Cereal straw and animal manures are two dominating biomass resources for anaerobic digestion (AD) and biogas production; they are available for AD without taking up land use and without compromising food or fodder production. Also, agriculture has direct access to both resources among its own operations. With this new technology, it is possible to launch a new substantial, robust, and profitable biogas production in Europe and elsewhere.
STRAW

Straw consists of air-filled pores from nano- to meso-scale and to macroscale. Straw is constructed to withstand the ambient conditions in the fields and attach by pests, microorganisms, and enzymes; and it is built very well. For these reasons, straw cannot directly be used for anaerobic digestion.

In order to effectively being able to utilize straw for biogas it is necessary to provide access for water and enzymes to the surfaces of straw. Here it is essential to note, that 80% of the surface area of straw is found in the smallest of pores, the nano-pores, and virtually all surface areas in pores as such. The picture below gives a good impression of the porous structure of straw.

Straw consists of pores from nano- over meso-scale and to macroscale.

From Hansen et al. Bioresource Technology 102 (2011) 2804–2811

PRE-TREATMENT VIA BRIQUETTING

Mechanical briquetting is a technique by which a reciprocating piston compresses the straw at high pressures in matter of split seconds – literally. The straw is compressed to a very high specific density of e.g. 1,0, where lose falling straw has a density of e.g. 0,05. In other words, lose falling straw weighs 50 kg per m³ while briquettes weighs 1000 kg per m³, the bulk density being around 500 kg per m³.

The briquetting also alters the properties of straw. The picture above to the right shows that briquetted straw can absorb water very fast compared to shredded straw. The advantages relative to use of briquettes straw as raw material for biogas are the following:

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1 - Direct feeding into biogas reactor

A briquetting line consists of a straw-line including conveyor band for big bales, shredder, stone and sand trap, a hammer mill before the actual briquetting and direct feeding into the biogas reactor. The briquetting offers a systems solution for actual managing and feeding big bales of cereal straw into the bioreactors. This is possible due to the altered properties of the straw.

It has been demonstrated for more than 3 years, at the biogas plant at Aarhus University full scale experimental facility at Foulum, that substantial quantities of straw briquettes can be directly injected into the reactors.

2 - Water absorption – the sponge effect

Straw is rendered highly water absorbent due to the briquetting treatment, and is therefore immediately dispersed and suspended after addition to the bioreactor. Because water penetrates into the straw matrix, the soaked straw, taking up 10-12 times its own weight, achieves the same density as water, and it will be evenly distributed in the reactor volume. No floating covers will develop, no sediments, dead volumes or clogging will appear.

Addition of straw briquettes does not require additional stirring effect.

3 - The straw pores are exploded

Because all pores of the straw are exploded and water can penetrate into the straw, it also renders access for those microorganisms and enzymes that are digesting the straw into biogas.

This ensures a relatively quick and effective digestion in the biogas plant.

4 - Straw briquettes do not impact the hydraulic capacity of any biogas plant.

The direct feeding of dry briquettes into bioreactors does not impact the hydraulic capacity of the biogas plant. It is unnecessary to suspend the briquettes in raw manure or digested manure under severe stirring or such before adding to reactors. No extra tanks fitted with stirrers are needed.
5 - Straw briquettes add heat and circumvent heat exchangers.

In the case of a briquetting plant being installed at the biogas plant and briquettes being added directly when produced, process heat is also added to the reactors, i.e., the kinetic energy dissipated into the straw is recycled into reactors. The electric power used is recycled as heat into the biogas process.

Also, the straw briquettes do not pass heat exchangers and possible clogging here is avoided.

6 - Straw briquettes are evacuated of air

The compressed straw is emptied for atmospheric air, notably free nitrogen and oxygen, and air is therefore not added to the biogas, when using straw briquettes. This is highly advantageous, when the biogas is upgraded to natural gas quality.

7 - The straw plant may be situated locally at the straw-resource or at the biogas plant.

Local circumstances and conditions will determine if it is advantageous to develop local satellite stations for local collection and processing of straw into briquettes before storing and transportation to one or more biogas plants.

8 - An energy optimal process.

Briquetting uses very little energy and no water for the pre-treatment. The electrical power use of app. 75 kWh per tons straw is mainly reused as heat in the biogas reactor if the processing plant is placed at the biogas plant.

Conventional pre-treatment of straw before a biogas or bioethanol process such as steam explosion at 180-200°C and 30-40 % dry matter is a highly water and energy demanding process, which also impacts the hydraulic capacity of the biogas plant negatively.

9 - A mechanical and robust and stable technology.

Straw inevitably contains gravel, soil or sand, or other impurities. A straw line removes all impurities before the briquetting. The mechanical press is not exposed for this wear and tear and the impurities are not imported into the biogas facility.

The straw line is easy to manage and service and can function fully automatic.

10 - High biogas yields.

Briquetted straw gives rise to high and stable biogas yields.

Straw generally contains 18-19 MJ/kg dry matter primary energy corresponding to app. 500 Nm$^3$ methane per tons straw dry matter.

The straw composition is 60-70 % cellulose and hemicellulose, 15-20 % lignin, other organics (5-10 %) and minerals (app. 5 %). Normally, it is the bulk of cellulose and hemicellulose, which, after briquetting, is digested into biogas, while lignin is largely un-digested.

With briquetting, biogas yields of app. 250 Nm$^3$ methane per tons straw can be achieved increasing to app. 300 Nm$^3$ methane per tons under optimal conditions.

