Project no.:	**019884**
Project acronym:	**EU-AGRO-BIOGAS**
Project title:	**European Biogas Initiative to improve the yield of agricultural biogas plants**
Instrument:	**Specific targeted research or innovation Project**
Thematic Priority:	**Sustainable Energy Systems**

Publishable Final Activity Report

Period covered:	**2008-07-15 - 2010-01-14 (18 months)**
Date of preparation:	**2010-02-14**
Start date of project:	**2007-01-15**
Duration:	**36 months (2007-2010)**

Project coordinator name: **Prof. Dr. Thomas Amon**
Project coordinator organisation name: **Universitaet fuer Bodenkultur**

Vienna, 14th February 2010

Publishable Executive Summary

EU-AGRO-BIOGAS is a European Biogas initiative to improve the yield of agricultural biogas plants in Europe, to optimise biogas technology and processes and to improve the efficiency in all parts of the production chain from feedstock to biogas utilisation. Biogas is a key technology for the sustainable supply of renewable energy. It offers a high flexibility in substrates, thus avoiding food-feed competition. Biogas is an essential part in the transition towards integrated bio-refinery concepts.

EU-AGRO-BIOGAS aims at the development and optimisation of the entire value chain – to range from the production of raw materials, production and refining of biogas to the utilisation of heat and electricity. All developments and strategies are demonstrated and proofed at real life conditions. An efficient utilisation of raw materials will be achieved through the definition of raw material quality, an increased input of secondary agrarian raw material components and by-products of the food and bio-fuels industry, and energy and economically optimised raw material mixtures (incl. pre-treatment). The state of technology, management, economy and environmental effects was assessed through benchmarking on selected medium- and large-scale biogas plants across Europe. The improvement of biogas efficiency, conversion and utilisation (technical, economical, ecological) was shown by demonstrations on selected biogas plant across Europe. Heat utilisation was improved through optimised management. Demonstration activities (technical, economical, ecological) were benchmarked and recommendations for an efficient biogas production were developed and widely disseminated.

European Feedstock Database and EU - Methane Energy Value Model (MEVM) standard methodology

Based on intensive literature surveys by all project partners and lab-scale experiments of feedstock from all participant countries, a substantial amount of data was collected and the main aim, the development of the new and comprehensive online European Feedstock Database (please, contact the Coordinator Thomas Amon for access to the database) on feedstock for biogas plants, was fully achieved. The online European Feedstock Database is designed as an open database (http://daten.ktbl.de/euagrobiogas/) where new data can always be fed in. It contains essential information on the quality of feedstock utilizable for fermentation including their methane production capacity. Feedstock of the following substrate groups are presented in the database: energy crops, animal manures, by-products of the food, feed, and biofuel industry and harvest residues. The database contains information feedstock that are most important for European biogas production from a quantitative and qualitative point of view. The database depicts the existing variety of available feedstock in Europe. In the Database 667 data on biogas yield, 767 data on methane yield and 9,291 data on substrate analysis from energy crops, animal manures, agricultural residues, other waste materials and substrate mixtures are currently available.

Methane energy value models (MEVM) were developed for the prevailing feedstock of maize silage, sorghum silage, triticale silage, and sun flower silage. The same was done for feedstock mixtures containing remains from bio-refinery systems, agricultural residues and energy crops. The online European Feedstock Database allows an initial testing of biogas potentials of regionally available substrates and substrate mixtures. The set up of quality definitions for feedstock enables the economic and energetic optimisation of substrate mixtures for anaerobic digestion. Hence, the online European Feedstock Database is a basis for the planning of biogas plants and is organised as an expert database to support planners, consulters, plant operators, plant breeders and advisors of agricultural biogas plants.

