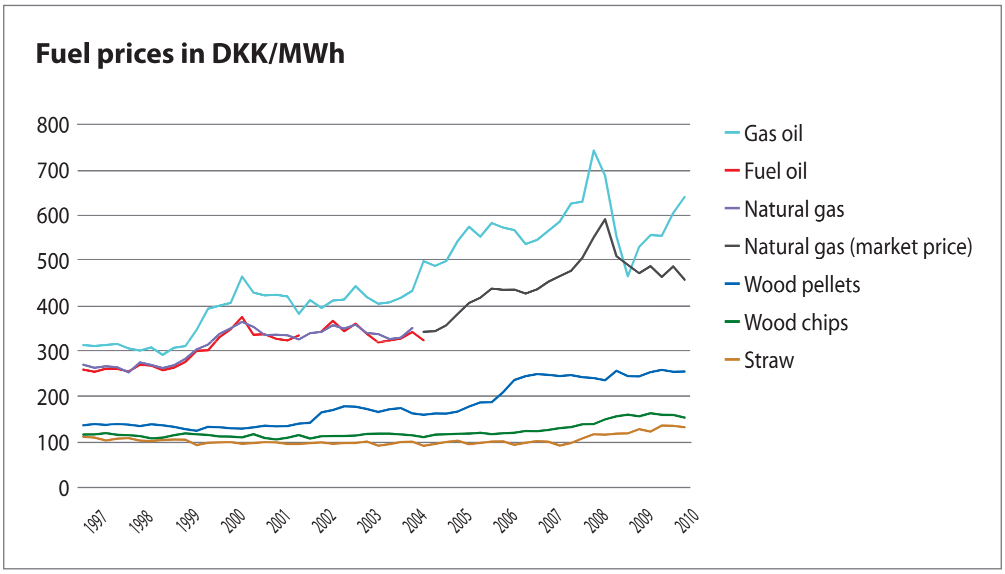


Figure 8. The development in fuel prices to district heating plants in the period 1997 to the second half year of 2010. Source: Danish District Heating Association.

Photo: Torben Skøtt/BioPress

The water content in the straw is controlled before the unloading takes place. If the water content is above 25% it is normally rejected.

Photo: Torben Skøtt/BioPress

The straw bales are placed in the stockroom with a forklift truck. The bales must be unloaded within the yellow marked area, so the crane automatically can collect the bales in the stockroom.

the design of the boiler chamber and control of the ventilation are crucial in order to ensure a correct combustion of the different gasses, some of which will not ignite until there is a temperature of around 800-900 degrees. Unburned gasses exit via the smokestack, which is poor energy efficiency and unnecessary pollution.

After the boiler chamber, the flue gasses are led through the convector, where the heat is transferred to the water, typically via a row of vertical water filled pipes. Most plants are equipped with a so-called economizer – a kind of heat exchanger, which is capable of drawing the last heat out of the smoke before it is led through the smokestack.

WHOLE BALES OR SHREDDED STRAW

The great majority of straw heated district heating plants make use of shredded straw, but there are also those that use sliced straw and a few plants where the bales are thrown directly into the boiler – also called cigar heating. These last named systems had their golden age up through the 1980's, but are rapidly on the decrease, as it is difficult for them to meet present environmental requirements.

The system with sliced straw consists of a feeding box, which tips the bale of straw vertically. When there is a need for new fuel, a hydraulic knife cuts a slice of the bale of straw, which is subsequently pushed into the boiler. It is a relative simple principle and can be considered as a cross between cigar heating and heating with shredded straw.

For shredded straw, a shredder is simply placed between the straw lane and the boiler. The shredder can have different designs, but in principle it is all about returning the straw to the same condition as it was before it was pressed. Over the years, many tests have been carried out to see whether it is possible to cut out the baling and shredding process and instead transport the straw directly from the field to the heating plant. It seems like an obvious solution, but the practical problems with storing and handling loose straw have been so large, that this system has been given up.

Boilers with shredded straw generally have high efficiency and low emissions. When the straw is shredded, it is easier to control the inflow of fuel and air, than if the straw is thrown in as whole bales. On the other hand, both plants and running costs are a bit higher than for whole bale boilers, but it is normally compensated by a higher efficiency. Plants with shredded straw should always be equipped with a safety lock between the shredder and boiler in order to prevent the fire spreading to the straw outside the boiler.

ENVIRONMENTAL CONSIDERATIONS

The environmental impact from straw fired heating plants attracts the attention of local authorities, as well as the local population, which has a vested interest that the plant does not cause any problems. All straw fired district heating plants in Denmark are equipped with a filter bag, which reduces the amount of fly ash, so that no particles are spread around the community.

The content of CO (carbon monoxide) in the smoke is a measure of how effective the combustion is. A high content of CO shows a low efficiency. The smoke smells and it will presumably contain PAHs (Polycyclic Aromatic Hydro Carbons), which can cause cancer. It is relatively simple to measure the content of carbon monoxide and public authorities have high standards in relation to how much carbon monoxide is allowed in the smoke.

Nitrogen Oxides (NOx) in the smoke can be transported over long distances and be converted into for example nitric acid, which can lead to damage to forests, lakes and buildings. In addition, nitrogen compounds from the air can cause over-fertilisation of sensitive nature areas, such as moorlands and heaths. Nitrogen oxides can furthermore reduce the lung function for people with asthma and bronchitis, but here it is especially NO_2

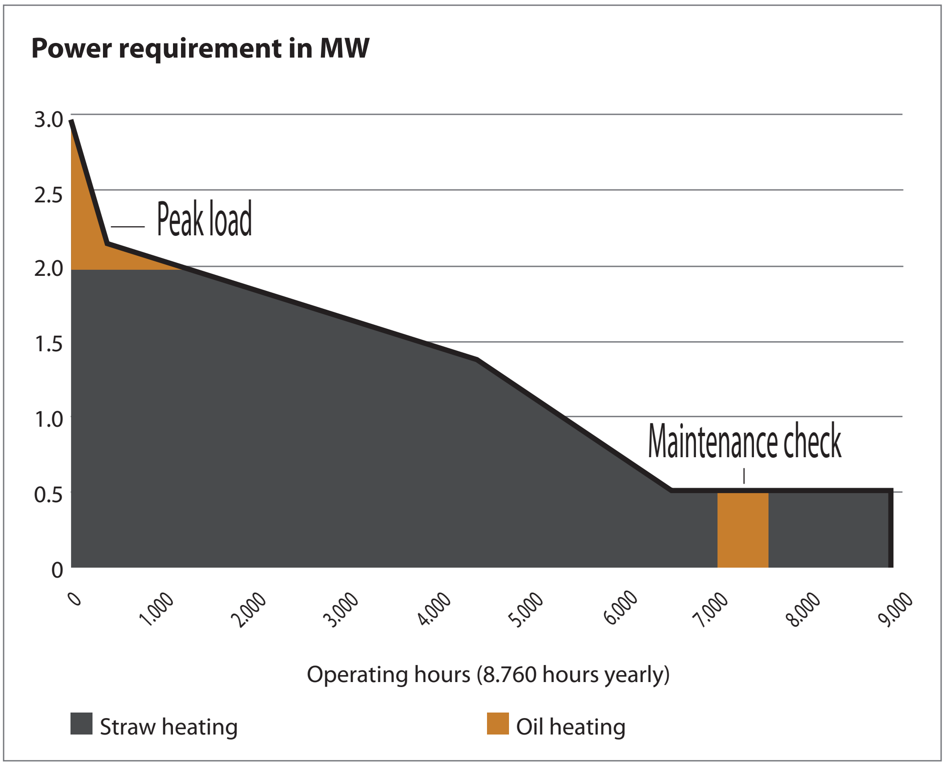


Figure 9. The straw boiler should be dimensioned, so it can cover about 70 per cent of the maximum load. When there is a peak load and when there is maintenance check, the heating demand is covered by an oil-fired boiler. The graph shows the distribution of straw and oil for a 3 MW district heating plant with a 2 MW straw boile- Source: Centre for Biomass Technology.

and not so much NO that is the problem. NOx can be removed from the smoke, but the filtering systems are costly, and as a result, are rarely installed at district heating plants.

It is also possible to clean the smoke for sulphur dioxide (SO_2), but as is the case with NOx, filtering systems are too expensive for the straw fired district heating plants to invest in the technology. By cleansing the smoke of sulphur dioxide, it is possible to avoid paying a sulphur charge to the state, but it requires investments in both desulphurisation plants and measuring equipment, which can prove that emmissions remain under the maximum permissible values.

Several plants have conducted experiments with installing plants for flue gas condensation in order to achieve better efficiency, but in most places these have been given up after a few years operation. In Høng north of Slagelse, a completely new plant for flue gas condensation was installed, which can both improve the efficiency by about 10% and at the same time remove the sulphur content. If this proves successful, it could become standard in both old and new plants – especially if it is possible to exempt the plants from sulphur charge, without having to install expensive and complex measuring equipment.

Photo: Torben Skøtt/BioPress

Straw stockroom at Terndrup district heating plant. The transport from the stockroom to the boiler takes place with an automatic controlled crane. The stockroom can contain straw for about one week's operation during winter.

Photo: Torben Skøtt/BioPress

Unloading of straw at Thisted district heating plant. Notice that the fork lift truck is capable of collecting the bales of straw, which are furthest away. When using a regular fork lift truck the unloading must take place from both sides of the vehicle.

Straw for centralised combined heat and power plants

Centralised combined heat and power plants based on straw is a Danish specialisation. Since the 1980's, considerable research funding has been used on developing a technology that makes it possible to use straw in coal-fired plants and establish purely straw-fired combined heat and power plants.

Photo: Torben Skøtt/BioPress

A power plant consists roughly of a boiler, a steam circuit, a turbine and an electric generator. In the boiler the fuel is transformed into heat and the energy from this is transferred to a steam circuit and then to the turbine, which is connected to an electric generator. When the steam has passed the turbine it is condensed into water by means of cooling water from the sea, after which it returns to the boiler.

In a traditional power plant, only 40-45% of the fuel is transformed into electricity. The rest of the energy disappears up through the smokestack, and along with the cooling water into the sea.

A combined heat and power plant produces electricity in the same way as a standard power plant, but instead of cooling the steam from the turbine with sea water, return water from a district heating network is used, which is thereby heated.

By producing both electricity and heat, 85-90% of the fuel can be harnessed for energy purposes, and as no sea water is required, the plants can be placed in all cities, where there is a sufficiently large heat demand.

In Denmark combined electricity and heat production has a high priority, also when it comes to power plants that are placed close to the sea. Earlier on, it was considered normal to have very large plants placed close to the big cities such as Copenhagen, Aarhus and Odense. However, in 1996 the parliament entered into a political energy agreement, which included the construction of new decentralised combined heat and power plants for biomass, waste and natural gas. This led to the construction of the world's first straw fired combined heat and power plant in Haslev in 1989. Since then another ten straw fired plants have been constructed, and in Studstrup close to Aarhus, a coal-heated power plant has been rebuilt, so it can fire with a mixture of coal and straw.

The development took off after 1993, when the parliament agreed on the so-called Biomass plan, which required that central power plants utilised 1.4 million tons biomass per year, of which at least 1 million tons should be straw. The experiences from other countries were very limited at this time and encompassed only the use of wood as fuel. Straw for energy production was basically, an unknown concept within the heating sector and, it was necessary to instigate an ambitious development and demonstration programme. The programme has solved many of the teething problems, which affected the first plants up through the 1990's and today, Denmark is one of the leading countries, when it comes to effective use of straw in electricity production.

Research and development efforts within combined heat and power plants for straw have been especially concentrated on grate firing, dust firing, circulating fluid bed systems and flux firing, where straw and coal are burnt in the same boiler.

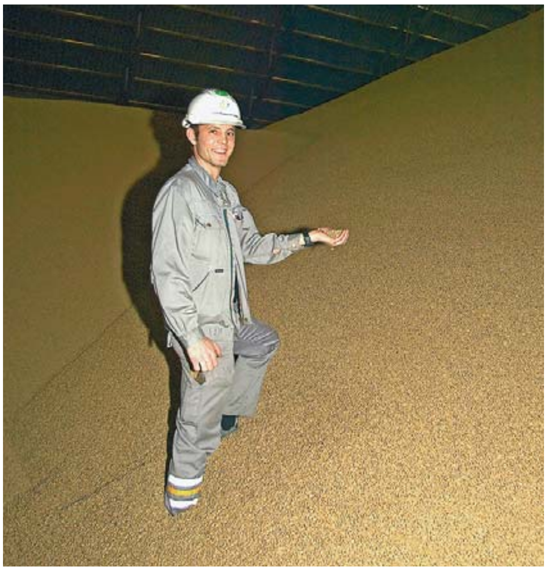


Photo: Torben Skøtt/BioPress

A look into Amager Power Station's storage building for straw pellets. The straw pellets are crushed before they are blown into the boiler like dust using the same principle as when firing with coal.

STRAW HANDLING AT THE PLANT

Combined heat and power plants handle far greater amounts of straw than district heating plants. A plant like the Funen plant, for example, takes 150-170,000 tons straw per year, equivalent to more than 300,000 big bales.

In order to handle the large quantities of straw, most plants are equipped with automatic cranes that can lift twelve bales at a time. Thereby, it only takes two lifts to empty a lorry and trailer and as the crane at the same time registers both weight and water content, there are rarely bottlenecks at the entrance of the straw stockroom. Registration of the water content takes place by means of micro waves and a load cell on the crane, which registers the weight of each lift.

The bales are led from the straw stockroom with a crane to a conveyor belt that takes care of the transport to the shredders. The number of conveyor belts can vary between each plant, but most plants have four parallel belts in order to be able to handle the large quantities of straw.

GRATE FIRING

Grate firing is the most widespread technology for utilisation of straw in Danish combined heat and power plants (see figure 10). As the name suggests, combustion takes place on a grate at the bottom of the boiler chamber. In most cases it refers to a slanting, water cooled grate, which vibrates at regular intervals, moving the straw slowly towards the ash removal exit. A smaller proportion of the ash - the fly ash - is led through the boiler plant and is collected in a filter bag, before the smoke is led up through the smokestack.

At the majority of grate fired plants, the straw bales are fed from the storage room through a shredder, after which the straw is fed onto the grate by means of an auger. In some of the older plants, however, the bales are fed directly into the boiler after the so-called "cigar burning principle". There is no division of the straw, as the bales simply burn from one end to the other. Some of the straw burns in the chamber above the grate while the rests fall down on the grate where it burns out.

DUST FIRING

Coal dust fired power plants can be rebuilt to fire with straw pellets instead of coal. This requires other storage room facilities and the grinder must be able to crush straw pellets instead of coal, but in principle the injection of the fuel in the boiler takes place in the same way. The combustion of straw can lead to the same problems with blockage and corrosion of the boiler's super heater pipes, so it can be necessary to lower the steam temperature in order to prolong the boiler's service life.

CIRCULATING FLUID BED

In a so-called fluid bed boiler, it is possible to burn straw together with coal. Here the combustion takes place in a bed of floating sandy particles, which allows a lower combustion temperature than when using flux firing and grate firing. As a result, the formation of NOx is reduced and it is possible to remove sulphur from the flue gas by adding limestone in the boiler.

Fluid bed boilers are flexible in relation to the choice of fuel, but are sensitive towards ash with a low melting point, including for example straw ash. The reason is that melted ash makes the sandy particles stick together so they are no longer floating. As a result, straw can maximum comprise 50% of the total fuel.

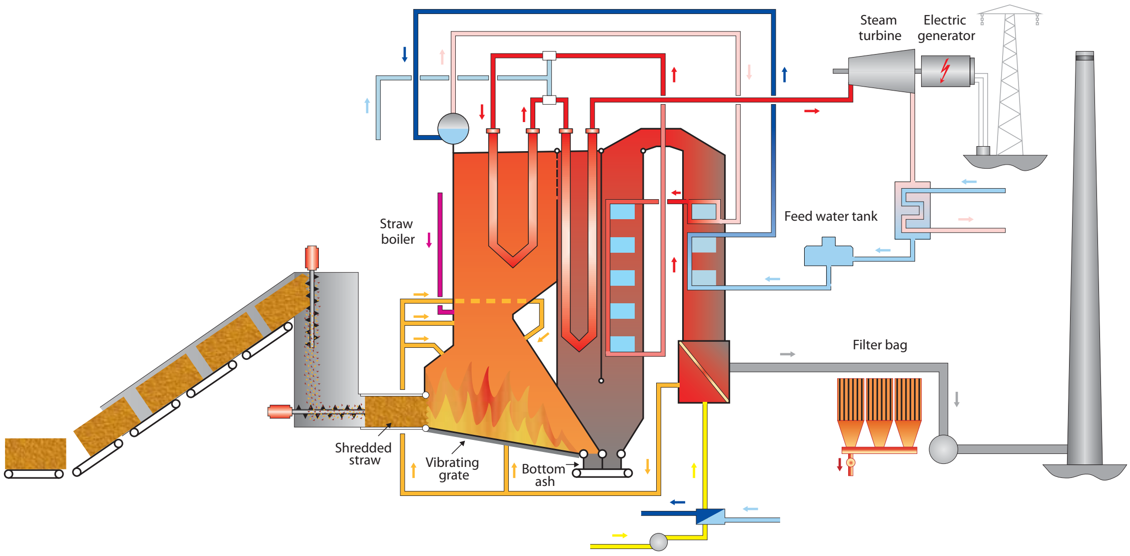


Figure 10. Schematic diagram of a grate firing power plant block at the Funen plant.

As seen with grate firing combustion plants, there have been many similar challenges with regards to coating and corrosion. Furthermore, there have been problems with mechanical wear on the boiler pipes, but various replacements and reconstructions have solved the biggest problems.

The fluid bed combustion method using coal and straw together results in a residual product which cannot be reused, and which is the main reason that the technology is used in only one plant in Denmark.

