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MAKING ETHANOL WORK
FOR THE WORLD

Demonstration of cellulosic bioethanol production at Kalundborg

SEVENTH FRAMEWORK PROGRAMME

Supported by the European Seventh Framework Programme

Inbicon

DONG energy

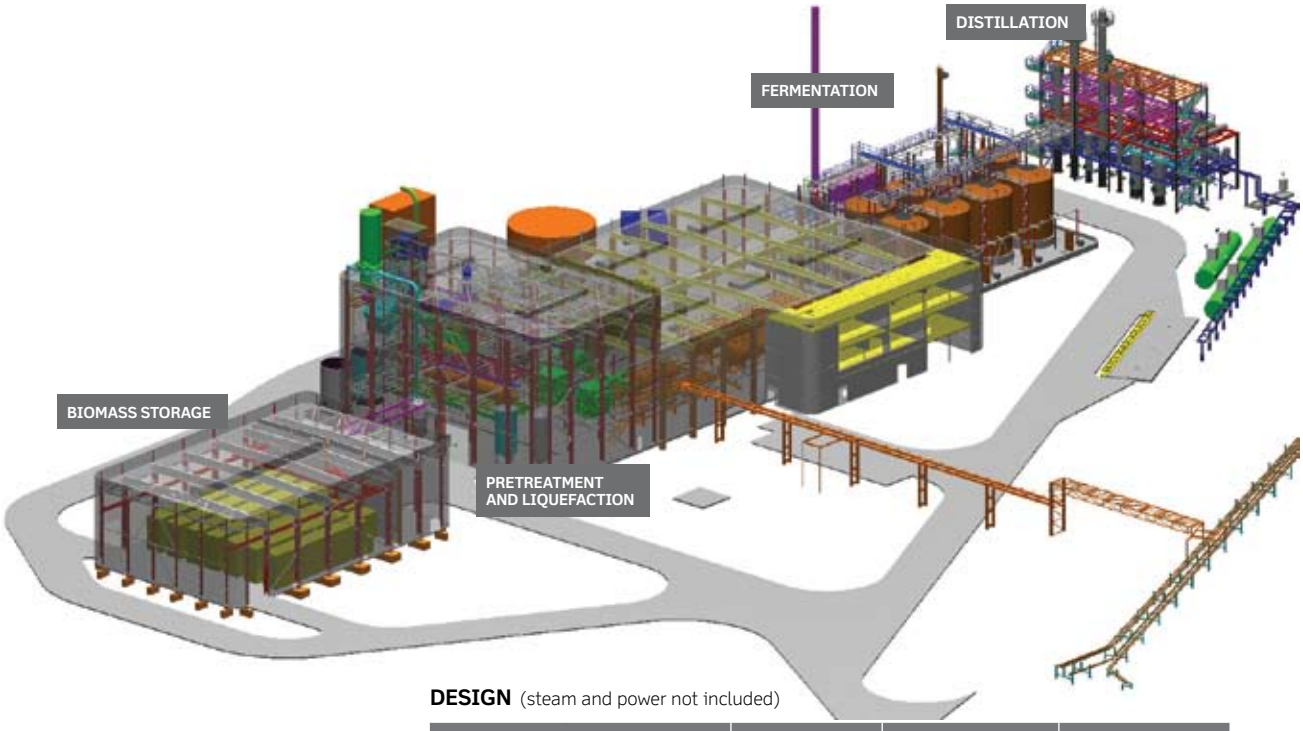
BRINGING CELLULOSIC ETHANOL PRODUCTION TO INDUSTRIAL SCALE AT KALUNDBORG

More than 10 years of development has brought about a robust process capable of producing substantial quantities of ethanol from cellulosic biomass like straw and other residues.

The Inbicon technology applied in Kalundborg has been developed in steps bringing it to the scale today where a 4 t/hr biomass-to-ethanol plant is now demonstrated in Kalundborg.

The plant will produce 5.4 million litres of ethanol annually. It is situated next to DONG Energy's power plant Asnæsværket at Kalundborg Harbour.

DONG Energy has invested significantly in developing the process with support from the Danish Government and the European Framework Programme. Construction of the industrial scale plant has been supported by the Danish Government's EUDP Programme and demonstration is now supported by the European Seventh Framework Programme through the KACELLE project.