A hydraulic retention time of 30-40 days at thermophilic temperatures are needed to achieve these yields. The highest yields can be achieved with addition of potassium lye during briquetting.

The quantity of straw, which can be added to a manure based biogas plants – the organic loading rate – is equally important. It is clearly demonstrated that 10 % straw briquettes relatively to the liquid manure can be added without any difficulties. See a comparison below:

### Biogas yields using dry straw; increased production

<table>
<thead>
<tr>
<th>Pre-treatment</th>
<th>Methane yield (m3 methane/tons straw)</th>
<th>*Estimated max quantity to be added manure plants (in % of slurry)</th>
<th>Increased yield per tons slurry (in Nm3 methane)</th>
<th>Increased yield per tons slurry (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredded straw</td>
<td>200</td>
<td>1 - 2 %</td>
<td>2 - 4</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Other mechanical processing of straw</td>
<td>225</td>
<td>2 - 6 %</td>
<td>5,5 - 13,5</td>
<td>27,5 - 67,5</td>
</tr>
<tr>
<td>Briquetted straw</td>
<td>250</td>
<td>8 - 12 %</td>
<td>20 - 30</td>
<td>100 - 150</td>
</tr>
<tr>
<td>Briquetted straw with catalyzer</td>
<td>300</td>
<td>10 - 12 %</td>
<td>30 - 36</td>
<td>150 - 180</td>
</tr>
</tbody>
</table>

11 - Straw briquettes contribute to a stabile biogas process.

Several manure based biogas plants, if not most plants, are at the brink of ammonia inhibition. In any case it is virtually impossible to add significant quantities of nitrogen containing wastes such as poultry manure.

Straw briquettes help alleviating ammonia inhibition and stabilize the digestion process. An increased yield of slurry is achieved when co-digested with straw briquettes.

12 - A win win

Mechanical briquetting of straw for biogas purposes is the most tested, documented, and safest technology of using straw for biogas purposes.

We are proud to offer this cost effective solution for industrial utilization of straw for biogas.

In Kinetic BioFuel A/S we are proud of our technology and company, and enjoy our work.

www.kineticbiofuel.com
The straw plant at Aarhus University full scale biogas plant at Foulum. For additional information on running and research data please contact senior scientist Henrik B. Møller.

The tests at the University of Aarhus in Foulum were performed on a briquetting line with a capacity of 800 kg per hour. (see a picture of the line above)

Straw briquetting plants can be installed with a capacity from 500 kg/h and up to 10 tons/h or more. The lines can be fully automatized if required. Below is shown a line with a capacity of approx. 3 tons per hour.
Important requirements for a stationary straw briquetting plant:

- Straw needs to have a moisture level below 15%, above this the productivity will decrease and the briquette quality will be poor. However, loose briquettes are fine biogas raw material.
- The raw material has to be clean with as low ash content as possible. Especially, a high sand level will impair operations, as the wear and tear on parts will be high.
- The right equipment is required to secure high productivity. It is important to have a full line supplier to combine all the shown items of the line.
- Trained operators. In order to secure high uptime it is important that the operators are well trained both with respect to machines and raw material handling.

Plant sizes and operational costs:

- Plant sizes from 0.5 t/h to 10 t/h or more.
- Power consumption for the line approx 100 Kwh per ton produced.
- Spare part costs with clean raw material – EUR 5-7 per ton.
- Labour cost will depend on degree of automatization.

Advantages for stationary briquetting plants:

- High efficiency - 24/7 production.
- Low power consumption.
- Relatively low spare part consumption.
- Low labor costs.
- Optimized use of raw material - the mixer/buffer silo can handle varying moisture levels from 12-18%.
- Stationary plants are best for straw volumes larger than 5,000 tons/year. We are currently working with capacities of the order of 50,000 tons/year.
- Drying can be included.
MOBILE STRAW BRIQUETTING PLANT
– IN CO-OPERATION WITH SVEND AAGE CHRISTIANSEN AS

- Hay-Buster shredding straw bales
- Fliegl trailer as buffer silo
- Trailer with generator and two BP7510 briquetting presses
- Screw conveyor with sand removal
- Container with finished briquettes to be supplied to biogas plant
Important requirements for a mobile briquetting plant:

- Straw needs to have a moisture level below 15%, above this the productivity will decrease and the briquette quality will be poor.
- The raw material has to be clean with as low ash content as possible. Especially, a high sand level will be damaging to operations, as the wear on parts will be high.
- The right equipment is required to secure high productivity.
- Trained operators. In order to secure high uptime it is important that the operators are well trained both with respect to machines and raw material handling.

Plant sizes and operational costs:

- Plant sizes from 1,5 tons – 6 tons/hour.
- The first plant is recently in operation - all operational costs are not yet available.
- Prices for straw briquettes are expected to be at the same level as for a stationary briquetting plant.

Advantages for mobile briquetting plants:

- Mobile – can be moved in one day.
- Low logistical costs.
- The contractor of the mobile plant can achieve optimized straw prices.
- Low logistical costs and an optimized straw price results in a competitive price for straw briquettes.
- Best for straw suppliers with quantities less than 5.000 ton/year.
- No investments in buildings.
- No machine investments when using a machine service.
The model requires that the machinery service provider handles all logistics and agreements.

It is a “win-win” situation:
- The farmer gets cheaper and better bedding
- The biogas plant gets cheaper straw and higher gas yield.
ACKNOWLEDGEMENT

The technology is developed with support from the governmental EUDP R&D programme. The participating parties were Aarhus University, C. F. Nielsen A/S and BioFuel Technology A/S.