abowe
Implementing Advanced Concepts for Biological Utilization of Waste

ABOWE AND BEYOND

BALTIC SEA BIOREFINERY PILOTING 2014

Disclaimer
This publication has been produced with the assistance of the European Union (http://europa.eu). The content of this publication is the sole responsibility of authors and can in no way be taken to reflect the views of the European Union.

Baltic Sea Region Programme 2007-2013
Part-financed by the European Union (European Regional Development Fund)

Finnoflag Industry Like Nature®

SAVONIA UNIVERSITY OF APPLIED SCIENCES

CONTENTS

1 Preface

The Baltic Sea Region Programme is part of EU's Cohesion Policy. The programme is funded by the European Regional Development Fund (ERDF), one of EU's Structural Funds.

The transnational cooperation programmes support the establishment and development of transnational cooperation through the financing of networks and of actions conducive to integrated territorial development.

In the 2nd call the Baltic Sea Region Programme 2007-2013 funded under priority 1 (Fostering innovations) the REMOWE project (Regional Mobilizing of Sustainable Waste-to-Energy Production). The project was led by Mälardalen University (Sweden) and involved 9 partners from Sweden, Finland, Poland, Germany, Lithuania and Estonia. The project's total budget was 1,6 M€, of which 1,2 M€ was ERDF (European Regional Development Fund) funding.

Based on the results of REMOWE, the partnership applied successfully for the ABOWE extension project (Implementing Advanced Concepts for Biological Utilization of Waste). The extension project was led by the Savonia University of Applied Sciences (Finland) and involved seven of the nine partners in the previous project. The project's total budget was 2,0 M€, of which 1,6 M€ ERDF funding.

ABOWE is a high-priority project. In the assessment the ABOWE project scored high in all quality assessment criteria (e.g. high transnational relevance, clear description of the work plan, well defined roles of the partners) and had several strong quality features (investments of transnational value, financial actors from the private sector).

In granting Finnish State co-financing, the ministry appreciated the strong and relevant partnership and the anticipated concrete results in a highly prioritised field.

The project not only promised, but has also delivered. From the Finnish side we are very pleased with the outcomes so far and are willing to support further development work based on the project.

Harry Ekestam

Counselor of Regional Development
Finnish Ministry of Employment and the Economy

2 Introduction to ABOWE and Pilot A

Future biorefineries will work according to the principles of Nature, using microbes and enzymes for upgrading wastes and other biomass into biofuels, other energy substances, platform chemicals, and organic fertilisers. The concept of 'waste' will become unnecessary in industries, communities, agriculture and forestry since all materials are now being refined and recycled. The ABOWE (Implementing Advanced Concepts for Biological Utilization of Waste, 12/2012-11/2014) project and pilots, of the EU Baltic Sea Region Programme, have paved the way for this industrial revolution, as introduced in this brochure which summarizes the ABOWE project Pilot A activities.

The novel biorefinery concept (Pilot A), innovated and developed by Adjunct Professor Elias Hakalehto, Finnoflag Oy and the University of Eastern Finland, was one of the two platforms of ABOWE. The second platform was biogas dry digestion technology (Pilot B) piloted under the supervision of Ostfalia University of Applied Sciences, Germany.

ABOWE (Implementing Advanced Concepts for Biological Utilization of Waste) belongs to EU Baltic Sea Region Programme 2007-2013. ABOWE was an extension project for REMOWE project (Regional Mobilization of Sustainable Waste to Energy Production 9/2009-12/2012) to continue with two promising technologies to unlock investments.

Objective was to test

- Effective pretreatments and hydrolysis of various industrial and municipal wastes.
- Enhanced natural microbial bioprocess for the upstream production of fuels and chemicals.
- Preliminary planning of the simultaneous product collection.

The goals of the ABOWE project and the movable Pilot A manufactured in Finland by Savonia University of Applied Sciences was to provide "proof of concept" on the ways, how biomass waste materials could be used as raw materials. The products are biofuels, organic platform chemicals, renewable energy, fertilizers and nutrients. These are to be produced in an economically feasible way, with the help of micro-organisms.

Novel production principles have been tested in three countries on various different wastes. The biorefinery process' novelty is in improved productivity, low initial investment costs and versatile product repertoire. The production exploits results by the PMEU enhanced cultivation unit (Portable Microbe Enrichment Unit), and in larger vessels in the Finnoflag laboratory since 1997. When products are produced faster, the facility size reduces enabling lower investment. Moreover, the end product concentrations can be increased and the total duration of the process shortened.

Elias Hakalehto

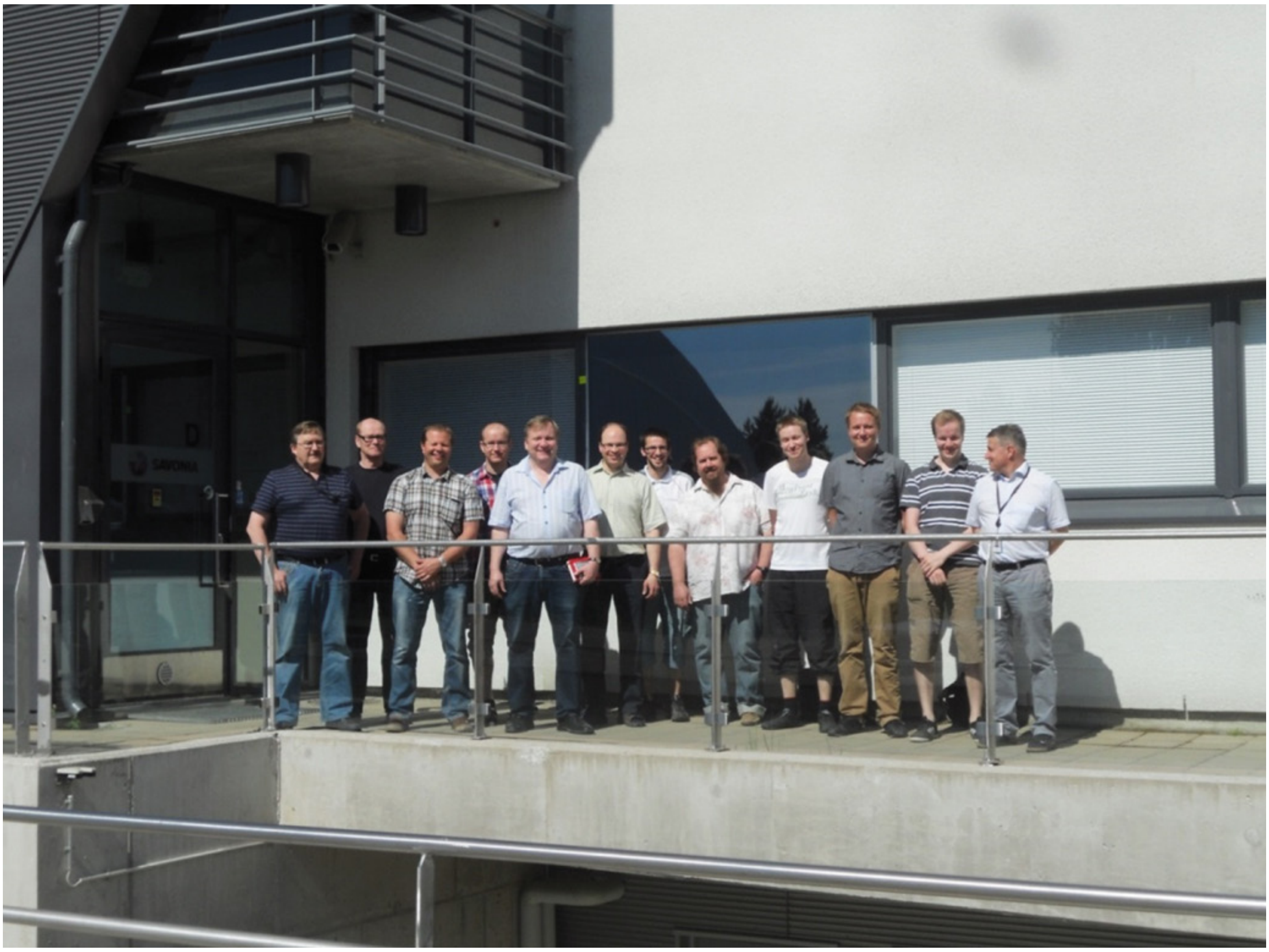
"Future biorefineries are industrial fields, where side streams from industries and municipalities are treated and refined into useful products in successive process solutions. All waste is then integrated as a raw material into them.