FLUX FIRING

When using the flux firing method, straw is combusted together with coal in a coal dust firing power plant boiler. There is no need to establish a new boiler and turbine plant, and plant expenditure is therefore very limited in comparison to a grate fired plant. At the same time, the emission of harmful substances in the atmosphere is limited, as the coal fired power plants are already equipped with effective systems for cleansing the smoke.

Flux firing was developed in the beginning of the 1990's, and was first demonstrated in full scale at the Studstrup Power Station, just outside Aarhus. Here it was proven that flux firing results in a very effective combustion, and the content of fixed carbon in the ash is generally lower than with combustion of coal alone. In the first years, it was problematic to dispose of the fly ash, but that problem is solved now, and today the ash is used in the production of cement and concrete. With regard to the use of ash, straw is restricted to 20% of the volume fired, corresponding to around 13% of the fired energy.

During the development of flux firing technology, a lot of attention was directed at the risk of increased corrosion in the boiler, as was the case with grate fired plants. However, it has been shown that coal ash has a very favourable influence on the corrosive elements in the straw. As long as the straw element is not too high, there is no chlorine coating in the boiler and the risk of corrosion is therefore limited.

Straw storage room at the Ensted Power Station in Aabenraa. Note that the crane is capable of lifting 12 bales at a time.

The bales of straw are transported to the shredders via conveyor belts – also called straw lanes.

Photo: Torben Skøtt/BioPress

Studstrup power station close to Aarhus, where a combination of straw and coal is used. Experience has shown that the coal ash has a beneficial impact on the corrosive elements in the straw. If the straw share is kept low enough, there is no chlorine containing surface coating in the boiler and the risk of corrosion is therefore limited.

The combination of straw and coal also has a beneficial effect on the catalytic converters, which reduce the amount of NOx in the flue gas. In grate fired plants, the catalytic converters are often destroyed by potassium combinations, but when using flux firing, potassium is sealed in coal ash and becomes less harmful.

CHALLENGES

One of the biggest challenges in relation to straw fired combined heat and power plants has been the design of the so-called super heater pipes in the boiler. In order to ensure high electricity efficiency, the steam must have a sufficiently high temperature and pressure, but as straw ash has a low melting point, there is a great risk that corrosion and coatings appear in the pipes.

In the first plants, it was often necessary to stop the boiler regularly in order to clean the pipes, but in newer straw fired plants, the distance between the super heater pipes is so large, that there is room for the build up of a thick coating of straw ash. Combined with the use of soot blowers, it has become possible to improve the operating time for straw fired power plants.

Coatings in connection with straw firing can be very aggressive and the problem rises with the temperature, so there are limits for how high the temperature should be to secure a reasonable service life for the plants. In the earliest plants the steam temperature was about 450 degrees, but today it has reached 540 degrees. This has resulted in a noticeable increase in the efficiency, though it is not on the same level as the newest coal fired plants that have steam temperatures of 580-600 degrees.

Much research has been done in relation to the formation of surface coatings and corrosion when grate firing straw. This includes the amount of potassium chloride from straw, which vaporises during combustion and is disposed on the super heater pipes. Furthermore, the corrosion mechanisms have been carefully studied. Super heater pipes contain iron, chrome and nickel and it has become evident that at high temperatures the chlorides selectively remove chrome from the steel, thereby weakening the mechanical strength of the pipes. A content of chrome of 12-18% has proven to provide the best protection of the pipes. Finally, experiments have been carried out with adding different additives to the combustion in order to reduce the corrosion attacks. This technology has worked well when firing with wood, but in straw firing the quantity of ash is so large that the consumption of additives is too high to be cost-effective.

Emissions and residual products

A great part of the straw ash contains nutritional material, which can be sent back to the farm land, but there are also heavy metals, which need to be treated with caution.

With all energy production, it is important to utilise the residual products in the best possible way, in order to reduce the environmental impact. When using traditional coal firing, the ash is used in the production of cement and concrete, while gypsum from the desulphurisation is used for production of plasterboards. When combusting biomass the possibilities of utilising the ash depends on the firing technology applied.

When grate firing straw, the ash is extracted as respectively bottom ash from the grate and as fly ash from the flue gas. Both types of ash contain plant nutrients, primarily potassium, which the crops have taken up from the land. Returning the ash back to the land ensures that part of the plant nutrients stays in the cycle and reduces the use of mineral fertilizer.

The spreading of straw ash is regulated by the "Ministerial order concerning use of ash from gasification and combustion of biomass and biomass waste for agricultural purposes" – colloquially called the Bio Ash Order. Under this, strict rules have been established to outline how much ash may be spread per hectare and which requirements the ash must fulfil. Today, the bottom ash from the straw fired plants is spread on farm land and, as a result, most of the ash is utilised.

The fly ash makes up about 20% of the total quantity of straw ash, but it contains large quantities of valuable fertiliser consisting of potassium chloride and potassium sulphate. The potassium salts are released during the combustion to the flue gas and are therefore concentrated in the fly ash. The same, however, is also the case for the heavy metal cadmium, which means that fly ash cannot meet the demands of the Bio Ash Order. At Kommunekemi in Nyborg, a process has been developed that makes it possible to produce liquid potassium fertilizer from the fly ash, without the heavy metals content. The fertilizer product can be delivered to a fertilizer producer or directly to the farmer.

When flux firing with straw, straw ash is only a small part of the total ash quantity, as coal ash makes the greater part. Focus has therefore been to secure the traditional utilisation of the ash for concrete and cement production, even though, large quantities of potassium are added with the straw. In co-operation with the main users of fly ash in the industry, it has been possible to demonstrate that fly ash from flux firing can be used on equal terms with the well-known coal ash, as long as the straw share is not too high and/or that the coal used has a low content of alkali.

Photo: Torben Skøtt/BioPress

Straw for bioethanol

The production of bioethanol from straw could become an exciting alternative for use of straw in boiler plants. The technology is, however, not commercially available yet, but Denmark has one of the largest pilot plants in the world and it will presumably not take long before the first full scale plants are in operation.

The use of straw as fuel in boilers is today the most thoroughly tested technology when it comes to using straw for energy. At the same time, it is also one of the most effective methods to achieve a high energy efficiency – especially if it concerns boilers in connection with combined heat and power plants.