Benchmarking, weak point analysis and early warning system

A selection of commercial plants have provided information on the fermentation parameters, economics, monitoring instrumentation and plant schematics. These parameters were benchmarked and compared to identify weak points from a statistical perspective. Additional weak point analysis was provided by the plant operators. This information was used to define the needs of the early warning system and to highlight demonstration activities in WP4. The constrictions of which parameters can be measured and those needed for process control were assessed and the means of process control and management of the biogas plant by software control were identified. The methods involved the use of a soft-sensor which is a means of using easily acquired data and mathematically constructing a more appropriate parameter also infrared spectroscopy, electronic nose technology, biogas volume and methane content and changes in volatile fatty acid composition and redox potential were identified as potentially effective. The new means of process control was identified by the work package that provide early warning of process failure and will ultimately lead to improved biogas production.

A pilot scale system, recently built at North Wyke Research was used to investigate both different sensors for fermentation monitoring and mathematical solutions to process control. The influence of different feedstock on biogas output, process control and monitoring was investigated. Feedstock types used include manure that is quickly digested and energy crops which are less easy to hydrolyse and may require different operational parameters. The generic approach will enable optimisation for different feedstock type. Successful mathematical models (such as rules based model) for process control were progressively identified and validated.

Technological innovations in process optimisation

An improved degree of efficiency in producing biogas at the lab-scale and pilot plant level was achieved. The efforts concentrated on the optimisation of feedstock pre-treatment, the use of enzymes and new approaches in feeding technology. Lab-scale experiments for the optimisation of feedstock mixtures, the pre-treatment of feedstock and the addition of additives were performed and partly transferred to pilot-scale level for further assessment. To avoid methane emissions from the digestate storage tank, a coverage system has been developed and tested at pilot scale to upgrade tanks that are not gas tight.

The EU-AGRO-BIOGAS project optimized the biogas process, by using optimized feedstock mixtures, pre-treatment of the feedstock and the addition of enzymes and by the development of a system for the automated process control. The efforts give the plant owner an improved possibility to control the process and to produce biogas at a higher level of efficiency while minimising greenhouse gas emissions.

Transforming biogas into heat and power

Extensive R&D and pre-demonstration activities were performed to reach improvements in the field of biogas utilization with Combined Heat and Power Couplings (CHP). New technologies, like the Organic Rankine Cycle add on power plants, and optimized technologies for heat utilisation or life cycle cost reduction through adjusted gas qualities were developed, designed and pre-validated. The drying and removal of ammonia from biogas with an improved gas scrubber has already shown the significant impact of gas impurities to the availability and operating costs of a CHP. A new more sulphur resistant type of exhaust gas heat exchanger was developed; the validation phase was completed. On two other plants, the validations of advanced heat utilization technologies, e.g. grain dryer, wood chips dryer or fermentation residue dryer, were carried out. Two guidelines/reports regarding the optimized CHP use in agricultural biogas plants and best practice and standard for using heat to feed the public network were produced.

Demonstration at commercial plant level

Field demonstrations of all developed technologies and methods during the EU-AGRO-BIOGAS project are the core element of the project. Researchers and companies from all participant countries validate there inventions, ideas and products under real time and rough field conditions. Demonstrations are planned by innovative approaches of feeding technologies, by a monitoring, management and early warning system and newly developed sensors at commercial biogas plant level, approaches to improve the degree of efficiency of the fermentation steps (enzymes, micro-organisms, stirring technologies) and a floating cover system. The cover traps a significant amount of methane escaping from the digestate storage tank without changes to the A.D. management chain and measures. As a consequence the degree of efficiency of the CHP and feeding into the heat network technologies was improved.

Results of a new feedstock mixture for high glycerol input, new systems for on-line measurements of process parameters (pH, conductivity, redox), NIR for process monitoring, thermo-chemical pre-treatment of feedstock, validations of drying of poorly storable fodder for cows with belt dryers, improvements of the biogas quality with gas scrubber and demonstrating the ORC technology, are very promising in improving the biogas yield at the selected commercial biogas plants.

