FINAL PUBLISHABLE REPORT

CONTRACT N°: ENK6-CT-2001-00518

PROJECT N°: NNE5-2001-00067

ACRONYM: AMONCO

TITLE: Advanced prediction, monitoring and controlling of anaerobic digestion processes behaviour towards biogas usage in Fuel Cells

PROJECT CO-ORDINATOR: PROFACTOR Produktionsforschungs GmbH

PARTNERS:

- Institute for Applied Microbiology, University of Agricultural Sciences (IAM)
- farmatic biotech energy ag (farmatic)
- Matadero Frigorífico del Nalón (MFN)
- SARIA Bio-Industries GmbH (Saria)
- GasCon ApS (GasCon)
- BIOGAS Barth GmbH (Barth)
- EBV Management Holding AG (EBV)
- Energieverwertungsagentur – the Austrian Energy Agency (EVA)
- Consejo Superior de Investigaciones Científicas (CSIC)
- Seaborne Environmental Research Laboratory, Ges. für Umwelttechnik mbH (Seaborne)
- Slovenská poľnohospodárska univerzita v Nitre (Uni Nitra)

REPORTING PERIOD: FROM 01.12.2001 TO 30.11.2004

PROJECT START DATE: 01.12.2001 DURATION : 36 months

Date of issue of this report: **28.01.2005**

Project funded by the European Community under the ‘Energy’ Programme (1998-2002)

1 Table of contents

2 Executive publishable summary

Objectives

AMONCO aims at the cost-effective utilisation of Biogas from the Anaerobic Digestion (AD) in Fuel Cells (FCs). The precondition for the use of Biogas in FCs is the avoidance, or elimination respective reduction of detrimental trace gases, which are potentially harmful for FCs. Thus AMONCO has the following core objectives:

a) Comprehensive Biogas analyses in quality and quantity on a detailed level - identifying harmful trace gases for FCs, b) Avoidance of detrimental trace gases in Biogas through optimal composition of the feedstock, c) Advanced controlling of the AD process to hinder the formation of trace gases while keeping a high CH_4 yield, d) Suitable and cost-effective Biogas Cleaning towards the utilisation in Fuel Cells, e) Investigation and Assessment of the effects of Biogas in FCs through Single Cell tests and f) Development of techno-economic implementation strategy for the candidate countries.

Description of work

The proposed RTD-work is twofold: A knowledge based Decision Support Tool (software) with the capability to predict trace gases in dependence of the fermented substrates and a cost-effective Cleaning Process removing the significant trace gases must be developed. It starts with a comprehensive and systematic analysis of the AD process incl. fermentation tests at laboratory scale. The experiments have the purpose to provide consistent data series as the basis for the training of a neural network which is best suited for predicting trace gases in Biogas. While the first feature of the DST is to avoid trace gases from the start, the second feature is the ability to in-situ control the AD-process towards lowest concentration of trace gases while keeping a maximum yield of CH_4. Finally the DST will be continuously improved and validated at five industrially scaled Biogas plants. Also a cost-effective cleaning process at laboratory scale will be developed to remove trace gases such as halogenated hydrocarbons or siloxanes. The investigation of the effects of Biogas on the different FCs will be assessed through Single Cells tests.

Achievements to date

For starting modeling and controlling the anaerobic process, a lot of data must be produced first. Therefore laboratory reactors are operated by partner IAM and Profactor. Two fuel cell stations has been designed and constructed by partner CSIC and the planned experiments were carried out. Profactor has done the analytical method development for a comprehensive Biogas analysis. And almost all partners were involved in an intensive study about available sensors for implementing on biogas plants. The biogas plant operator has collected the necessary data for training the neural network and IAM has developed the DST. Partner Seaborne and Profactor have tested new biogas cleaning processes. And economic feasibility studies were worked out.

Expected end results

The expected end results of the project are to achieve viable controlling of the AD-process through the DST and viable prediction of trace gases depending on the used biomass. Additional it is expected to develop cost-effective Biogas cleaning processes to remove trace gases and recommendations regarding the FCs Balance of Plant.

Intentions for the Use of results

The dissemination activities and deliverables are intended to target three dissemination levels having different impact for implementation: scientific community, industrial players and public bodies/authorities. One focus lies on the identification of key market barriers for the implementation of RTD results into competitive markets and the formulation of strategies to overcome identified barriers.

3 Publishable synthesis report

3.1 *Objectives and strategic aspects*

Scientific/ technological objectives

Trace gases like H_2S, mercaptanes, halogenated hydrocarbons, siloxanes, etc. frequently occur in Biogas with co-fermentation. Those trace gases are detrimental for Fuel Cells and significantly lower their durability. The scientific and technical objectives of AMONCO are focused on the necessary Biogas conditioning for the wide spread utilisation in FCs. Consequently a comprehensive investigation for trace gases in Biogas must be performed first, because no such data exist until now because of a lack of technological relevance. Only now, where those trace gases are crucial for the utilisation of Biogas for FCs a technological reason is given. For the purpose of the construction of an adjusted cost effective Biogas cleaning system the knowledge about the occurrence and formation of those trace gases is essential, too. Else, there is no tool available for the assessment whether a new substrate can be safely used in the Biogas plant. The successful management of these critical loading conditions is of high relevance for the economy of industrial applications of the AD process. Therefore the nucleus in AMONCO will be the training of an artificial neural network. By such a mean the necessary supervision and control of bioprocesses can be realised. The advantage of neural networks for bioprocesses is that they do not require any prior knowledge about the structure of the relationships that exist between important variables. In a first step it is necessary to specify the architecture of the net, and to feed it with sufficient and consistent information. Subsequently the system is able to learn the input-output relationships. As the neural network will be the basis for the Decision Support Tool, the quality of such a neural network depends on the consistency of data.

Socio economic objectives and strategic aspects

The project is expected to secure employment in renewable energy industries, in agricultural structures as well as in the Fuel Cell industry within the European Union and its new associated countries. A successful outcome to the project will provide the enabling technologies for a new generation. The partners will improve their competitiveness and increasing employment levels. A large expansion potential can be seen in Spain, which is shown in the results of the work done by Volker Jaensch in his MBA dissertation “Marketability Analysis for an Innovative Fuel Cell / Biogas Technology in Spain”. AMONCO contributes strongly to the EU policies in the energy and environmental sector. In the White Paper “An Energy Policy for the European Union” three key energy policy objectives are defined: improved competitiveness, protection of the environment and security of supply. The project complies with all of them by opening a new market in the relevant sector, by using biogas as a renewable source of energy and finally by improving the security of supply in the rural areas by combining Biogas and Fuel Cells. The project also complies with the Green paper for a community Strategy: Energy for the future: Renewable Sources of Energy, [Brussels, 19.11.1996 COM(96)576] which encourages actions as improvement in market penetration of Renewables. AMONCO also contributes to increase by the year 2010 a level of 12% of gross inland energy consumption of Renewable Energy. AMONCO contributes to the “AGENDA 2000” – Commission proposals in the area of rural development, where measures in particular promotion of agro-environmental activities are mentioned. This project also complies with the Kyoto objectives which implies for the EU a reduction of 8 % of the greenhouse gas emissions (corresponding to + 600 million tons per year CO_2 equivalent) between 2008 and 2012 (compared to 1990 level).

3.2 *Scientific and technical assessment*

The following information has been prepared on the basis of the reports from the AMONCO partners.

3.2.1 *Workpackage 1: „Project Management, Dissemination and Exploitation“*

The relevant objectives were:

- Technical Management of AMONCO (Obj. 1)
- Outline and execute the Dissemination Plan (Obj. 2)
- Project Manual and Consortium Agreement (Obj. 3)
- Outline and refining of Exploitation Plans (Obj. 4)
- Keeping the project align with the objectives (Obj. 5)
- Follow up, join or propose Clustered project and thematic networks (Obj. 6)

Achievements:

The main activities were concentrated on the administrative and technical management of the project. The project started with 01.12.2001 and the partners started to prepare for the Kick-off meeting which took place from the 31st of January to the 1st of February 2002 in Steyr. Topics were the review of the Project Manual (Del. 1) and of the preliminary Consortium Agreeement, a detailed planning of the first year workpackages and the preparation of the preliminary Table of Activities. The basis for that was Annex 1 to the EC-Contract.

The Consortium prepared a Dissemination plan (Del. 2) and the Exploitation plan (Del. 3). Further the partners have elaborated detailed internal Work Plans including budget for the complete participation in AMONCO.

The second partners meeting took place in Nitra from 13th -14th of June 2002, where 11 partners participated. The minutes of the meeting was sent to every partner.

In September 2002 Mr. Ortner, the Project Technical Assistant (PTA), has visited Profactor for getting an overview about the work done until then.

The third partners meeting took place in Hamburg from 5th – 6th of December 2002, where 11 partners participated. At this meeting workpackage 6 was discussed intensive, because it is an important task, to measure the right parameters at the biogas plants for implementation a decision support tool based on a neural network.

The Mid Term Meeting was held in Brussels from 16th – 17th of June 2003. The partners presented the EC representative the actual status and the next steps. The Consortium recommended the continuation of the project, as all activities were been carried out as planned.

The next meeting was held in Madrid from 28th – 29th of November 2003, organised by MFN. The first day was reserved for the meeting itself, the second day the partners visited the biogas pilot plant of MFN in Oviedo.

Unfortunately, Farmatic went bankrupt, so they had to leave the project. The contract was amended, their remaining tasks were taken over by the partners, mainly GasCon. EBV changed name and its legal situation, so that the contract had to be amended.

The 6th meeting was held in Herning, Denmark, in June 6th 2004, where also the Hodsager Biogas Plant was visited. At this point, Marianne Haberbauer, the Coordinator of the project, announced that she would leave the project in August 2004 due to maternity leave. Her colleague Steven Trogisch took over her tasks.

The final meeting was held in Vienna from 11th – 12th of November 2004. The results were presented to Mr. Schuppers as scientific officer and to Mr. Ortner, PTA of the project. Both had a good impression of all work done.

Concerning the clustering of project and networks it can be mentioned that Profactor is chair of an ESF Network “Biomass fermentation towards usage in fuel cells (BFCNet)”. This network has started in January 2002 for a three-year period. Also partner CSIC and IAM are members of this Network. It will be used as platform for a broad dissemination to the scientific community.

Deviations:

All partners collaborated, so that the mentioned aims could be achieved. With this, within WP1 no deviations can be mentioned.

3.2.2 *Workpackage 2 “Detection of significant parameters of the AD process via laboratory experiments“*

The relevant objectives during the reporting period were:

- Data series to feed and train the neural network (Obj. 7)
- Complete analyses of the selected substrates (input and output) (Obj. 8)
- Complete analyses of the resulting Biogas (Obj. 9)
- Determination of the significant parameters for online monitoring in WP7 (Obj. 10)

Achievements:

Data series to feed and train the neural network

For starting modelling and controlling the anaerobic process, a lot of data must be produced first. Therefore four reactors, two mesophilic (35°C) and two thermophilic (60°C), are operated in steady-state conditions, with the appropriate sensors and analyses.

Complete analyses of the resulting biogas

Anaerobic digestion is a world-wide applied principle to stabilize municipal sewage sludge, treat organic wastes, products and waste-waters from industries, households and farmers. Thereby a highly energetic biogas is produced which is used in combined heat & power generators. The advanced application of biogas into fuel cells will result in a significantly higher electrical efficiency (NTEL, 2000) and can contribute to an increase of renewable energy production. However, besides methane and carbon dioxide, biogas can contain by-products like hydrogen sulfide, ammonia, halogens and non-methane organics, which will reduce the fuel cells life time dramatically (NREL, 2001). Table 1 shows a summary of the currently known tolerances for different FCs. Table 2 contains data of biogas from anaerobic digestion.

Table 1. Summary of known fuel cell tolerances (Ratcliff, 2001).

Fuel cell	PEFC	PAFC	MCFC	SOFC
Operating T. (°C)	70-90	160-210	600-700	800-1000
H2	Fuel	Fuel	Fuel	Fuel
CO2	Dilutent	Dilutent	Re-circulated	Dilutent
CO	Toxic	Toxic	With water shifted to H2	With water shifted to H2
C2-C6		Toxic	Fuel, plugging & coking	Fuel, plugging & coking

Sulfur	Toxic	Toxic (< 1 ppm H2S)	Toxic (1 ppm H2S)
NH3	Toxic	Fuel or inert?	Fuel (< 5000 ppm)
Halogens	Toxic	Toxic (< 0,1-1 ppm)	Toxic (1 ppm)
Alkali metals		Electrolyte loss (1–10 ppm)	

Table 2. Composition of biogases from anaerobic digestion.

Component	Dimension	Biogas [A]	Biogas [B] (average)	Biogas [C]
CH_4	**vol-%**	**55-70**	**51.8-85 (65)**	**55-75**
CO_2	**vol-%**	**30-45**	**14-48 (34.8)**	**24-49**
C_2H_6	**vol-%**	**---**		
C_3H_8	**vol-%**	**---**		
C_4H_{10}	**vol-%**	**---**		
N_2	**vol-%**	**---**	**0.6-7.5 (traces)**	
O_2	**vol-%**	**---**	**0-1 (traces)**	
H_2S	**vol-%**	**1**	**0.008-5.7 (0.2)**	**0.1-0.7**
NH_3	**Ppm**	**0-320**		
H_2	**Ppm**		**0-50,000 (traces)**	**15-1,500 [D]**
CO	**Ppm**		**0-21,000 (traces)**	**200-1,000 ppb [E]**
Halogens	**Ppm**			**< 1-4 F**
Mercaptanes	**mg/m^3**			**32 [G]**
Total Siloxanes	**mg/ m^3**			**28-40 [H]**

A (Schomaker, 2000), B (Braun, 1982), C (ATV, 1996), D (Hicky, 1991), E (Kidby, 1991), F (Spiegel, 2000) , G (Bayrisches Landesamt für Naturschutz , 2002), H (Martin, 1996)

Comparison of the FC tolerances and biogas composition makes clear that biogas from anaerobic digestion cannot be applied directly. Hydrogen sulfide will be very harmful. Mercaptanes could be harmful as a sulfur compound in biogas. Halogens are under suspect, however biogas data is limited. FC tolerances for siloxanes are currently under investigation. However, they can be present in biogas and cause severe problems in gas engines (Martin, 1996).

Determination of the significant parameters for online monitoring in WP 7

The from the substrate analyses selected parameters (Tab.3) which are important for measurement for the optimal run of biogas plant were summarised in the next table. Some parameters are called in the software as a condition and these parameters should therefore measured regularly or must be known from experiences.

Table 3. Selected parameters which are important for measurement for the optimal run of biogas plant.

Condition	Parameter	Remark
If Total Nitrogen in feed and Total Inorganic Nitrogen reactor is > 400 mg/l (mesophile) or > 200 mg/l (thermophile)	Ammonium/ammonia/pH reactor Total Nitrogen feed Propionic acid and acetic acid	Measurements are necessary so potential inhibitions can be observed and the right measures can be taken
If H_2S in the biogas > 0.2-1.5 vol.%	Sulfate in feed	Measurement of sulfate is necessary so extra precipitation can be installed so the potential of increased sulfides can be precipitated.
Under higher Organic Loading rates	Organic Loading Rate, pH, VFA, biogas production, methane content	The more a system will be pushed to its limit the more parameters have to be measured so the reactor can be controlled

Assessment of Results and Conclusions:

In a period of 3 years four lab-scaled bioreactors were operated and the biogas composition, the input- and the output of substrates were successfully analysed. Different process situations were simulated, especially in the critical range, to find out the necessary decision support tool inputs. These inputs described the process-condition to avoid a process overload, minimise the methane production and minimise the toxic compounds for a fuel cell. The necessary input combinations, to control an anaerobic biogas-process, for the different control-requirements, were successfully chosen. Alle milestones were reached just in time.

3.2.3 *Workpackage 3: "Identification of the effects of Biogas on different FCs via Single Cell tests"*

The relevant objectives during the reporting period were:

- Identification of the impact of trace gases in Biogas on the different Fuel Cells (Obj. 11)
- Analyses of the corresponding operational data pool on single cell and recommendations for the requirements of use of Biogas (Obj.12)

Achievements:

Planning of single cell test using and constructed of test stations:

Due to a lack information about the influence of the impurities of biogas; the work that was carefully planned in order to quantify the influence of impurity ions in the fuel cells.

It was pointed out that impurity ions in the different fuel cells would exert harmful effects on it performances and in the endurance of the fuel cells.

Even if the fuel cell starts operation in a pure hydrogen system, the contaminant will occur easily in the cell by way of impure fuel and or oxidant gas, corrosion of piping or stack materials and so on. So, we have chosen CO, NH_3 and H_2S, decamethylcyclopentasiloxane and hexamethyldisiloxane as the main impurities to study.

On the other hand, an innovation approach was proposed by CSIC: a new pulse system was development and tested. Two test stations were constructed and adjusted to the study: a low temperature fuel cells facility, and a high temperature fuel cells facility.

The experimental system consists of a set of mass flow controllers (MFC) to feed the reactant gases in both anodic and cathodic sides. The mixtures of gases pass through the humidifiers. In the anodic side, the contaminant is fed by a MFC and then, by means of capillary tube, it reaches a point of union with the anode tube. Gases continue along pipe to the fuel cell. Finally the water from the exhausted gases is condensed before being removed. The control and the data acquisition are developed by CSIC lab, allow us to have the total control of whole operation parameters, as temperature, pressure, gas composition, etc, and register all data during the operation. For the load demand, a DC electronic load was used.

Study of the influence of contaminants using a PEMFC: The influence of CO, H_2S NH_3 and siloxanes in the performance of PEMFC were studied. The methodology used allowed us to obtain different responses in the performance. Other complementary studies, as well as the recovery of the performance, the influence of the load demand and long-term experiments were also performed.

Physico chemical characterisation of PEMFC: After finishing the first experiments, the components of the PEMFC were analysed. The electrodes (anode and cathode) were separated from the membrane and investigated using SEM-EDX technique. Also the membrane was analysed using Raman spectroscopy.

Study of the influence of contaminants using high temperature fuel cells*:* One of the largest barriers to continue our studies was the difficult to buy high temperature single cells. In the case of Molten Carbonate Fuel Cells (MCFC), the two principal European companies that

develops and manufactures materials, ANSALDO and MTU, are focused on the industrial production and commercialisation of MCFC power plants in the of range 250 kW, and they are not interested in sell small prototypes.
For SOFC, most of the technology are still under development and the biggest companies follow the same philosophy that the previous one. The alternative was contact with spin off companies that prepare different components and, after exhaustive enquired, only a micro tubular solid oxide fuel cell and single components could be purchase.
The micro tubular SOFC consist in a cubic zirconia tube with coated inside with nickel cermet anode, outside two layers of cathode coating was deposited. The current collector wire is inserted down the tube to ensure the contact with anode layer, and a silver wire is wrapped around the cathode.
For this type of fuel cells, CO is not a poison and, in the bibliography few studies conclude that the use of NH_3 does not lessen the performance, but up to now few experiments have done. Nevertheless, H_2S clearly has an adverse effect on cell performance, and at present exist controversy about the concentration that affects it.
To study the influence of NH_3 and H_2S in SOFC, several adaptations were necessary and were made to complete the task on time. The methodology of the experiments was the same than the used with low temperature fuel cell.

Physico-chemical characterisation of SOFC.

SEM-EDX analyses were performed with the aim to support the experimental results. Modification on the surface structure was observed, the grain boundary grown with the poisoning, but not residual sulphur was found. Complementary studies must be performed in the future to help us to the understanding the phenomena.

<u>Assessment of results and conclusions</u>

The principal conclusion obtained after these three years is that biogas used, as fuel for fuel cell devices, is an attractive alternative. Moreover, biomass-energy systems are considered to be environmentally superior to traditional ones from the viewpoints of the CO_2 mitigation and the effective utilization of resources. As a consequence, investigations of alternative energy strategies have become important, particularly for future word stability.

Deliverable 6 (“Report on Single Cell Tests”) and **Deliverable 7** (“Guidelines for the use of biogas in fuel cells”) were elaborated by CSIC.

Based on analysis performed and evaluation of our experience, the conclusions could be summarised as follows:
The presence of CO, variations in this concentration may suppose a significant decrease in the fuel cell performance for PEMFC. The poisoning process is reversible with the only injection of clean hydrogen so a suitable control of kinetic and mass transfer process can let operate a fuel cell system using biogas. The overpotential in fuel cell favours the water electrooxidation mechanism that recovers the initial performance, but this process can be incomplete and part of CO remains adsorbed. In this case, the contaminant is accumulated and both the kinetic and mass transfer process are modified which cause changes in fuel cell performance. The lower concentrations of CO for PEMFC in continuous feeding achieved were 30 ppm.
For high temperature fuel cell a Solid Oxide Fuel Cell (SOFC) was used. As CO is a fuel, no tests of poisoning were performed.
In case of H_2S, it has been observed that the H_2S poisoning is an accumulative process for both fuel cells (PEMFC and SOFC). The contaminant concentration, the duration of pulses and the time between pulses affect the voltage drop, but in the case of PEMFC the onset of contaminant can be removed by addition of oxygen in the anode side up to 10 ppm.

The impact of 0.8-1.5 ppm of H_2S in SOFC showed detrimental effect for their performance. Decreases over 50% in the power density were observed when these concentrations were increased.
The poisoning process by NH_3 occurs in an irreversible way when a PEMFC is used. The NH_3 concentration, the duration of pulse and the time between pulses affect the voltage drop. Long exposure time (>15 h) result in severe and irreversible losses in performances, due to replacement oh H^+ ions by $NH4^+$ ions in the membrane modifying its conductivity.
For SOFC, in the range of concentrations under study, transient NH_3 pulsing does not seem to significantly affect fuel cell performance, so that no noticeable poisoning seems to take place.
The most typical siloxanes present in biogas as contaminants, hexamethyldisiloxane (L2) and decamethylcyclopentasiloxane (D5), were at first time studied using a PEMFC. The preliminary results show that, for concentrations increasing from 0.76 to 106 ppm of L2, none fuel cell voltage decrease was observed. The fuel cell performance was significantly worse after the injection of increasing D5 concentrations (started with 0.93 up to 111 ppm). Apparently the effect of siloxanes is to block the catalysis layer, avoiding the reaction of platinum with hydrogen to produce the electrochemical reactions.

Finally for the near future, the environmental improvement and the economics of a biomass-energy system need to be analysed and wide spreading.

3.2.4 *Workpackage 4: "Development of the artificial neural network and simulation"*

The relevant objectives during the reporting period were:

- Correlation analyses of substrates and Biogas (Obj. 13)
- Development and definition of neural network structure (Obj. 14)
- Feed and training of the neural net (Obj. 15)

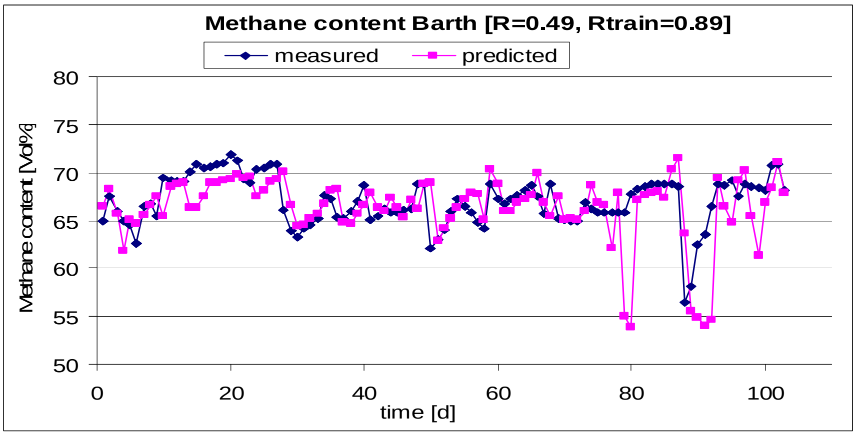
Achievements:

Correlation analysis of substrate and biogas

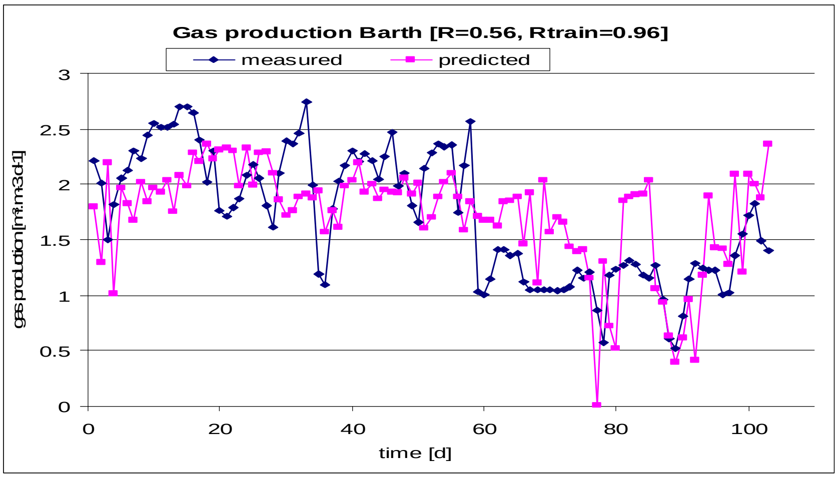
Based on the produced data correlation analysis were made of the input and output of the reactor. From literature there is no exact data available. Next follows a selection of the graphs. When a correlation is good (R^2>0.8) a model would not be necessary since then the biogas composition can be directly calculated from the incoming feed. Only in one reactor this occurred for methane production. However, as the graphs show correlation's are lower than 0.8. This means the neural network models are needed to be able to model and predict the right outcome of a certain feed. Next graphs show the correlation analyses of the reactor treating pig manure medium under thermophlic conditions of methane, hydrogen sulphide and ammonia.

Validation of the neural net by the help of the data pool from WP7

MFN, Saria, Barth. Hodsager and Uni Nitra have measured different parameters during a long period.
The data of Barth and MFN were used to the neural networks and the Barth-model-results are shown in Fig. 1. The NN-models were trained with the measured laboratory data and validated with the data of the partner Biogas plants. The input values were adapted to the measured parameters of the partner plants. The input variables of the "Barth-Model" were the gasproduction (GP) the methane content (MC), the organic loading rate (BV) from the actual day the next day and the day before. The modelled parameters were MC and GP for the next day. The input variables of the "MFN-Model" were pH, MC, GP, BV(t), BV(t-1), BV(t+1) and volatile fatty acids (VFA). The modelled variables were GP, MC and VFA for the next day.



a)



b)

Figure 1. Modelled MC (a) and GP (b) with Barth data

Models can be built but the models trained with the lab data are not really suitable for the plant data. The problem is the different biology and also the different reactor-conditions between the lab reactors and the biogas-plants. It makes sense to train and update every model with the specific biogas-plant data. But the data coming from the plant are very stable and more or less all the same, building a model based predictive control system will be rather challenging. Also more data are necessary to train the model.

<u>Assessment of Results and Conclusions</u>

After the correlation analysis, it was clear that simple models up-to 2 dimensional-polynomial can not describe the process sufficiently. An artificial neural network structure was successfully developed and trained with data produced by the lab-scaled reactors. The ANN-models were successfully used to simulate several biogas compounds and reactor conditions. The developed models were also used to simulate the bioprocess of the real-scaled biogas plants of the partners.

3.2.5 *Workpackage 5: "Controlling thechnique and development of DST"*

<u>The relevant objectives were:</u>

1. Decision Support Tool to predict Biogas Quality and Quantity (Obj. 18)
2. Decision Support Tool for control the anaerobic digestion (Obj.19)

3. Validation of the DST by testing in laboratory and at industrially scaled Biogas plants (Obj. 20)

Achievements:
For the compounds H_2S and NH_3 extra new Neural Network (NN) models were developed with data of the IAM laboratory reactors. Confirmed was the expectation that ammonia can be present in biogas in a range up to at least 93 ppm (from results of the tests with PEMFC made by CSIC). Both researched trace compounds in biogas from anaerobic digestion were modeled successful using artificial neural network. H_2S and NH_3 were predicted very well and the developed neural network models are therefore suitable in predictive control tools as previously was proposed by Steyer et al. (2000). The use of a neural network model predictive controller of the H_2S concentration in biogas from anaerobic digestion towards the practical use of biogas in fuel cells was demonstrated successful. Since only measurements of sulphate, COD and hydrogen sulphide were integrated, this predictive controller was stated as a cost effective tool. From the results it was concluded that for all partners the IAM models were not simulating correct the H_2S data of the partners. With the MFN data it was possible to make a new specific model. Since all H_2S measurements are below 2000 ppm it was expected the pre-treatment technology will function properly. Some Biogas Plants already apply sulphide precipitation and this control method can be used in the future. An extra NN H_2S control will in most cases not be necessary. The ammonia model was for the Hodsager plant applicable. Neural network models were developed also for volatile fatty acids, gas production and methane content with the lab reactor data.
Two hierarchical fuzzy logic based control tools written in LabView G® 6.1 (National Instruments, Austria) are used to control the anaerobic process. It has been shown that the control of anaerobic digestion by fuzzy logic based tools and an organic loading rate (OLR) increase during a start up period is possible. All used input parameters are economically measurable and well suited for practically use. Only VFA-concentration has to be measured off-line by a photometric toolkit. These control tools are also online useable as internet based client-server tool. The IAM models, trained with the lab reactor data are not applicable to model biogas production, methane concentration and volatile fatty acids. To get acceptable results, specific trained models by using their own or very similar process data, are necessary. This was possible for the Saria biogas plant. For the other plants it will be necessary to use an expert knowledge based system.

3.2.6 *Workpackage 6: "Sensoric layout and Implementation"*

The relevant objectives were:

- Definition of the types of sensors or gaschromatograph (Obj. 21)
- Design of the plan for the installation of the sensors (Obj. 22)
- Installation and put into operation of the sensors / gaschromatograph incl. training of personnel (Obj. 23)
- Installation of a server incl. Lab View to enable on-line monitoring and recording of data (Obj. 24)

Achievements:
Research approach: The measurement parameters, determined in WP 2, was used to make a long-list of measurement technologies applicable, and suppliers were identified.
Experience from the partners utilizing various equipment were drawn in, resulting in a shortlist with suppliers and measuring technologies.
Finally tests and comparisons was made, both at the Farmatic laboratory, and at some of the better equipped partners, and Farmatic then decided upon the best and for the Amonco project realistic and practical feasible technology.

Emphasis had to be laid on measurement technologies giving reliable results without requiring skilled laboratory assistance, as such would not be available at the industrial biogas plants involved.
At the same time, time consumption and cost of operation had also to be considered, not only for the purpose of this project, but also to select methods applicable for future use.
It became evident after some testing, that titration methods could not be used, as results were simply not consistent.

Distillation methods were already in use at the farmatic laboratory, and at Genthin, and was known to produce good results, if sufficient care was exercised.
Photometric methods were tested in cooperation by Profactor and Farmatic, and was deemed suitable, although the narrow range of measuring is a disadvantage. But the method is very fast and produces reliable results without demanding specific skills.

The final decision by Farmatic was to use a combination of both analytical instruments, photometric system and Distillation unit, should be in use. This was the case be in Genthin, Frieres and Alteno.
In Barth no laboratory analysis is feasible, and analysis of the substrates was performed by an external laboratory, while a gas analyser was installed to perform the analysis of the gas
In Hodsager, it was decided to implement the photometric systems of Dr. Lange, because they provide a system, which offers test covering most of the ranges needed, without requiring skilled staff.

It became clear, early in the period, that no commercial available sample system could be trusted to operate in the very inhomogeneous substrates used in the industrial biogas plants involved, and a decision was made to continue with manual sampling.
Gas measurements for Methane, Carbon dioxide was done by in-line gas analyzers supplemented by portable equipment, while Hydrogen sulphide and Ammonia were measured by Dräger tubes.
Main result achieved within *WP* 6 has been the foundation for the measurement campaign in WP7, which has provided all data for the development of the DST.
All plants have been specified with sensoric equipment and data measurement procedures, enabling the data pool for the DST development to be created. Barth and Hodsager have purchased measuring equipment according to Farmatic specifications.
Assessment of results: The results of WP6 have contributed to valuable knowledge about the practical challenges in providing the analytical background to appliance of a neural network based Decision Support Tool.

Conclusions:
Sensors and analytic methods enabling data series of WP2-measurement parameters have been established at all participating biogasplants.
Experience with manual sampling and analysis has made it obvious, that the task is rather time consuming, and more demanding than can be handled by standard industrial biogas plants and also what could be foreseen by planning of the Amonco project.
It is possible to purchase and install an autosampling, autoanalysing system, capable of providing the results needed for the DST. However, costs of this would be far beyond the financial frames of the Amonco project and also not evident feasible to be applied upon existing biogas plants but possessing a promising scope in planning for new biogas plants.
Commercial systems must be able to produce results from automated sampling routines, in a reliable and consistent way.

3.2.7 *Workpackage 7: "Long-term monitoring, data pooling and analyses at industrially scaled Biogas plants"*

<u>The relevant objectives during the reporting period were:</u>

- Analysis of the Biogas composition in detail as a time series of data at industrially scaled plants (Obj. 25)
- Analysis of biomass substrates as a time series of data at industrially scaled plants (Obj. 26)

<u>Achievements:</u>

The parameters which were to be monitored at the different biogas plants were chosen by IAM and PROFACTOR within the workpackage 2. They are divided into three categories:

I. data related to the supplied biomass
II. data related to the AD process
III. data related to the produced biogas

Decisions on the appropriate technical equipment to ensure the monitoring process were taken within the workpackage 6.

At the beginning of the WP 7 a common methodology for the long-term monitoring at the particular biogas plants of the project partners was created. This was done and submitted by UNI Nitra as the workpackage leader. The created methodology *Specification of the measurement methods* presented a list of the parameters to be measured as well as a list of the methods by which the selected parameters were to be measured in a given frequency. In discussion with all project partners a decision was made to divide the parameters to be measured into three groups according their priority value.

During the work on the workpackage 7 the relevant partners submitted the recorded values of the parameters they measured to the workpackage leader UNI Nitra who processed them into an agreed Excel sheet form. The data were also sent to the project partners IAM and PROFACTOR for the DST development and optimisation purposes.

Because of various technologies used by the separate biogas plants and various measuring facilities which had these biogas plants at disposal it was very difficult to come to a unified rules of the monitoring processes carried out in such different conditions. That was why each relevant partner implemented the prepared methodology on his own conditions. The following tables (Tables 3 a &b) present which parameters from which priority group were measured by the relevant partners:

Partner	BARTH	MFN	SARIA	GasCon		UNI Nitra
Biogas Plant	BARTH			HODSAGER	THORSOE	KOLÍŇANY
Period of measurement	June 2003 – July 2004	March– September 2003	Sept. 2002 – Nov. 2003 January – April 2004	November 2003 – September 2004	August – September 2004	December 2003 – October 2004
Priority no. 1						
COD feed	X	X	X	X	X	X
Organic loading rate (OLR)	X	X			X	
Feed of digester	X	X	X	X	X	X
Total solids (TS)			X	X	X	X
Volatile suspended solids (VSS)		X	X	X	X	X
Sulphate in feed	X	X	X	X	X	X
Total nitrogen			X	X	X	X
Ammonia nitrogen in reactor – NH_4	X	X	X	X	X	X
Volatile fatty acids in reactor – VFA	X	X	X	X	X	X
Biogas production	X	X	X	X	X	X
Methan – CH_4	X	X	X	X	X	X
Hydrogensulphid – H_2S	X	X	X	X	X	X
Ammonia – NH_3				X	X	X
Dissolved iron			X	X	X	X
Specific biogas production	X	X	X	X	X	X
pH in reactor	X	X	X	X	X	X

Partner	BARTH	MFN	SARIA	GasCon		UNI Nitra
Biogas Plant	BARTH			HODSAGER	THORSOE	KOLÍŇANY
Period of measurement	June 2003 – July 2004	March– September 2003	Sept. 2002 – Nov. 2003 January – April 2004	November 2003 – September 2004	August – September 2004	December 2003 – October 2004
Priority no. 2						
Siloxanes	X					
Halogenes						
Mercaptanes						
COD effluent	X	X	X	X		X
Ammonium in feed	X		X	X		X
Priority no. 3						
Total organic carbon – TOC in feed		X				
Total organic carbon – TOC in effluent						
C/N ratio feed		X				
Acetate	X					
Propionate	X					
Sulphate in effluent	X					
Hydrogensulphid liquid						
CO_2 in biogas		X		X	X	X

Tables 3 a & b: Parameters measured by the relevant partners

From the tables it can be seen that all involved partners paid the highest serious attention to the parameters highlighted as of the first priority and they endeavored to cover this group in its whole range.

Concluding it can be said, that during long-term monitoring of anaerobic digestion of biomass a lot of data was collected from six biogas plants. About 17 parameters were measured. The data pooling ran since January 2003 till November 2004. Measured parameters are processed in unified tables. The values of the measured parameters vary for each biogas plant where they were collected. The results were applied at neural network optimisation. All values of the measured parameters are completed in deliverable 18.
Such massive measurements from 6 industrially scaled biogas plants which use different sorts of entry biomass give important information about anaerobic digestion process and can be used as appropriate information for its optimizing and modelling.

3.2.8 *Workpackage 8: "Development of the Biogas Cleaning unit towards FCs"*

<u>The relevant objectives during the reporting period were:</u>

- Reduction of VOCs and Siloxanes in treated Biogas for usage in FCs (H_2S via EFFECTIVE) (Obj. 28)
- Optimising of operating parameters of the gas cleaning process (Obj. 29)
- Combining of the different technical cleaning process to a cost-effective Biogas cleaning process (Obj. 30)
- Reduction of traces gases in the fermentation process (Obj. 31)

PROFACTOR and NITRA have worked with respectively biological methods and investigated how mechanical pre-treatment might minimise resulting trace gases in the Biogas or present other impacts.
SEABORNE has solely worked with development of chemical/physical processes to target the objectives.
For both PROFACTOR and SEABORNE it has been a refinement to what already achieved in respectively biological and chemical regenerative removal of Hydrogen Sulphide under the EFFECTIVE project.

The **working approaches** have been

- Analytical investigations for Siloxanes and VOC´s.
- Laboratory tests
- Drafted engineering plans for full-scale installations and its economy

The 3 main stakeholders in WP 8 have had support on the Biogas production side from project partner FARMATIC – later GASCON when FARMATIC left the project by the end of second project year – and from CSIC on the Fuel Cell side. These inputs have been materialised in reply to questionnaires formulated of and further led to all the main WP 8 partners through the plan of work presented also of .
The research approach: SEABORNE and PROFACTOR have coordinated their analytical procedures in analysing for Siloxanes and VOC´s. SEABORNEs analytical work has been based upon biogas from its own semi-industrial biogas plant whereas PROFACTOR, as not being in possession of an own biogas plant, has based its analytical work upon different samples from digesters around – mainly sewage plants. NITRA has based its approach to mechanical pre-treatment upon a specific constructed mechanical pre-treatment unit related to its own biogas plant.

Only SEABORNE and PROFACTOR have been doing analytical pre-work for Siloxanes and VOC´s whereas NITRA has had focus upon Hydrogen Sulphide, Mercaptanes and Ammonia – trace gases as a function of mechanical pre-treatment.
Target setting for the WP 8 has been a cost reduction of 30 % in purification of biogas for Fuel Cell application. The combined cleaning of biogas for both the common trace compounds like Hydrogen Sulphide and also Siloxanes plus VOC´s has innovative aspects.

The final findings from the 3 main participants were presented in due time as

1. Deliverable 18 from NITRA "Report of the pre-treatment of wastes". May 2004.
2. Deliverable 20 from PROFACTOR "Results of the biological cleaning process". November 2004
3. Deliverable 21 from SEABORNE "Results of the chemical / physical processes". November 2004

Main achievements:
Deliverable 18 from NITRA concludes a.o.:
The investigations carried out at the Biogas plant in Kolinany (Slovak Agricultural University in Nitra –NITRA, SK) have proved a significant influence of the substrate mechanical pre-treatment on the biogas production. However, it is not possible to assess the level to which this substrate treatment can really affect the biogas production. The obvious is that almost always after adding the first dose of the newly treated substrate mixture the biogas production has been a higher one and it has an ascending tendency. This tendency in the time of the first three days can be expressed also by a mathematical function (polynomial function of 2nd degree).
Although the obtained graphical courses and results show on an impact of the mechanical pre-treatment on the biogas production it should not be omitted that there have been more determinants affecting together the substrate digestion and biogas production. What should be mainly stressed is the fact that there are more treated substrates meeting together in the digester. The slightness of their particles, and that is also their decomposition and sedimentation, varies according the pre-treatment duration. That is why the substrate main decomposition by bacteria could be done in another time interval as it was expected. A data distortion could be caused also by other factors as are the substrate quality, keeping the silage – manure ratio, stabile conditions of the digestion (e. g. temperature, pH level), technical problems of the small gasholder handling, etc."
The WP 8 works of NITRA have been done under circumstances, which are close to practice with a similar climatic environment. Thus, they do not represent laboratory experiments and the effect upon FC deteriorating trace gases of mechanical pre-treatment remain uncertain although in general being close coupled to the production rate of biogas.

Deliverable 20 from PROFACTOR presents main findings in biological biogas cleaning:
Basic is by means of biological methods to remove detrimental gases of Hydrogen Sulphide, Siloxanes and halogenated Hydrocarbons under simultaneous development of a Simulation Tool enabling reliable predictions upon output leading to basis for industrial scaled biofilter control. Lab experiments have been extensive and have ended up with definition of a Biotrickling Filter in a specific PROFACTOR design – part of which being subject to patent pending. The nature of the biological approach calls for the necessity of an almost equal load of trace compounds to be removed – peaks have to be avoided as far as possible as the bacteria cannot adapt. The biological concept thus depend much of the DST and its possible ability to govern the biogas process in detail.
PROFACTOR has notified a high grade of industrial interest for its biological concept although mainly to biogas plants with a modest capacity of 10 – 15 m^3 biogas / hourly. Thus, the biological concept at its present premature stage seems to have good chances to be realised within a 3 years time.

Deliverable 21 from present main findings in chemical/physical biogas cleaning together with a consolidated draft to engineering and a cost calculation fulfilling the target setting of WP 8: The removal of Hydrogen Sulphide (H_2S) takes place in a regenerative process without any necessity to dispose applied means of operation later on. This is innovative and part of an IPR held by SEABORNE but to a high degree adapted and further developed in this project for Fuel Cell application of biogas. The system was furthermore tested on pilot basis for MCFC application of biogas in the EFFECTIVE project 2000 – 2004. Downstream the primary removal of Hydrogen Sulphide filters with activated Silcarbon SC40 has a three fold function:

1. Removal of Siloxanes
2. Removal of halogenated Carbon compounds
3. Removal of remaining residuals of H_2S

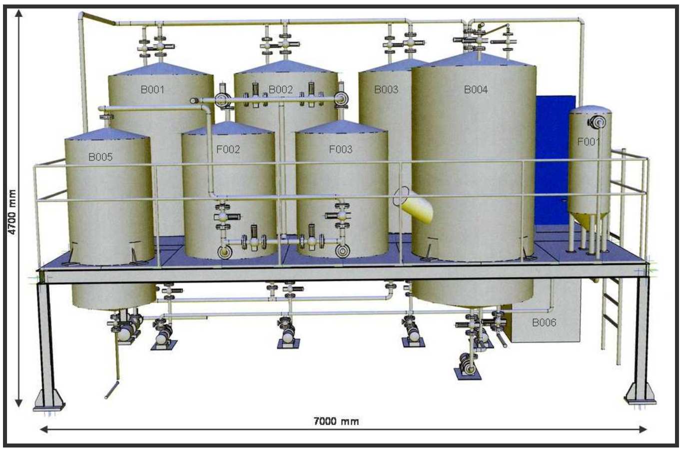


Fig.2: Visualised front view of the developed chemical/physical biogas cleaning installation.

SEABORNE has made cost calculations based on tendering for potential suppliers and presented the following consolidated cost calculation for a 650 kW (100 m^3 biogas/hourly) biogas plant presuming loads of deteriorating compounds around 1,000 ppm/H_2S and 100 mg Si/m^3 biogas:

Costs of installation:	<u>180.000 €</u>	
Capital costs per kWh_E :	0,55 €cent	(Electrical FC efficiency: 50%)
Variable costs per kWh_E:	0,66 €cent	
Total costs per kWh_E:	1,21 €cent	
Total costs per m^3 biogas p.a. in average:	<u>3,9 € cent</u>	

The WP 8 RTD work of SEABORNE has materialised in a DST independent concept for larger biogas plants. However, the neural network principles of the project DST might be applicable within the SCADA governing of the SEABORNE plant itself, which, however, is beyond the scope of this project.

The target setting in WP 8 of a cost reduction amounting to 30 % has to be seen in relation to that costs in state of the art varies up to 30 times – from 0.2 €cent to 6.0 €cent each m^3 biogas treated. Cost variations like such are not unusual in environmental technologies and clearly reflect matters of efficiency and quality more than expressed in the calculation of costs.
Removal of Siloxanes and VOCs is of upcoming interest and the highest cost level within state of the art is related to a much secure but expensive method towards which the consolidated SEABORNE installation, developed under Amonco, might well compete. Thus, the target

setting for WP 8 has been well fulfilled with a cost reduction from 6.0 €cent to 3.9 €cent each m^3 biogas equal to 35 % reduction of costs compared to the target setting of 30 %.
The PROFACTOR concept is premature to any reasonable cost setting but represent highly innovative biological aspects which along the lines of further development of the neural network based DST for the biogas process itself might led to further cost reductions.

Assessment of results: WP 8 has fulfilled its objectives within showing ways for a complete FC related upgrading of biogas.

The results comprises both

- Valuable in depth investigations upon impact of mechanical pre-treatment applicable for the day to day practise in biogas production for FC´s. (NITRA)
- A highly innovative concept to a pure biological upgrading possessing a potential of being a further justification to apply neural network principles in the biogas production.(PROFACTOR)
- A consolidated RTD work based upon chemical/physical principles under an innovative element of regeneration and ending up with a reliable cost setting for full-scale engineering fulfilling the economical target setting of WP 8.(SEABORNE).
- The works have been much complementary and consequently provided many mutual benefits to WP partners in this specific area.

Conclusions:

- Pre-treatment of biomass wastes does not in itself present any impact upon deteriorating compounds but influence the hydrolysis and later the biogas production itself which are of importance for specifically the biological way of biogas cleaning.
- The biological gas purification has as stand alone method in the short run only justification to be applied in smaller biogas plants producing 10 – 15 m^3 biogas hourly.
- The chemical/physical way is justified for in the short run to be applicable for medium sized biogas plants producing at least 100 m^3 biogas hourly and possesses potential for even larger biogas installations.

3.2.9 *Workpackage 9: "Technological strategies for the combination of Biogas / FC and economic aspects"*

<u>The relevant objectives during the reporting period were:</u>

- Investigate the impact of trace gases on FCs technology through analysing data series (Obj 32)
- Derive technological consequences for FCs through the results of this project (Obj 33)
- Dissemination to end-users through a Business Interest Group (Obj 34)
- Co-ordinate activities towards thematic networks and clustered projects (Obj 35)
- Economic feasibility studies (Obj 36)

<u>Achievements</u>
Dissemination:
Two Business Interest Group meetings were organized within the AMONCO project. The first BIG meeting took place on the 1st April 2004 in Vienna (Austria) in the frame of an International Conference on "Hydrogen and fuel cell based future energy systems". The second BIG meeting was arranged on 17th September 2004 as a side event to the trade fair "H2-Expo" in Hamburg. Besides the AMONCO project participants the company MTU, holding a technology leadership in biogas FC application, was invited as a speaker to both BIG

meetings in order to present the state of the art of the MCFC fuel cell technology and the potential utilisation of biogas. Over 160 participants from 18 countries took part at the first BIG meeting. Relevant stakeholders with different business background – in total 37 participants from 9 countries – participated at the second BIG meeting. Summarising the performance of both AMONCO BIG meetings it may be concluded that those were a big success both by the contributions of the speakers, by the number of participants (and their interventions) and the represented companies (from all over the world).
CSIC organized a specific Seminar related with the topic “Biogas and Fuel Cell: From Waste to Clean Energy”, to disseminate the use of both technologies was held in Madrid, February 18-19 2004, with the participation of numerous people from industrial and academic areas. The conference points out the technological and logistic elements necessary to build up a future use of both combined technologies.
As a specific dissemination material 10.000 information folders were produced. The contents of this folder regarded the objectives, major work tasks and estimated results of AMONCO. The second information folder was produced in edition of 3.000 units and published in November 2004. Its purpose was to give a summery of the project at a glance, comprising the core objectives, a presentation of the business interest group, the main results and an outlook.
Pamphlets for dissemination included two forms of posters. One standard form with fixed contents enabled all partner organisations to disseminate AMONCO – Biogas Fuel Cells results in a more general way. The second form with flexible contents gave the partner organisations the possibility to present their specific project results staying in the AMONCO – Biogas Fuel Cell design. This opportunity for disseminating the aims, tasks and results of AMONCO had been taken very frequently by all project partners.
Furthermore it was decided to make an AMONCO – Biogas Fuel Cell website (http://www.eva.ac.at/amonco). Regular updates have been made in order to provide latest results of AMONCO project. At about 3.400 website visits were counted for the period from December 2003 to November 2004, the last third of the entire project duration.
The first AMONCO newsletter was published in May 2004 in an edition of 4.000 exemplars. It contained some background information on the AMONCO project and on the current status of the project and provided a projection on the second BIG-Meeting. The second newsletter was designed to pose as an announcement for the second BIG meeting, including information on the topics and aims of this expert workshop, a short presentation on AMONCO project and the Business Interest Group and a detailed workshop program as well. It was produced by the beginning auf August 2004 in a volume of 4.000 pieces.

Techno-economic assessment

Important result were the Deliverable 27 “Holistic assessment to the economic efficiency of different input substrates for AD” and Deliverable 26 “Assessment of the market Biogas/FCs”. The aim of this Deliverable was to assess the potential and the economic environment for the innovative fuel cell / biogas technology in countries represented in the AMONCO consortium. In the first part the present day situation regarding the utilisation of biogas technology was evaluated for each respective country. Furthermore, the total market potential for the innovative technology was derived from available organic substrates utilisable as fuel for the biogas process. The second part of the study assessed the country specific business environments in which the innovative technology has to compete. In this respect a so called PEST-Analysis was conducted addressing the Political, Economic, Social and Technological Environment in a formalised way. In order to get country-specific input a questionnaire was sent to the involved AMONCO-Partners and its results were integrated in the deliverable.

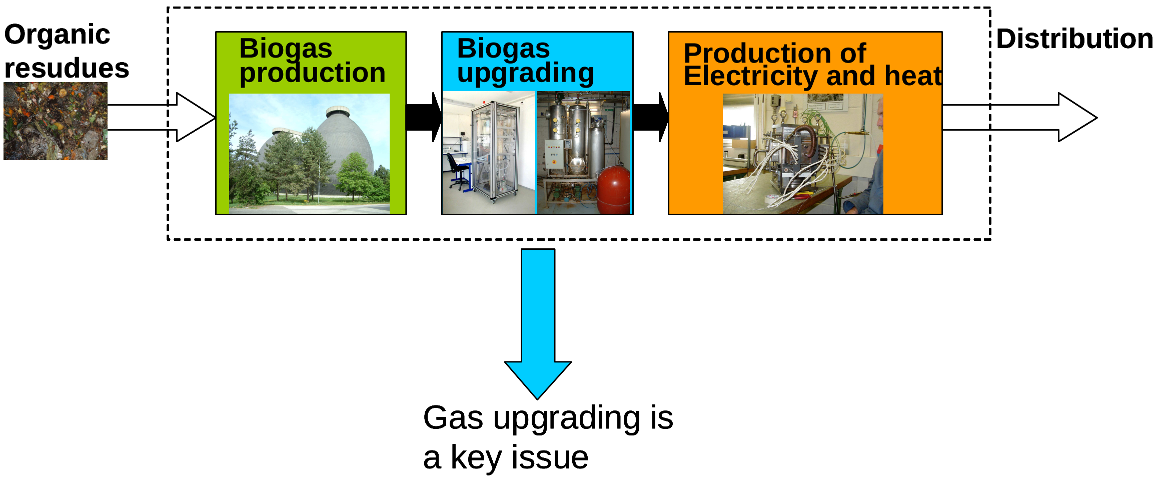
Assessment of results and conclusions of WP 9

The accomplished actions within AMONCO project integrated in the R&D and business environment in the countries covered by the project’s consortiums evolve fair to strong effectivity. Reasons therefore are a more or less developed market for biogas applications, still

facing a great potential in general, and dynamic established technology suppliers and a relative high amount of installed biogas plants, giving encouraging best-practice examples.
The implementation of a Business Interest Group was aimed to establish an open forum for interested companies, operators of biogas plants and other stakeholders to be among the first to implement AMONCO biogas fuel cells into competitive markets. Both Business Interest Group meetings (Vienna, April 2004 and Hamburg, September 2004) achieved great success on a quantitative and qualitative level. This can be illustrated by the contributions of the speakers, by the number of participants and the represented companies. The interventions of the auditorium in the Q&A (questions and answer) session also proved the high interest, that AMONCO project creates in the public in general and for industrial end-users in particular.
The project's website (www.eva.ac.at/amonco) was intended to be a unique information platform in the framework of AMONCO and worked as a very effective tool for dissemination. Evidence could be provided for instance due to the fact, that the search engine "google.com" ranks this website on the first page querying "anaerobic digestion fuel cell" or "biogas fuel cell". At about 3.400 website visits were counted for the project's final year (from December 2003 to November 2004).
E.V.A.'s as well as all project partner's dissemination activities made a significant contribution to a wider spreading of the results of AMONCO, to an intensification of the discussion on biogas fuel cells and additionally to the awareness rising of opinion leaders and policy makers on this topic.
The performed dissemination efforts covered participations on workshops and conferences on a national and international level, including talks and poster presentations. The circulation of project relevant data and outcomes was embedded in every partner's regular business and research activities. Many publications were made concerning AMONCO project.
The outcomes of the AMONCO project are fully in line with the EU energy policies and can support future agenda settings. A higher market penetration of biogas fuel cell systems will help to meet the targets of the Kyoto Protocol and will improve the security of supply to a great extent.
As factors for success appear this technology's characteristics, like high energy efficiency, even of small scale systems, modularity, and capability for decentralised heat and power generation. The involvement of the company MTU CFC Solution, which is possessing technology leadership in biogas fuel cell applications, in the project's dissemination activities aims at the direct exploitation of the project's outcomes.
Further market development of this technology will be based on renewable energy sources, which have a huge potential for the European Union, like organic wastes, plants and manure. Therefore the market assessment for biogas fuel cell application identifies a great potential, but also some barriers to be overcome in the future (mainly the costs for investment, operating and maintenance) in order to gain higher FC's market shares compared to conventional CHPs.
Next steps for the deployment of fuel cell technology have to be taken. Therefore the Strategic Research Agenda and the Deployment Strategy published by the "European Hydrogen and Fuel Cell Technology Platform" (www.hfpeurope.org) and the 7th RTD Framework Programme are suggested to provide an ideal framework for continuous research activities.

4 Assessment of results and conclusion

The world tendency for use of energy goes towards a clean and efficient energy conversion. In a future scenario, based on hydrogen and fuel cells, the AMONCO project can contribute with its results. Fuel cells are efficient energy converters, however, it is important that the fuel they use comes from renewable energy sources.
From an overall view, the projects results seem to strengthen the potential of using bioenergy and fuel cell technology. However, in this long chain there are several risk areas that demand further research for a future widespread implementation.
Following table shows the projects process chain:



1) An overall risk is that the Amonco works and results represent RTD work under best scientific practise but as such obviously not can make reference to an already constructed full-scale installation or statistical references to a number of installations operated over a longer period.
2) Evidently all judgements upon real installation costs represent a risk as long as an installation not de facto has been constructed.
3) Biomass source: there are many different sources of biomass. Not all sources are suitable for anaerobic digestion. Some present a higher demand on the controlling of the process. Here further research demand is needed in order to take full advantage of the biogas potential in these wastes.
4) The project showed that the pre-treatment of the wastes is in some cases difficult, due to the variety of substrate (-quality). Processes are needed which are not too increasingly energy demanding and that don’t require constant monitoring of the operator
5) Anaerobic digestion: the process itself is well known when using conventional materials for the process. However, the neural network showed that there is still a large potential that is not been used and that could be easily taken advantage of if the AD process was optimised. Here the consortium suggests a follow up project in order to test the results of AMONCO on an upscaled biogas plant. This is imperative for a successful implementation of the neural network. The current risk is that the system has not yet been tested on large scale and that no plant operator wants to risk testing it. Therefore we suggest a first step with special anaerobic pilot plants (like the one at MFN or UNI NITRA), where the aim of such plants is the educative and testing.
6) Gas upgrading: at the moment, there are several technologies for gas upgrading. However, these are expensive in investment and/or operation costs, and sometimes produce additionally a secondary waste stream. This is however something that kills any enhanced biogas application, as the financial margin is very narrow. Therefore the approach taken in the project leads to an economical and sustainable gas cleaning (for

H2S and siloxanes). The risks seen in this area are focused on the biological siloxane removal, being this area a very young one. Here intensive research is still needed. A specific process risk should be minor as regard the concept from SEABORNE

7) In the area of fuel cells, the risks are to be seen in the gas purity. However, a main obstacle for their implementation are the still substantially higher costs compared to internal combustion engines.

Summarising, it can be said that the risks can be handled and that further research will be needed to enhance the topic of biogas and fuel cells to a competitive status. From the technical point of view it can be said that the risks are manageable and that the technology has a bright future.

5 Acknowledgments

The Consortium thanks the European Commission for the funding of the project.
Profactor acknowledges the financial support received from the Austrian *"Bundesministerium für Bildung, Wissenschaft und Kultur*" for part of the equipment needed for the project.

6 Updated lists of names of contact persons

PROFACTOR

Ms. Marianne Haberbauer
Profactor Produktionsforschungs GmbH
Im Stadtgut A2
A-4407 Gleink -Steyr ,Austria
Tel: +43 7252 885 100
Fax: +43 7252 885 2101
E-mail: Marianne.Haberbauer@profactor.at

Mr. Rainer Schöftner
Profactor Produktionsforschungs GmbH
Im Stadtgut A2
A-4407 Gleink -Steyr ,Austria
Tel: +43 7252 885 412
Fax: +43 7252 885 101
E-mail: Rainer.Schoeftner@profactor.at

Mr. Steven Trogisch
Profactor Produktionsforschungs GmbH
Im Stadtgut A2
A-4407 Gleink -Steyr ,Austria
Tel: +43 7252 885 413
Fax: +43 7252 885 2101
Steven.Trogisch@profactor.at

IAM

Mr. Peter Holubar
Institute for Microbiology, University of Agricultural Sciences Vienna
Muthgasse 18, Haus B
A-1190 Wien, Austria
Tel: +43 1 36006 6212
Fax: +43 1 3697615
E-mail: holubar@mail.boku.ac.at

FARMATIC

Dr. Klaus Hack
Farmatic biotech energy ag
Kolberger Straße 13
D-24589 Nortorf, Germany
Tel.: ++49 (0) 43 92 / 91 77 - 151
Fax: ++49 (0) 43 92 / 91 77 - 497
e-mail: hack@farmatic.com

Dipl.-Ing. (FH) Sven Reher
Farmatic biotech energy ag
Kolberger Straße 13
D-24589 Nortorf, Germany
Tel.: ++49 (0) 43 92 / 91 77 - 403
Fax: ++49 (0) 43 92 / 91 77 - 497
e-mail: reher@farmatic.com

MFN

Mr. Marcos Díaz Prado
Matadero Frigorífico del Nalón
Polígono Industrial Riano 2
E-23929 Frieres/Langreo, Spain
Tel: +34 985 673500
Fax: +34 985 699504
E-mail: hllaneza@correo.uniovi.es

SARIA

Mr. Eckart Müller
SARIA Bio-Industries GmbH
Ziegeleistraße 56
D-39307 Genthin, Germany
Tel: +49 3933 873231
Fax: +49 3933 873230
E-mail: eckhart.mueller@saria.de

GASCON

Mr. Kim Paamand
GasCon ApS
Nisset Bygade 12
DK-8632 Lemming, Denmark
Tel: +45 86 80 03 66
Fax: +45 86 805803
E-mail: kim@gascon.dk

Mr. Frank Teisen
GasCon ApS
Nisset Bygade 12
DK-8632 Lemming, Denmark
Tel: +45 86 801953
Fax: +45 86 805803
E-mail: teisen@email.dk

BARTH

Mr. Eberhard Reiher
BIOGAS Barth GmbH
Mühlenberg 24
D-18311 Ribnitz-Damgarten, Germany
Tel: + 49 3821 2764
Fax: +49 3821 2764
E-mail: EReiher@t-online.de

EBV

Mr. Michael Schlieker
EBV Management GmbH & Co. KG
Staulinie 14-17
D-26122 Oldenburg, Germany
Tel: +49 441 92540-0
Fax: +49 441 92540-325
E-mail: schlieker@ebv-gruppe.de

EVA

Mr. Günter R. Simader
Energieverwertungsagentur – the Austrian Energy Agency
Otto-Bauer-Gasse 6
A-1060 Wien, Austria
Tel: +43 1 5861524-24
Fax: +43 1 5861524-40
E-mail: Simader@eva.ac.at

CSIC

Dr. Loreto Daza Bertrand
Instituto de Catálisis y Petroleoquímica (CSIC)
C/ Marie Curie 2, Campus Cantoblanco
E-28049 Madrid, Spain
Tel: +34 91 5854786
Fax: +34 91 5854760
E-mail: loreto.daza@icp.csic.es

SEABORNE

Mr. Niels Ole Vesterager
Seaborne Environmental Research Laboratory -
Gesellschaft für Umwelttechnik mbH
Mooshörner Weg
D-24811 Owschlag, Germany
Tel: +49 4336 99760
Fax: +49 4336 997619
E-mail: info@seaborne-erl.de

Ms. Dagmar Matthiesen
Seaborne Environmental Research Laboratory
Gesellschaft für Umwelttechnik mbH
Mooshörner Weg
D-24811 Owschlag, Germany
Tel: +49 4336 9976234
Fax: +49 4336 997619
E-mail: dagmar.matthiesen@seaborne-erl.de

UNI NITRA

Mr. Ján Gaduš
Slovenska Polnohospodarska Univerzita v Nitre
Tr. A. Hlinku 2
SK-94976 Nitra, Slovakia
Tel: +421 37 7336073
Mobile: +421 905 925013
Fax: +421 37 7336073
E-mail: jan.gadus@uniag.sk

7 Glossary

AD	Anaerobic digestion
BOP	Balance of Plant
BV	Organic loading rate
COD	Chemical Oxygen Demand
CSTR	Continuous Stirred Tank Reactor
DST	Decision Support Tool
D3	Hexamethylcyclotrisiloxane
D4	Octamethylcyclotetrasiloxane
D5	Decamethylcyclopentasiloxane
ESF	European Science Foundation
FC	Fuel Cell
FPD	Flame Photometric Detector
FID	Flame Ionisation Detector
GC	Gaschromatograph
GP	Gas Production
L2	Hexamethyldisiloxane
L3	Octamethyltrisiloxane
MS	Mass Spectrometry
MCFC	Molten Carbonate Fuel Cell
MEA	Membrane Electrode Assembly
MC	Methane Content
PTA	Project Technical Assistant
PDMS	Polydimethylsiloxane
PEMS	Polyethermethylsiloxane
PEMFC	Proton Exchange Membrane Fuel Cell
SOFC	Solid Oxide Fuel Cell
SPE	Solid Phase Extractions
SPME	Solid Microphase Extraction
TCD	Thermal Conductivity Detector
TD	Thermal Desorption
VOC	Volatile Organic Compounds
VMS	Volatile Methylsiloxane
VFA	Volatile Fatty Acids