# Final report

## 1.1 Project details

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|---|---|
| **Project title** | CopenhagenBioFuel (CBF) - Phase 1 |
| **Project identification (program abbrev. and file)** | Journal nr.:<br>64009-11 |
| **Name of the programme which has funded the project** | EUDP<br>Biomass (production of bioethanol, lignin, biogas) |
| **Project managing company/institution (name and address)** | BioGasol ApS<br>Mileparken 28<br>2750 Herlev |
| **Project partners** | Siemens A/S, Alfa Laval Copenhagen A/S<br>DI Teknik A/S, CKJ Steel A/S, Cowi<br>Green Biologics, Grundfos, Estibio |
| **CVR** (central business register) | 2921 1655 |
| **Date for submission** | 10th October 2016 |

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## 1.2 Short description of project objective and results

The project objective was to realize a demonstration plant capable of converting biomass (straw) to ethanol at a capacity of five (5) million liters ethanol per year using a combination of acid catalysed thermal hydrolysis, anaerobic, high-temperature fermentation of C5 sugars and enzymatic conversion of cellullose and yeast fermentation of C6 sugars. The project demonstrated two innovative technology solutions: 1) A highly efficient pretreatment reactor (Carbofrac®) and process for achieving mild acid hydrolysis / steam explosion pretreatment of biomass (straw) and 2) an anaerobic, high temperature process, equipment and production organism, for C5 sugar conversion to ethanol (Pentoferm®). The scale realized for 1) corresponds to more than two (2) million liters per year (at 80% availability), while for 2) the realized scale corresponds to 20.000 liters per year. The solutions developed in the project are being evaluated by the industry, including the world's largest ethanol producer. Three Carbofrac® reactors (50kg/h and 500kg/h under the BornBiofuel1 project and a 1 t/h unit under the CBF project) have been manufactured and demonstrated with external partners.

Formålet med projektet var at etablere et demonstrationsanlæg til fremstilling af ethanol fra biomasse (halm) med en planlagt årlig kapacitet på fem (5) millioner liter. Demonstrationen omfatter hydrolysering af biomassen med syrekatalyseret 'steam explosion', anaerob, højtemperatur fermentering af de frigjorte C5 sukre til ethanol og enzymatisk omsætning af cellulose til C6 sukre, som gærfermenteres til ethanol. Projektet demonstrerede to innovative teknologiløsninger: 1) En højeffektiv reaktor (Carbofrac®) til omsætning af biomasse med syrekatalyseret 'steam explosion' og 2) en anaerob, højtemperatur proces omfattende procesudstyr og fermenteringsorganisme (Pentoferm®). Den realiserede skala for 1) svarer til mere end to (2) million liter ethanol om året (ved 80% oppetid), medens for 2) svarer den realiserede skala til 20.000 liter om året. Projektets teknologiløsninger er under evaluering af industrielle samarbejdspartnere omfattende verdens største ethanolproducent. Der er bygget tre Carbofrac® reaktorer med støtte fra EUDP (50kg/h og 500kg/h under BornBioFuel samt én 1 t/h under CBF), som alle er demonstreret sammen med eksterne partnere.

## 1.3 Executive summary

The project built on the results from the integrated biorefinery demonstration plant 'Maxifuel' (EFP granted project) developed at and with the collaboration of the Technical University of Denmark (DTU). It was apparent that attempts to scale this plant to production size would result in untenable economics, due to the CAPEX requirements, process stability and low yields. The main aim of the project was to solve the scalability issues by redesigning reactors for hydrolysis/steam explosion of biomass the Carbofrac® and for C5 fermentation using high temperature fermentation, Pentoferm®. This was planned to take place in two phases: Phase one aiming for proof of concept at an intermediate scale and phase two aiming for demonstration in a fully integrated plant with a capacity of 5 million liter ethanol per year.

Proof of concept was achieved in the summer of 2010 (under the EUDP project BornBioFuel) and the next phase commenced, which primarily was concerned with the further development and scaling of the two processes. The Carbofrac® reactor was scaled to 1 t/h capacity and several mechanical and process control improvements were implemented and tested as a part of the CBF project. Subsequently a scaled-up Carbofrac® reactor was designed, based on the learnings gathered from the 1 t/h Carbofrac® unit. This development led to a Carbofrac® unit capable of of a 4 t/h capacity and roughly with the same footprint, see appendix C. The Pentoferm® development led to a high-yielding, marker-free stable fermenting organism as well as a process capable of eliminating product inhibition by implementing a continuous removal of product (ethanol).

In conjunction with the developments in both pretreatment and fermentation technology, basic engineering was conducted in order to devise a demonstration facility as well as validating economic feasibility through techno-economical modelling.

The processes were operational in the pilot plant of BioGasol from 2011 until summer 2015 and in this period feedstocks from numerous potential collaborators from the Americas, Asia and Europe were tested (though not as a part of the EUDP project).

The performance of the pilot plant surpassed expectation in terms of yield and projected economics and BioGasol achieved its first commercial sale to Sweetwater in 2013 founded on the results from the CBF project.

Currently (the fall of 2016) a new pilot plant is being built at Teeside, UK in collaboration with Nova Pangaea. The UK company Nova Pangaea is developing a new type of biorefinery using the Carbofrac® reactor as a first step followed by its own proprietary technology for the downstream treatment. Also the use of the fermentation technology, Pentoferm® is being evaluated for the biorefinery. BioGasol has built and will be delivering reactors to this plant.

The main design criteria for the Carbofrac® reactor aimed to address two issues. One is excessive wear of the reactor due to grit entering with the feedstock and the other is low yields due to suboptimal processing.

Although commercial scale has not yet been achieved, the Carbofrac® reactor design has continually attracted attention from the industry, mainly by virtue of a very efficient and practical implementation of the design criteria.

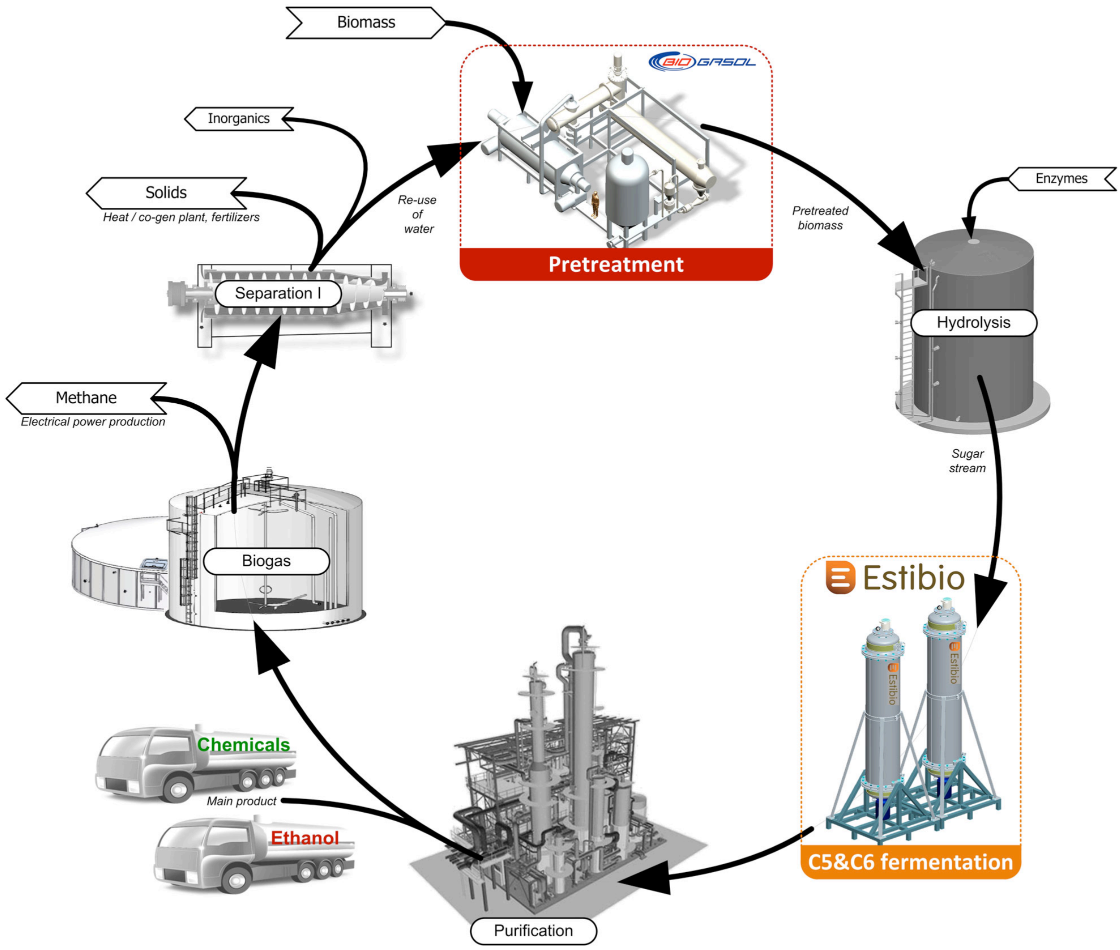
The Pentoferm® reactor concept and production organism Pentocrobe® developed under the Project has attracted interest from Sweetwater and from certain major Brazilian ethanol manufacturers. The engineering design package is accessible through the company Estibio, a sister company to Biogasol, and access to the production organism is secured via deposition in publicly accessible culture collections.

The sector in which the CBF project has developed is characterized by unpredictable conditions both regarding investor interest and market conditions, which dominantly are influenced by political initiatives to abate environmental concerns and the price of oil. The owner of BioGasol and Estibio, Fjord Capital Partners, has continued to support the BioGasol effort to realise the CBF project and BioGasol has been able to place the results of the CBF project on a footing which will enable commercial realization once the positive long term trends in the industry emerges. In that respect the Biogasol relationship with Nova Pangaea is important, but also the awareness of the industry in general of our solutions developed under the CBF project. From the jointly run demonstration plant in Teeside, UK, BioGasol will be able to demonstrate and manufacture Carbofrac® reactors in the future.

### 1.4 Project objectives

The original objective was to establish a 5 million liter a year ethanol demonstration facility on the island of Bornholm, based on the results from the BornBioFuel1 project, thus the project was intially dubbed BornBioFuel2. Please refer to a detailed description of the original project in Appendix A and the latest revision of the project in Appendix B and lates request for revision in Appendix C.

The demonstration was planned to encompass the two main processes, pretreatment and C5 fermentation, depicted in the figure below with associated equipment, developed in the course of the CBF project, together with commercially available process equipment provided by third parties and by partners of the project. The total project cost was estimated at 205 million DKK at the outset, later reduced significantly, only encompassing the two core-technologies.




The initial demonstration of the processes and equipment under the BornBioFuel1 project (a separate EUDP grant) was provided during the course of the project:
1) Pretreatment reactor and process and 2) fermentation reactor and production organism went according to plan and was timely delivered according to pre-agreed milestones, described in the intial conditional grant notices of 13th of May 2009 and 13th of October 2009. The milestone requirements were in principle demonstration of 1) pretreatment reactor at 50kg/h and 500kg/h respectively and corresponding C5 fermentation capability, a 250L reactor and a 2.5m$^3$ reactor. This was reported to EUDP on 27th of September 2010 and subsequently evaluated by external experts (NNE Pharmaplan[1] and Knut Berge[2]). The EUDP funding was granted on the The fulfilment of these requirements resulted in retaining the grant for the CBF project (then the BornBioFuel2 project) on the 30th of November 2010.

After initiating the second phase of the Project, which came to be known as Copenhagen Biofuel, the Company set about retaining corporate collaboration to secure matching funds in order to meet the Project timelines. EUDP granted a number of extensions and accepted a number of revisions while the Company’s effort continued, please refer to Appendix D for a more detailed overview. A considerable number of prospective partners engaged in the project and much effort was expended on negotiations and due diligence to secure finance. The general difficulties of the sector precluded Biogasol as the project owner from raising sufficient finance in time to

[1] NNE Pharmaplan: Evaluation of BioGasols C5 technology, 4. November 2010

[2] Knut Berge: Report of the status of BioGasols BBF project, 9. November 2010

realise the end goal of an integrated demonstration plant and EUDP retracted the remainder of the grant on 30th May 2016.

Since 2010 Fjord Capital Partners has continued to fund the Company and by this funding and the grant from EUDP, a number of intermediate objectives have been met and consequently results have been created during the course of the CBF project, which may prove their commercial utility in the future. Most importantly, the Carbofrac® reactor concept has been demonstrated by building a total of four reactors, based on results primarily from the EUDP granted projects, and by testing them in a fully equipped pilot facility (BioGasols facilities in Ballerup and Køge) as well as with Sweetwater in the US.

Also the Pentoferm® demonstration has resulted in the final configuration of the production organism Pentocrobe® and an engineering package allowing users to implement the highly efficient and high yielding fermentation system.

**1.5 Project results and dissemination of results**

Activities fall in three main categories: Fermentation system development, development of pretreatment processes and reactor technology and ancillary technology to complete the demonstration plant.

**Pretreatment processes and reactor technology**

Processes for conversion of biomass to sugar (C5 and C6) and lignin i.e. biomass fractionation were researched and on this basis the favoured process: 'Dilute Acid catalysed Steam Explosion' (DASE) was mapped in reaction diagrams (surface response diagrams based on design of experiments statistical methods) on a plethora of feedstocks. The input for the diagrams were provided by batch reactor work, as well as small-scale Carbofrac® operation, and analysis of the hydrolysed material in the analytical laboratory associated with the pilot plant.

The reactor technology was developed through a requirement analysis borne out from the findings from the previous 'MaxiFuel' pilot plant. The implementation was developed over several experimental rigs and theoretical modelling. Eventually the Carbofrac® design was realized as a small capacity version (R-mini, later renamed as Carbofrac® 5) with a piston driven infeed device. This reactor was used extensively for preparing samples of hydrolysed feedstock for potential collaborators.

This design was further developed to the Carbofrac® 50 during the BornBioFuel1 project and later revamped completely to become the Carbofrac® 100, capable of very high sugar yields up to 1 ton pr. hour. The Carbofrac® 100 was continuously improved and modified in order to test design features for the Carbofrac® 400 which was designed under the CBF project, but never manufactured. The level of detail in the design includes manufacturing drawings, control system and firm quotations from several vendors for major components for the unit.

**Fermentation system development:**

This involved two lines of activity: 1) Microbiological development of the production organism 'Pentocrobe®' and 2) Development of engineering solutions for implementation of the fermentation system, Pentoferm®.

1) The development of the production organism from the original strain of Thermoanaerobacter Italicus required deletions of two parasitic pathways, in order to increase ethanol yields. This, in turn, necessitated the development of new methods for isolating the desired strains as standard technology could not deal with the combination og high temperature and anaerobic conditions. The production organism was adapted to actual feedstocks by prolonged fermentation in test fermenters (bioreactors).

The fermentation was scaled up in two steps: From laboratory reactor to a 250 L reactor size and further to a 2500 L reactor. The performance in terms of yields and productivity met the set targets.

2) The engineering dealt with a) Reactor design and b) Design of process equipment downstream.

   a. Considerable work was expended in flow simulation and modelling of the reactors, inter alia to aid the decision to use either immobilized or free suspension bacteria. On the basis of the design work, two upscaled reactors (250 L and 2500 L) with control systems were built and mounted in a contained section of the pilot hall compliant with regulations for work with genetically modified organisms. The first reactor design was based on a internal plug-flow mode of operation through an immobilisation matrix, on which the microorganism would grow and convert free sugars to ethanol. Later, this was changed to a suspended bacterium growth in a continuously stirred tank reactor (CSTR), but always a completely oxygen free (e.g. $N_2$ headspace) environment and thermophilic conditions in a continuous process was applied.

   b. Additonally a design package for the equipment downstream from the reactors, was developed. This entails the continuous removal of ethanol from the fermentation broth, in order to circumvent product inhibition issues, due to the limited ethanol tolerance of the microorganism. This system was partially developed to semi-industrial scale with Swiss distillation expert Sulzer Chemtech.

**Ancillary technology to complete the demonstration plant**
Apart from the two core-technologies described in the above, much effort has been devoted to the engineering of a demonstration plant, ranging from the original fully integrated 2G bioethanol plant to a test facility focussed on the pretreatment and small-scale fermentation only.The full demonstration plant included multiple unit operations e.g. biomass handling, enzymatic hydrolysis, anaerobic digestion, distillation and lignin recovery. Furthermore balance-of-plant incl. utilities and energy balances have been engineered. Several industrial partners have been identified and selected for this purpose incl. Siemens, Alfa Laval, Grundfos, St1 and CKJ Steel. Also cooperation with multiple companies, though not directly project partners, and potential supplers such as Sulzer Chemtech, Passat, ACO Engineering, Pöyry, Novozymes, Vogelsang has taken place. In order to execute the project, BioGasol has used COWI as the engineering partner, for both additional resources and special areas of expertise incl. project management.

**Main activities and technical results**
The main activity is as previously mentioned the development and demonstration of the two core technologies, pretreatment and C5 fermentation. An industrial design for a commercial 4 ton pr. hour pretreatment system was achieved, based on the results from the 1 t/h Carbofrac®, which is the key activity within the project, as it is the enabling technology for virtually any process that follows down-stream, which relies on some degree of biomass fractionatisation and sugar accessability. For a thorough description of the Carbofrac® technology, please refer to Appendix E "BioGasol Pretreatment System Description PUBLIC 008".

The yields obtained on various feedstocks during the project are very high compared to what has been reported and can be found in the literature prior to the CBF project, especially when considering the scale at which the results have been obtained. An overview of the yields obtained from the two Carbofrac® units can be seen in the below (not all are from the CBF project). Note that the glucose sugar release is after enzymatic hydrolysis.

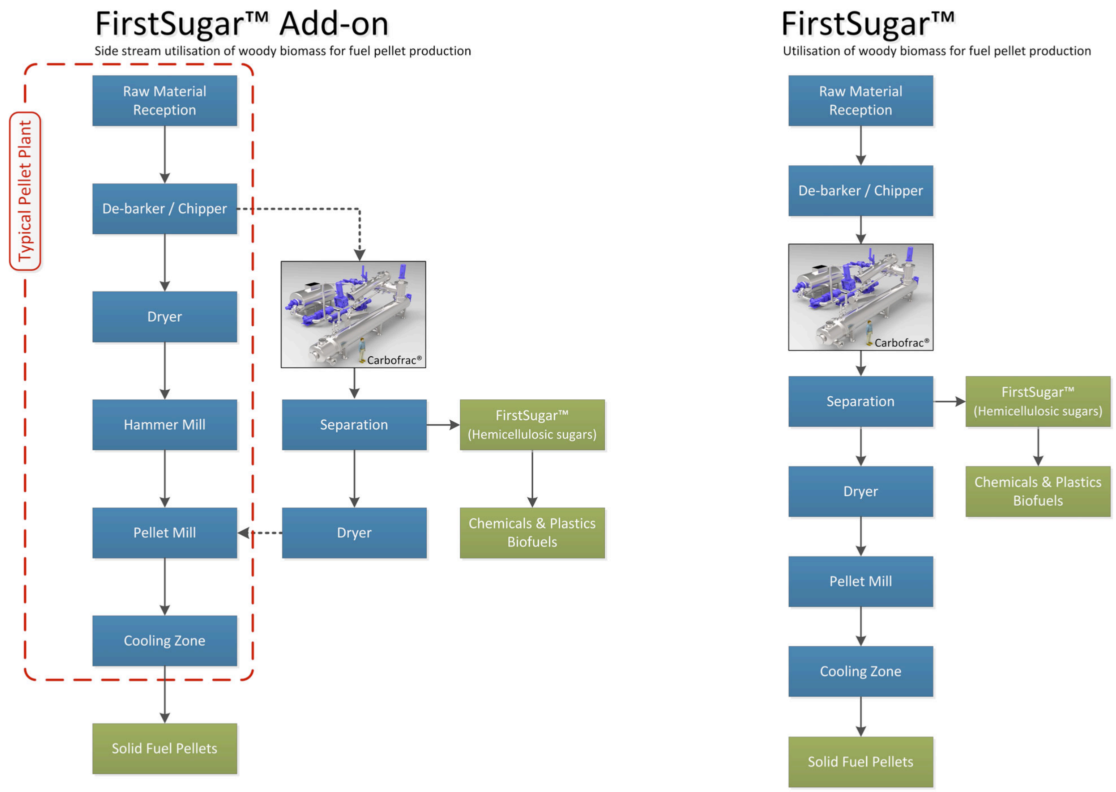
| **Biomass (examples)** | **Picture** | **Carbofrac®** | **Glucose Sugar** | | **Hemicellulosic Sugar** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | | | kg/ton | % | kg/ton | % | kg/ton | % |
| Hardwood Birch |  | 5 | 299 | 82 | 193 | 87 | 492 | 84 |
| Corn Stover |  | 100 | 275 | 85 | 174 | 85 | 449 | 85 |
| De-starched Oat Hulls |  | 5 | 247 | 89 | 267 | 78 | 514 | 83 |
| De-starched wheat bran |  | 5 | 393 | 87 | 247 | 96 | 640 | 90 |
| Empty Fruit Bunches |  | 5 | 273 | 91 | 315 | 95 | 588 | 93 |
| Palm Frond |  | 5 | 223 | 84 | 204 | 95 | 427 | 89 |
| Sugarcane Bagasse |  | 5 | 492 | 88 | 187 | 85 | 679 | 87 |
| Hardwood Mixed |  | 100 | 328 | 83 | 168 | 92 | 496 | 86 |
| Hardwood Poplar |  | 5 | 388 | 80 | 143 | 98 | 531 | 84 |
| Softwood Pine |  | 100 | 124 | 27 | 174 | 86 | 298 | 45 |
| Wheat Straw |  | 5 | 402 | 89 | 240 | 99 | 642 | 92 |
| Wheat Straw | | 100 | 377 | 84 | 210 | 83 | 587 | 84 |

The other main technology that was developed under the CBF project is the Pentoferm® C5 and C6 sugar conversion process including the proprietary Pentocrobe® microorganism. The most comprehensive description of this unique fermentation process is publically available on the Internet (the full text available in Appendix F) and the fermentation organism itself can be obtained from a German microorganism bank.

**FirstSugar™**

An impotant aspect of the Carbofrac® development is the ability to liberate an extensive amount of hemicellulosic sugars without enzymatic hydrolysis. This is primarily xylose, but also mannose and even glucose can be found in this fraction and is thus hydrolysed primarily to monomeric sugars, which are available for fermentation without other process steps. Enzymes for biomass are notouriusly known to be very expensive and therefore have a great impact on process economics. By only utilising the liberated sugars directly from the Carbofrac® process, which can be as much as 40%, production costs can be minimised. However this requires e.g. a fermenting organism that can convert the hemicellulosic sugars to ethanol (or other products), but this is exactly the main advantage of the Pentocrobe® as it is "sugar agnostic" and converts all lingocellulosic sugars to ethanol.

The remainder of the biomass, containing the bulk of the cellulose and lignin can be used for other purposes, also biofuels if a suitable technology (e.g. enzymes) is applied. During the CBF project, BioGasol came up with the idea to use this fraction for biofuel pellets, which have several advantages that have been confirmed by Teknologisk Institut (Danish Technological Institute). One major advantage is the increased energy density a second is the significant reduction of inorganics (chloride and potassium), which makes the fraction very well suitable for fuel pellets for combustion. This concept is known as the FirstSugar process and two variants can be seen in the figure below.




The FirstSugar™ process concept lends itself well to the wood pellets and CHP sector, why the last revisions of the CBF project was based on this concept and cooperation with actors in this field was attempted incl. Blue Point Pellets and Danish Utility supplier DONG Energy. Unfortunately, a shift in priorities meant that the cooperation was abandoned.

## Commercial results and expectations

The project was revised several times over the years, but two crucial aspects remained unchanged throughout; the pretreatment and the fermentation. Much knowledge and experience with biomass fractionation and conversion has been obtained, however a large semi-industrial scale plant, which was the original objective, was never actually built.

The design for the Carbofrac® 400, which included several improvements, was frozen and ready to manufacture. Many of the improvements were tested on the Carbofrac® 100, which was modified significantly under the CBF project. Also functional models, e.g. a 10m$^3$ vortex fluidisation was tested as a part of the development effort under the CBF project. In general the pretreatment development has been a great success as it has demonstrated very high yields in terms of sugar release from biomass at relatively large scale, but the last step, to verify the results at full commercial scale, was not achieved.

The Pentocrobe® fermentation organism was developed as far as it was possible, so a marker-free production organism was obtained. Pilot scale and lab scale fermentations have taken place incl. co-fermentations of both C6 and C5 sugars during the project. However, the largest scale at which the fermentations have been conducted were done in the 2.5 m³ reactor, even though a 15 m³ reactor incl. in-situ ethanol removal was planned. Results have been very convincing, especially the co-fermentations, and the system to handle the product (ethanol) inhibition was engineered (and patented), but never operated.

**Dissemination**
Many of the project results have been disseminated e.g. several times at the World Bio Markets conference, which is the largest of its kind for the industry, and the Symposium on Biotechnlogy for Fuels and Chemicals (SBFC), which is the largest scientific conference in this field. Also, other conferences e.g. Lignofuels, F.O. Lichts, Sugar and Ethanol, COP15, Clean Fuels Summit etc. have been attended. The Biogasol website is to a large degree focussed on the technologies developed through the CBF project, the pretreatment and fermentation, as well as the FirstSugar concept. Finally some contributions and articles in e.g. Forskning i Bioenergi (FiB), Ethanol Producer Magazine, Ingeniøren and Sugar Journal have been published.

### 1.6 Utilization of project results
As previously mentioned, the Carbofrac® pretreatment technology is currently being implemented at the Nova Pangaea Technology demonstration plant and it is expected to be a key process in the future value chain for Nova Pangaea. The primary reason is that the Carbofrac® is extremely good at removing hemicellulosic, primarily C5, sugars, which is required for the Nova Pangaea downstream processes which utilises the remaing C6 sugars in a novel process, which is more cost efficient than other processes e.g. enzymatic hydrolysis.

Furthermore, a major ethanol producer is currently evaluating the Carbofrac® technology at their pilot facility in order to tailor the technology for their specific challenges. This can potentially lead to the implementation of the technology on a large, commercial scale.

Finally, virtually all the actors within the biofuels (and biochemical) sector are familiar with the existence of the Carbofrac® technology. Biogasol has conducted test trials on the various pretreatment systems for many of these, however the names of most of these companies can not be disclosed due to active non-disclosure agreements. Those who can are St1, Sweetwater, Green Biologics and Nova Pangaea, but far larger companies' incl. actors within the established oil and chemicals industry have also sought assistance from BioGasol for the pretreatment, as well as the fermentation, technology. The projects conducted for these, more than 25 companies (not a part of the CBF project), were all successful, however very few lead to the next step, being sale of technology or partnering on development projects, incl. the CBF project. The reasons for this had primarily to do with the economic prerequisites not being present, i.e. the low oil price and lack of other financial support. One very clear example of this was the St1 withdrawal of their commitment to partially fund the EUDP project as well as contribute with resources and technology. The rationale was that 2G ethanol was not commercially viable due to the lack of support from the EU, which at the time was reduced.

The majority of the more than 25 companies that BioGasol has worked with saw no technical reasons, but only commercial reasons, not to proceed with the technologies. Therefore, provided the economic conditions change, e.g. oil prices rising, customer awareness or political incentive schemes, the BioGasol technology will most likely come into play for applications in future biorefineries.

If the industry as a whole evolves, the market potential is still significant, especially within 2G bioethanol due to the vast quantities required for transportation fuels. Regarding competitors there have been relatively few success stories, if any. Biogasols pretreatment competitors are relatively few and access to data is limited, but it is unlikely that any of these have shown the same yields from the pretreatment step, as they do not have a comparable technology but typically rely on enzymes to achieve liberation of fermentable sugars. Relevant pretreatment competitors include Andritz, Valmet (previously Metso), AdvanceBio, SunOpta, Iogen, Comet and possibly EdenIQ, all with their strengths and weaknesses.

For the fermentation technology, the same challenges apply and even more so, since the technology only converts sugars into ethanol and therefore relies exclusively on the ability to produce ethanol at a competitive price. One advantage however is the ability to convert all sugars, making the technology interesting for the established 1G ethanol sector also. The microorganism and process offers many advantages, incl. very limited risk of contamination and high yields, and is rather unique from a technical standpoint. Apart from not very many 2G projects being commercial, this is one of the main reasons why it has not been adopted, since yeast technology is more commonly known in both 1G and 2G industry. Competitors are therefore mainly yeast companies incl. Lallemand, DSM (previously Royal Nedalco), Terranol, Taurus and Cargill.

The BioGasol business model is to sell technology as a margin business (profits from equipment sales) combined with a license and possibly royalty business. This has not as such changed, but currently BioGasol is in more of a stand-by mode, when it comes to 2G bioethanol, waiting for the business perspectives, driven by the market conditions, to emerge. In the meantime other routes are being pursued incl. green chemicals and plastics as well as the previously described FirstSugar™ concept.

Some patents have been applied, but not as a part of the project. The BioGasol / Estibio patent portfolio include (but not complete) the following patent families, some of which are related to the CBF project:

| # | Title | PCT No. |
|---|---|---|
| 0 | Production of fermentation products in biofilm reactors using microorganisms immobilised on s | PCT/EP2007/05652 |
| 1 | A METHOD FOR PROCESSING LIGNOCELLULOSIC MATERIAL | WO0160752 |
| 2 | METHOD AND EQUIPMENT FOR MONITORING SYNTROPHIC RELATIONS IN A BIOLOGICAL PROC | WO0201220 |
| 3 | ASSEMBLY FOR WITHDRAWING AND FILTERING PARTIAL VOLUMES OF PROCESS FLUID | WO0200324 |
| 4 | METHOD FOR TREATING BIOMASS AND ORGANIC WASTE WITH THE PURPOSE OF GENERATING | WO2006032282 |
| 5 | THERMOANAEROBACTER MATHRANII STRAIN BGl | WO2007134607 |
| 6 | METHOD AND APPARATUS FOR IN-FEEDING OF MATTER TO A PROCESS REACTOR | WO2010081476 |
| 7 | AN APPARATUS FOR RAPID MIXING OF MEDIA | WO2010081477 |
| 8 | TREATMENT, SUCH AS CUTTING, SOAKING AND/OR WASHING, OF ORGANIC MATERIAL | WO2010081478 |
| 9 | INCREASED ETHANOL PRODUCTION IN RECOMBINANT BACTERIA | WO2010010116 |
| 10 | THERMOPHILIC THERMOANAEROBACTER ITALICUS SUBSP. MARATO HAVING HIGH ALCOHOL P | WO2011076797 |
| 12 | MARKER-FREE DELETION | EP11171328.5 |
| 13 | PROCESS FOR THE PRODUCTION OF ETHANOL | PCT/EP2013/06798 |
| 14 | PINS-MDA | PA 2012 70822 |
| 15 | PINS-UNG | PA 2012 70823 |
| 16 | Marker-free genetically-engineered double mutants of Thermoanaerobacter | PA 2012 70824 |

The technology development and the results obtained have demonstrated that it is technically possible to obtain a high degree of utilisation of the biomass resource. However, the macro conditions, i.e. the very low oil price and the lack of substantial and firm political incentives, have shown that it is difficult to obtain a breakthrough for the industry with such conditions.

Through the FirstSugar™ process concept development it has been demonstrated that there are alternative approaches which combine two different sectors; the power plant (solid fuel pellet) and biofuels / biochemical sector. Provided that the conditions are right, the FirstSugar™ concept could very well be further developed and implemented in the future.

The Carbofrac® pretreatment technology is very universal, as it deals with biomass fractionation, why it is bound to be used for this application in the future, even though it may not be for biofuels due to the difficult economic conditions in this sector. The Pentoferm® fermentation technology is not quite as universal, but since it can convert all sugar types simultaneously it is an interesting technology for the future biofuels projects, both 1G and 2G, provided that the conditions are suitable.

As previously mentioned, the Carbofrac® technology is currently being implemented at Nova Pangaea Technologies in the UK at various scales. Also the worlds' larges ethanol producer evaluates a Carbofrac® pilot unit, and if it works to their satisfaction, the technology will be implemented in these two companies future demonstration projects.

### 1.7 Project conclusion and perspective

From a technical perspective, the project met some of the objectives; the pretreatment technology primarily developed during the first EUDP project (BornBioFuel1) was scaled-up, matured and an industrial design, which could form the basis of the first commercial production units, was achieved. Also, the Carbofrac® technology attracted much attention from various potential customers and partners incl. St1 (Finish oil company), Sweetwater Energy (US technology developer) and Green Biologics (UK-US fermentation company), all of which at one point in time were interested in contributing financially to the project as partners.

In addition, the Pentoferm® fermentation technology showed great promise and was like the Carbofrac® technology developed further, on the foundation of the BornBiofuel1 project, in order to address the industrial challenges ahead, when implementing new technology in a production setting.

However, for both technologies the lack of investments from strategic partners resulted in our failure to raise sufficient funds for the full CBF project. This happened even as the technology did show promise, and that the CBF project was seen as an important effort in the commercialisation of the technology. It had more to do with the lack of external conditions and drivers. As previously mentioned, the very low oil price makes 2G ethanol unable to compete on equal terms in the marketplace and the lack of politically driven financial support (e.g. taxation of fuels with higher carbon footprint, tax exemption of biofuels, loan guarantees or simply directly subsidised biofuels), has resulted in close to non-existing economic conditions, rendering the 2G ethanol business virtually unfeasible for the near future at least.

The whole biofuels sector has been the subject of several unfortunate macro conditions, since before the low oil price, it was primarily the global financial crisis, that held investments back.

The technology development under the CBF project was strongly supported by the EUDP grant, which has provided the possibility to investigate the potential both technically and economically.

Also, alternative solutions and economic sweet spots have been identified, which provides promise for a "biobased" future, also if the oil prices do not rise to the high levels previously seen in oil business. A spin off could very well be in the chemical sector, where the same technology can be used for creating biochemicals and materials, and the conditions, even though closely coupled to the oil prices, are somewhat more favourable. The primary reason for this is the value increase throughout the production chain is somewhat higher and the volumes required are somewhat less.

**Links**

BioGasol Website
http://biogasol.com

BioGasol Pretreatment Technology
http://biogasol.com/products

Estibio Fermentation Technology
http://www.estibio.com/products
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0136060

SBFC
http://www.simbhq.org/sbfc/

World Bio Markets
http://www.worldbiomarkets.com/

Nova Pangaea Technologies
http://www.novapangaea.com/