The demonstration actions were done at 12 different commercial biogas plants from all over Europe. The idea was to show different innovative technologies and approaches along the life-cycle of biogas production and to scientifically proof their effectiveness. The aim of most biogas operators is to increase the biogas yield which means higher output in power and heat which then can be sold. All these measures have then shown the increase in revenues

and reduction of costs. For this purpose, specific software programme “ECOGAS” was demonstrated.

Partner	Plant	planned improvments (%); objectives	Demonstration activities done at the selected biogas plant	real improvements reached (%)
BOKU	Mureck	Improving spec. Methane yield and reducing feedstock costs ≈ 30%	feedstock mixture (addition of glycerol) additives	Increase of 30% in methane yield and reduction of costs about 60%
	Utzenaich	50 – 60 % on farm CHP heat utilisation through different drying activities	heat utilisation	Increase of annual heat utilization efficiency of about 30-40%. Annual average of 70 % CHP heat was reached. 90% usage is possible
North Wyke Research	Northwyke	reduce process failure, improved performance (biogas yield 5-10 %)	pilot plant was equiped with sensors and scanned with near infrared reflectance spectroscopy to determine the best means of automatic monitoring, management and early warning system	Increase in 30% methane productivity
North Wyke Research	Holsworthy	improving biogas yield or reducing feedstock volume throughput	changing feedstock from manure to higher biogas producing substrates such as food and vegetable wastes	50% reduction in feedstock volume
ATB	Fehrbellin	-50% labour, +100% feeding security	new feeding technology	Minus 50% labour effort, plus 100% feeding security
ATB	Fehrbellin	90 % usage of CHP heat	"Riela" feed and turn dryer	in average plus 70% up to 90% CHP heat usage
ATB	Fehrbellin	-50% risk of formation of swimming layer / utilisation of solid cattle manure as cost neutral feedstock	technology for application of enzyme-mixtures	total reduction of swimming layer and obvious reduction of risk of re-formation

ATB	Fehrbellin	-50% risk of formation of swimming layer / utilisation of solid cattle manure as cost neutral feedstock	technology for thermo- treatment of solid cattle manure	assumption confirmed in lab-scale experiments. Transfer into praxis is considered for 2011
UNIT	Bagnod	10-20% more gas yield	Coverage of digestate storage tank	+ 3% biogas yield
		Increase biogas yield and reduce HRT	Simulation of different organic loading rate (lab-scale activity)	Up to + 58% biogas yield; - 37% HRT
		10% more gas yield	Digestate mechanical separation and recirculation of the solid fraction within the fermenter (lab scale)	Up to +12.7% biogas yield
AH (DIAS)	Foulum	5-10%	Serial coupling digesters, on-line measurement of VFA	Plus 8-27% at pilot scale increase of biogas yield
	Lojstrup	20%	Documentation of pre-treatement by pressure cooking+lime. NH_3 stripping/scrubbing, post treatment	Plus 20% increase of biogas yield
VUZT	Knezice	8-15% in specific methane yield	feedstock mixture (optimization C:N ratio by addition of various types of feedstock oleaginous remains, kitchen leftovers) , additives, utilization of residual biogas	Plus 18% in specific methane yield
Vogelsang / vTI	Lamping	increased gas yield reduce hydr. retention time	compare new feeding device with feeding by screw conveyor	Increase of specific gas yield by 15 % with a reduction of hydr. retention time by 34 %
	Scherbing	reduction of a) energy consumption for feeding by 70%, b) labor for feeding by 50%, c) emission of bad odor; extend range of coferments to be handled	compare new feeding device with feeding by a mixing pit	reduction of a) energy consumption for feeding by 89%, b) labor for feeding by 50%, c) emission of bad odor; extend range of coferments to be handled
ASG/PRI	Nij Bosma Zathe	10-50 % more gas yield	Management optimisation using a decision support system	30% increase of biogas yield