Birch tree is a valuable raw material also for the bioindustries. Photos of the trees by Vicente Serra.

Objective is to achieve industrial action which is implementing same principles that are maintaining the ecosystems. In the Nature there are not e.g. landfills anywhere, but all organic matter is recycled.

For ABOWE official Kick-off meeting in Kuopio February 2013 a draft lay-out of the Pilot A Biorefinery was already designed. Overall designing of novel biorefinery pilot plant's (Pilot A) bioprocess was conducted by Adjunct Professor Elias Hakalehto (Finnoflag Oy and University of Eastern Finland).

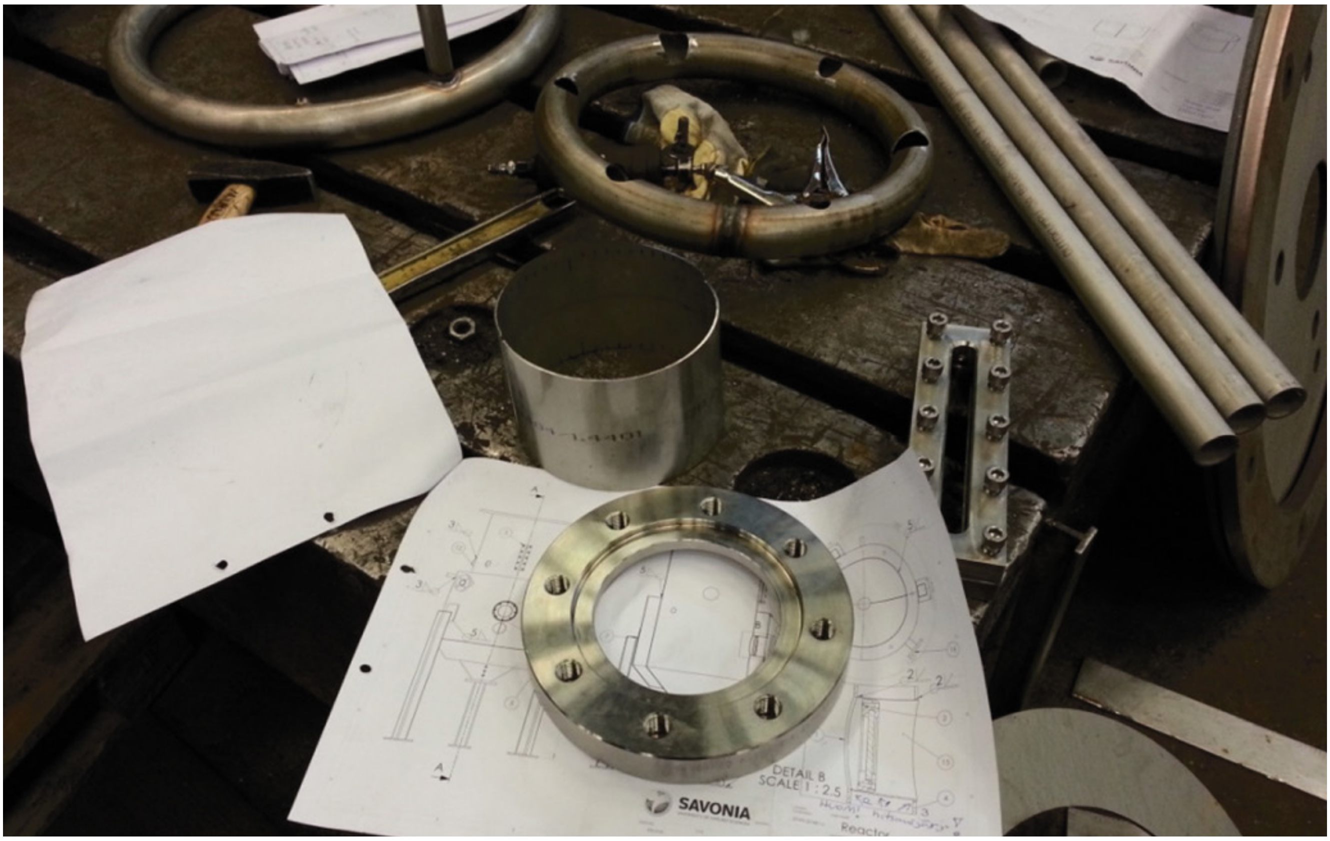
The Engineering team worked intensively during Spring 2013 and consisted of Finnoflag Oy, teachers, project engineers and engineering students from the Technology department of Savonia University of Applied Sciences as well as other companies.



Versatile engineering know-how from biotechnology, process and instrumentation, lay-out, mechanical, automation, electrical, IT and environment as well as manufacturing skills were utilized for the common goal. During ABOWE a joint team of about 50 experts have been participating in the planning and realization of the Pilot A.

Lead partner, Savonia University of Applied Sciences manufactured Pilot A in its educational workshop. In Pilot A manufacturing were participating as component suppliers many locally operating industrial and commercial enterprises. The first vessels were procured as recycled to be modified in the Savonia Welding Laboratory in Kuopio for their new uses as elementary parts of Pilot A.

An empty used 12 m long sea freight container was received just before Mid-Summer 2013. The place at Opistotie 2, Kuopio was very lively being in the middle of three educational institutions and a sports hall, having several hundred of passers-by daily during seven months.



BioReactor was manufactured by Brandente Oy in Kuopio according to the instructions of the innovator Adj. Prof. Elias Hakalehto of Finnoflag Oy and Technical Manager Anssi Suhonen of Savonia UAS. The patented design is based on numerous bioprocess runs in Finnoflag Oy's laboratory projects preceding the ABOWE project.

Savonia UAS students from versatile fields participated in many parts of the engineering, installation and testing phases. Also many trainees from Savo Vocational College, Finland participated in the manufacturing of Pilot A. For example, two electrical installer students were in charge of electrical and automation installations in the lead of an electrical engineering student and his teacher.

Autumn 2013 was a very intensive time for various installations. The mechanical process equipment was needed first to be installed.

