Final report

1.1 Project details

Project title	Ultraformaling af halm øger dansk biogasproduktion
Project identification (program abbrev. and file)	EUDP 14 II j.nr. 64014-0523
Name of the programme which has funded the project	EUDP
Project managing company/ institution (name and address)	Euromilling A/S. Højvangsvej 8 4340 Tølløse
Project partners	Lynggarden v. Peder Andersen
CVR (central business register)	17731947
Date for submission	15-12-2014

1.2 Short description of project objective and results

DANSK
Målet med projektet har været at arbejde med halm som biomasse. Halm er en meget tilgængelig samfundsressource, som har et stort potentiale som biomasse, men som for en stor dels vedkommende ikke anvendes. Ved at neddele og senere formale halmen vil vi være i stand til at øge halmens brugsværdi for biogasanlægget. Dels vil halmen opnå en bedre forgasning, og dels vil formalet halm, når den er opblandet i gyllen blive nedbrudt og forgasset langt hurtigere end hele strå. Dermed øges biogasanlæggets kapacitet, og lønsomheden for producenten forbedres drastisk.

Projektets formål har således været at udvikle en teknologi, der sikkert kan håndtere findeling af halm. En operation, der kompliceres af halmens væskeindhold og de relativt lange fibre, halmstråene er bygget op af. Det nye anlæg er færdigudviklet og implementeret som forsøgsanlæg hos samarbejdspartner Lynggaard Biogasanlæg.

ENGLISH
The project objective has been to optimise straw for biogas production. Straw is a plentiful resource with a strong potential for biogas production. Nevertheless, large amounts of straw are never used due to technical difficulties and low production yields. By shredding and subsequently grinding straw, we would be able to increase the straw production value from the producers' point of view. Processed in this way, straw will produce more gas per ton raw material, and the gas production will occur at a faster rate when the ground straw is mixed with slurry — thus improving the capacity of the biogas plant.

The aim has therefore been to develop new technical equipment for pre-grinding and handling straw for biogas production, an operation which is complicated by the water amount in the straw and by the relatively long straw fibres. The new equipment has been developed and implemented for further tests at project partner Lynggaard Biogasanlæg.

1.3 Executive summary

In regard to straw, there is a large untapped resource. Straw can be converted into biogas, and various efforts have been made to find a way to ensure the efficient use of these resources. Although straw is a high-energy resource, and in Denmark a very accessible one, it is still important to find a new and better pre-treatment method. Such a method should take into account both mechanical and operating conditions in the digestion tank that produces the biogas. Previous studies have shown that the way to make better use of stalk lies in shredding, and in this project we have taken that step in full: Our consortium has experimented with various technical approaches to how to optimally use the knowledge of straw as biomass and of the transferability of fine fractionation. Grinding straw to about 1 mm of the powder grain size breaks stalk fibres and cells, which gives direct access to the energy-containing cellulose of the straw. The mixing of slurry can thus be done much more efficiently. From the start we expected to achieve a faster and more efficient stalk 'turnover' – for the benefit of the biogas plant, and consequently of agriculture and of the consuming society seeking better solutions for renewable energy.

It was our initial experience that each material that is to be crushed og ground must be treated differently. That is in terms of preparation, process transportation sifting, milling etc. Differences in materials, fibrous structures, binders, moisture levels, etc. can have a great impact, meaning that the handler must approach the process anew each time, counting straw as well. Powdering a light and relatively soft material such as straw presents a great challenge.

The biogas part of the project was carried out in the biogas plant in Peder Andersen's hog production, where manure and slurry from local hogs are degassed. The degassed slurry mixed with straw has a high fertilising value and can be reused as a resource in crop production. Before this project, there had never been a previous attempt with biogas production from ultra-fractionated straw, but it was our reasoned assumption that we could increase the gas yield from stalk by 10 to 15% and further reduce the cycle of degassing by a third. This assumption was supported in particular by the evaluation of biogas and resources made by the Danish Agriculture & Food Council in 2012.

The project resulted in a fully developed pilot plant installed at Peder Andersen's biogas plant, which means that we are able to display the subsequent deployment in markets that have similar challenges in regard to the use of straw as biomass.

1.4 Project objectives

The main objective of our project was to optimise straw as a biomass product. Through pre-grinding stalk we wanted to reduce the residence time in the digestion tank. A particle size of 0.5–1.5 mm is much easier to convert organically, and we expected to reduce straw residence time by about 30% — and further to increase gas yield by 10 to 15% per ton straw converted, compared to more compact stalk structures.