	SNO	+10% economical impact	separation+drying of slurry	10% improvement of economic impact
GEJ	Wallsee	Heat utilisation increase	Exhaust gas exchanger improvement	Heat output +15% New exhaust gas heat exchanger concept up to 30% reachers
GEJ	Högl	increase of availability and unplanned downtime, decrease power consumption of auxilliaries proper conditioning of fuel gas with wet scrubber (combined drying/cleaning	proper electrical design and use of advanced plant control	With frequency converters approximately +75 h/year more energy production plus additional cost savings through reduced maintenace; ~19 % power savings auxilliaries
GEJ	Wasmerslage	Organic Rankine Cycle – increase of efficiency	ORC improvement	Increase electrical efficiency by 7% (ORC) as add on technology for waste heat recovery 60 kW additional electricity (6 % increase), over 17.000 operating hours

Improvement of economic output and environment protection

A crucial task within the EU-AGRO-BIOGAS project was the economic and environmental assessment of the demonstration measures. Most of the demonstration actions were finalised successfully and the main goals achieved. The partners agreed to use the following indicators to assess the environmental effect of the different demonstration activities:

- energy balance
- emission of CO_2 equivalents and CO_2eq mitigation costs

Two existing tools (ECOGAS, FOODPRINT) used for the calculation of these parameters was adapted for the requirements of the project, while for the economic part the ECOGAS tool developed by Partner 1, BOKU, was applied. The economic and environmental impact of the demonstrated activities are clearly lined-out and assessed against the current status quo – comprising the whole biogas production process from feedstock provision (esp. cultivation of energy crops) to the feed-in to public power or heat supply systems. The results of the

assessment serve as a decision support for biogas planners and consultancy, plant operators as well as regulatory public bodies. The assessment provides easily available sound economic and ecologic information (costs, benefits, potential side-effects) on a range of different optimisation measures.

Both assessment tools (ecologic footprint tool, ECOGAS tool) are designed in an open and flexible way so that the whole range of biogas plants can be depicted and assessed in the future – independent of feedstock, technical equipment, process solutions etc. Consequently, an evaluation of new, innovative approaches at plant level is already possible during the planning process. Together with the online European Feedstock Database this substantially improves planning security and thus provides an important decision support to the biogas community as a whole.

Conclusions and Outlook

The EU-AGRO-BIOGAS project objective was to optimize the biogas process, beginning with optimized feedstock mixtures, pre-treatment of the feedstock and the addition of enzymes and develop a system for automated process control. The efforts improve the possibility to control biogas production and increase the methane yield. These efforts give the plant owner the possibility to control the process and to produce biogas at a higher level of efficiency while minimising greenhouse gas emissions. A crucial task within the EU-AGRO-BIOGAS project is the economic and environmental assessment of the demonstration measures.

Biogas as an energy source was shown to be effective at reducing GHG emissions compared to energy production from fossil resources. However, reductions achieved vary significantly depending on the conditions: one of the main factors for efficient GHG mitigation is the utilization of the heat produced in the conversion process, accounting for up to 20 % of the CO2eq credits for the replacement of fossil resources. Within this investigation, the importance of avoiding residual methane emissions during the storage of fermentation residues was outlined. Even with residual methane emissions of about 3 % the GHG reduction potential of biogas production is significantly reduced. Gas-proof covering of the final storage is therefore strongly recommended by experts, especially as the captured methane can be used in the CHP.

The use of other feedstocks e.g, glycerol from biodiesel production can increase biogas production and reduce GHG emissions at the same time. CO2eq mitigation costs consequently vary according to the strategy followed at the plants. Significantly higher CO2eq mitigation costs at an Italian biogas plant were identified, caused by high residual methane emissions from the final storage and the comparably low rate of heat utilization.
Through the EU-AGRO-BIOGAS activities and innovations it was possible to achieve the given project objectives:

- To improve the degree of efficiency in the fermenter of about 35%
  - A reduction of the overall GHG emissions per kWh electricity produced of up to 43 % was achieved. GHG mitigation costs could be reduced by upt o 39 %.
- To increase the biogas yield of up to 40%
  - Between 3% and 35% were achieved depending on the plant and the demonstrated improvements
- To reduce the investment and operational costs of medium and large agricultural biogas plants of about 20 to 30%

- Investment costs could be reduced between 4 and 21 %.