Heating, ventilation and air conditioning (HVAC) installations were a major part and here was needed a local installation company which also got very interested about the novel biorefinery concept.

In January 2014 Pilot A was completed and was ready for the testing series in three countries within ABOWE.

Pilot A was moved in the coldest day of that Winter, -25°C.

Savon Sellu cartonboard factory's waste water treatment plant was the first testing site, for February-March 2014. The factory is using birch as the raw material for cartonboard.

The Operators’ Manual was compiled by the Engineering team with help from environmental technology students. Finnoflag Oy brought their microbiological and bioprocess know-how to the testing periods.

Training for the representatives of Polish and Swedish testing personnel took place in February 2014 in Kuopio.

Pilot A was transported to Lower Silesia, Poland for tests during May to early July 2014 with potato waste from chips production and municipal biowaste. Wroclaw University of Technology operated Pilot A tests together with Finnoflag Oy.

In Sweden Pilot A was tested at the Hagby's bird farm in Enköping with chicken manure and slaughterhouse waste during August-early October 2014. Mälardalen University operated Pilot A tests together with Finnoflag Oy and Savonia UAS.

3 Tests in Finland at Savon Sellu Oy cartonboard factory's waste water treatment plant

Savon Sellu Oy's cartonboard factory in Kuopio.

Dried waste water treatment sludge piled at Savon Sellu Oy's waste management area.

Products from the test runs in Finland were:

- Ethanol
- Butanol
- 2,3-butanediol
- Organic acids
- Hydrogen
- Fertilizer biomass
- Biogas
- Purified water
- Decreased waste treatment expenses
- Lesser environmental and climate load

During the testing at Savon Sellu waste water treatment site, the initial break-in test runs and international training periods were accomplished in January and February 2014. The first 3-4 runs were targeted, besides these objectives, for pretreating the available biomass material in the Pilot A installations. The test runs were both anaerobic and aerobic ones. In all cases, regardless of the hygienization during the hydrolysis step, the natural microflora from the activated pools, especially the sulphur bacteria, contaminated the bioreactor broth. They were then restricted by the inoculated *Klebsiella/E.coli* strains which were preincubated in the reactor as a nutrient bed type of inoculum. This same strategy was later used in the two anaerobic cultivations with *Clostridium sp*. In these runs considerable amount of hydrogen were formed, besides several biochemicals. However, the gas measurement on H_2 was restricted below 10 000 ppm which was exceeded many times during the runs. Therefore, the substantial potential of the biohydrogen production could not get estimated during ABOWE.

According to the GHG (greenhouse gases) analysis on the climatological consequences of the biotechnological processes, a combined production strategy including both biorefining of chemicals from biomasses and biogas process based on its residues could add value, if technologies applied together. This approach could also bring along an effective solution for eliminating the waste problems. In this case the biorefining and the downstreaming should take place preferably in a consolidated bioprocess (CBP) where the waste macromolecules would be hydrolyzed simultaneously with the actual upstream process. In case of Pilot A the hydrolysis was partially going on also after the transfer of the pretreated biomass waste from the hydrolysis tank into the bioreactor. Fast moving of the broth, where the biochemicals have been collected using the CBP principles, into the Pilot B type of biogas production unit from a Pilot A type of biorefinery, could contribute to the optimal result in the lowering of any climatological effect of the waste treatment. Then the remaining organic acids in the solid fraction could boost the biogas process. In fact, in the Swedish tests the using the digestate from the biorefinery process as a starting material for the biogas production after 3-4 days could improve the methane yield during 2-3 weeks. The elevated biochemical and gas production levels after optimization of the biorefinery could also produce improvement in GHG (Greenhouse Gas) reduction.

4 Tests in Poland at ZGO Gac Ltd's waste management centre

ABOWE representatives at ZGO Gac Ltd's waste management centre in Olawa, Poland.

24 students and six experts from Wroclaw University of Technology participated in the tests together with Finnoflag Oy.

In the experiments with sole Polish potato waste (consisting mainly of potato peels) ethanol was the principal chemical product, besides the high amounts of hydrogen produced from the waste for extended periods of time. The latter one was not measurable due to the limited capacity of the gas measurement unit. In any case, the hydrogen production exceeded 10 000 ppm for long periods of time during each run. It should be taken into account that this flow of volatiles was produced into a carrier gas flow which was not diminished in the calculations. In fact, the proportional hydrogen production was consequently on a much higher level.

In the beginning of the test runs in Poland it was believed that the heterogenous composition of sorted biowaste would disturb the process set up and control. However, this did not turn out to be a remarkable problem. Instead, the additions of miscellaneous food waste clearly boosted the production of various organic chemicals which reached a few percent of the total volume, and 15-20% of the dry weight. During these tests, as like at other experimental sites, the highest yields were not achieved or even tried to get achieved due to time limitations. In the future, efforts should be made also to concentrating the raw materials into adequately high substrate concentrations. However, with more time and some technical improvements into the Pilot A equipment, still much higher levels and productivities could easily get achieved. This is deducible also from the amounts of unused substrate in the process residues. However, even by the current experimentation several industrial levels of biochemicals were obtained.

The analysis results from on-site Gas Chromatography (GC) and the Nuclear Magnetic Resonance (NMR) studies, performed by Prof. Reino Laatikainen, School of Pharmacy, University of Eastern Finland, produced somewhat different results, in the former the levels being about 2-3 times higher. This is possibly due to the fact that samples for the NMR were stored in cold and transported to Finland, where they were analyzed much later on. It is then quite expectable that some changes could occur. Otherwise the NMR gave clear identification of the substances whereas the GC seemed to give some peaks close to each other which caused difficulties in identifying the compounds. This was the case especially with 2,3-butanediol and valeric acid, the latter of which was not expected to come out in the fermentation in large quantities. However, it was produced in high amounts. The same occurred in Sweden where it was also measured by NMR. This organic acid was probably resulting from the condensation of acetic acid (two carbon mo-lecule) and propionic acid (three carbon molecule). Both 2,3-butanediol and valeric (pentanoic) acid could be valuable products for producing butadiene (plastics, synthetic rubber) and in cosmetic pro-ducts.

Otherwise GC turned out to be a rather reliable method and it was successfully used in the Pilot A in all three series of experimentations (in Finland, Poland and Sweden). In all sampling and sample treatments it was important to separate the solids quickly enough for preventing any degradation caused by bacteriological activities. The amount of products bound to the precipitating solid fraction could not be analyzed, and in future applications this issue related to the separation of the products in the liquid forms needs to be studied further. In any case, the Polish experimentation indicated clearly the potential of the biorefinery concept for producing soluble chemicals for industrial raw materials, as well as for the hydrogen gas generation from these processes. In fact, the hydrogen production started quickly, and it was produced on remarkable levels even though that this flow was integrated into the carried gas.

5 Tests in Sweden at Hagby's bird farm

Group at Hagby farm in Enköping at 7:00 on 9.9.2014. From right to left: Fadi Atif Fakhir, Henny Andersson, Yuying Li, Anneli Heitto, Erik Dahlquist, Elias Hakalehto.

ABOWE representatives at Hagby farm in Enköping, Sweden.

During the tests at Hagby farm, some 30% of chicken slaughterhouse waste was mixed with other biomass. The latter were chicken manure from the farm, some saw dust used as litter in the bird shelters, and occasionally some waste apples available from the farm. Also some potato flour, sugar or blueberry soup were occasionally used as additives. During the testing considerable problems emerged due to the inability of the pumps to work on the sticking feathers, as well as with the small stones originating from the bird digestion. Even though the pumps had enough capacity for forwarding the biomass, they got easily stuck with these miscellaneous particles or substances. Therefore, the final density and dry mass content was too low for higher product yields. However, the proof of concept was clearly demonstrated, and valuable products formed within the limits of the raw material offered. It was possible to convert a tedious mixture of protein and lipid wastes first into yellowish milky broth were no particles were detected practically in overnight, and further to a solution of organic acids and alcohols. This could take place without significant loss in the dry weight of the soluble substances.

The slaughterhouse located some 40km from the testing site. Therefore the chicken inner organs and other remaining parts were cooled for transportation. This cooling was probably fast or not effective enough, and provided time for the mixed flora to develop too far for the optimal raw material use in the biorefinery. In order to boost the biochemical production after the hygienization (in the hydrolyzer), strains of *Clostridium acetobutylicum* and *Clostridium butyricum* were inoculated. It is noteworthy that these bacteria have been reported to withstand some oxygen occasionally, even though they are generally considered as obligate anaerobes. They also could stay active under 100% oxygen flow. This was used as a selective factor during the experimentation. Earlier it had been reported that the clostridial growth was boosted by CO_2 as well, which has been exploited for the rapid onset of growth. In some runs subsequent inoculations seemed to initiate the production of some chemicals which is implying to some quarum sensing type of signaling in the bacterial cultures. Also, addition of blueberry juice into some runs clearly had a positive boosting effect which is an indication of the need for some trace elements and minerals for best production levels.

The combination of 1. biorefinery process with subsequent 2. biogas production turned out a promising approach for treating this type of agricultural biowastes. Methane production from the biorefinery digestate was increased compared with the direct biogas production from the substrates. Hence, this combination of unit processes turned out a useful solution for the processing of biowastes.

Besides the expected products, short chained organic acids, hydrogen and some 2,3-butanediol, analysis by the NMR in Finland revealed some additional products such as valeric (pentanoic) acid and amyl alcohol. They were obtained partially from the apple waste, but could get produced also without the apples. In an overall consideration, the Swedish testing period gave a proof of concept on a reasonable method to deal with tedious wastes from slaughterhouse and bird farm in a short time. Also, a multitude of products could be obtained potentially from the chicken farm.

6 ABOWE Pilot A at Heureka

Introductory seminar and Investor event on Finnoflag Biorefinery Technology and the Pilot A was held on 25.4.2014 at the Finnish Science Centre Heureka, Vantaa. Research Manager Eero Antikainen presented Savonia UAS' activities in general, and Project Manager Ari Jääskeläinen presented the path of ABOWE Pilot A. Adjunct Professor Elias Hakalehto held the main speech about Finnoflag biorefinery technology and its impacts. Finland-scale feedstock potentials were introduced by researcher Tuomas Huopana, University of Eastern Finland.

Almost 90 interested stakeholders and potential investors participated and approximately dozens via livestreaming. Pilot A was shown in Heureka's exhibition yard.

Based on the first testing period the concept was presented as a potential application to deal with community and industrial organic wastes in a way, where they could be converted into useful products by microbiological processes. Resulting biofuels and chemicals could then turn the economics of waste treatment very much on the positive side, not to mention the sustainability effects.

From the ABOWE web-site can be downloaded the programme and the presentations can be watched as videos.


BIO
REFINERY
JALOSTAMO


SAVONIA
Finnoflag
REFINERY
JALOSTAMO

7 ABOWE Pilot A in Viikki and Gardenia

Another public presentation of ABOWE Pilot A was during the Concluding seminar at Helsinki University Viikki campus on the 30th of October, 2014.

In the Concluding seminar the test results were heard from three countries (Sweden, Poland, Finland) as well as future trends of biorefining. The topic was “Biorefining around the Baltic Sea and Global Ecodevelopment“. The topics integrated the regional and global aspects of developing biorefining. Then acting locally would produce global ecodevelopment.

The seminar was held in Lecture Hall 1 of the B-Building of Helsinki University. The exhibition of Pilot A was organized in the area of Gardenia Tropical Garden.

From the ABOWE web-site can be downloaded the programme as well as the presentations of this event and the presentations can be watched as videos.

The announcement was published in the national newspaper Helsingin Sanomat and local newspapers in the whole Helsinki metropolitan area.

Adjunct Professor Elias Hakalehto (left) and Project Manager Ari Jääskeläinen.

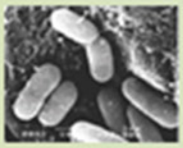
Pilot A was exhibited in the yard of Gardenia Tropical Garden for all passers' by and invited stakeholders.

BIOREFINERY TECHNOLOGY

RESEARCH IDEA

Utilization of the metabolism of the invisible microbes (and their enzymes)

- bacteria
- yeasts
- molds
- algae
- protozoa



TOOLS

Biorefinery concept, where biological components and technological solutions have been developed hand in hand.

GOALS

Production of

- Energy
- Fuels
- Bulk chemicals
- Nutritional components
- Cosmetics
- Medicinal substances
- Purified water, air, soil

Industry Like Nature®

In :"Biorefining around the Baltic Sea and Global Ecodevelopment"
Elias Hakalehto, Viikki 30.10.2014

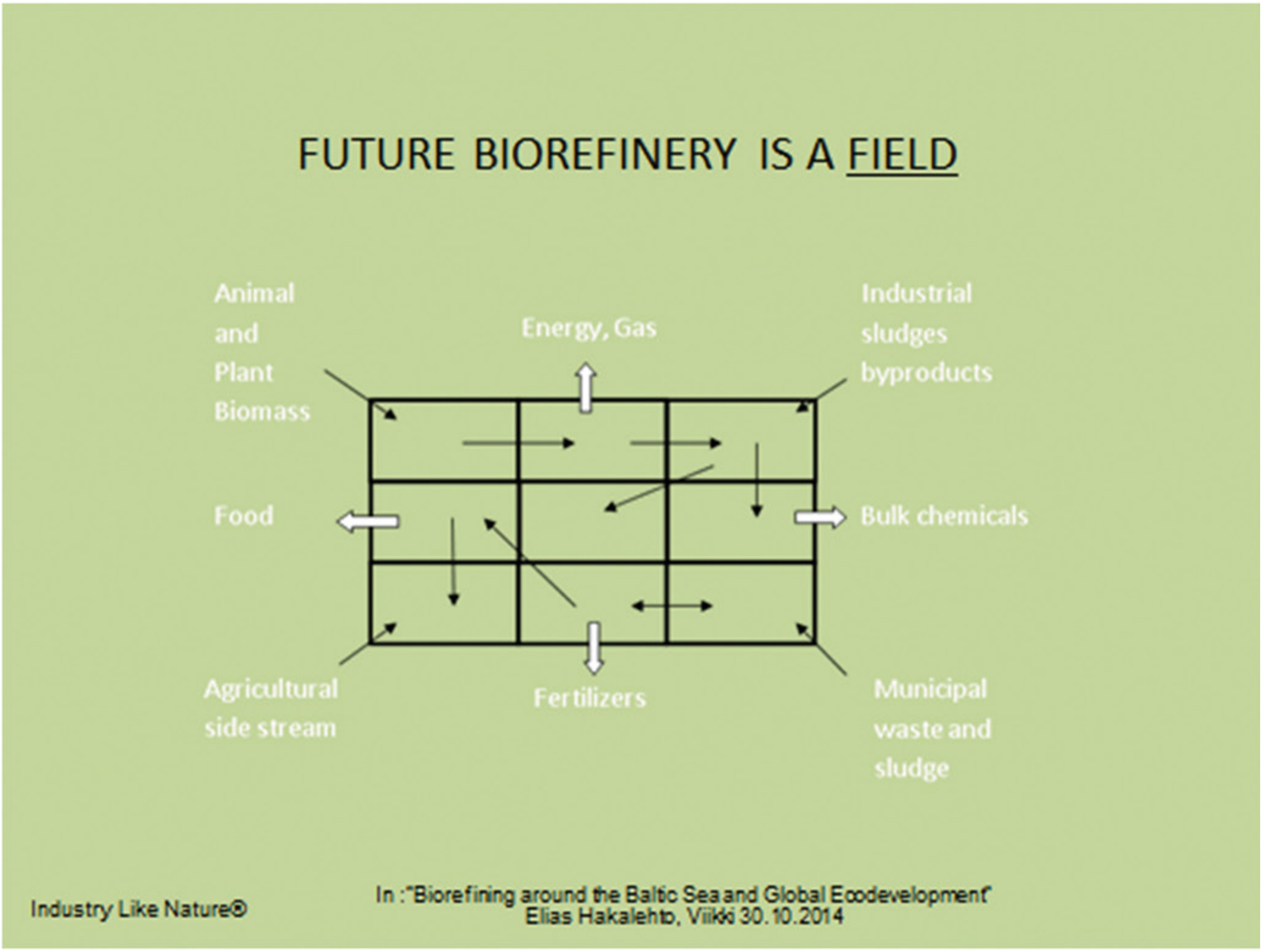
POTENTIAL AS HYDROGEN FUEL ACCORDING TO PRELIMINARY TESTS ONLY

FROM SAVON SELLU FACTORY WASTE WATER TREATMENT →

PROVISIONAL H_2 (HYDROGEN) PRODUCTION/DAY CORRESPONDING TO 10 000 -20 000 KM WITH A FCV (Fuel Cell Vehicle). THIS VALUE WAS OBTAINED AS "NATURAL GAS FLOW" FROM THE BIOWASTES.

Industry Like Nature®

In :"Biorefining around the Baltic Sea and Global Ecodevelopment"
Elias Hakalehto, Viikki 30.10.2014



Global biomass production

Today´s biomass production appr **160 000 - 270 000 TWh/y**

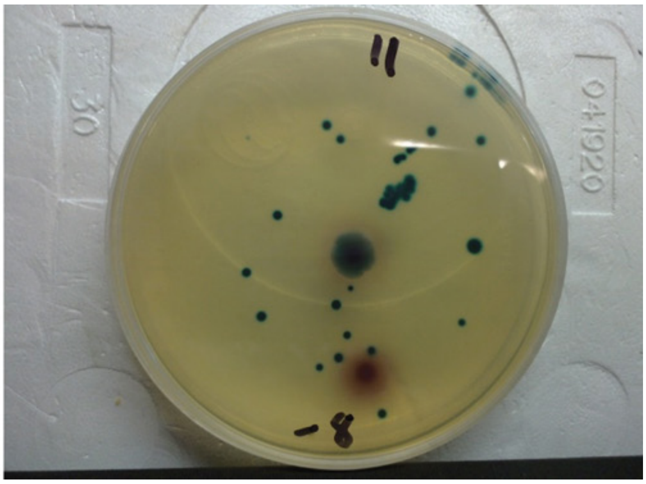
– agriculture incl straw 95 000 - 190 000
– forests 65 000 - 80 000

This can be compared to the **150 000 TWh** energy used today per year

Professor Erik Dahlquist, Mälardalen University

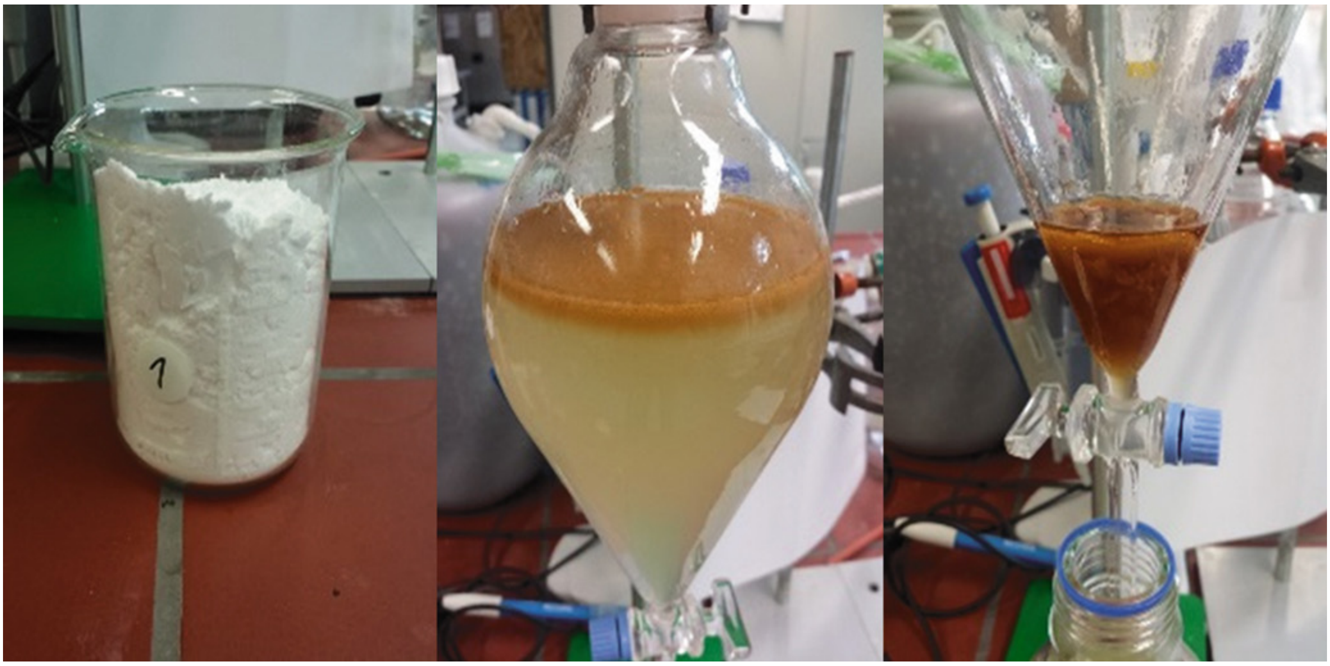
8 Product formation and Downstream

Product fluid in a decanter at Ostfalia.



Bioprocess bacteria. Each colony represents 100 million cells in a ml of the process broth in the ABOWE Pilot A process run.

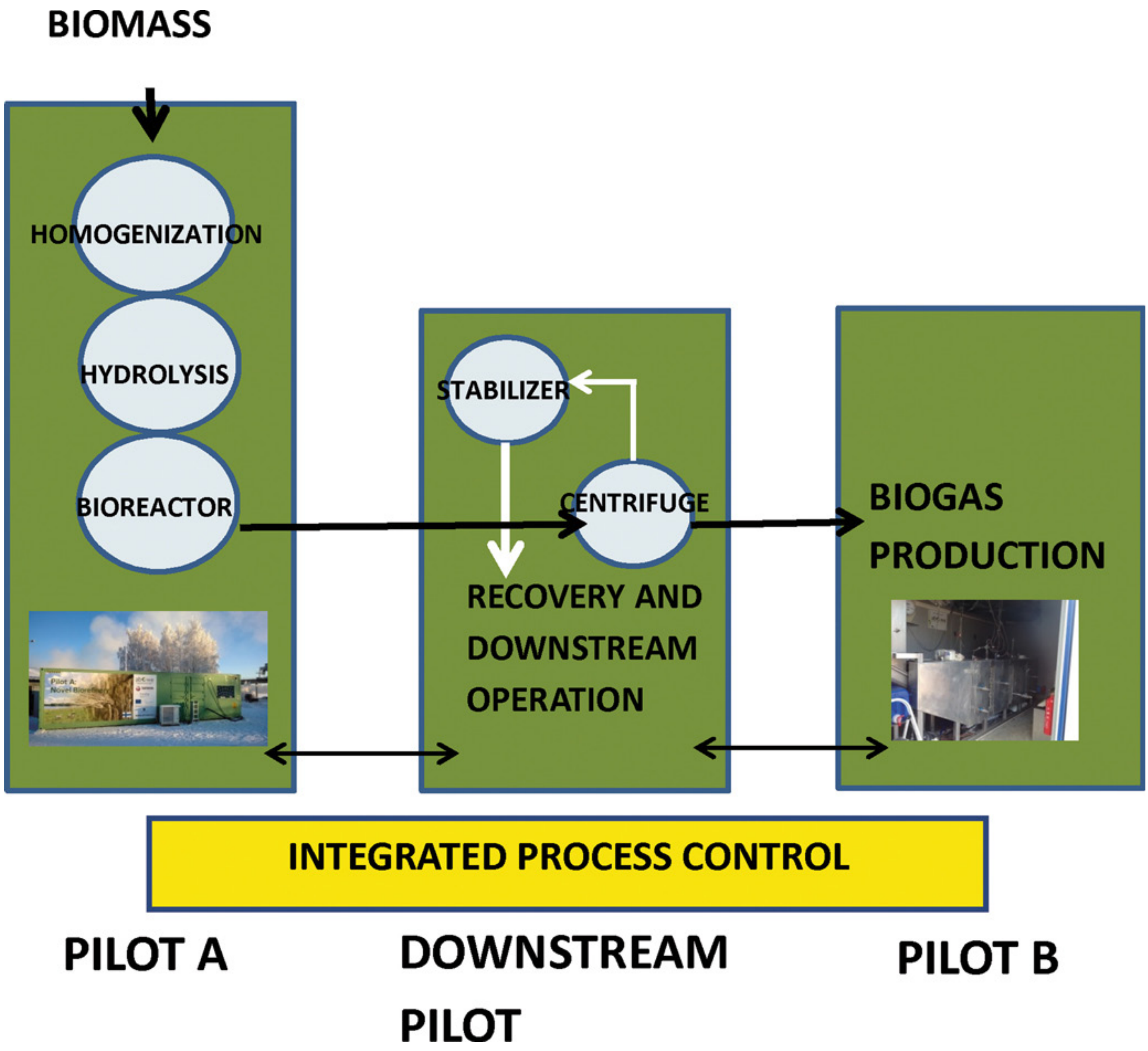
Laboratory Manager Anneli Heitto, of Finnoflag Oy, using the Gas Chromatography equipment in Pilot A at Savon Sellu Oy.



Downstream techniques have been developed in cooperation with Ostfalia University of Applied Sciences from Germany. Salting Out Extraction was tested for 2,3-Butanediol.

9 Future plans: three pilot plants

One basic idea is to combine the above described upstream process with a parallel downstream operation(s). This helps to avoid biological regulation mechanisms of the production organisms, since the products are recovered at the same time as they are formed into the process broth or suspension. Then the end-product inhibition or other suppression mechanisms of the cell metabolism cannot influence the result. Therefore, it is also possible to achieve higher productivity in the bio-processing using the concept of Consolidated Bioprocessing (CBP). The following figure depicts the process in detail:



Various biomass rounds need to be re-circulated in the process after the valuables have been collected from them. The entire bioprocess also needs to be operated in a continuous or semi-batch mode. New raw materials are fed in gradually. This new level of functionality requires more advanced planning, selection and construction e.g. of the pumping and other technical 29 equipment, as well as process control system where the recovery operations for the down-streaming have to be interlinked with the real-time data on the product formation.

As a result practical solutions where any biomass waste can be converted into valuable energy products, chemical raw materials, or fertilizers can be obtained. Also thermal energies are produced in the process. In the heart of the operations is the consolidation of up- and downstream processes under effective automation and operator control. The human factor as the supervisor for the system is required during the runs, since we deal with biological materials whose behaviour cannot be fully predicted. However, a practical way to convert any organic waste treatment unit into an ecologically and economically feasible industrial unit can be made conceivable and achievable using the natural microbes, their metabolism and enzymes for the process design.

Besides achieving the scientifically ambitious objective put forward in the previous passage, the solution has also to be economically feasible and viable, to obtain the desired objectives of "valuable products". Therefore also various sophisticated data-analysis and processing methods have to be used in combination with the ones previously described.

10 PROOF OF TECHNOLOGY
- Ecologically sustainable is also economically feasible

It is important to pay attention to the preliminary nature of the experiments. Nevertheless, a Proof-of-Concept actualized in all three countries with three different biowaste mixtures. This gives a sound basis for future developmental work on the basis of the novel biorefinery technology concept using the undefined microbes together with some known strains for the production of chemical goods in a low cost non-aseptic environment. Such arrangement underlines the sustainable values combined with reasonable investment and operation costs.

In order to enhance further the yields and productivities of the biorefineries specific attention should be paid to the bioprocess on the following points based on the experiments with ABOWE Pilot A:

- increasing dry weight
- improved bioprocess storage of the raw materials
- consolidated bioprocessing: simultaneous hydrolysis with the upstream reactions
- combining upstream and downstream activities
- integrated R & D system for 1. upstream process, 2. downstream process, and 3. biogas production (Pilot B)
- elevating the concentrations of readily usable carbohydrates in the bioprocess

Besides the intensified energy production from the organic wastes, which are facilitated by interconnected, interlinked and intercontrolled biological units, the biorefineries produce utilizable chemicals, whose value could be as high as up to 2000 € per ton in the case of 2,3-butanediol, or up to 5-7000 € per ton in case of valeric (or pentanoic) acid. These types of chemicals are being produced together with many other alcohols or organic acids, which could be converted into energy or into useful platform chemicals for the industries.

On the basis of above-mentioned economic values, theoretical calculations could be facilitated. For example, if some biorefinery broth resulting from glucose-rich biowaste could be used as a raw material for 2,3-butanediol production with possible recycling of carbon oxides, this could facilitate roughly 30% conversion of the dry weight substances (15%) into the product. This sums up to about 5-10% of the dry weight into the products (e.g. ethanol and hydrogen besides the 2,3-butanediol). If 5% is 2,3-butanediol, every volumetric ton of waste could produce 50 times 20€ during the process time (approximately 24 hours). This productivity had been enhanced to 8 grams per liter per hour in previous experiments with potato waste in the Finnoflag laboratory, and it could be further elevated by:

1. consolidated bioprocessing (hydrolysis combined with biochemical synthesis)
2. simultaneous downstreaming
3. recycling of volatile emissions

During ABOWE Pilot A runs in Poland some 2,3-butanediol was formed, but it was approximately 10% of the concentration of the valeric acid at best according to the NMR (nucleic magnetic resonance) imaging. Butyric acid and ethanol yields were also remarkable. The reason for the relatively low yields when compared with earlier studies was the dilute biomass raw material from which almost all utilizable glucose was exhausted too swiftly. In any case, a remarkable proportion of the dry weight (15-20 %) was collected as useful products. In the Finnish and Swedish tests, the 2,3-butanediol was also found in relatively small concentrations due to the same reason. In Sweden, higher levels of valeric acid were measured, besides some other organic acids.

In fact, the valeric acid (being more valuably priced than 2,3-butanediol) could also be used as a platform chemical from waste utilization bioreactions. As like 2,3-butanediol, it could be also used as substrate for 1,3-butadiene (leading to synthetic rubber and plastic monomers). Valeric acid is microbiologically formed as a condensate of acetate and propionate. If we repeat the theoretical calculations above, and carefully estimate its potential yield to be 2% of total process suspension, the resulting economic output could reach 20 times 50€, making also 100€ per ton in a day, as purified chemical substrate. This equals with the theoretical economic output of 2,3-butanediol production. This output was given a proof in the Polish tests at the ZGO Gac Ltd. waste management centre near Wroclaw in Lower Silesia during two month testing period as a result of cooperation of Polish and Finnish teams.

In budgeting bioprocesses, these economic calculations should take into account the relatively high recovery and purification costs (downstream processing) of the biochemicals. During ABOWE, this was also paid attention to in a parallel downstream experiment in Ostfalia University of Applied Sciences, Germany, where novel method for 2,3-butanediol downstream process was developed and successfully tested.

The rapid conversion of relatively difficult organic mixtures, e.g. proteins and fats in Swedish tests, or lignocellulosic substances with high sulphur content in the Finnish tests at Savon Sellu factory in Kuopio, was drafted, carried out and reported during the approximately two month testing period in each country. In Enköping, Sweden, similar productivities for valeric acid as measured in the Polish tests were achieved by cooperation between Swedish and Finnish teams. The valeric acid measurement, as well as other confirmation of the on site chemical tests in Kuopio, Silesia and Enköping by Pilot A gas chromatography was carried out at the School of Pharmacy of the University of Eastern Finland by Prof. Reino Laatikainen.

In the biowaste homogenisation and pretreatment, commercial enzymatic products were utilized besides the natural activities of the biomass microbes. The results were promising, with the formation of homogenous solutions or suspensions practically in overnight. However, the attempts to elevate the levels of glucose and other sugar monomers in the broth were left underway at each testing site during the two month testing periods. In any case, the inadequacies seemed to be possible to get overcome by careful planning of waste mixtures, better transport and storage conditions for it, as well by improved construction of the piloting/full scale production units. These could be further developed in future experiments.

One main purpose of the ABOWE project was to introduce some unique and innovative features into microbiological biorefining, such as

- use of undefined microbe cultures (UMC)
- fortification of the inocula with UMC with known production organisms
- selection of active microbial strains with gas applications
- search for novel products by the NMR (Nucleic Magnetic Resonance)
- rapid conversion of mixed organic wastes into useful substances
- consolidated bioprocessing (CPB) involving hydrolysis directly linked with the actual bioreaction
- remote satellite controlled processes
- simultaneous collection of products with the upstream production

In fact, the two last objectives were not fully achieved, due to technical obstacles. For example, IT connections to the testing sites in Poland or Sweden did not work without disturbances.

The product level optimization during the two month testing periods at each location would not have worked out properly. Therefore, main focus was in giving a proof of technology on the basic principles of the novel technologies.

Summa summarum, during ABOWE experimentation in three Baltic Sea countries, it was demonstrated that biorefining and biogas production from biowastes could be planned as an economically feasible integrated process from miscellaneous organic sources. This could be achieved regardless of the country or waste type, and the outlines of the production reactions were documented in the various test runs in different countries. Naturally, there is a lot of room for technical improvement of the facilities, biomass pretreatments, and other arrangements of the runs, but the limitations in time for the testing periods left optimization work to be carried out in future projects.

11 Full-scale Biorefinery plant's pre-engineering and investment calculation using Savon Sellu fluting factory's waste treatment as an example

Pre-Engineering work of an industrial scale biorefinery was done based on Savon Sellu's annual waste water sludge amount, 30 000 t/a (25 % Total Solids). The biomass which was used during the pilot tests was the dried sludge from the waste water treatment plant which consists of:

- Surplus of pulp factory's circulating water
- Hard wood pulp reject
- Flue gas scrubber's washing waters
- Surface waters of the sludge field
- Factory's sanitary waters

The aeration process of the active sludge treatment plant reduces the amount of valuable chemicals that can be recovered; therefore this study will concentrate on a solution where the biomass will be collected from the vertical clarifier surplus, before the active sludge treatment. In the calculations, it is assumed that we can collect equal amount of dried sludge compared to collected sludge from the present waste water treatment plant.

Investment cost for an industrial scale biorefinery based on ABOWE Pilot A technology was calculated by M.Sc. Jyri Pelkonen from Pöyry Finland Oy. Technical initial values and the process description was given by M.Sc. Anssi Suhonen of Savonia UAS. The microbiological process is invented and patented by Adjunct Professor Elias Hakalehto, Finnoflag Oy.

Overall estimate of the investment requirement of the whole plant (30 000 t/a)

Construction work	2 340 000 €
Machinery and equipment	1 410 000 €
Electric, automation and instrumentation	550 000 €
Overhead costs (app. 15 %) including engineering and erection work	650 000 €
Cost booking (app. 15 %)	660 000 €
Indirect costs	1 300 000 €
Biorefinery total	5 600 000 € (not including vat.)

The pre-engineering was done based on the results of the pilot runs performed between February and March, 2014. The technology is new and the dimensioning of the plant is based on the data received from Savon Sellu, Finnoflag Oy and Savonia UAS. Pöyry's expertise and design experience of different bioprocesses and sludge fermentation was used in the dimensioning principles.

The crucial factors in plant operation that have risen up during the pre-engineering phase were:

- handling and pumping of sludge at 10 … 15 % TS higher dry mass content
- energy consumption and recovery in sludge heating and cooling
- bioreactor design with internal chambers in pool shape reactors -> higher TS%
- air lift principle in fermentation works when dry mass concentration is at levels of 4…6% TS
- the operational costs of liquid nitrogen and carbon dioxide will be approx. 50 …60 000 €/a
- bioreactors’ mixing using only nitrogen in large reactors
- handling of sludge residue left over after the bioprocess
- collection of biogas for energy use in post treatment of sludge
- scaling up pilot A’s technology and technical solutions for a full scale plant

The result of the pre-engineering has still some assumptions in technological solutions and cannot therefore be precise in all aspects. The investment calculations have approximately a 30 % deviation on accuracy. The downstreaming process for chemical recovery has not been included in these calculations.

PÖYRY

12 PROLOGUE: PROOF OF TECHNOLOGY

During the ABOWE Pilot A experimentation it was possible to give a three time proof of concept with various biowaste. It could be documented that the process optimization could take place in the next phase with some tested principles. Also several improvements to the equipment were suggested. Consequently, it could be stated that Pilot A biorefinery pilot could operate as an upstream biorefinery for all kinds of organic wastes. The microbiological processes are operable. Best results could be obtained by connecting this unit to simultaneous downstream processing, and biogas production, such as ABOWE Pilot B. This overall concept of Pilot A turned out functional at all three different Baltic Sea countries (Sweden, Poland and Finland), and technological cooperation was established between different institutes, also with Ostfalia University of Applied Sciences in Germany. The Pilot B was successfully tested in Lithuania, Estonia and Sweden. Many potential testing sites for future studies have emerged during the testing period, and this concept of microbial biorefinery technologies has given the proof of technology during the ABOWE project. The sustainable aspect was also fulfilled. Joint efforts of the Baltic Sea Region's ABOWE community in six countries was taking part in refining the technologies and in estimating their impacts.

Aspects of sustainability in ABOWE biorefinement

Since the biorefinery trials with Pilot A and Pilot B used local waste materials as substrates, no transportation or combustion of fossil fuels was required for that part. Also other transportation of substrates becomes unnecessary, provided that the sources were converted into energy at site. Therefore, the actual idea forming about the energy balances according to the piloting experiments could be divided at least into five basic parts:

1. utilization of biomethane and biohydrogen from the wastes
2. solvents and organic mixtures from biorefining are combustible
3. co-combustion of some solid fractions from or outside the process
4. recirculation of the incineration outflow gases into bioreaction, e.g. carbon oxides
5. collection and reuse of the thermal energies from the industrial or waste treatment processes

These above-mentioned novel ways should be implemented into the planning and implementation of any new facilities planned to deal with industrial (or municipal) organic wastes. In such arrangements, the microbes are circulating, besides the substances, also in a way the chemical energies bound to them. This makes the emissions, their climatological consequences and environmental burden all the way declining. The ABOWE piloting has revealed the potential of total planning in biotechnical waste utilization and bioprocess design. For instance, the residues from the Pilot A type of biorefinery could be effectively used as raw materials in the Pilot B type of dry digestion biogas unit. This was confirmed e.g. by the results from the Swedish tests. Any solid fractions could then be used as organic fertilizer, composted or combusted, depending on the type of the particular fractions. Gaseous emissions could be at least partially redirected into the biorefinery, with the recollection of their thermal and chemical energies. The carbon oxides, and some volatile nitrogen compounds, for example, could then be bound into the biomass in the Pilot A type of biorefinery.

Besides the industrial or municipal biowastes, also agricultural wastes could be recycled according to the ABOWE experiences. Then the organic fertilizers potentially are produced from the biological process e.g. as precious wastes could be returned back to the cycles in the fields and forests. This type of mineral addition is associated with the organic molecules, thus being slowly liberating source of power and building blocks for the farm or forest vegetation. In future, the industries will be interlinked with the agriculture and housing on the basis of the networks of circulating substances and of liberating chemical energies, as well as reducing gas emissions.

In case of recycling the biomasses in the ABOWE way from industrial, municipal or agricultural sludges, also the microbial cell mass load to the environment could be restricted, as the microbial biomass is being reused effectively in the combined biorefinery, biogas production, organic fertilizer output and combustion operations. This would further lower the effects of human activities on the ecosystems.

ABOWE won the Finnish KÄRKI (SPEARHEAD) competition

ABOWE project was chosen as the winner among the projects of all Finnish universities of applied sciences in the series Soveltava tutkimustieto ja innovaatiot (Applied Research Knowledge and Innovations) in the national KÄRKI (SPEARHEAD) 2014 competition.

The Award was announced on 13.5.2014 at Sibelius House in Lahti as part of the Evening Gala of national Universities of Applied Sciences Days. Project Manager Ari Jääskeläinen from Savonia University of Applied Sciences received the Award on behalf of the whole ABOWE team. He also brought greetings from Adjunct Professor Elias Hakalehto who was participating in Biotech Japan 2014 Conference.

All ABOWE Reports available

ABOWE Pilot A and Pilot B Manuals, Technical reports from each testing country, Proof of Technology reports, reports from regional modelling as well as Investment memos are publicly downloadable at the ABOWE web-site

www.abowe.eu

References on the background of Pilot A

Hakalehto E., Humppi T., & Paakkanen H. (2008). Dualistic acidic and neutral glucose fermentation balance in small intestine: Simulation in vitro. Pathophysiology 15, 211-220.

http://www.pathophysiologyjournal.com/article/S0928-4680(08)00028-X/abstract

Hakalehto E., Jääskeläinen A., Humppi T., Heitto L. (2013): Biorefineries using waste – production of energy and chemicals from biomasses by micro-organisms. In Dahlqvist E (Ed.): Biomass as Energy Source: Resources, Systems and Applications. CRC Press, Taylor & Francis, London, UK.

Thorin E., Ahrens T., Hakalehto E., Jääskeläinen A. (2013): Organic waste as biomass resource. In Dahlqvist E. (Ed.): Biomass as Energy Source: Resources, Systems and Applications. CRC Press, Taylor & Francis, London, UK.

Dahlqvist E., Hakalehto E., Silveira S. (2013): Concluding remarks and perspectives on the future of energy systems using biomass. In Dahlqvist E. (Ed.): Biomass as Energy Source: Resources, Systems and Applications. CRC Press, Taylor & Francis, London, UK.

All: http://www.crcpress.com/product/isbn/9780415620871

Hakalehto E. (2015): Bacteriological indications of human activities in the ecosystems. In Armon R. & Hänninen O. (Eds.): Environmental Indicators. Springer, Dordrecht, Germany.

http://www.springer.com/environment/pollution+and+remediation/book/978-94-017-9498-5

Hakalehto E. (2015): Enhanced microbial process in the sustainable fuel production. In Jinyue Y. (Ed.): Handbook of Clean Energy Systems, part 1/6. Wiley-Blackwell, J R Wiley, New York, USA. Print due May 2015.

http://eu.wiley.com/WileyCDA/WileyTitle/productCd-1118388585.html

Hakalehto E. (2015). Editor in the series: 1. Microbiological clinical hygiene, 2. Microbiological food hygiene, 3. Microbiological industrial hygiene, 4. Microbiological environmental hygiene. Nova Science Publishers, Inc. New York, USA.

Lõõnik J. et al. (2012). REMOWE Report 4.3.1. Guidelines on action plans and strategies to mobilize waste-to-energy production. http://www.remowe.eu

Vicente Serra