There are, however, other technologies which in the long term could become just as interesting as the simple combustion. Bioethanol produced from straw could replace petrol and contribute to reducing the transport sector's emission of greenhouse gasses, which seen from a global perspective, causes 25% of CO_2 emissions. This share is rising and it has proven difficult to break this pattern. As a result, bioethanol could be a solution, especially in the short term, as it is possible to mix up to 10% bioethanol in petrol without changing configuration engines.

Production of bioethanol based on grain, maize or sugar cane is a well-known technology. A number of 1st generation plants are established in for example the USA and Brazil, where they deliver large quantities of bioethanol as a petrol substitute.

Photo: Torben Skøtt/BioPress

Experiments with the production of bioethanol at Skærbæk Power Station nearby Fredericia. The results from here have been used to establish a large pilot plant nearby Kalundborg.

The use of agricultural products for production of bioethanol has, however, led to a lot of criticism over the past years. Many people fear that a massive use of bioethanol will lead to drastic food prices increases and worsen the hunger problems in poor countries. This has led to a considerable development effort towards the so-called 2nd generation technologies, where the production of bioethanol is based on use of residual non-food products.

2ND GENERATION BIOFUELS

Straw and other residual products can be used as raw material, as they contain sugar substances in the form of cellulose and hemi-cellulose, although access to the sugar substances is problematic. It requires a complex pretreatment, where the straw is heated under pressure, and enzymes must be added in order to break down the biomass.

The process can be compared to our digestion of food. If we for example eat a potato, we are capable of, via saliva, breaking down the potato into sugar molecules, which the body then can transform into energy. On the contrary, if we try to eat straw, our body cannot digest it because our digestive tract does not offer the necessary physical, enzymatic, chemical and microbial treatment.

Previously, reliable technologies for pretreatment of the biomass were not available and the enzyme expenses were too high. Now, however, a considerable development has taken place, and Danish companies are close to being able to deliver commercial plants for production of 2nd generation bioethanol. This is to a great extent due to DONG Energy's subsidiary Inbicon, which has a large pilot plant in operation, as well as Novozymes and Genecor, which are global leaders in the development and production of enzymes, which can transform cellulose and hemi-cellulose into sugar.

In general, production of bioethanol requires a lot of energy and it will often be an advantage to integrate the process with other energy plants or industrial companies, for example a power plant, which may have a large periodic energy surplus.

The production of bioethanol results in a number of by-products, which can be used amongst other things for fodder and fuel. If the plant is built in connection with a power plant, the by-products can be used as fuel at the power plant instead of coal. Other residual products can be converted into biogas, hydrogen, methanol chemicals or plastic.

INBICONS PLANT IN KALUNDBORG

In November 2009, DONG Energy's subsidiary Inbicon was able to open a plant close to Kalundborg, which can convert 30,000 tons straw into bioethanol, fodder and fuel pellets annually. According to Inbiocon, it is one of the world's biggest plants for production of 2nd generation biofuels, although it is not a production plant in the traditional sense. If the plant is to run commercially, it is necessary to have a capacity of about 500,000 tons straw per year, so the primary purpose is to be able to further develop the technology and sell licenses to other projects around the world.

A major challenge has been the development of a technology, which makes it possible to feed the straw into a reactor, where there is a pressure of 15 bar and a temperature at about 185 degrees. Here the straw is pretreated, after which it is broken down into sugar substances by means of enzymes. The rest of the process resembles a traditional 1st generation plant, where the central process is yeast cells, which convert sugar into bioethanol (see figure 11).

DONG Energy has carried out research on bioethanol since the 1990's. In 2003 the company built the first pilot plant and since then the technology has been further developed, so that today the whole production is mastered from raw material to finished bioethanol. The development effort has, however, focused on pretreatment of the biomass, and today the company is among the world leaders in this field. The work has taken place in cooperation with the entrepreneur Børge Holm Christensen and Danish science institutions such as Risø DTU (National Laboratory for Sustainable Energy) and Copenhagen University.

BIOGASOL

The Danish development company BIOGASOL has developed another Danish concept for production of bioethanol, where the by-products - besides solid biofuel - also include gaseous fuels in the form of methane and hydrogen. The principle in this process is shown in figure 12.

Firstly, a thermal pretreatment of the straw with inflow of oxygen is completed, after which the biomass is broken down by means of enzymes. The following fermentation is carried out in two steps, where the first step converts cellulose, and the second step converts hemi-cellulose into bioethanol. In the final step of the process, water and remains of biomass are led to a reactor, where methane and hydrogen are produced.

In September 2006, a pilot plant named Maxi-fuel opened at the Technical University of Denmark, and the plan now is to establish a larger pilot plant on the Danish island of Bornholm in 2011 for a sum of DKK 200 million.

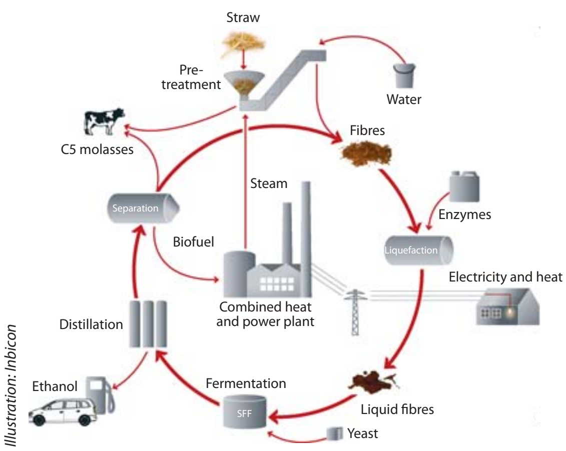


Figure 11. Schematic diagram of Inbicon's ethanol production.

A schematic diagram of Inbicons plant for production of bioethanol from straw. One of the central elements is pretreatment of the straw, which takes place with a pressure of 15 bar and a temperature of about 185 degrees. The plant is built in connection with a power plant, so that the surplus heat can be used for production of ethanol, and the power plant can utilise a part of the biomass from the ethanol plant as fuel.

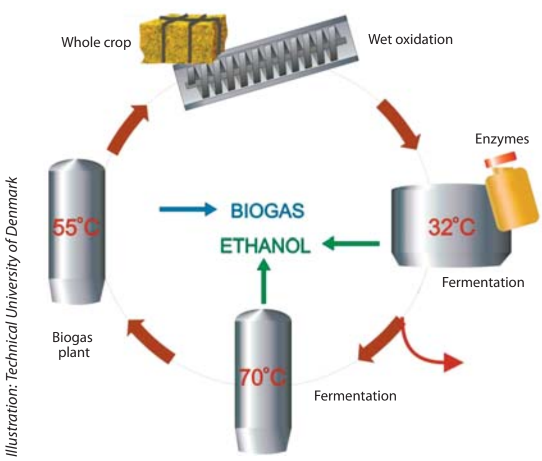


Figure 12. Schematic diagram of Biogasol's ethanol production.

At Biogasol's pretreatment the biomass is "opened" by the method of pressure cooking in a mild acid or base dissolution. As a result, the sugar chains become accessible for the further treatment with enzymes and/or fermentation. In addition, Biogasol has developed a genetically modified thermophilic microorganism, which is capable of converting C5 sugar to ethanol, which increases the ethanol yield from straw with 30-40%.

From straw to gas

In Kalundborg, DONG Energy has built a large gasification plant, where the straw is firstly converted into gas, which afterwards is combusted at an existing power plant. If it becomes a success, it could become the future technology for utilisation of some of the problematic biofuels, such as straw and solid fractions from slurry separation. Another possibility is to use straw in biogas plants, but the experiences in relation to this are relatively limited.

In a circulating fluid bed gasification (CFB), biomass is converted into gas, after which the gas can be combusted in a power plant boiler. In that way, the ash can be kept out of the boiler chamber, which provides the possibility for utilising a number of different biofuels, without heavy and corrosive coating appearing in the boiler. The system can be used for example for co-firing of straw and waste in existing coal boilers, as the different types of ashes are separated and can be reused separately.

Traditional CFB gasifiers require typically temperatures of 850-900 degrees and when biomass from agriculture is used, there is a great risk that the ash melts, and similarly, high concentrations of vaporised ash components can cause problems when the gas is cooled down and is being cleansed. Therefore, in Denmark, Danish Fluid Bed Technology has developed a special version of the plant with the less idiomatic name, Low Temperature Circulating Fluid Bed (LTCFB). Here biomass is converted into gas at a temperature that is just below the melting point of the ash, and this makes the plant, among other things, suitable for degassing straw.

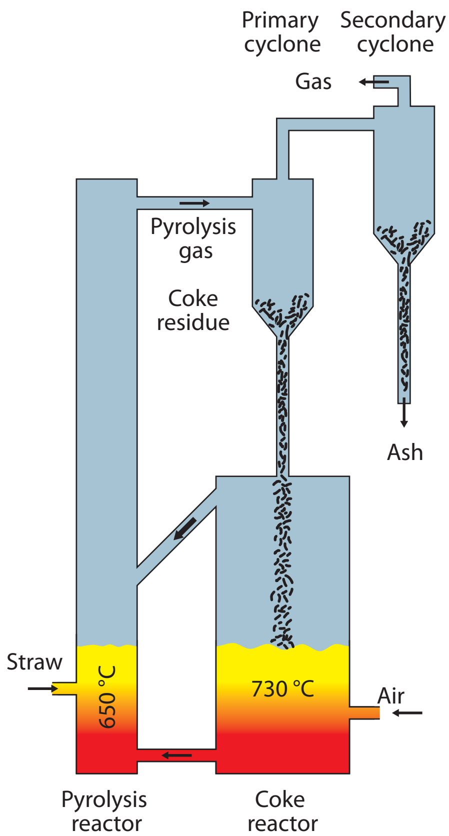


Figure 13. This is how the LT-CFB gasifier is able to convert straw to gas.

As in a traditional CFB gasifier, the biomass is led into a reaction chamber, where it is quickly heated by means of sand and ash particles that circulate around the system (see figure 13). In the LTCFB gasifier the primary reaction chamber is smaller and the temperature is lowered, as the intention is to achieve a quick pyrolysis and not the more time-consuming gasification of coke.

As there is no oxygen present, the biomass does not set alight, but is converted to about 80% pyrolysis gas and 20% coke. The coke particles become gasified via inflow of air and potentially water vapour in a separate coke reactor.

The concept was first tested in a small scale experimental plant at the Technical University of Denmark in 2000 and three years later, a 500 kW plant was established, which can gasify up to four tons fuel per day. Recently, Dong Energy has started a 6 MW demonstration plant in Kalundborg, where the gas is going to be utilised at a nearby power plant.

In the LTCFB gasifier, the straw is added at the bottom of the pyrolysis chamber, where it is heated to about 650 degrees. As there is no oxygen present, the straw does not set alight, but is instead converted into 80% pyrolysis gas and 20% coke. A stream of circulating sand particles tears the coke particles along with it, after which they are extracted by a primary cyclone and re-circulated to the bottom of the pyrolysis chamber via a reactor, which converts the coke into gas.

By gasifying the coke part in a separate chamber, it is possible to keep the process temperature low, so that the ash does not melt. As a result, the ash including alkali salts and phosphorus can be separated, so a gas is obtained that does not cause coatings and corrosion. The nutritious ash can subsequently be reused as fertiliser.

A CHEAP AND FLEXIBLE SOLUTION

The LTCFB gasifier is relatively simple in its composition and, as a result, plant expenses are significantly smaller than with other types of gasifier plants. At the same time, the plant has proven to be incredibly flexible with regard to choice of fuel, and over the course of time, there have been successful experiments with:

- Wood, but only short-term, as wood fuels also can be fed directly into the boiler plant.
- Several kinds of straw, including types with a considerable content of ash, potassium and chlorine.
- Several kinds of separation solids from biogas plants.
- Several kinds of dry manure from production of thickener from citrus peel and seaweed.

The success criteria is to be able to control the temperature in the gasifier, to prevent the ash from melting – this has succeeded in all the tests.