Effect of implemented optimisation measures on the economic and environmental performance of the EU-AGRO-BIOGAS demonstration plants (status quo = 100%; min = most negative effect, max = most positive effect) [1].

		Effect of optimization measure compared to status quo conditions [1] [%]	
		min	**max**
Greenhouse gases			
GHG emissions	kg CO_2eq per kWh_{el} produced	0	-43
GHG savings compared to fossil resources	kg CO_2eq per kWh_{el} produced	-11	54
	kg CO_2eq per year	14	54
GHG mitigation costs	€ per ton CO_2eq saved	-3	-68
Primary energy demand			
Energy demand	MJ per kWh_{el} produced	9	-40
Energy savings	MJ per kWh_{el} produced	-5	31
	MJ per year	1	57
Economics			
Average costs of capital per year	€Cent per kWh_{el} produced	18	-25
Feedstock costs	€Cent per kWh_{el} produced	8	-32
Other costs	€Cent per kWh_{el} produced	0	-31
Total costs	€Cent per kWh_{el} produced	9	-21
Total costs less surplus for sale of heat	€Cent per kWh_{el} produced	-3	-20

[1] **Please note:**
Positive values = increase compared to status quo conditions; i.e. for GHG emissions, energy demand and costs negative effect, whereas for GHG as well as energy savings positive effect.
Negative values = reduction compared to status quo conditions; i.e. for GHG emissions, energy demand and costs positive effect, whereas for GHG as well as energy savings negative effect.

Total GHG savings per year (kg CO_2eq/year) compared to fossil resources (national references)

	all plants (12)	only plants with demo (9)
status quo	68 404 977	53 881 788

demo	66 665 150
Differenz	**12 783 362**

Total primary energy savings (MJ/year) compared to fossil resources (national references)

	all plants (12)	only plants with demo (9)
status quo	68 404 977	53 881 788
demo		66 665 150
Differenz		**12 783 362**

Communication measures

During several regional dissemination workshops and seminars the results of the EU-AGRO-BIOGAS project were presented in Germany, United Kingdom, Italy, Poland, Denmark, the Czech Republic. All together more than 700 stakeholders participated at these workshops and seminars.

A final symposium EU-AGRO-BIOGAS was organised in Wels, Austria and was combined with a national biogas congress in order to use synergies in organising and approaching participants. The symposium attracted more than 100 experts from all over Europe to come to Wels. The respective proceedings to the symposium can be found on the project website www.eu-agrobiogas.net.

List of partners:

- University of Agricultural Sciences and Applied Life Sciences Vienna, Austria
- Rothamsted Research Ltd., UK
- Association for Technology and Structures in Agriculture, Germany
- Institute for Renewable Energy, Poland
- Leibniz Institute of Agricultural Engineering, Germany
- Johann Heinrich von Thünen-Institut, Germany
- Universitá degli Studi di Torino, Italy
- Research Institute of Agricultural Engineering, Czech Repu-blic
- Vogelsang GmbH, Germany
- GE Jenbacher, Austria
- RTD Services, Austria
- Animal Science Group, Netherlands
- Plant Research International, Netherlands
- Aarhus University, Denmark

Contact: Amon Thomas Ao. Univ.Prof. Dipl.-Ing. Dr.agr.
Address: Peter-Jordan-Str. 82; A-1190 Vienna, Austria
Tel./e-mail: +43 (0)1 47654 3502 / thomas.amon@boku.ac.at
Website www.eu-agrobiogas.net

Photos of selected biogas plants for the demonstration activities:

AUSTRIA:

GERMANY:

POLAND:

ITALY:

UNITED KINGDOM:

CZECH REPUBLIC: