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Breakthrough in ethanol research

New research from the Danish Royal Veterinary and Agricultural University (KVL) and energy company Elsam puts Denmark at the forefront of the development of technologies to convert straw and other cellulosic biomasses into ethanol. If the results receive political support, the first straw fuel plant could be ready in three to five years.

By Torben Skøtt

Driving to Paris and back on a bale of straw is no longer a pipe dream. It is a completely realistic scenario, if the latest research results within the field of ethanol production based on cellulosic biomasses receive political support.

Scientists at KVL and Elsam have reached a milestone in their efforts to convert straw and other residual products into ethanol. The basic process has been known for years, but now it has been improved, allowing commercial production.

"A few years ago, we said: 'This technology may be ready in ten years.' Today, it is a fact that we have this technology. Now, all we need to do is build a big plant. Certain processes can be tested in the laboratory, but unfortunately, we cannot develop a plant there. In one year, we have progressed five or ten years. We have been lucky, but that is allowed once in a while," says KVL Professor Claus Felby. Together with engineer Jan Larsen of Elsam Engineering, Professor Felby has contributed to making the breakthrough that has now resulted in a universal patent for the process.

Known technology

The traditional technology for converting biomasses into ethanol using yeast cells has been known for centuries. In Brazil, the US and Sweden, there are numerous plants producing ethanol from glucosic raw materials such as sugar cane, grain and corn.

The problem with this process, however, is that large areas have to be reserved for producing the raw materials. In the EU, where large agricultural areas have been set aside, this may not be a major problem in the short term, but if ethanol is to replace petrol and diesel on a global scale, it is necessary to develop a technology for using residual agricultural products like straw and manure.

In Denmark, Elsam has headed an ambitious ethanol project for years with a preliminary budget of DKK 100 million. The aim of this project, entitled IBUS (Integrated Biomass Utilization System), is to develop a commercially viable technology for converting straw and other cellulosic biomasses into ethanol. In addition to ethanol, the process can be used to produce feed, and the residual product will be a better fuel than straw, which has often caused boiler corrosion problems at power plants.

From glucose to cellulose

Traditionally, ethanol is produced by converting glucose from sugar cane or grain into ethanol using yeast cells. Using e.g. straw instead of raw materials containing sugar requires technology for degrading cellulose into glucose. This is a difficult process, as straw contains hemicellulose and lignin, which are bound to cellulose in a complicated network.

In the process developed in connection with the IBUS project, the straw is first rinsed, then boiled at a temperature of up to 230°C. The wet fibre fraction is then treated with enzymes, degrading the cellulose into glucose, which can then be fermented into ethanol.

Scientists have long been aware that the use of enzymes is an important ingredient in the efforts to implement this process successfully. Consequently, Novozymes, among others, has put considerable effort into developing new and effective enzymes. This is one of the results of four years of research

photo: torben skøtt/biopress

The IBUS project test plant for producing ethanol, feed and fuel. The test plant is located at Fynsværket, a power plant on Funen, in order to utilise excess heat from the power plant.

funded by the US, during which the costs of the central enzyme process have been reduced by an impressive 90%. Great advances in the field of enzymes prompted Executive Vice President of Novozymes Peder Holk Nielsen to declare that the cost of enzymes no longer constitutes a barrier to producing straw-based ethanol.

Universal patent

There have been no major technical problems in making the IBUS process work. The greatest challenge has been to optimise the individual sub-processes, allowing the system to compete with traditional means of ethanol production.

photo: torben skøtt/biopress

EU Minister of Agriculture Mariann Fischer Boel at the opening ceremony for the IBUS project test plant at Fynsværket.

Recently, KVL Professor Claus Felby and Elsam engineer Jan Larsen announced that they have applied for a universal patent for a process which can result in a considerable reduction of the cost of converting straw into ethanol.

"We have discovered a new and very simple method of mixing the biomass with enzymes, which requires less water than existing methods. This also entails lower energy consumption when distilling the alcohol afterwards, allowing far larger amounts of biomass to be processed in the plant. The process creates more ethanol, and consequently has greater environmental effect, as greater amounts of carbon dioxide can be displaced," explains Professor Felby.

"If the project receives political support, we can establish a plant capable of producing straw-based ethanol and fully competitive with traditional ethanol production in three to five years."

"At the moment, we can produce one litre of ethanol for about DKK 4.3. The market price for glucose-based ethanol is DKK 3.3, which we are confident we will match. We know where to focus our efforts and how to produce the ethanol. All we need is a larger plant."

Outlook

Today, the process of using straw to produce ethanol is thus virtually competitive with traditional means, but according to Professor Felby, the financial aspect is not the only exciting feature of the IBUS project.

"Our outlook is to be able to reduce our dependency on fossil fuels by producing fuels and feed from many different types of biomass instead, including residual products from households and agriculture," explains Professor Felby.

One of the arguments against bio fuels is that they require far too much land, but according to Professor Felby, that argument is no longer valid:

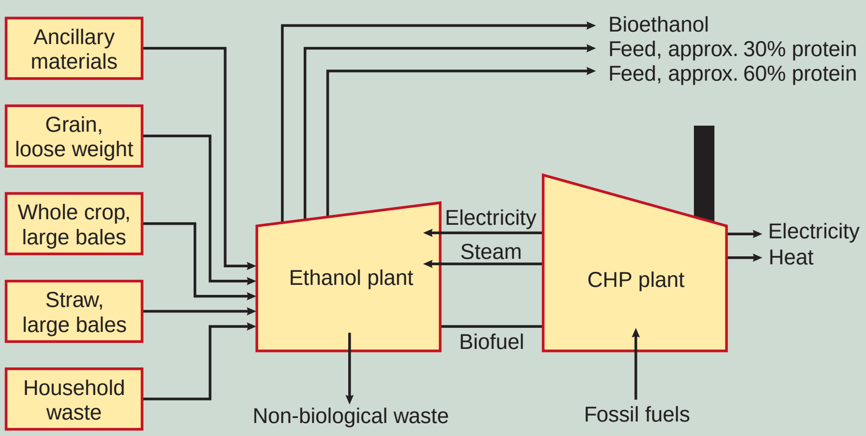
"The IBUS process makes it possible to produce ethanol, feed and fuel for power plants simultaneously. The field previously used only for growing feed is now used for growing crops that can be used for both energy and feed. That is a definite advantage in terms of energy and the environment," says Professor Felby, who does not conceal his strong doubts about the figures used by the government for estimating the pros and cons of using bio fuels in Denmark.

photo: torben skøtt/biopress

The fibre fraction from the ethanol plant can be used as fuel at the power plants.

At Elsam, head of research Charles Nielsen is vexed by the lack of political support.

"Internationally, we are clearly ahead in producing ethanol based on residual products. We have the research environment and the industry to handle these tasks, but it is a difficult situation because we cannot establish a base of production in Denmark. That gives us a bad image, and it is unfortunate for Denmark that the politicians do not think more long-term," says Mr. Nielsen.



The principle of the IBUS plant, which will be integrated with a CHP plant. Thus, excess heat from the CHP plant can be used in the ethanol plant, and conversely, the fibre fraction from the ethanol production can be used as fuel at the CHP plant.

Alcohol for your moped

Pollution from moped exhausts can be halved by adding 10% ethanol to the petrol.

While car engine pollution has been reduced significantly in recent years, this does not apply to small two-stroke moped engines. According to the Danish Environmental Assessment Institute, the environmental and socio-economic costs of mopeds amount to DKK 1.3 billion a year, one-fifth of which is due to health impairment caused by moped pollution.

However, research conducted by the Technical University of Denmark shows that adding 10% ethanol to the petrol will reduce pollution significantly. This reduces the emission of both carbon monoxide and carbon hydride, and virtually halves particle emissions.

"Research from India inspired us to conduct tests involving the addition of ethanol to moped petrol," explains Professor Jesper Schramm from the Technical University of Denmark. He emphasizes that the method only applies to two-stroke engines, and that the same effect cannot be expected in a regular car engine.

"At the moment, we are testing whether the strong effect of adding ethanol is due to the lack of oxygen in moped petrol. If the petrol contains oxygen, no particles are formed, which is why very few particles are formed in regular four-stroke engines," Professor Schramm explains.

The results from the Technical University of Denmark are not only relevant to the 160,000 mopeds in Denmark. Two-stroke engines are also used in boats as well as many gardening tools. *TS*

The handling of domestic animal manure as solid manure and black liquid may be approaching a renaissance. In the US, systems capable of separating solid manure from black liquid within the livestock building itself are being developed. This leads to a reduction of odour nuisances, a halving of ammonium emissions and the possibility of increased use of solid manure in gasification plants, which produce far more energy than biogas plants.

photo: torben skøtt/biopress

Solid manure yields more energy

Odourless pig breeding, effective use of manure and the production of liquid fuel are no illusion. At least not in the US. Over there, scientists are far advanced in developing new livestock building systems and thermic gasification plants, which make it possible to obtain far more energy from domestic animal manure than by biogas plant processing.

By Peter Kai, Henrik B. Møller and Theo van Kempen

At North Carolina State University, scientists are far advanced in developing a complete system for processing domestic animal manure, resulting in fewer odour nuisances, less ammonium evaporation and effective use of manure energy contents. The system, dubbed RE-Cycle, is based on the separation of solid manure from black liquid in livestock buildings, thermic gasification and subsequent conversion of gas into ethanol or biodiesel.

In Denmark, the main focus has been on biological gasification in biogas plants, but thermic gasification seems to be more effective for obtaining the largest possible amount of energy from domestic animal manure. This is the result of the American university's research on a special form of thermic gasification called steam reforming gasification.

The techniques involves heating the dry matter from the manure with 800°C hot steam in an oxygen-free environment. This converts the manure into combustible gas consisting mainly of hydrogen (H_2), carbon monoxide (CO), methane (CH_4) and carbon dioxide (CO_2). The addition of superheated steam helps to increase the temperature, but also encourages the production of especially hydrogen and, to a lesser extent, carbon dioxide.

The results from North Carolina State University show that the gas contains approx. 30% of the total nitrogen emission by a pig for slaughtering. The ash consists mainly of minerals, including nearly 90% of the amount of phosphor originally contained in the manure.

70% more electricity

The gas can be purified of ash, ammonium and hydrogen sulphide for use in a motor/generator plant producing electricity and heat. Alternatively, the gas can be used in a gas turbine, which can produce an electricity efficiency level of approx. 40%. Thus, about 100 kWh of electricity and 125 kWh of heat can be produced from the dry matter found in one cubic metre of liquid manure containing 5% dry matter. However, approx. 40% of the heat is used internally at the plant for process heating.

By way of comparison, a biogas plant is capable of converting one cubic metre of liquid manure containing 5% dry matter to 60 kWh of electricity and about 90 kWh of heat. Theoretically, the production of electricity can thus be increased by nearly 70% by employing thermic gasification instead of biological gasification in a biogas plant.

Note, however, that gas turbines are sensitive to particles and alkali salts, thus requiring a highly effective gas purification system. In addition, a 50% content of dry matter in the manure is required, making this technique highly suitable for livestock building systems where the solid manure is separated from the black liquid. If the dry matter content is below 50%, the energy advantage is proportionately smaller. If liquid manure is used and separated afterwards, the difference between thermic and biological gasification will probably be insignificant.

Solid manure

In Denmark, nearly 80% of all manure is handled as liquid manure. In the US, however, livestock building systems capable of separating manure and black liquid are being developed. These reduce odour nuisances and in many cases halve the emission of ammonium.

The plants for separating manure in livestock buildings consist of a manure belt placed under the slatted floor. The belt tilts slightly, allowing urine to run off and dry excrements to be collected as solid manure. The system is capable of producing solid manure with a dry matter content of 50% - considerably higher than the 35% obtained from treating liquid pig manure in a decanter centrifuge.

Tests conducted at North Carolina State University have shown that the best results are obtained by mucking out once a day, preferably early in the morning. More frequent mucking out results in the manure not drying properly. On the other hand, too infrequent mucking out leaves so much manure on the belt that pools of urine form, leading to increased ammonium evaporation and odour nuisance as well as less dry matter in the manure. Emptying the belt early in the morning may further increase the dry matter contents, as some of the manure liquid evaporates over night, when less urine is also produced.

Liquid fuels

Instead of using the gas for producing electricity and heat, some of it can be converted into ethanol or biodiesel through a so-called catalytic process. These processes are more demanding technically and financially, but produce liquid fuels which can be stored and used in the transport sector. It is estimated that

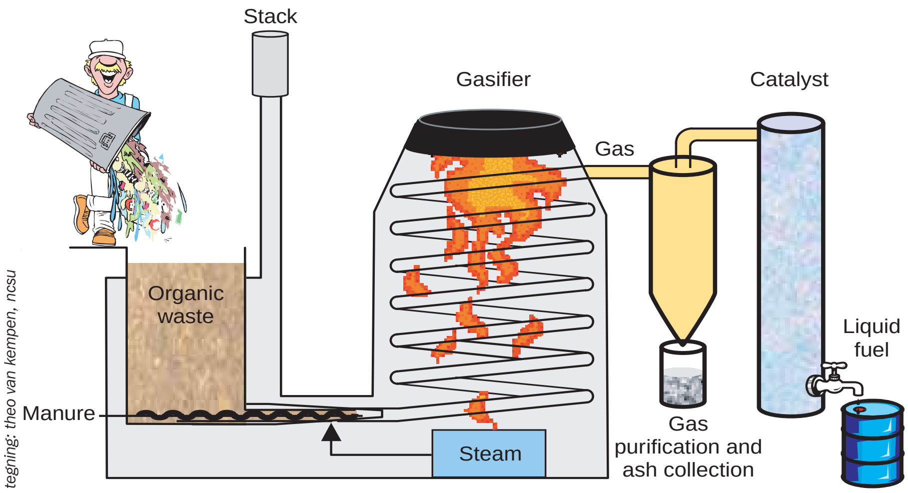


Figure 1: Diagram showing the process of gasification of domestic animal manure. Manure and any domestic waste are led into the gasifier via an infeed screw while adding superheated steam. In the gasifier, the manure is converted into combustible gas consisting mainly of hydrogen (H_2), carbon monoxide (CO), methane (CH_4) and carbon dioxide (CO_2). Subsequently, the gas can be converted into ethanol or biodiesel in a high-pressure, high-temperature catalyst. Alternatively, the gas can be led to a gas turbine and used for producing electricity and heat.

a ton of manure dry matter can be converted into 300-340 litres of ethanol. The remaining gas still contains energy, which can be used partly internally at the plant, partly externally for district heating.

Ethanol can replace fossil fuels, e.g. petrol and the groundwater-contaminating MTBE, which is used as a petrol additive in several foreign countries. The outlook is that a farm supplying 7,560 pigs for slaughtering can produce 72,000 litres of ethanol a year. This can replace 48,000 litres of petrol and reduce CO_2 emissions by 110 tons.

Pros of the RE-Cycle system

- Ammonium emissions are halved.
- Nitrogen emissions from storage and deliveries are virtually eliminated.
- Nitrogen losses during deliveries are reduced to 5-10% against approx. 30% from deliveries of raw liquid manure.
- Odour nuisances from livestock buildings are decreased.
- Odours from storage and deliveries are eliminated.
- The production of electricity or liquid fuel as well as district heating can replace an equal amount of energy from fossil fuels.

Large plants

One of the main issues is of course the cost of thermic gasification compared to biological gasification at biogas plants. So far, only laboratory tests of the system's components are being conducted. A demonstration plant has not yet been built in the US, which of course makes it difficult to produce accurate estimates of the cost of a complete plant.

American scientists estimate that a full-scale plant must have a daily capacity of at least 250 tons of manure. This corresponds to an annual production of 650,000 pigs for slaughtering, which should be located near the plant to minimise transport costs. In other words, a considerable livestock production within a limited area must be available, but finding such a location in Denmark is by no means unrealistic. Possibilities include the Mors or Als regions in East and South Jutland, respectively. Pig manure ▶

can be supplemented with other biomasses, e.g. domestic waste or poultry manure from chicken farms.

According to the project team, the financial implications of the system in American conditions range from a balance of income and costs to an annual profit of DKK 50 per pig.

These calculations do not include the reduced costs of storing and delivering manure and land purchases. Actual savings depend on factors such as the existing storage capacity of the property and the area available for livestock production.

The calculations are based on American conditions, which differ from Danish ones in a number of ways. An estimate based on Danish conditions shows that a balance of income and costs is achievable at an ethanol price of DKK 2 per litre, or an electricity price of DKK 0.3 per kWh. This estimate includes free collection of biomass from the farms.

By way of comparison, producing a litre of petrol costs DKK 3. Adding a maximum of 7% ethanol to the petrol results in a 1:1 replacement ratio, i.e. a saving of approx. DKK 1 per litre.

However, the savings from CHP plants are even greater. Gasification plants are considered new technology; therefore, the current production cost is estimated at DKK 0.6 per kWh for a ten-year period. In addition, the calculations do not include the sale of district heating, which could improve the figures considerably. A combined gasification and CHP plant for producing electricity and heat therefore appears to be of great interest in Danish conditions.

Theo van Kempen is a scientist at North Carolina State University. Peter Kai and Henrik B. Møller are both scientists at the Danish Institute of Agricultural Sciences, and in this connection participate in Knowledge Centre of Manure and Biomass Treatment Technology (see www.manure.dk).

Combustion or gasification?

photo: jørgen schytte

The combustion of dry matter from biogas plants can lead to great advantages for the agricultural sector as well as the environment, but burning manure in power plant boilers is far from unproblematic. Technically, a gasification plant is better suited for the task, and it also further utilises the nutrients.

By Peder Stoholm

The main problem with the combustion of domestic animal manure is that the dry matter of the manure has a high content of ash-forming substances, primarily phosphor and alkali salts, which may leave considerable sediments. Firing the manure directly in a modern electricity- producing boiler entails a significant risk of corroding the superheater pipes, due to chlorine-containing sediments. Any catalysts may be deactivated within a relatively short time. Finally, direct firing in a coal-fired boiler results in a loss of the valuable nutrients as a result of the mix with coal ash. It is also doubtful whether the mixed ash can be sold to the cement industry.

For years, Danish Fluid Bed Technology and partners have worked on developing a gasification plant with the rather unidiomatic name of Low-Temperature Circulating Fluid Bed gasifier - commonly known as the LT-CFB gasifier.

At first, it may seem laborious to convert domestic animal manure into gas and then burn it in a boiler, instead of firing it directly in the boiler. There are several reasons for this, however: Firstly, you avoid problems with slagging, corrosion and ruined environment plants, which cost power plants a lot of money every year. Secondly, you can burn a range of difficult fuels. Finally, the gasifier is capable of recycling the nutrients of the biomass.

The gasification plant has proven effective for fuels that leave large amounts of low-melting ash, including corrosive substances. Therefore, processing temperatures are both exceptionally low and highly controlled, and there are no metal heating surfaces. Finally, the gasifier has a very low output temperature, making it easy to separate the nutrients along with the ash.

Outlook

The outlook in connection with utilising domestic animal manure is considerable:

- Utilisation of the calorific value of the dry matter for CO2-neutral energy production at both existing and new boiler plants.
- Production of sterile and odourless ash for fermentation purposes and distribution in nutrient-deficient areas. Alternatively, the ash can be used as a raw material for the production of artificial manure.
- Simultaneous or periodical firing of other forms of biofuels, allowing the establishment of large plants without significant transport costs.
- Excellent opportunities for exporting Danish technology and know-how for solving agricultural, environmental and energy problems, which in many foreign countries are worse than in Denmark.

Large plants

Some of the points mentioned rest on the assumption that the gasifier can be produced in sizes providing an input effect of up to 100 MW. This corresponds to firing almost 200,000 tons of manure dry matter a year. This assumption is based not only on the fact that the gasifier uses the fluid bed technology, which exists in even larger formats in other plants, but also on the upgrading of a 50 kW test plant to a 500 kW pilot plant. The next plant is expected to be a 5-10 MW plant, which corresponds to the amount of dry matter available in Måbjerg near Holstebro, where the world's largest biogas plant is to be built.

If the plants are made even larger, mainly to make them of greater interest to power plants, it will be easier to establish biogas plants in the surrounding area, as they will be able to sell their fibre fraction to the gasification plant.

Tests

The new 500 kW plant has undergone two tests at the Technical University of Denmark in May and September last year, using both raw and biologically degassed dry matter from liquid manure. In both cases, the tests were conducted largely as planned, and with a very high operational reliability. The tests, lasting 40 and 60 hours respectively, were carried out with a satisfactory 90% efficiency. The nominal effect of the plant was even exceeded by approx. 50 and 100 kW, respectively, despite an ash content of up to 28 and 44%.

Analyses of the ash content have shown that meeting the criteria for spreading ash for fertilisation purposes will not be a problem. For instance, the PAH content is only about one-third of the 3 mg/kg limit value.

photo: jørgen schytte

The 500 kW gasification plant at the Technical University of Denmark.

Danish Fluid Bed Technologi

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In preparation for the tests using domestic animal manure, the new plant was tested using a highly difficult straw type from Kolindsund containing 12% ash. In addition, until spring of 2004, tests of the gasification of wood, straw, dry matter from raw liquid pig manure and dried chicken manure were conducted at the small 50 kW plant.

However, biologically degraded dry matter from liquid manure has been the greatest challenge so far. So when the test was completed on Friday 9 September at 12.30 am, spirits were so high that a bottle of champagne was included in addition to the 12 tons of used dry manure from Peder Andersen's biogas plant at Præstø.

The future

After these successful tests, we are now preparing for an upcoming demonstration of a 5-10 MW gasification plant. So far, we have not been able to secure financial support from the various schemes under the Action Plan for the Aquatic Environment III. Furthermore, Danish Fluid Bed Technology, as a private developing company with no commercial activities, is unable to finance further efforts in any significant way. Other potential investors are reticent, because the future rules on combustion and domestic animal gasification remain unclarified. If the development of gasification technology utilising domestic animal manure is to continue, it is therefore imperative that representatives from the agricultural sector also support the continuation of the results achieved so far.

Peder Stoholm is Managing Director of Danish Fluid Bed Technology. The work on developing the gasification technology is funded by the PSO agreement of Energinet.dk. In addition to Danish Fluid Bed Technology, the Technical University of Denmark, Force Technology, Rica-Tec Engineering and Elsam Engineering have contributed to the development work.

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Biogas and ethanol

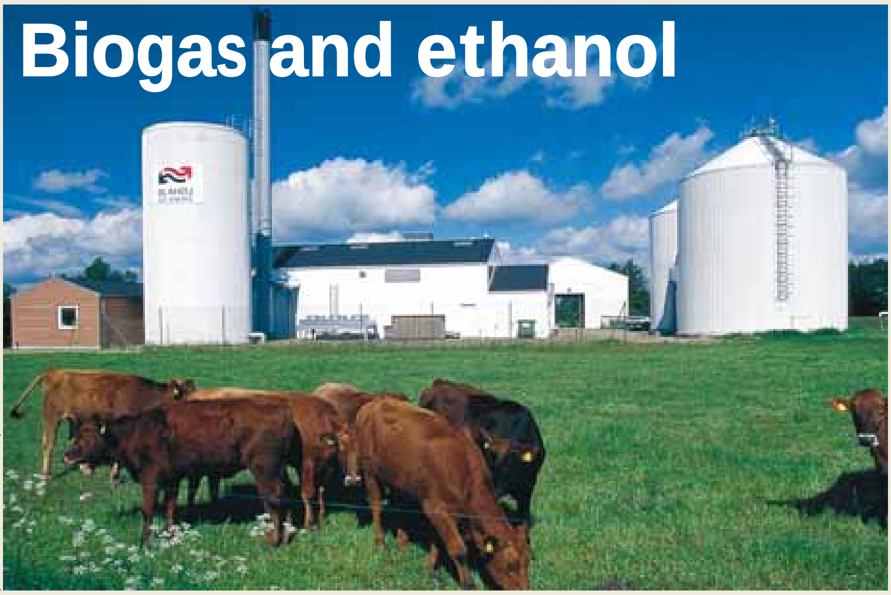

photo: torben skøtt/biopress

Danish research in the field of ethanol production focuses on the utilisation of agricultural residual products as primary raw materials. Prices of raw materials are crucial to Denmark's ability to compete with foreign-country ethanol productions. Developing a technique capable of converting different waste products into liquid fuels is therefore the main aim.

"If we were to produce ethanol in Denmark using traditional methods, we would be outsold by Brazil in a flash. There is no future in that," says Professor Birgitte Ahring, head of a major ethanol project at the Technical University of Denmark.

Like the IBUS project team, Professor Ahring is working on integrating the individual processes, minimising energy consumption and utilising all residual products. But whereas the IBUS project team has chosen to integrate the ethanol plant with a power plant, Professor Ahring wants to combine the ethanol plant with a biogas plant. All steps of the complicated process are being tested individually, and a pilot plant is being established for inauguration in spring 2006.

"Using a full-scale plant, and with a straw price of DKK 550 per ton, we have calculated that we can produce one litre of ethanol for DKK 2.35 - nearly DKK 1 cheaper than the current price of petrol," explains Professor Ahring.

"The important thing is that we get an opportunity to test this technology in practice. If we are able to establish a demonstration plant after having tested our pilot plant, we are probably four years from our goal."

Birgitte Ahring rejects the government's claim that investing in other forms of bioenergy is better for the environment.

"Their calculations are based on traditional means of producing ethanol, where the estimated cost of displacing a ton of CO_2 is DKK 700-1,100. However, if residual products are used as raw materials, the costs are reduced significantly. We do not know the exact figure yet, but it will probably be between DKK 0 and 200 per ton of CO_2," says Professor Ahring. *TS*

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