DESIGN (steam and power not included)

Demonstration Plant, 4t / hr of straw		Tonnes / year	Tonnes DM / year	GJ / year
Input	Straw	30,000	25,000	432,000
Output	Ethanol	4,300	4,200	114,800
	Lignin pellets	13,000	11,700	* 215,000
	C5 Molasses	11,100	7,210	85,500

** Equivalent to 8,600 tonnes of coal*

EU SUPPORT FOR DEMONSTRATING AND OPTIMIZING INDUSTRIAL SCALE

In November 2009 six partners signed the Kalundborg Cellulosic Ethannol Project (KACELLE) under the EU Seventh Framework Programme, devoted to demonstrating and further optimizing the Kalundborg plant.

The aim of the KACELLE project is to bring the patented Inbicon Core Technology to industrial scale, making the technology available in the market and attractive to investors.

The project will demonstrate 4 t/hr continuous operation at industrial scale and further develop selected process steps resulting in significant cost cuts in ethanol production.

The aim is to:

- Reduce the energy consumption
- Improve the water balance
- Add a fermentation step for C5 sugars
- Reduce the enzyme consumption
- Increase the plant capacity.

The ethanol produced will be characterized and tested in engine test rigs and in cars, thus covering the whole value chain from the straw entrance to the gate of the ethanol plant production to end-users in cars.

The process will be assessed from an environmental perspective through LCA analysis and results will be published for scientific purposes and for expanding the use of the technology to future business partners.

The team of partners in this project are industrial players who have a relevant business role in the demonstration of this value chain, a research center, and universities with internationally recognized competences in key areas.

More project info on www.inbicon.com

Partners

Inbicon – DONG Energy

Inbicon is a developer and provider of technology for 2nd generation bioethanol production, Inbicon provides the Kalundborg cellulosic ethanol plant for this FP7 demonstration project. Inbicon is a fully owned DONG Energy subsidiary.

Statoil

Statoil is a leading ethanol supplier in Europe and was the first to offer Bio95 in Scandinavian countries. Statoil will characterize and test the lignocellulosic ethanol produced in engine test rigs and in cars.

Royal DSM

Royal DSM creates innovative products and services in Life Sciences and Materials Sciences that contribute to the quality of life. DSM White Biotechnology strives to develop new business in the area of industrial biotechnology. DSM White Biotechnology will further develop and demonstrate the advanced C5 ethanol yeast fermentation, which will allow 2nd generation ethanol producers to increase their ethanol yields substantially.

University of Copenhagen – LIFE and University of Minho, Braga

University of Copenhagen LIFE and The University of Minho, Braga, Portugal are considered to be amongst the worlds leading centers in work on enzymes and fermentation. Both will work on recycling of enzymes to significantly reduce cost of lignocellulosic ethanol.

German Biomass Research Centre

German Biomass Research Centre (DBFZ) is highly respected for its work in environmental and economic assessments. DBFZ will evaluate and validate the process and cost setting as an independent non-industrial partner.

A NEW GENERATION OF ETHANOL

Worldwide, lignocellulosic biomass like straw and other biomass residues is a vast unexploited resource which has the potential of an extensive sustainable production of biofuel for transport. Further progress in this area will decouple the production of food and bioenergy, increase the value of the world's production from agriculture and forestry, contribute positively to the reduction of CO_2 emissions, and ensure a more reliable supply of energy.

To convert lignocellulosic biomass into sugars, enzymatic hydrolysis, is presently considered as the most promising technology. Cellulose is converted into bioethanol, lignin into a high quality solid fuel, and hemicelluloses into feed molasses, additional ethanol production or other valuable products.

The Core Technology

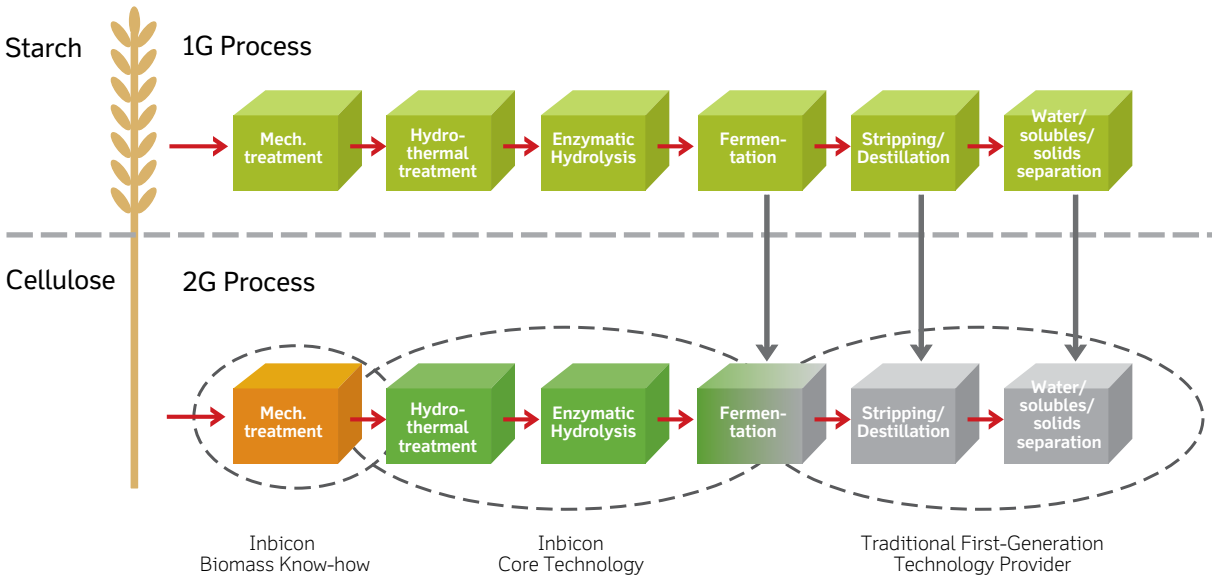
The Inbicon process is a new, proven process for converting lignocellulosic biomass to bioethanol.

The plant features Inbicon Core Technology. It is continuous and energy efficient technology developed for pretreatment and liquefaction of lignocellulosic biomass, which has been operating and optimized in pilot scale for five years with promising results. In the Inbicon process biomass is converted using only steam and enzymes.

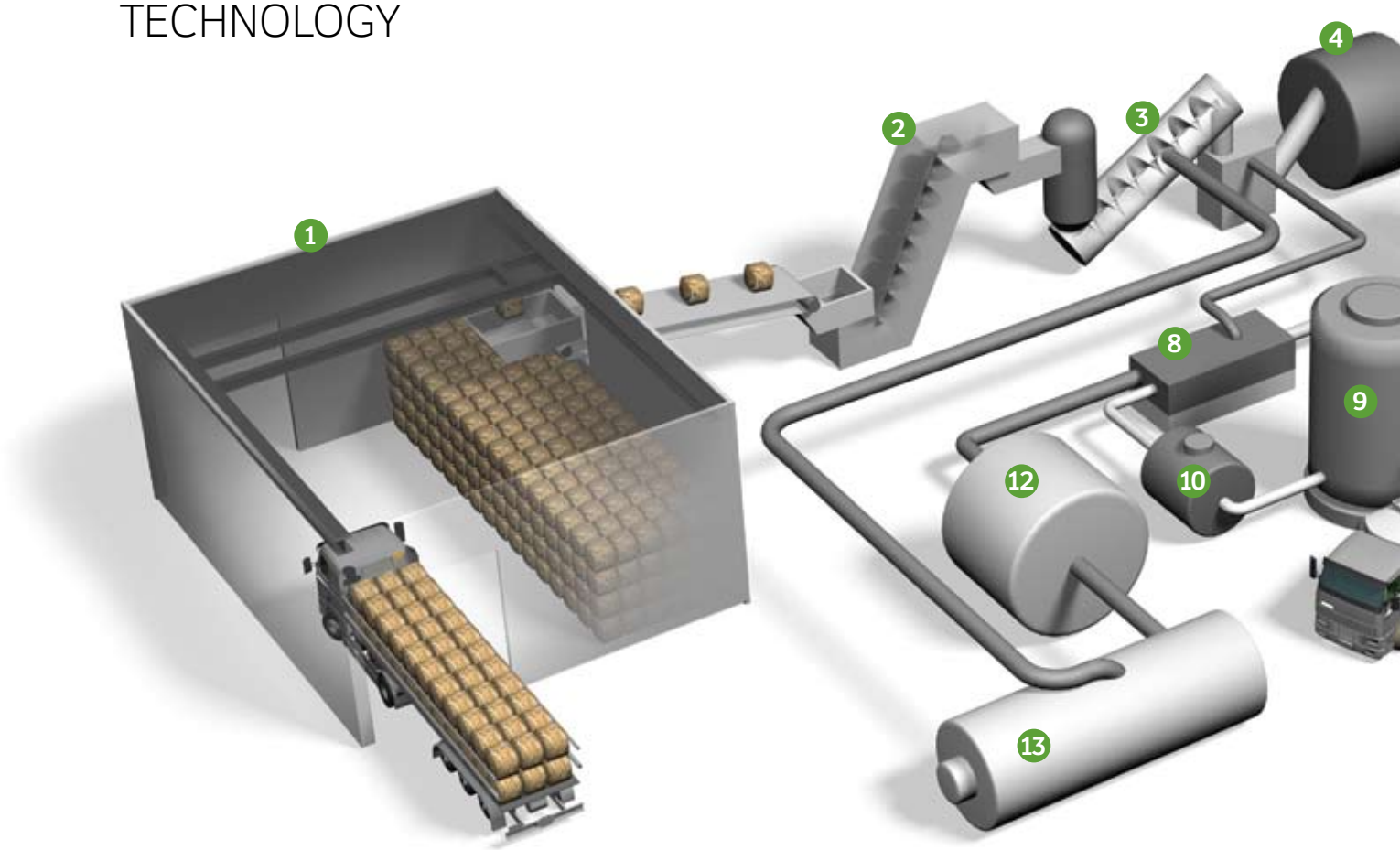
The process is energy efficient due to very high dry matter content in all process steps and by integrated energy solutions.

Inbicon technology has several advantages:

- Very high dry matter concentrations (25-40% DM)
- High ethanol concentration of approx 10vol/vol% in the fermentation liquid (broth)
- Very low energy requirements
- No catalysts or chemicals added – only steam, enzymes and yeast.



THE PROCESS
TECHNOLOGY



1 Biomass Storage
Biomass (e.g. baled wheat straw) is delivered by truck or rail to the ethanol plant where it is unloaded and stored in a building designed to hold about a week's supply.

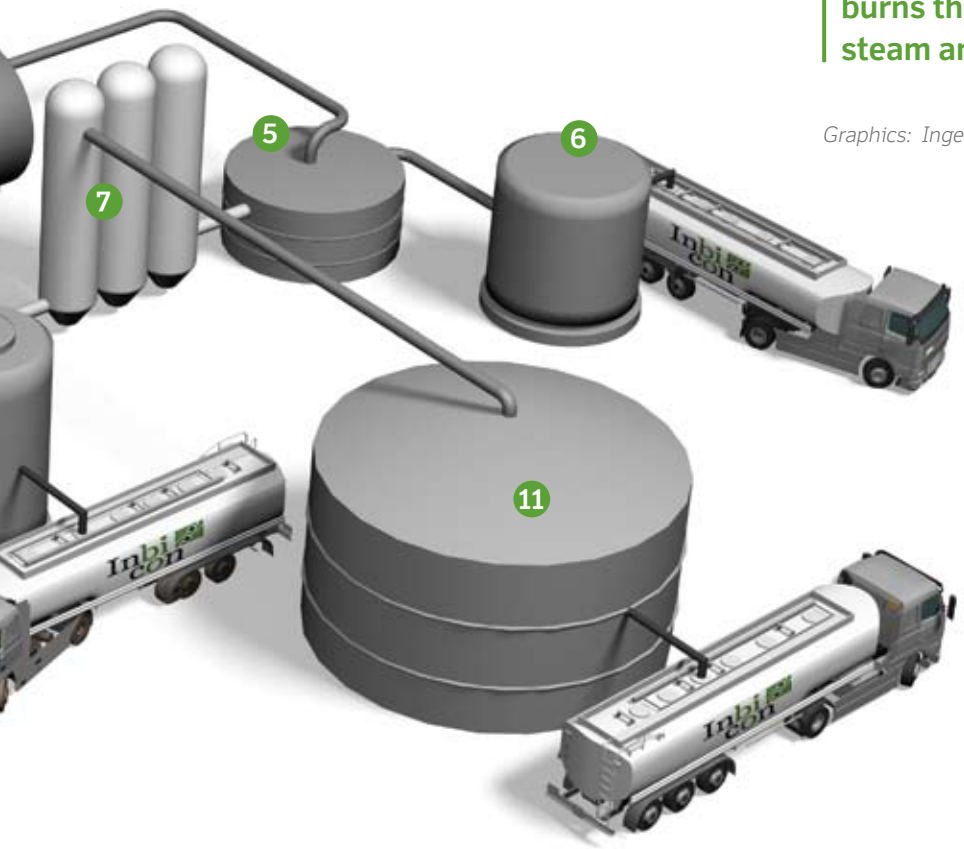
2 Mechanical Conditioning
We cut the biomass into small pieces and condition it using a proprietary method.

3 Hydrothermal Pretreatment
Using patented Inbicon technology we pressure-cook the biomass to open the protective lignin structure and make the cellulose available for enzymes. The process operates at high (30% - 40%) dry matter content, minimizing the consumption of water and energy.

4 Enzymatic Hydrolysis
We add enzymes to the fiber mass, which consists mainly of cellulose and lignin. As the fiber is liquefied, part of the cellulose is converted to lower carbohydrates. When the fiber leaves the reactor, its viscosity has been so dramatically reduced that the liquid can be pumped to traditional fermenters, the type used in 1st generation bioethanol technology.

5 Fermentation
Inside the fermentation tanks, the mixture is referred to as beer. Yeast is added to convert the sugar to ethanol and carbon dioxide. The beer is then allowed to ferment for 140 hours.

6 CO_2 Capture
As the yeast ferments the sugar, large amounts of carbon dioxide gas are released. It is captured, purified, and marketed for use in carbonated beverages and flash-freezing applications.



A co-generation plant burns the lignin to produce steam and power.

Graphics: Ingeniøren / Lasse G. Jensen

7 Distillation
After fermentation, the ethanol is passed through a molecular sieve to physically remove the smaller water molecules from the ethanol. This step produces 200-proof anhydrous (waterless) ethanol.

8 Solids/Liquid Separation
The solids are sent to an evaporator for drying. Some of the water is also separated out and put back into the process to be used as make-up water, reducing water usage.

9 Molasses Storage

10 Evaporation
The stillage is further reduced to 65% solids and is sold as C5 molasses.

11 Ethanol Storage
Before the ethanol is sent to storage tanks, a small amount of denaturan is added, making it unfit for human consumption.

12 Drying
The solids are dried to a fine powder that can then be used as a solid biofuel.

13 Cogen
A co-generation plant burns the powder to produce steam and power. The energy produced is enough to operate the entire Inbicon Biomass Refinery™, plus an excess which is sent to the power grid as electricity for nearby homes.

THE PROCESS STEPS

Mechanical treatment, straw handling and milling

DONG Energy has solid experience with straw handling and handles around 1 million tonnes of straw per year for use in power plants.

The technology used for handling, storing and cutting the straw for the Inbicon ethanol plant is based on equipment already developed and used at power plants in DONG Energy. The know-how with respect to construction, operating and maintenance is available internally at DONG Energy at capacities up to 20-30 t/hr.The demonstration plant uses 4 tonnes of wheat straw per hour and will on average receive trucks every three hours.

The straw storage has been designed to avoid straw transport at night and during weekends. Before the straw enters the thermal pretreatment, the strings are removed and the straw is shredded into a suitable size. Furthermore, foreign particles, such as stones and metal pieces, are removed.

Hydro thermal pretreatment

The hydro thermal pretreatment is the first step in the process of converting biomass to bioethanol.

During pretreatment, the straw is continuously soaked in processed water containing acetic acid and heated to around 180-200°C with steam (approximately 15 bar) for 5-15 minutes in order to destroy the protecting lignin structure and make the cellulose available for enzymes. Another important function of the pretreatment is to separate the alkali content from the lignin. The straw is fed into a pressure reactor with a proprietary particle pump.

The particle pump (pressurised feeder) has been developed and tested over the last 10 years. The fifth generation of the patented design, is presently being operated at 1t/hour, and has proved to operate satisfactorily at our test facilities in the last year.

The pressurised reactors in which the straw is heated with steam has been tested and modified over the last six years.

Enzymatic hydrolysis (liquefaction)

After hydro-thermal pretreatment, enzymes are added to the fibre mass consisting mainly of cellulose and lignin. The fibre mass fraction is liquefied as part of the cellulose is converted to lower carbon hydrates. The process takes place in a horizontal reactor. The process is continuous,

Inbicon thermal pretreatment pilot plants, 100 kg/h and 1000 kg/h

and the fibre mass leaving the pretreatment with 25-35% Water In Solubles (WIS) content enters the reactor in one end.

After a few hours it leaves the other end of the reactor as liquid. When the liquefied biomass leaves the reactor, the viscosity has been dramatically reduced, and the substance can be pumped to traditional fermenters and fermented by traditional SSF technology.

The process is a patented technology and various reactor designs and configurations for this process have been tested over the last four years.

Fermentation

After the substrate has been reduced in viscosity it can be fermented in traditional vertical fermenters. The fermentation is a simultaneous saccharification and fermentation process (SSF) in which the cellulose is converted into ethanol by industrial yeast.

The Inbicon process is economically viable even though only the C6 sugars in the fibre fraction are converted into ethanol. The hemicellulose sugars (C5) are converted to high value animal feed (molasses). To potentially further improve the economics and energy efficiency of the technology, a C5-organism will be tested in the KACELLE project.

Distillation/rectifying column system

The first part of the distillation process strips the ethanol from the fibre beer. The fibre beer contains all the lignin from the straw as well as other solids, and the ethanol is removed from this fibre fraction. This is done in a stripper, where the mass is heated by steam, and a mixture of ethanol and water evaporates from the fibre fraction. This is an old and proven technology, but the trays in the stripper have to be designed to this specific fibre beer that originates from the straw. Special trays have been developed and successfully tested in our pilot plant.

The rectifying technology will not be different from 1st generation bioethanol plants, because at this state, only a mixture of "pure" ethanol and water will be present. All suspended solids and solubilized sugars have been removed in the stripper section.

The distillation is operated under vacuum, to obtain a low temperature in the stripper, and hence the enzymes are still present in the system and not destroyed. The enzymes will end up partly in the thin stillage and partly in the solid lignin. A part of the thin stillage will be recycled to the liquefaction process and the remaining part will go to evaporation. Further research will be focused on making it possible to also regenerate the enzymes from the lignin, before the lignin is burned in the power plant or dried and formed into pellets.

Evaporation

Besides ethanol and solid biofuel, the third product of the Inbicon process is feed molasses (C5 molasses). This product consists of the thin stillage and liquid fraction from the pretreatment. It contains a large amount of oligosaccharides and sugars originating from the breakdown of hemicellulose. At present the use of this product as feed is considered the most optimal solution.

The molasses has been evaluated by Danish agricultural organisations and assessed to be of the similar value as sugar beet and sugar cane molasses for the purpose of feeding cows. In the near future, however, other products, such as fermentation to ethanol or conversion into other valuable products, are also considered possible parts of the Inbicon process.

The C5 fermentation awaits a suitable industrial strain which has a proven high stability. In the KACELLE project a C5 fermenting organism from DSM will be tested. Before the sugars can be sold as molasses they have to be concentrated further, which will be done by multi stage evaporation.

The molasses are virtually free from suspended solids and contain a high concentration of C5 sugars. When the right technology is developed it will be possible to convert this stream into ethanol or other high value chemicals, but presently these technologies are not ready for demonstration on full scale. The more C5 sugar we choose to convert, the higher the bioethanol yield, but the less animal feed and vice versa.

Decantation and lignin burning

The lignin can be used for several high value products. In Kalundborg a fraction of the lignin supplies all process requirements for heat and power. The lignin fraction has to be separated from the non-fermentable solubles of the stillage. For this purpose various decanter designs have been tested in pilot scale.

The decanter design is developed together with sub-suppliers, and successful tests have been carried out. The lignin leaving the decanter will contain around 65-70% water. The lignin cake will be dried and pelletized, and will replace coal in one of DONG Energy's power plants.

Distribution and sales of end products

The ethanol produced complies with the standards set for bioethanol (primarily the draft for bioethanol standard EN15376). The first 5 mio. litres of bioethanol have been sold to Statoil. The production of 2nd generation bioethanol will probably be started before the framework conditions have been finally agreed upon.

The lignin fraction will be sold as solid biofuel for power plants. During the project period, other marketing possibilities will also be investigated and potentially implemented.

The C5 molasses will be marketed for livestock feed. During the project period, alternative applications will be investigated.

BIOMASS TECHNOLOGY
CAMPUS AND FUTURE

Since 2003, the process has been well-tested at large pilot scales (100-1,000kg/h wheat straw) and has now been scaled up to 4t/h.

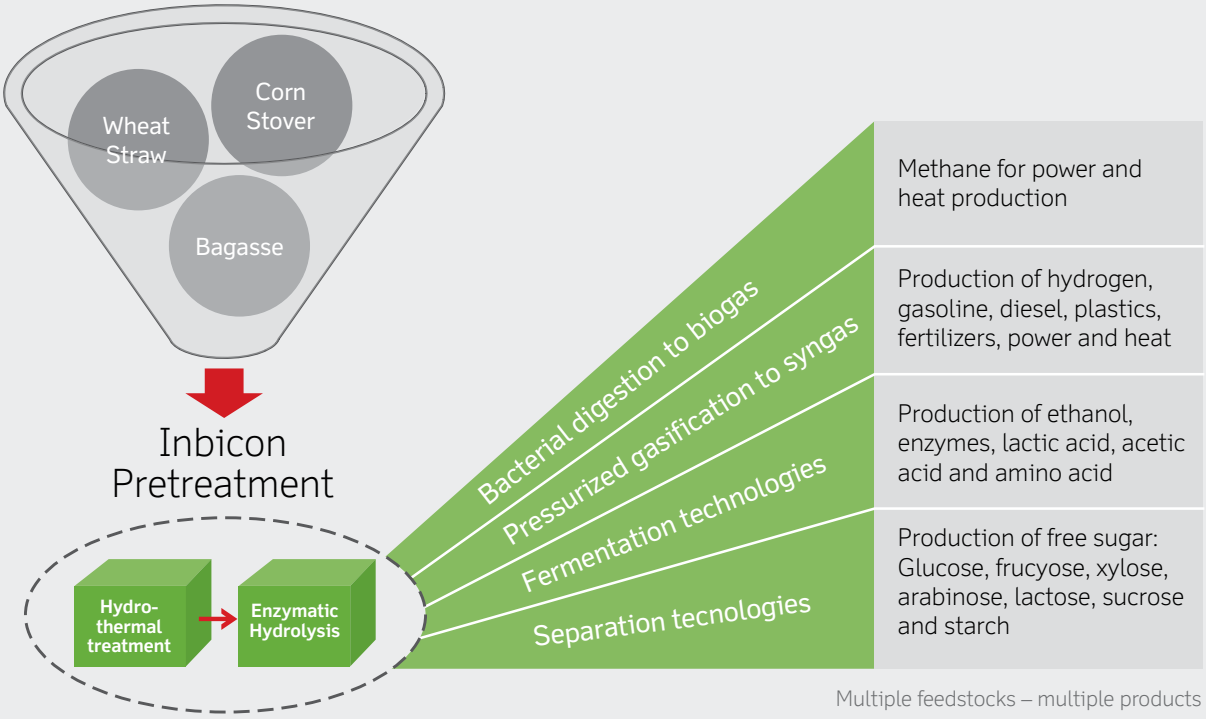
It is our vision that the Inbicon plant is the first stage in creating an evolving Inbicon Biomass Technology Campus in Kalundborg. A technology campus which goes beyond a comprehensive research and development center, by also becoming a technology transfer station, idea incubator, collaborative lab for ongoing feedstock testing, and international round table for exchanging knowledge on biomass conversion.

Prospective clients will get a hands-on understanding of Inbicon technology. Collaborating partners can come to test their new concepts and equipment, e.g. C5 converting micro organisms. Clients can learn how to run their new operations before they are built, and key staff can be trained.

Next steps

The pilot plants have been tested with feedstocks as bagasse, corn stover, corn silage and miscanthus. The results have been promising and we are confident that we can get as good results with them as with wheat straw. We also believe that our promising results can be extended to other large feed stocks e.g., empty fruit bunches, rice straw and garden waste.

The Inbicon Biomass Refinery



Multiple feedstocks – multiple products – The Inbicon Biomass Refinery.

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