During the latest tests at the Technical University of Denmark, it has been possible to clean the gas in a cyclone, cool it down to 300 degrees and then carry out another cleansing in a filter bag. It is then important that the ash and the heavy tar substances do not condense in neither the cooler nor the filter.

Bag filtration of the highly tarry gas provides the opportunity of using the gas in natural gas fired plants and in boilers, which are solely intended for gasification gas. Without bag filtration the gas will primarily be used at coal fired power plants. A short attempt with tar cracking of the filtered gas shows, however, that the gasifier in time also will be able to be used for processes, which require a gas with low tar content.

Photo: Torben Skøtt/BioPress

The gasification plant in Kalundborg, where the straw is converted into gas before it is burnt at the nearby power plant.

FROM GAS TO LIQUID FUEL

One of the big challenges in a future energy system based on renewable energy is to adapt the electricity production from solar cells and, not least, the many wind turbines, which will provide half of the electricity production in 2050. This requires super flexible power plants and this is where the gasification plants have their great strength. Most gasification plants can quickly change production levels, and the gas can be converted into liquid fuel in the form of methanol, which can be used as fuel in cars. In periods where there is a lot of wind it is, thereby, possible to let the gasification plants produce storage stable fuel for the transport sector, and then in reverse periods with only a little sun and wind, use a larger quantity of biomass for electricity production.

Today, methanol is especially used as antifreeze, solvent and in the chemical industry, but it can also be used in internal combustion engines or for fuel cells.

STRAW IN BIOGAS PLANTS

Today, many biogas plants use energy crops for the production of gas and several plants have become aware that straw might become a future raw material for the production of biogas. The energy yield is though only about 60% of the profit that can be achieved by means of burning, but the gas has far more possibilities for application and the nutrients are led back to the farm land together with the carbon, which was not transformed in the plant.

So far it has been problematic to mix straw with liquid manure but new feeding systems are contiuously being developed, which facilitate the handling, and there are also new pretreatment technologies, which can increase the gas yield by about 50%. One of the more well-known technologies is pressure cooking, which is also used for production of 2nd generation bioethanol. However, research is also being carried out in relation to mechanical processes, where the straw is compressed so hard that it becomes explosive. The advantage of that system is that it is far less energy intensive than pressure cooking.

Companies with Expertise in the Use of Straw for Energy Purposes

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	Knowledge Centre for Agriculture Agro Food Park 15 DK-8200 Århus N Tel: +45 8740 5000 www.vfl.dk	Keeps local agricultural consultants abreast of the latest professional knowledge of crop production, and develops tools for managing plant production. New knowledge is produced through the national research trials, the FarmTest and in interaction with research, and preferably disseminated via www.landbrugsInfo.dk and www.landmand.dk.	•					•
	Fasterholt Maskinfabrik A/S Ejstrupvej 22 DK-7330 Brande Tel: +45 9718 8066 www.fasterholt.dk	Main products are: • Irrigation equipment for professional field use. • Straw wagons that can be fixed to balers - for both square and rolled bales.	•	•				
	FarmerTronic Industries A/S Nyskovvej 13 DK-6580 Vamdrup Tel: + 45 7692 0200 www.farmertronic.com	Develops and manufactures moisture meters for agriculture and industry. Professional users are offered a calibration procedure which ensures the instruments meet the strictest requirements that are reflected in the quality management systems of combined heat and power plants.		•				
	Guldhammer Engineering Aps Gl. Silkeborgvej 33, Ø. Velling DK-8920 Randers NV Tel: +45 8646 1462 www.guldhammer.net	Production of straw wagons for professional transportation of all types of large bales.		•				
	Johs. Randløvs Maskinfabrik A/S Vroldvej 49 DK-8660 Skanderborg Tel: +45 8652 1022 www.randloev-maskin.dk	Production of straw wagons for professional transportation of big bales.		•				
	Parkland Maskinfabrik A/S Vejlemosevej 14 DK-4160 Herlufmagle Tel: +45 5764 2105 www.parkland.dk	Production of straw wagons to be fixed to big balers in order to have a quick and efficient collection of big bales in the field. The wagons can also be equipped with weights for weighing bales.		•				
	POMI Industri ApS Abildvadvej 5, Thorup DK-9610 Nørager Tel: +45 9855 2000 www.pomi.dk	Production of straw wagons to be fixed to large square balers in order to have a quick and efficient collection of big bales in the field. The wagons can collect all types of big bales.		•				
	Supertech Agroline Hestehaven 5 DK-5400 Bogense Tel: +45 6481 2000 www.supertech.dk	Manufactures equipment for measuring humidity and temperature of hay, straw, silage and wood chips, measuring ranges from 8.5% to 60% water.		•				
	C. F. Nielsen A/S Solbjergvej 19 DK-9574 Bælum Tel: +45 9833 7400 www.cfnielsen.com	Mechanical and hydraulic pressure installations for the production of briquettes. Wood and agro-products like straw are turned into valuable biomass briquettes. Complete production lines for the manufacture of briquettes of all types of wood, agri-products, including straw, Miscanthus, rice husks, etc.			•			

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	Lin-Ka Maskinfabrik A/S Nylandsvej 38 DK-6940 Lem St. Tel: +45 9734 1655 www.linka.dk	Produces and develops complete biomass plants for the production of heat or steam, containing boiler, straw shredder and straw conveyor.			•	•	•	
	Passat Energi A/S Vestergade 36, Ørum DK-8830 Tjele Tel: +45 8665 2100 www.passat.dk	Produces fully automated biofuel plants from 140-1000 kW for e.g. straw. Has technology and know-how to handle straw in large-scale industrial solutions for e.g. second generation bioethanol plants, both for boilers and logistics.			•	•	•	
	Skelhøje Maskinfabrik A/S Møllegårdsvej 52 DK-8600 Silkeborg Tel: +45 8695 1590 www.skelhoje.dk	Manufacturer of straw boilers for heating for agriculture and industry.				•		
	Alcon A/S Frichsvej 11 DK-8464 Galten Tel: +45 8666 2044 www.alcon.nu	Manufacturer of manually fired combustion plants for all types of biofuels, steel chimneys, storage tanks and smaller boilers for stoking bales of straw and other solid fuels with under and reverse combustion. Also sells stokers for most fuels.				•	•	
	Faust Vester Fjordvej 2 DK-9280 Storvorde Tel: +45 9831 1055 www.faust.dk	Works mainly with development and production of wood chips and straw boilers, both manual and automatic, with a focus on high energy efficiency and boiler performances of 150 kW to 1.5 MW.				•	•	
	Kaas Staalbyg A/S - KF Halmfyr Hjulmagervej 12-16 DK-9490 Pandrup Tel: +45 9618 3232 www.kaasstaalbyg.dk	Developer and manufacturer of large straw combustion plants with manual firing. All types have high efficiency and are DTI approved in terms of compliance with applicable standards for CO_2. These plants, which are produced in Denmark, can handle a high water content, which ensures stable combustion.				•	•	
	Overdahl Kedler ApS Hjallerupvej 21 DK-9320 Hjallerup Tel: +45 9828 1606 www.overdahl.dk	Produces mainly mechanical stokers and boilers, including stokers for combustion of waste grain, pellets, wood chips, etc. - also combined with solid fuel consisting of pieces of wood and/or straw.				•	•	
	REKA Vestvej 7 DK-9600 Aars Tel: +45 9862 4011 www.reka.com	Produces both manual boilers and fully automatic combustion plants for most types of solid fuels (biofuel), including automatic plants from 10-6500 kW for straw, wood chips, wood shavings, sawdust, pellets, coal, grain and husks.				•	•	
	Scanboiler Varmeteknik A/S Vangvedvænget 1 DK-8600 Silkeborg Tel: +45 8682 6355 www.scanboiler.dk	Specialises in sales and design of biofuel plants for wood pellets, wood chips, solid fuel or straw with boilers from 10.5-600 kW. Scanboiler also sells solar and geothermal energy systems.				•	•	

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	Aarhus Universitet Department of Biosystems Engineering Blichers Allé 20 DK-8830 Tjele Tel: +45 8999 1900 www.agrsci.au.dk	Research in engineering technologies and methods for storage, harvesting and handling of straw and energy crops. Implements testing of straw boilers, which includes determination of the energy efficiency and measurement of the smoke's content of oxygen, carbon monoxide, dust, etc.						•
	AgroTech A/S Agro Food Park 15 DK-8200 Århus N Tel: +45 8743 8400 www.agrotech.dk	Knowledge of: • Straw yields of different crops, straw resources in a geographic area, as well as straw quality for combustion purposes. • Technique for storage and transport of straw from field to buyer.						•
	Con Terra Niels Pedersens Allé 2 DK-8830 Tjele Tel: +45 8999 2540 www.conterra.dk	Targeted geographical surveys and statistics, e.g. for documentation of market research and feasibility studies, based on updated public registers, such as the straw production on the basis of data on crop choice at field level.						•
	Dansk Fjernvarme Merkurvej 7 DK-6000 Kolding Tel: +45 7630 8000 www.danskfjernvarme.dk	Trade association to protect the interests of the Danish district heating plants. 62% (equivalent to 1.6 million) of Danish households are heated with heat from the Danish District Heating Association's member plants. Members include both small, local district heating plants, and the big companies such as DONG (www.dongenergy.dk) and Vattenfall (www.vattenfall.dk).						•
Danske Halmleverandører	**Danske Halmleverandører** Axeltorv 3 DK-1609 København V. Tel: +45 3339 4990 www.danskhalm.dk	Private supplier association which aims to serve members' interests. The association follows closely the political framework for the use of straw, keeps close contact with the buyers of straw and follows the development of new technologies for the use of straw.						•
	Landbrug og Fødevarer Axeltorv 3 DK-1609 København V. Tel: +45 3339 4000 www.lf.dk	Trade organisation whose purpose is to handle common tasks and business interests of farmers and food companies, including production of biomass for bioenergy, energy savings and energy taxes.						•
	KU-life - Forest & Landscape University of Copenhagen Rolighedsvej 23 DK-1958 Frederiksberg C Tel: +45 3533 1500 www.sl.life.ku.dk	Research on the use of straw for energy, including topics such as genetic variation and selection, the structure and chemical composition of straw, enzymatic interactions, sustainability issues, and bio-refinery.						•
	PlanEnergi Jyllandsgade 1 DK-9520 Skørping Tel: +45 9682 0400 www.planenergi.dk	Offers advice in all phases of the plant establishment - from planning, including feasibility studies, design, applications, tender documents to supervision tasks.						•
	Risø DTU National Laboratory for Sustainable Energy Technical Universty of Denmark Frederiksborgvej 399 DK-4000 Roskilde Tel: +45 4677 4677 www.risoe.dtu.dk	Research projects and other activities related to analyses and analysis methods, pretreatment and conversion technologies such as enzymatic hydrolysis and fermentation, as well as mass balances.						•
	Danish Technological Institute Kongsvang Alle 27 DK-8000 Aarhus C Tel: +45 7220 2000 www.teknologisk.dk	The competences of the institute include resource inventories, logistics and handling, organising supplies, setting up straw-fired plants from farm to power plant size, combustion technology and other conversion and residue management.						•

Photo: Flemming Nielsen/Story2Media

Notes

Danish companies have a leading international position on innovative technologies for converting straw to energy, as a result of a determined and visionary policy on the topic, set into motion as a response to the oil crisis in 1973.

Today, straw is widely used as a biofuel in central and decentralised power/heating plants whereas it was mainly used for self production of heat at farms in the first years. At the same time new technologies, such as pyrolysis and production of 2nd generation biofuels, offer new perspectives for giving straw a more flexible role in the energy supply of the future, in combination with other renewable energy sources, and to satisfy the demand for climate friendly fuels in the transport sector.

This pamphlet takes stock of the use of straw for energy purposes in Denmark and provides a review of technologies, policies and innovative solutions. It also includes a list of companies and organisations with specific skills and technologies in the supply chain for straw to energy, ranging from production, logistics, preliminary treatment, conversion and utilisation, taking into account different disciplines such as production of equipment, consultancy, research and innovation.

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