The project was initiated in January 2015, and designs and requirements specifications were made for the individual plant components. Meetings were held at Lynggaard with civil engineering companies for the purpose of preparing existing buildings for the new plant. This planning phase was completed in the autumn of 2015, and the plant was mounted to perform test runs.

The pilot plant has a pre-treatment section that constitutes the critical part of the process. This is where straw is shredded before reaching the mixer unit where it is mixed with slurry. Subsequently, biogas is produced under usual conditions in the digestion tank, except that the process is more efficient, resulting in an increased total capacity. The primary technical challenges were quickly identified and they did indeed relate to pre-treatment: We had to examine how large a straw water content the installation could handle as an excessive water content results in clogging. The higher the water content technically acceptable, the better the economy of the project, as available straw resources largely do not undergo a drying process. Internally, we have calculated with three operational intervals:

1. Straw with low water content = direct application.
2. Straw with medium water content = limited drying time before application.
3. Straw with high water content = process too expensive compared to yield.

It is interesting to look at how large a water content the plant can handle. It is preferable to grind to a very small powder size, but if the water content is too high, small fractions will clog and obstruct sifting and air transport in the tubes towards the mixing tank. This increases equipment requirements, making the area one of great development potential also in the years to come. Here, the need is to improve the efficiency and design of machine components; and some of the knowledge and experience gained during the project will be very useful in the further process. If grinding at a water content of for instance 50% is done successfully, a very large part of straw accessible will be usable. During the project, we achieved a satisfactory process at a water content of approx. 20%, or equal to the content in straw harvested at the usual harvesting time under usual, dry conditions in Denmark. At the same time, this is a commonly applied standard for when it is no longer allowed to use straw as fuel in straw-fired heat and power plants.

The project plan comprised phases and milestones that have been concluded and reached as anticipated. The actual development and design of a pre-mixer was crucial to the project as it is important to make the straw into a pulp before it reaches the digestion tank. The pre-mixer was developed in the first half of 2016 and mounted in the summer of 2016 together with the other plant prototype. Subsequently, the first tests were run on a fully mounted and complete pilot plant, and those tests first identified a number of challenges in handling the powder. The final result will be a fully automatic plant where straw can be fed to the plant where it is shredded and then ground. Contaminants must be removed from the straw, after which the powder is blown towards the pre-mixer where slurry is added.

We encountered mechanical challenges, the major ones being a secure and stable blowing process and further transportation between the grinder and the pre-mixer.

We had to realise that the blowing capacity originally foreseen to handle the job probably was not adequate, and the subsequent optimisation tests still did not provide a fully satisfactory result. Too small an amount of straw got through the process — especially if the straw was not very dry. It is a complex blow-technical process during which the powder resulting from the grinding passes through a sieve before rapidly being blown from the process in order to make room for new straw. We experienced that if the straw starts "clogging", it has a cumulative effect that is difficult to correct.

On a test basis, the project prototype plant has shown that it is possible to grind straw and that there is thus an unused potential for biogas production. This is to the advantage not only of biogas plants, but also of the farmers whose straw may consequently increase in value. The grinding process breaks down the lignin in the straw cells, which gives free access to the energy-rich straw cellulose. The breaking down of the lignin binding thus increases the efficiency of the process where energy is released far more quickly than when whole straws are fed.

The individual plant processes:

1. Conveyor
2. Straw-shredder
3. Cyclone with outflow gate
4. Hammer mill for fine-grinding
5. Ventilator with ongoing exhaustion through sieve
6. Self-cleaning nozzle filtres
7. Pre-mixer
8. Connection and feeding to digestion tank
9. Control panel

During our tests, we have surveyed the below parameters:

- Energy consumed for working up biomass
- Decomposition time and gas yield
- Fertilising value of digestate
- Mixture ratio straw/slurry and impact on the other parameters.

At the end of the project, there are promising results regarding decomposition time and gas yield. The decomposition time is considerably quicker, and the gas yield has therefore increased. At present it is too early to conclude whether we will achieve an increased production per ton straw produced, as this would require a long-term production at a larger scale than possible hitherto. In order for the prototype plant to be scaled up to a large-scale operation, adjustments are needed, especially in respect of blowing, as stated above. These adjustments will have an impact on energy consumption, on which we therefore cannot draw any conclusions. The work is continued in this area after the formal termination of the project, and we expect to see positive results.

1.5 Project results and dissemination of results

Using straw for biogas production has a socially attractive perspective because today, we use virgin crops — that might have been used for foods — for biogas production. Farm crops can be produced as energy crops, but in a future where foods may be in short supply, it will be a better solution to let farmers produce foods and animal feed — and use residues such as straw for energy production.

The straw applied in the plant is from Peder Andersen's own fields and from other nearby farms. We are able now to process about 1,000 tons per year and expect to be able to increase the amount to 3000 tons per year when we have finished adjusting the various mechanical parts. At present, we are able to operate with a particle size of 1.5–2 mm using ground straw. Our ambition is to be able to reduce the size to maybe as little as 1 mm, but already now we find the output satisfactory. Also, the main priority for a plant in operation must be that there are no interruptions, and we are very satisfied in this respect.

As far as gas production is concerned, we have measured an obvious advantage of applying fine-ground straw. With slurry alone, production is about 20 m3 gas per ton, whereas the use of fine-ground straw yields close to 450 m3 gas per ton. The higher the dry matter content (straw) fed to the digestion tank by the biogas producer, the better the result.

Overall, the project has meant a big step forward regarding the feasibility of producing biogas from fine-ground straw, and we have documented its potential very well — technically as well as in terms of yield.

In the course of late summer/autumn of 2016, the pilot plant was installed and prepared for the first tests that have since been performed under the project for the past six months. Adjustments of the plant have been made on an ongoing basis and are still being made after the end of the project, as mentioned above. Furthermore, we have organised some events where we have demonstrated the new plant:

On 10 June 2016, an article written by Maria Berg Badstue Pedersen was published in the magazine Energy Supply. The title of the article was "Fintsnittet halm opgraderer biogasanlæg" *(Fine-ground straw upgrades biogas plant)*, and it can be found at Energy Supply's website.

On 6 August 2016, there was an open house event at the biogas plant where we invited guests to come and see the plant and hear about the perspectives of using straw for biogas production. The event was advertised in the newspaper Sjællandske, and the text below is an excerpt of the advertisement (translated from Danish):

"Partly subsidised by Energiteknologisk Udviklings- og Demonstrationsprogram (EUDP) (Danish Energy-Technological Development and Demonstration Programme)*, Peder Andersen, Lynggaard and EUROmilling A/S have together developed a complete plant that handles straw and fine-grinds it into straw powder for feeding into biogas plants. During the fine-grinding process, the bacteria found in the biogasification process can convert cellulose into methane in a shorter period of time. The technology differs from previous technological development in the area in that straw is fine-ground, and biomass is mixed with slurry before feeding into the digestion tank. Our technology will contribute to the strengthening of the biogas industry, and to efficiently utilise available straw resources."*

Another event was held at Bioøkonomisk Vækstcenter Guldborgsund *(Bio-Economic Growth Centre Guldborgsund)* where managing director Rasmus Jørgensen made a presentation for invited professionals and people interested in biogas, focusing on:

- Presentation of EUROmilling and Lynggården
- Presentation of project
- Description of process
  - Photos and designs
- Presentation of product and gas production
- Presentation of installed pilot plants
- Challenges during test period
- Questions from audience

More demonstration events will of course be held after the end of the project, but in the present phase, we have focused our efforts on finalising the adjustments of the technical part, with a view to achieving our goals for the gas production in terms of capacity. This is crucial to the future commercial success of the project.

1.6 Utilisation of project results

The market segments for our process plant for shredding and grinding of straw are owners of slurry-based biogas plants in Denmark and in the international markets. By investing in our pre-treatment technology, biogas producers will in future gain an added value from not being limited by the lack of accessibility within traditional biomass products, including crops that could be used for the production of foods. They will be able to utilise straw as a very accessible and inexpensive waste resource that even has a very great gas potential — a potential that can now be utilised far better than before. Moreover, it can be done cost-effectively because biogas producers will benefit from a reduced residence time of the straw in the digestion tank. From a social point of view, our treatment technology will contribute to making investments in slurry-based biogas plants more attractive.

When we take a look at the operating economy of our pre-treatment technology, farmers who are often co-owners of small biogas plants will be able to generate earnings from the biomass that today hardly yields any profit. Freely accessible straw will for instance eliminate the need to purchase corn silage and organic waste, on which biogas production relies today. Moreover, the prices of those products may be expected to increase concurrently with a reduced waste accessibility as well as an increased competition for the utilisation of energy crops for a purpose such as first-generation biofuels. And add to this the said ethical dilemma of cultivating energy crops on agricultural areas that might be exploited for food production in a world where food shortage gives rise to considerable growth in food exports.

The technical development of the project will be finished by EUROmilling who will also be in charge of its commercial distribution. EUROmilling currently operates in a number of markets promoting various grinding technologies. Focusing also on the rapidly advancing biogas sector is obvious to the company when planning its future product portfolio. Biogas is very much about solving waste problems, whether it's about slurry, sludge, or something entirely different. The best biogas production is obtained by using organic substances in a form that optimises transformation, and the grinding technology is clearly a technical improvement in that respect.

Competition in the Danish biogas market is limited, but in the export markets it is growing as you move further away from Denmark. However, the knowledge and expertise we have in Denmark and, in our case, especially at EUROmilling, is crucial to the creation of a well-run process. Fine-grinding of straw has not been tested elsewhere in the world for the purpose of biogas production, and the technology differs greatly from grinding of for instance grain into flower, or wood pellets into fuel powder. Straws have long fibres that protect the cellulosic straw cells from breaking, so these fibres complicate the process. We therefore expect to be able to operate commercially for a number of years without much competition. At the same time, though, the market for biogas production and straw-grinding is so big that there is room for several players, who will be able to establish individually interesting business foundations.

Implementing the project broadly in the market will mean a great contribution to improving economy — not only for farmers whose straw will now be an actual asset for them, but also for biogas plants that can be run much more profitably. We have taken the development within biogas production into a new direction with focus on pre-treatment that can be extended to forms of grinding of organic materials other than straw. In markets with relatively large amounts of other types of organic waste (with a reasonably low water content), the grinding process can be adapted to such types, repeating the success. The process requires homogeneous biomasses in available quantities that are large enough to justify investments in new plants individually targeted for specific sources of organic waste, and it also requires that the biogas production as such is profitable. Add to this that the waste situation differs from country to country. The more expensive it is to produce waste (and energy), the better are the economic conditions for working with biogas and fine-grinding.

The results we have achieved in the project are paramount to the subsequent success of the plant in the market. This is due partly to the novelty value of the plant, partly to the novelty value of the actual development of methods for efficient pre-treatment of straw for biogas production. The validity of the documentation that we will obtain in the future will contribute to convincing prospective customers of the plant potential and operating economy, and thus to spurring interest in investing in it. — The biogas plant at Peder Andersen's farm will also be part of future commercial activities in relation to our marketing of the plant as the pilot plant is of great demonstration value.

Since 2005, Denmark has had the policy aim of 50% of all manure being exploited for energy production. Our project contributes to achieving this aim by increasing the profitability of slurry used as biomass. Straw needs slurry for it to be treated in the digestion tank and thus produce gas, and the yield of the total mix of slurry/straw is considerably larger than that of slurry alone. Important nutrients such as phosphorus found in slurry are returned to field crops together with degassed biomass, with limited obnoxious smells only.

1.7 Project conclusion and perspective

Agricultural and industrial waste and residue will become important energy and raw material sources in future. Our project has proven relevant to future energy production. As a society, we need to prioritise the study of new exploitation methods, and straw is a very accessible resource. The alternative — ploughing down straw in fields — does provide fields with nutrients, but the gas vanishes without being exploited. When straw is processed in a biogas plant, exploitation is improved, and straw nutrients are returned to the field afterwards. Straw being accessible locally reduces handling and transportation, which may make the method relevant to small, local biogas plants in particular.

The project has had no other focal points than straw. However, we see a far-reaching perspective of working with grinding of organic materials for biogas production. Other agricultural residue, industrial residue, domestic waste, manure and sludge are energy-rich resources when transformed into biogas, and in Denmark alone, achieving the aim in relation to renewable energy is absolutely realistic. It will take further development of new production methods, but in our opinion, fine-grinding is an obvious contribution in that respect.

Every raw material has its own cell/fibre profile, so the approaches to the treatment process vary. Nevertheless, we do not find it vitally important that the development within this area favours our project in terms of succeeding in obtaining a particle size for straw powder of less than 1 mm. This is an objective because decomposition and gasification will occur at a faster rate, but in the project, we did achieve a satisfactory test production with a particle size of 1.5–2 mm. Achieving that size has increased gas production per hour and per weight unit, and we see a similar improvement when using other raw materials — also at reduced levels of ambition. In time, the development within the area will make us fully succeed, but already today, our production equipment is competitive.