

# AD-WISE

## *Automated system based on on-line VFA sensors for an optimised control of anaerobic digestion plants*

Research for the benefit of specific groups - Research for SMEs  
Grant Agreement Number 315115  
FP7-SME-2012

### **FINAL PUBLISHABLE SUMMARY REPORT**

Date: January 2015

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## 1 EXECUTIVE SUMMARY

**OBJECTIVE.** The objective of AD-WISE was the development of an on-line system to optimise the anaerobic digestion process in biogas plants, to simultaneously maximize biogas production and maintain process stability.

**PROBLEM TO BE SOLVED.** One of the main research lines in anaerobic digestion in recent years is focused on the optimisation and control of biogas plants. Due to the special characteristics of these plants, the only parameters controlled on-line are temperature, methane concentration in biogas and sometimes the pH. This information is not enough to control the process, since these parameters do not predict a process malfunction. In this context, many plant operators are forced to manage the process in a conservative way, thus under-utilising the potential of energy production of the plant due to the acidification risk if the plant is operated at its limit without adequate control parameters. Among all proposed control parameters, the most reliable is the volatile fatty acids profile (VFAP) that consists of acids such as: acetic, propionic, butyric, etc. This parameter allows checking not only the state of the process but also predicting and avoiding a process malfunction (acidification), which is not possible to do with other parameters such as pH or biogas composition. Nevertheless, it is not currently possible to perform real-time on-line measurements of this parameter. It is necessary to take a sample and send it to an external laboratory for analysis of its volatile fatty acids (VFA) by gas chromatography (a precise but expensive technique that requires specialized equipment and staff). It usually takes 1-2 weeks between the sampling and the results and therefore the measurement loses its value as a control parameter and becomes merely informative.

**RESULTS.** The main result of AD-WISE is a prototype of an on-line equipment capable of real-time measurement of the VFA profile, based on optical techniques, and the validated use of these measurements to optimise the process (maximise biogas production while simultaneously maintaining the stability of the process). The resulting equipment is easy to use in the environment of the biogas plant, and allows for real-time measurements of VFAP. The AD-WISE prototype provides good measurements of VFA concentration in the range that may be a risk to the anaerobic digestion process (>1000 ppm). This makes the system suitable for control purposes in agroindustrial biogas plants

**WORKPLAN.** The research project included an initial laboratory stage. At that point, the measurement equipment and the mathematical models to obtain VFAP measurements and their interpretation were developed. With these results, a prototype of the equipment was built in IPMS and tested first in the AINIA's pilot plants and then in the agroindustrial biogas plant of Farm San Ramón (Spain).

**PARTNERSHIP.** In addition to the AINIA Technology Centre (Spain), that is the project leader, the project has four European partners: the Fraunhofer Institute (Germany), Farm San Ramón (Spain), Interspectrum (Estonia) and The National Microelectronics Applications Centre (Ireland).

**FUNDING.** The AD-WISE project received funding from the European Union's Seventh Framework Programme managed by the REA – Research Executive Agency <http://ec.europa.eu/research/rea> (FP7/2007\_2013) under Grant Agreement N.315115.

## 2 SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND THE MAIN OBJECTIVES

### 2.1 Project context

Anaerobic digestion (AD) is a biological process where the organic matter is degraded to form biogas and a digestate. Biogas can be fired in combined heat and power (CHP) engines or purified and injected into the gas grid. The total primary energy produced from biogas in Europe was 13.4 million toe in 2013, and there is still growing potential, since there is a huge amount of organic waste available that is disposed without valorisation.

Control and optimisation of AD plants is a key issue and one of the main research topics of this field. AD plant operators usually have to drive the plant with only information of pH and biogas composition. This often leads to a situation of underuse of the plant, if the operator prefers to drive the plant in a conservative way, or process malfunction, if the operator chooses to drive the plant near the load limit.

Out of all parameters proposed to control the process, the most reliable is the volatile fatty acids profile (VFAP) that consists on the single VFA concentration (acetate, propionate, butyrate, etc.). This parameter allows checking not only the process state but also predicting and avoiding process malfunction, that is not possible with other parameters (pH, biogas composition, etc.). With the information of VFAP, AD plants operators could optimise the plant, increase biogas production and avoid process stops. The currently available technique to measure VFAP is gas chromatography (GC): an off-line measurement that needs specific equipment and trained specialists, and takes 1-2 weeks between the sampling and the results, making the measurement no longer valuable for process optimisation.

### 2.2 Main objectives

AD-WISE aimed to develop an on-line device able to get real time VFAP measurements based on optical techniques and to integrate these measurements in the control system of the AD plant in order to optimise the process (maximise biogas production while maintaining process stability).

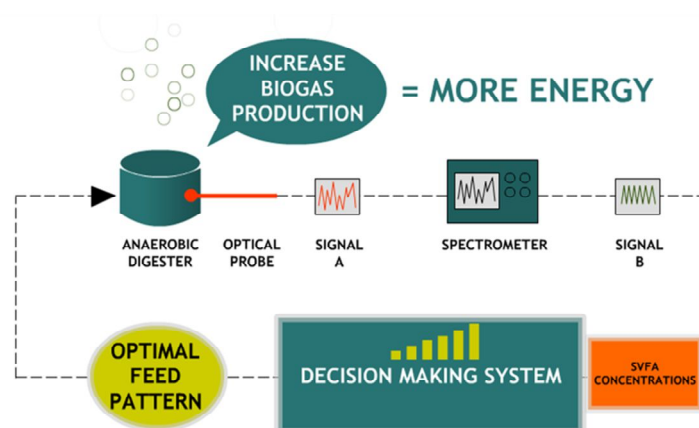


Figure 1.1. AD-WISE project concept.

The following technological specific objectives were defined to reach the above stated main objective:

O1. To define the relationship between the concentrations of single volatile fatty acids that set up the volatile fatty acids profile (VFAP) and the operating conditions of the AD plant. It is well known that VFAP is highly dependent on the operating conditions of the plant, especially on the feed characteristics (organic load and composition). The objective is to create a mathematical model that correlates changes in the feed with changes in the VFAP (model 1).

O2. To develop a new VFAP on-line monitoring system based on spectroscopy (optical technology). The monitoring system includes three main parts: the optical probe, the spectrometer and the mathematical model (model 2) that correlates the optical signal into VFA concentrations.

O3. To develop a decision-making system for the control of AD plants based on the on-line monitoring of VFAP. This software joins model 1 and model 2 and supports the plant operator on the basis of VFAP measurements.

O4. To validate the full system at pilot and industrial scale.

### 2.3 Work plan

In order to achieve the aforementioned objectives, the following work packages were carried out:

WP1. Management. The main objective of this work package was to monitor and coordinate all activities within the project to ensure its optimum development.

WP2. Modelling the effect of feed on VFAP concentration. The first step of the project was the development of the model to simulate the effect of feed on VFAP (Model 1) and the development of the monitoring system, that includes both the physical measurement system (probe, spectrometer, etc) and the mathematical model to correlate signal with VFAP concentration (Model 2).

WP3. Development of the monitoring system for measuring concentration of VFAP. The requirements of the AD-WISE system were translated into technical specifications to guide the development of the prototype. Then the hardware part of the system was designed and manufactured following these specifications. The SVFAM Model – Model 2 to measure the concentration of SVFA was built by using a collection of spectra obtained from the biogas pilot plant.

WP4. Integration. The main objective of this work package was to integrate the complete monitoring system (control software + measuring device) and to test it at pilot scale.

WP5. Validation at industrial scale. The lab prototype developed was scaled up and adapted to the working conditions of a full scale plant, and its functioning validated.

WP6. Dissemination and exploitation. The objective of this WP was on the one hand, to disseminate the aims and the results of the project and, on the other, to facilitate access to market for future exploitation of the developed system.

## 2.4 Main results

Four main results have been identified from the AD-WISE project, which are described as follows.

R1. Optical Probe. Optical probe designed specifically to measure samples within an anaerobic digester using optical spectroscopy. This has a significant advantage over the commercially available multi-purpose optical probes, since it is designed to produce the best possible signal on the operational measuring conditions of the sample taken from the anaerobic digester.

R2. Software application for AD control. The second result from the project is the software application that implements AD-Control Model as an easy tool for biogas plants to control their day to day operation. This is a unique software application based on the measurements of VFAP. The use of this application will automatically prevent overloads in the anaerobic process and will save several chemical analysis per year to biogas plants.

R3. Software application for VFAP concentration's measurement. The third result is the software application that implements SVFAM Model as an easy tool to predict the concentration of single volatile fatty acids (VFAP) through their spectra. This application is a major improvement in the field for its possibility to give an accurate measure of VFAP in a few minutes, compared to days or even weeks when outsourcing analysis to traditional laboratories.

R4. Integrated system for measurement of VFAP and AD control. The fourth result is the complete system installed in an operational biogas plant: the optical probe to capture the signal; the spectrometer that converts that signal into a spectrum able to be processed; the application using the SVFAM Model that converts that spectrum into the right value of VFAP in the digester and finally, the software application implementing the AD-Control Model, that according to that value suggests changes in the feed rate of the digesters to be made by the operator. Then, this complete system allows for an accurate, reliable and precise control of biogas plants, using an online real-time measurement system never applied before, able to detect and prevent overloads in digesters and regulate the feed rate to have them always in the optimum situation.

## 2.5 Project consortium

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GRANJA SAN RAMÓN (Spain). Contact person: Ramón Garcerá (ramon@gruposanramon.com, +34962338170). <http://www.gruposanramon.es>

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THE FRAUNHOFER INSTITUTE FOR PHOTONIC MICROSYSTEMS (Germany). Contact person: Susanne Hintschich (susanne.hintschich@ipms.fraunhofer.de, +49 3518823362). <http://www.ipms.fraunhofer.de>

INTERSPECTRUM (Estonia). Contact person: Teofilus Tonnisson (info@interspectrum.ee, +37 27383008). <http://www.interspectrum.ee>

## 2.6 Further information

Project website: <http://www.ad-wise.org>

Video of the project (English):

[https://www.youtube.com/watch?v=X\\_Cpapmd7DE&list=UUurewArMDiT\\_HlfCmJ4ApoA](https://www.youtube.com/watch?v=X_Cpapmd7DE&list=UUurewArMDiT_HlfCmJ4ApoA)

Video of the project (Spanish):

[https://www.youtube.com/watch?v=72YaCLCNomw&list=UUurewArMDiT\\_HlfCmJ4ApoA](https://www.youtube.com/watch?v=72YaCLCNomw&list=UUurewArMDiT_HlfCmJ4ApoA)

## 3 MAIN S&T RESULTS AND FOREGROUNDS

### 3.1 WP1. Management

The management activities have been carried out by AINIA as project coordinator. Those activities included:

- Organisation and hosting of kick-off meeting;
- Drafting and updating the risk and contingency plan;
- Definition of roles, tools and duties;
- Drafting and preparation of the Consortium Agreement;
- Setting-up and maintenance of a workplace (FTP server) to facilitate coordination and information sharing;
- Development of guidelines on management tasks and coordination tools;
- Partners’ compliance monitoring (technical and financial);
- Financial follow-up.

Several face-to-face meetings were celebrated along the project:

- Kick-off meeting in Paterna, Valencia (Spain), 19th-20th September 2012 (month 1);
- Consortium meeting in Tartu (Estonia), 19th-20th February 2013 (month 6);
- RTD partners meeting with visit to Granja San Ramón biogas plant, in Paterna and Requena (Spain), 28th May 2013 (month 9);
- Consortium meeting in Dresden (Germany), 24th – 25th September 2013 (month 13);
- Consortium meeting in Requena (Spain), 7th – 8th April 2014 (month 20);
- Final meeting in Paterna, Valencia (Spain), 11th – 12th November 2014 (month 27).

Additionally, a number of video-meetings were held in order to coordinate and monitor the research work.



*Figure 1.2. AD-WISE partners at the kick-off meeting.*

### **3.2 WP2. Modelling the effect of feed on the concentration of single volatile fatty acids**

The main objective of this WP was to establish a correlation between the feeding scheme and the effect of it on SVFA concentration (AD-Control Model – Model 1). In order to achieve this objective, the following specific objectives were proposed:

- To review previous research works on the field of SVFA correlations with AD plant feed schemes.
- To design the anaerobic digestion experiments.
- To study the behaviour and evolution of SVFA after introducing changes in the feed of the anaerobic digester.
- To define mathematical equations to represent this SVFA evolution and to define the limits and conditions at which feed regulation has to be done (Model AD-Control).
- To validate the model with additional experiments with different feed patterns.

The first step was to review previous works done on single VFA dependence on feed flow and composition. In this task, a thorough review was performed in scientific databases, in order to avoid research duplicity. Also, previous work done by AINIA was used. The review was focused on the effect of feed composition, inhibitors and organic overload in the SVFA evolution in anaerobic digesters treating different types of wastes.

Taking into account these previous results, an experimental design was elaborated with the objective of recording the response of the digester to different feeding patterns / shock loads. Three different aspects were taken into account:

- 1) Feed composition: to test the effect of protein, fat and carbohydrates on the response variables.
- 2) Feed rate: tests with ideal mixtures to test the effect of the OLR increase.
- 3) Inhibitors: effect of the presence of common inhibitors on the SVFA concentration.

Following the experimental design, the behaviour and evolution of VFAP was experimentally evaluated in its dependence on feed composition and rate. The experiments were carried out in semi-continuously fed digesters, available in AINIA. The effect of several inhibitory compounds was assessed as well. Mathematical equations were obtained to represent VFAP evolution and the AD – Control model was outlined with the limits and conditions at which feed regulation has to be done.



*Figure 2.1. AINIA's pilot digesters used for the study of the VFAP evolution depending on the feed.*

The results of the experimental tests were used for modelling the evolution of VFAP concentration with the changes of feed (either substrate composition or OLR pulse). This was done by fitting the experimental data of VFAP measured during the experiments to mathematical equations. Thus, a prediction of the SVFA behaviour could be done according to the introduced change. Besides, the feed regulation actions were defined as a function of the concentration limits of VFAP.

The main results of this WP are summarised below:

- Literature review of VFAP evolution with operation parameters and inhibitors.
- Experimental design to evaluate the effect of feed composition on VFAP.
- Effect of feed composition on VFAP, described by mathematical equations and limits that will be used as set points in the control software.

- Effect of feed rate on VFAP, used to choose the most adequate recovery strategy after instability detection.
- Effect of inhibitors on VFAP, described by mathematical equations and limits that will be used as set points in the control software.
- Code of the predictive module of the model.
- Definition of feed regulation actions as a function of the VFAP concentration (corrective module of the model).

### 3.3 WP3. Development of the monitoring system for measuring concentration of SVFA

The objective of this work package was to develop a monitoring system based on optical spectroscopy to measure VFAP in digester slurry. In particular, this required:

(a) establishing the most important technical specifications in relation to the cost of the system: The technical specifications for the prototype were fixed early in the project and duly documented.

The requirements of the final AD-WISE system were fixed by project partners GSR, MAC and AINIA, translated into technical specifications by IPMS. Thereby, we ensured that the harsh environmental conditions near an industrial digester are considered as well as the challenging spectroscopic demands for measuring VFA in very low concentrations. These specifications were then used to evaluate the spectroscopic methods available, and design the prototype.

(b) a preliminary evaluation of the monitoring system to decide the optimum approach for the design of the prototype: Three optical methods underwent extensive evaluation.

The three methods under consideration were tested extensively. Initial laboratory experiments were arranged to test three different spectroscopic methods with digestate samples taken from anaerobic digestion plants. Five VFA were diluted in deionised water at three concentrations each and spectra recorded. Then, five different VFA were added in three concentrations each to two types of digester slurry provided by AINIA, and spectra were recorded. In conclusion, signals were observed for all VFA, as expected. Despite their financial and logistic advantages, two methods had to be discarded due to either low sensitivity or interferences. The most sensitive method was chosen. Based on it, the design and construction of a meaningful and functioning prototype could begin.

(c) the design of an online optical probe and an optical spectrometer adapted to the specifications fixed at the beginning of the project.

In order to meet the specifications, the optical technique, the material of the optical probe, the configuration of the measurement procedure, etc. were selected. For a smooth integration, the diameters of pipes were designed to be compatible with the viscosity of the slurry and with the pipework of the pilot plant at AINIA. Material resistant to corrosion was selected.

(d) developing the prototype according to the design previously decided. The equipment was designed in such a way that no further sample pre-treatment was required for use at the pilot AD plant.

The construction drawings were created at IPMS. The probe was designed to be compatible with previously developed hardware. Attention was also paid to ensure compatibility with the pilot plant at AINIA. IPMS manufactured the probe elements that comprise the prototype. Finally, these elements were integrated and a monitoring system prototype was built.

(e) a test of this prototype to check its proper operation and redesign if any element needed to be improved to meet technical specifications.

The prototype status comprised an spectrometer equipped with a self-cleaning flow-through probe to avoid biofilm build-up after several measurements, taking into account the microbiological load of the digestates to be measured. Further tests of the prototype included measurements of mixtures of different VFA in slurry.

(f) building the SVFAM Model – Model 2 to predict concentrations of SVFA through spectra collected from the AD pilot plant at AINIA.

The monitoring system developed by IMPS was used to build the calibration model able to predict the concentration of SVFAs in the digester through the optical spectra (SVFAM Model – Model 2).

In order to do so, first, a experimental design was devised to select different concentrations of the VFAs and different digestates, to have enough variability in the samples to create robust models. Then, measurements were performed in these samples and the results stored for the development of the calibration models for the prediction of the concentrations of the VFAs. The spectra obtained were studied to improve their characteristics prior to apply multivariate statistical algorithms to create the models.

The main results of this WP are summarised below:

- Specifications of the prototype were fixed.
- Three optical techniques were tested extensively.
- The best optical technique (more sensitivity and less interferences) was selected.
- A flow-through probe head was designed.
- A self-cleaning system was designed for the probe head and optimised via a 3D flow model.
- An initial version of the prototype was constructed including the self-cleaning probe head.

### 3.4 WP4. Integration

The main objective of this WP was to integrate and tune the automated system based on the on-line VFA sensor. This system comprised the monitoring system developed in WP3 combined with a software application including AD-Control Model – Model 1 from WP2 and SVFAM Model – Model 2 from WP3.

This main objective was achieved in several steps:

- (a) development of the software application to control the biogas plant in the AD-Control Model – Model 1 to regulate the plant feed and the SVFAM Model – Model 2 to perform the measurement of SVFA concentration.
- (b) integration of the monitoring system and the software application to check its proper operation.
- (c) implementation of the monitoring system in the biogas pilot plant available in AINIA.
- (d) testing the operation of the whole monitoring system in this pilot plant.

A software module was programmed in order to translate the SVFAM Model – Model 2 into a software application. This application can be used with the optical spectrometer to calculate the concentration of SVFA from spectra. A Graphic User Interface (GUI) was also developed to facilitate the interaction of the user. The software was installed in a PC, connected to the PLC that controlled all parts of the prototype. When the user presses the “Start” button in the GUI, the following sequence starts: (1) reference measurement; (2) slurry measurement; (3) transformation of the spectra into VFAP concentration; (4) display of the spectrum and the acid concentrations in the GUI graphs; (5) compare the values with the set points; (6) display indications to biogas plant operator to correct the feed if necessary; (7) save data.

The developed prototype was installed in a pilot plant in AINIA. This pilot plant has two digesters, operating in series, which allows very different VFAP concentrations due to the different stages of the process reached in each digester. The prototype was installed so that samples from both digesters could reach the measurement chamber of the prototype. In order to allow this, a valve plate with 5 valves, some 2 and some 3 way, was designed to easily make the measurements. The valve plate was connected to the measurement chamber and to the digesters, and with a combination of openings and closings of the valves, the digestate could move from the digesters to the prototype.

Once the prototype was installed, the first task was to check the behaviour of the calibration models with real samples. Measurements were taken for some weeks and the results analysed. Later on, some of these measurements were used to optimize the calibration models, as the error for small concentrations of VFAs was considered significant. A combination of measurements from the previous and this phase were used in the optimization process, and models with greater accuracy in the prediction of the concentrations of VFAs were obtained.

The main results of this WP are summarised below:

- The prototype was installed in AINIA’s pilot AD plant
- A valve plate was used to allow measurements from both digesters
- The software application for predicting the VFAs concentrations from spectra was developed
- The calibration models were tested with real samples
- The calibration models were optimized

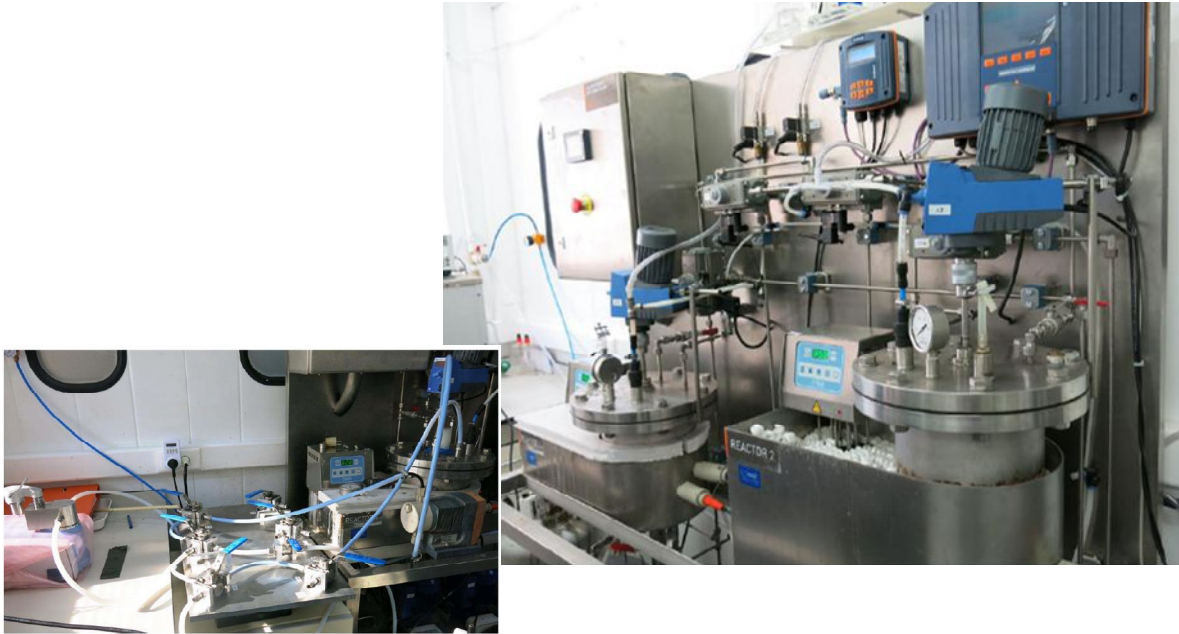


Figure 4.1. AINIA's pilot digesters used for the integration of the prototype at pilot scale.

### 3.5 WP5. Validation at industrial scale

The objective of this work package was to develop a prototype that can measure VFAP concentrations in a full scale operational biogas plant. In particular, this implied:

(i) Upscaling: adapting the laboratory size prototype to the harsh working conditions of a full scale plant and prototype installation. Prior to this task, risk assessment was carried out in much communication between all project partners to reveal the critical issues to be addressed during the adaptation, installation and operation of the full-scale prototype. The adaptation of the optical prototype for full scale use comprised the protection of the sensitive optical instrument as well as the development of a sampling device.

(ii) installing software extensions in the control system of the biogas plant of project partner GSR.

The software was the one developed in WP4 and previously described, with the necessary features to allow for a smooth interface with the biogas plant operator in order to be friendly and easy-to-use software.

(iii) validating the prototype function.

The prototype was installed and connected to the main pipe of the operational biogas plant of GSR. The prototype allowed sensing the effluent with the conditions needed for the VFAP measurement at pre-set times or manually. Several sets of measurements were designed and executed in order to evaluate the repeatability and the accuracy of the measurements of VFAP with the AD-WISE prototype installed in GSR. To do so, comparison with the standard technique (gas chromatography) was carried out in two ways: with a GC equipment installed

ad hoc in the biogas plant of GSR (same sample, same time of measurement as the AD-WISE prototype), and with a laboratory GC in AINIA (same sample, but with a time delay).

The result of this Work Package is a pre-commercial prototype, which demonstrates that the selected technique can indeed be used to measure single volatile fatty acid (VFA) concentrations at a full-scale operational biogas plant with a sensitivity that is adequate for advanced process control. The possibility to work in the environment of a biogas plant, without the need of pretreatment other than a solid-liquid separation, was also demonstrated.



*Figure 5.1. Biogas plant of the partner GSR where the prototype was installed and validated*

In order to achieve a smooth transition from the pilot-scale prototype to a full-scale industrial installation, a joint risk assessment was carried out by the entire consortium, which covered the adaptation, installation and operation of the full-scale prototype. By implementing an appropriate response to each risk we ensured that the measurement system could be implemented at GSR with minimal complications and maximal reliability.

Hardware adaptations were an important subtask in up-scaling the pilot-scale prototype. Several components of the hardware of the pilot-scale prototype had to be modified or amended in order to adapt it to the industrial environment. The challenges addressed here included the protection of the measuring instrument, sample solid-liquid separation as well as the automation of sampling, measuring and cleaning as described below.

(A) Protection: the spectrometer is sensitive to changes in temperature, moisture, mechanical vibration, and dust, which inevitably occur at a biogas plant. All of these factors are detrimental to system performance and may damage the instrument. Therefore, part A of the adaptations concerned maintaining the specified working conditions of the spectrometer. A comprehensive protection unit was set up in the form of a climate chamber. The chamber included air conditioning, a dehumidifier, a shock absorber, and a glass door to enable inspection of the measuring instrument without exposing it to dusty air.

(B) Sampling of liquid: The pilot-scale prototype used liquid slurry only. Here, samples were obtained by pumping the slurry into the flow-through sample chamber of the spectrometer,

without any pre-treatment of the digestate. However, industrial digestate is a mixture of solid and liquid components. Only the liquid fraction can be processed by the measuring prototype due to the limited diameter of the sample chamber (9 mm). To extract liquid from digestate, screw presses are commonly used. At IPMS, a screw press was customised to fit the measuring prototype and successfully tested. No further slurry pre-treatment was needed to perform measurements, which greatly added to the simplicity of the final setup.

(C) Sampling/cleaning hardware: A standalone spectrometer requires a sampling device to connect to the slurry flow of the biogas plant. In both prototypes, this was achieved via a hydraulic setup, which performs a fixed measurement cycle. This cycle is described as follows: 1. Cleaning, 2. Reference measurement, 3. Slurry inflow, 4. Slurry measurement, 5. Cleaning. In the pilot-scale prototype, all valves and pumps as well as the spectrometer were controlled manually. For the full-scale prototype, the sampling device was automated using stainless steel ball valves to control the liquid flow, a double diaphragm pump to drive slurry to the spectrometer, a pressure pump to provide water pressure for cleaning. Further, the automation of the cleaning procedure required the use of a larger, 100L tank to store water for many cleaning cycles.

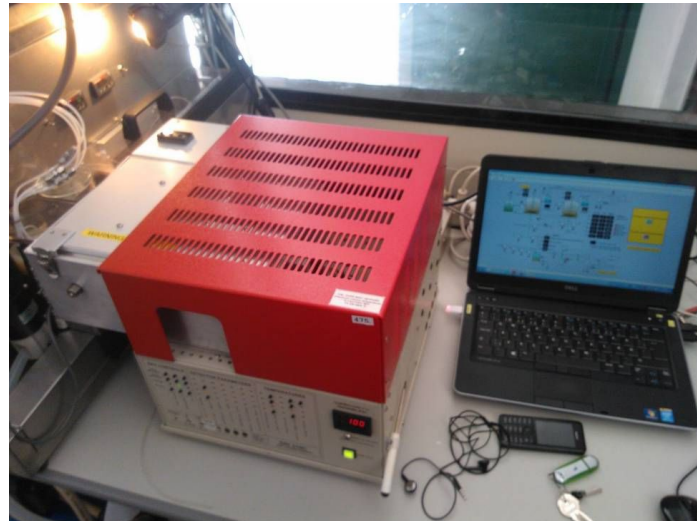
(D) Sampling/cleaning automation: All new components of the sampling device, including the solid-liquid separator are driven either electrically or pneumatically. A PLC (programmable logical computer) was installed in a switching cabinet to provide a hub for all electrical and pneumatic connections. This PLC was then programmed to control all valves, pumps and the separator, in order to perform the modules of the measurement cycle described above. Via Ethernet, the PLC was linked to a PC, which also controlled the spectrometer.

(E) Software: the software was installed in a PC to coordinate the interaction between spectrometer measurements and PLC actions. For the integration of the PLC control into the master software of the prototype, a close and efficient communication was established between hardware and software engineers.

(F) Infrastructure: At the biogas plant, the consortium identified the location of a sampling point to which the prototype could be attached. This plant consists of two fermenters. The consortium decided to take samples from the pipe that connects these fermenters. Here, slurry can be pumped back and forth in both directions. Thereby, the prototype can access slurry from both fermenters at the choice of the plant operator.

(G) Communication and documentation: The electrical installation was set up according to the German DIN standard. A hardware copy of all diagrams is stored inside the switching cabinet to provide a reference for maintenance or emergencies. Arising from the risk and contingency plan, a crucial element in ensuring safe operating conditions is a comprehensive and standardised training of the staff handling the prototype. Therefore, a training document was prepared, which is the basis for all instructions to staff. This training document is kept at the biogas plant, where it serves to keep a record of the persons authorised to operate and maintain the prototype. Only trained staff is authorised to handle the prototype.

Once the prototype was installed and working, the validation step was initiated. At this stage, the measurements taken with the spectrometer were compared with a GC instrument adapted to be installed in parallel to the spectrometer, so as to have the GC measurement for comparison at the same time and from the same sample. The GC instrument adapted to work in the biogas plant was provided by the Danish Technical University.



*Figure 5.2. Gas chromatograph (GC) installed in GSR for comparison with the spectrometer.*

The validation period allowed to demonstrate the feasibility of the measurement of VFAP with the selected optical technique, without other pretreatment than the solid-liquid separation, and with the quality requirements needed for the control of AD plants in terms of accuracy and detection limit for the key VFA.



*Figure 5.3. AD-WISE prototype installed in GSR.*

First, the uncertainty of the AD-WISE system was determined by performing several measurements of the same sample. This was a key point to check since the prototype has to work in the harsh environment of an operational agro-industrial biogas plant, which involves vibration, temperature variation, etc that can affect the results of the measurement. The results were satisfactory, for instance the uncertainty was found to be lower than 10% for the acetic acid concentration.

Second, the AD-WISE system performance was evaluated with the real effluent coming from the GSR biogas plant, and compared with the GC equipments (one working in the biogas plant and other working in the lab of AINIA). This allowed the validation of the system in the range of concentrations existing in the biogas plant at that moment, which were also similar to the ones reported as close to inhibition problems.

Third, additional measurements were performed with dilutions of the GSR effluent and artificial mixtures in order to have results of lower concentrations of VFA and increase the robustness of the model and ensure wider applicability.

In summary, the project achieved its main goal – the validation of VFA measurements via an optical method, at an industrial biogas plant. This result demonstrates that important mechanical specifications of the prototype are met: The instrument is robust, it can stably operate in a harsh industrial environment and produce consistent, reliable results over an extended time.

Additionally, the challenging spectroscopic demands are met to the extent that is necessary for the performance of the process control model.

The main results of this WP are summarised below:

- A risk and contingency plan was set up for the development, installation and operation of the prototype at a full-scale operational biogas plant.
- The measuring instrument is now adapted to operation under harsh industrial conditions.
- The prototype is capable of working fully automated including sampling. Potential future modifications for digestates with a very high solids content are identified.
- The prototype is installed at the full-scale biogas plant.
- Staff is trained to operate and maintain the prototype; instructions dedicated for training further staff are available on-site.
- The complete documentation of all prototype components is finalised and available on-site.
- A master software was programmed to integrate the spectrometer operation, automated sampling, evaluation of the spectra via the SVFAM model and output of the evaluation results to a user - interface.
- The function of the full-scale prototype is validated over an extended time and the most important specifications are met.

### 3.6 WP6. Dissemination and exploitation

The main goal of WP6 was to develop a Dissemination and Exploitation Plan. On one hand, the Dissemination Plan aimed at providing clear and useful information about the project, the developed technology, the main results, the benefits and the EC funding; on the other hand, the Exploitation Plan's main objectives were to take as much advantage as possible from the project results and to focus these results on the expected impacts.

The specific objectives of this WP were:

- To develop the appropriate tools and materials to reach the dissemination goals and targets.
- To actively communicate AD-WISE results to industry, academia, policy makers and general public.
- To make a "live" demonstration of the system for end-users.
- To develop a business plan in order to analyse the best exploitation possibilities and develop adequate strategy to reach the market.
- To promote the results in specific technology transfer networks.

The Plan for Use and Dissemination of the Foreground is available in section 4.2.

A project website was developed and launched in month 3, and is available at [www.ad-wise.org](http://www.ad-wise.org). More than 800 visits were registered during the project. It gathers public up-dated information on the project: background, objectives, work plan, expected results, benefits for end-users, all of them described in a common language in order to reach a general public. Information on the partnership, contact details, as well as related news and public deliverables and reports are also available in the site. It is structured in several main sections. The section "The project" describes the system to be developed, the project main objectives, the organisation of work packages and the expected results are described. The section "The partnership" includes a brief description of each participant and contact details. In "News", information on main project events was periodically uploaded. In "The documents", relevant downloadable documents are gathered. "The links" section includes references to other EU projects related to anaerobic digestion and automation of waste/wastewater treatment processes. Finally, two additional sections, "Benefits for Biogas Plants" and "Contact", describe the project impact on the biogas market and include the contact details of the Project Coordinator, respectively.

Besides, two electronic leaflets have been produced and disseminated through the project website.

Other dissemination activities of the project were presentations in 7 national and international events, promotion at 4 fairs, 2 articles in specialised magazines and 3 press releases with more than 20 impacts. An article has been submitted to Wikipedia and is currently under review. Details of these actions can be found in the website and in the section 4.2 of this final report.

Additionally, social networks (LinkedIn and Twitter) were used in order to increase the impact of the dissemination actions.

Contact with related projects, technology platforms and associations was done in the framework of the project. In particular, the following actions were carried out:

- Related projects: a collaboration with the project CONTROL-AD4H2, as the GC device implemented by DTU was initially developed within this project.
- Contact with technology platforms: REDIT and BIOPLAT were informed about the project. A specific presentation of AD-WISE was done in a workshop organised by REDIT.
- Contact with associations: the European Biogas Association (EBA) was informed about the project. A technology offer was published through the Enterprise Europe Network (EEN). A press release of AD-WISE was published in the website of the Spanish Biogas Association (AEBIG).

Two workshops were held during the later part of the project in order to communicate AD-WISE final results. The first one was organised by AINIA on the 18th September 2014 in Spain, and included the technical visits to the prototype. The second was organised by IMPS on the 7th October 2014 in Germany. More than 40 potential end-users or key stakeholders were reached, and expressions of interest regarding either the use or the commercialisation of the system were received.



*Figure 6.1: Attendants to the workshop and visit tour organised by AINIA.*

A specific action has been carried out to train the participant SMEs on the developed technology, its potential and the details of the functioning of the prototype. This training took place during the last project meeting in November 2014.



Figure 6.2. Training to SMEPs.

Finally, a video has been produced and is available in English and Spanish on Youtube:  
[https://www.youtube.com/watch?v=X\\_Cpapmd7DE&list=UUurewArMDiT\\_HlfCmJ4ApoA](https://www.youtube.com/watch?v=X_Cpapmd7DE&list=UUurewArMDiT_HlfCmJ4ApoA)  
[https://www.youtube.com/watch?v=72YaCLCNomw&list=UUurewArMDiT\\_HlfCmJ4ApoA](https://www.youtube.com/watch?v=72YaCLCNomw&list=UUurewArMDiT_HlfCmJ4ApoA)

The business plan and marketing strategy have been developed by the SMEs led by MAC.

The main results of this WP are summarised below:

- Plan for the Use and Dissemination of Foreground.
- AD-WISE website.
- AD-WISE internal work tool.
- 3 press releases with more than 20 impacts in national press.
- Two electronic leaflets.
- Participation in 7 specific conferences and 4 fairs.
- Publication of 2 articles in specialized magazines.
- Dissemination through social networks.
- Publication of technology offer
- Submission of article to Wikipedia.
- Production of a video available on Youtube.

#### **4 POTENTIAL IMPACT (INCLUDING THE SOCIO-ECONOMIC IMPACT AND THE WIDER SOCIETAL IMPLICATIONS OF THE PROJECT) AND MAIN DISSEMINATION ACTIVITIES AND EXPLOITATION OF THE RESULTS**

Projects under the “Research for SMEs” aim at strengthening the competitiveness of the SME participants and improving industrial competitiveness of SMEs across the EU. These projects also aim at bridging the gap between SMEs and research community, and having an impact in society.

This project has resulted in a process monitoring, prediction and control system (AD-WISE) that enables the efficient control of the anaerobic digestion process. This project was expected

to have an impact on three main groups: i) end-users of the technology (mainly SMEs), ii) participating SMEs and iii) society.

From the point of view of the end-users, the developed system improves the efficiency of the existing processes and allows setting up new and optimised biogas plants, thus resulting in a direct improvement of their competitiveness. This possibility has been validated through the activities of WP5 in the project.

For the participating SMEs, AD-WISE is a real business opportunity and is going to have a clear commercial and economic impact soon, as demonstrated by the business and exploitation fact. The AD-WISE partners are preparing a second project to optimise the final product in order to be able to start with the commercialisation. This will allow the participating SMEs to improve their competitiveness by increasing their turnover and opening new markets for them. Besides, they have expanded their research groups network with the RTD partners of AD-WISE and the second project. This will have an impact in their future development as well.

To society at large, the project has addressed community societal objectives like: renewable energies, employment, and environment, among others. As long as the developed system allows for a more stable and efficient process, the production of renewable energy and the benefit for the environment is improved. Moreover, when the system is ready to be produced and commercialised, new direct and indirect employments are expected to be created, related to the industrial production of the system, installation, maintenance, technical service, etc.

#### **4.1 Impact on SME end-users of the technology across Europe**

In order to assess the impact on the end-users, some characteristics of the AD-WISE system have to be highlighted. AD-WISE is a system for AD monitoring and control that will help biogas plant operators to improve the efficiency of the process. AD is a complex biological process that produce volatile fatty acids (VFA) as intermediate product. This parameter is the most relevant for the process control and AD-WISE will allow for the first time to have this information on-site, real-time. This represents a great advantage for the optimisation of the process control. The main causes that can lead to instability and consequent VFA accumulation are organic overload (too much feeding), process inbalance (lack or excess of any main component of the base feeding mixture or nutrients) or inhibition due to a toxic compound present in the mixtures. While these causes can be kept under control in biogas plants where the feeding is constant and constantly controlled, process inbalance and stops can occur more likely in plants with variable feedstock (waste).

The biogas market in Europe is different in each Member State. Thus, the expected impact on the SME end-users depends on the maturity of the market and other factors.

In countries where the biogas market is mature (Germany, for instance, with more than 8,000 running biogas plants) the AD-WISE system will contribute mainly to the improvement of the efficiency of the existing plants, and will also facilitate the shift of the raw materials utilization. Indeed, the majority of the biogas plants in Germany run with energy crops as main feedstock.

This is due to the German renewable energy act (EEG), that promoted in the past this kind of materials as feedstock. This feedstock is quite constant all over the year and does not imply many risks for the biogas plant operators. However, the new EEG is promoting the shift to other feedstocks such as manure and organic waste. These materials are variable and can lead to instabilities in the digester since their composition is changing and many times unknown. In this scenario, the AD-WISE system can support this change of the paradigm.

In other countries where the biogas market is developing, the AD-WISE system can be used both in existing and new plants. In most of the countries the biogas plants run on manure and waste, with the risks described above. In this sense, AD-WISE system, providing real-time measurement and control of the AD process, will allow the operators of biogas plant running on waste to increase the efficiency and competitiveness of the plants by avoiding process stops. Plants like those treating varying organic waste, sewage sludge digesters performing co-digestion, etc. are likely to suffer process stops, especially if plant operators try to optimise the plant by increasing the feed rate, which is the only way to do it in existing plants. If the process is stopped, it takes 2-3 months to recover steady state conditions.

The savings thanks to the AD-WISE system have been estimated in over €20,000 per year. This figure corresponds to a standard 500 kW anaerobic digestion plant producing 4GWh in a year and an energy price (feed-in tariff) of 6 €ct/kWh, which is under the average price in Europe (pessimistic scenario). Even considering one process stop every 2 or more years, the payback period would be below 3-4 years, which is usually considered as economically feasible for industrial investments. Additional savings can be considered due to the fact that external analysis of SVFA is not needed anymore.

## 4.2 Impact on participating SMEs

For the participating SMEs, AD-WISE is a real business opportunity and is going to have a clear commercial and economic impact soon, as demonstrated by the business and exploitation fact. The AD-WISE partners are preparing a second project to optimise the final product in order to be able to start with the commercialisation. This will allow the participating SMEs to improve their competitiveness by increasing their turnover and opening new markets for them. Besides, they have expanded their research groups network with the RTD partners of AD-WISE and the second project. This will have an impact in their future development as well.

MAC develops, manufactures, sells and maintains individually designed process analysis systems for industrial processes. AD-WISE brings them the possibility to increase their market share in the biogas sector and expand their portfolio of customers. Moreover, this project will give them the lead in the market in this kind of installations. Thus, the profit of the company is expected to experience an important raise on the following years. Even if the company finally opts for the licensing of the product, the impact of AD-WISE will be very significant due to the increase of the turnover thanks to this new income.

GSR has a biogas plant that uses the manure from cows mixed with different co-substrates to produce electricity in the digesters. This plant has been used for testing and validating the

control system developed in the project. Their main benefit from the project has been to have an improved control system in their digesters, able to advise on the rate of feed to the plant to prevent overloads, saving them hundreds of analysis of samples and avoiding undesired stops of the process which would cause a huge economic loss to the company. GSR has now received the most advanced system to automatically optimise and control the operation of their biogas plant.

INTERSPECTRUM manufactures and sells measurement devices. AD-WISE has opened a new important market for this company, the biogas market. The company will be able to extend the range of their offered products and to consequently increase the sales volume and revenue.

For a more quantitative estimation of the impact on the participating SMEs, the market size has to be estimated. According to the trend:research institute<sup>1</sup> there will be 16,000 biogas plants by 2020 from 8,000 in 2010. Considering that the AD-WISE system will be sold for plants with bigger capacities (above 300kW), the market size is estimated to be 50% of the above figure<sup>2</sup>. Due to the current decrease trend of the public support, maximum efficiency of biogas plant will be a priority, and therefore retro-fit upgrades (such as AD-WISE system) to achieve this efficiency are expected to have a market opportunity. Thinking globally, the EU market is about 50% of the global market potential. There are no competitors in the market currently, since there is no commercially available equipment for the measurement on-line of single VFAs.

In addition to the new markets and increased turnover, the participating SMEs have increased their network of collaborator RTDs. They already had in some extent relationships with the research community, since they had participated before in R&D projects in collaboration with research entities (universities and technology centres). This project has contributed to reinforce the linkage between these innovative SMEs and the research community, by setting them in contact with other research groups from other Member States, and with other research fields different from their former R&D activity.

### 4.3 Impact on society at large

To society at large, the project has addressed community societal objectives like: renewable energies, employment, and environment, among others. As long as the developed system allows for a more stable and efficient process, the production of renewable energy and the benefit for the environment is improved. Moreover, when the system is ready to be produced and commercialised, new direct and indirect employments are expected to be created, related to the industrial production of the system, installation, maintenance, technical service, etc.

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<sup>1</sup> trend:research, 2010. Biogas in Europa bis 2020 (Biogas in Europe till 2020): Potenziale, Wettbewerb und Marktentwicklung bis 2020 in 16 europäischen Ländern (Potential, competition and market development till 2020 in 16 European).

<sup>2</sup> FNR e.V., 2009. Biogas-Messprogramm II - 61 Biogasanlagen im Vergleich: (Biogas Measurement Program II - A comparison of 61 German biogas plants). 1st ed. Gülzow: Fachagentur Nachhaltige Rohstoffe (Agency for Renewable Resources).

RENEWABLE ENERGY. As demonstrated before, the biogas sector is of great importance in Europe, and it is going to grow in the next years due to the new renewable energy policies. Thus, a technological improvement of biogas plants which increases their efficiency or contributes to produce more energy from biogas will have a very high economic impact at a European level. Taking into account the 50% of the expected 16,000 biogas plants and the 6 ct€/kWh scenario, the economic impact of AD-WISE on renewable energy production could be estimated in around 500 M€. Moreover, AD-WISE contributes to the improvement of the renewable and decentralised energy production; an increase of biogas plants in agricultural scenarios allows for an increase of renewable energy sources which is a strategic issue for European countries due the reduction of external energy dependency. Finally, this contributes to the fulfilment of European compromises stated in the White Paper and Green Paper on Renewable Energy all European countries that have set a target of 20% of the final energy consumption to be produced from renewable energy sources by 2020.

ENVIRONMENT. This point is related to the environmentally friendly waste management and the environmental positive impacts of producing and consuming renewable energy instead of fossil energy. The main impact can be quantified as savings of fossil-CO<sub>2</sub> emissions. Just one biogas plant power operated flawlessly can produce 850 tons oil equivalent (TOE) annually, 4.000.000 GWh of green electricity, heat for 307 families and energy save 2.808 tons CO<sub>2</sub> equivalent/year. Assuming a price of CO<sub>2</sub> ton of around 15 €, this will mean around 42,000 €. The contribution of AD-WISE to this is the equivalent of 1 month of electricity production, i.e. 3,500 € per 500kW-plant each year.

EMPLOYMENT. When the AD-WISE system starts commercialisation, new direct and indirect jobs will be created, related to the industrial production of the system, sales, maintenance, technical assistance, etc.

#### 4.4 Main dissemination activities

The complete list of dissemination activities is included in section 4.2 of the final report. Detailed information on the main activities is given as follows.

The AD-WISE website was launched in November 2012 and it is hosted at the following address: <http://www.ad-wise.org>. It includes seven main sections:

1. The project; 2. The partnership; 3. News; 4. Documents; 5. Links; 6. Benefits for biogas plants.

Concerning the website statistics, the website received 825 visits during the project. The visit average duration was 2'45" much higher than the average residence time on the internet. The first 10 countries in number of visits were Spain (52.61%), Germany (8.12%), Netherlands (4.00%), UK (3.39%), India (3.39%), Estonia (3.03%), United States (2.67%), China (2.18%), Ireland (1.94%) and Italy (1.70%).

In addition, a highlighted reference on the project can be found at the Interspectrum homepage, where the AD-WISE logo has been displayed and linked to the project website.

The social networks used for dissemination purposes are LinkedIn and Twitter. Both ainia's account and the project coordinator's account have been used to disseminate issues like the website launch, press releases publications, or the project objectives. An approximate total audience of 600 people have been reached, mainly including industry representatives.

A total of 3 press releases with more than 20 impacts were published, informing on AD-WISE objectives, expected results and benefits for the industry. All press releases are online, and the estimated audience attained is more than 2000 people, including civil society and industry (renewable energy, biogas, food and beverage).

Two project electronic leaflets have been produced and published in the website (documents Section). The leaflet shows information on project objectives, expected results and benefits for industry.

In addition, the AD-WISE project was promoted within the following specific events:

- Energy Show 2013 and 2014, Ireland. Organised annually by the Sustainable Energy Authority of Ireland (SEAI), this is Ireland's largest and most long-established energy conference, attended every year by all the key players in the Irish energy sector, as well as many from further afield who maintain an interest in how the energy sector in Ireland is developing. Energy in Ireland is now a broad industry with appeal to those working in numerous sectors from local councils to construction companies to local economic development organisations, as well as those directly employed across the industry itself. MAC promoted AD-WISE on a one-to-one basis with potential biogas partners at the show in the future exploitation and use of the AD-WISE system.
- Export Europe Day, Ireland. Organised by the Irish Exporters Association (IEA) this event celebrated Europe Day on May 9th 2013. 2013 was a significant year for Ireland and its role in the European Union, as it held the Presidency of the EU and Ireland was also celebrating the 40th anniversary of its accession to the Union. The event focused on the importance of the European Union to exporters and key industry speakers detailed their exporting expansion over the past years. MAC presented AD-WISE as an example of EU SME Innovation support that will result in new markets and future commercial opportunities.
- MAC made a similar presentation at the symposium "Celebrating Four Decades of Innovation, Integration and Inspiration" organised by the University of Limerick to similarly celebrate Ireland's EU membership, but addressed more to policy makers.
- 13th IWA World Congress on Anaerobic Digestion. AINIA presented the project with the poster "Control and automation of anaerobic digestion plants based on real-time measurement of VFA profile: the AD-WISE project". This international congress is the most important in the field of anaerobic digestion, and it was held on the 25-28 June 2013 in Santiago de Compostela (Spain). It was addressed mainly to the scientific

community but many delegates from the industrial sector also attended. It had around 800 attendants from all over the world.

- Fair of Environment and Energy. In the framework of this fair, a Workshop of Technology Offers in the Energy and Environment Sector was held on the 15th November 2013 in Valencia (Spain). AINIA presented the AD-WISE project in the speech “Towards the economic and environmental sustainability of biogas plants through technological innovation. The AD-WISE project”. The audience was composed mainly by industry representatives, but also addressed to scientific community and policy makers.
- AD Europe 2014. This conference was celebrated on the 20-21 February 2014 in Dublin (Ireland). MAC presented the project in an oral presentation with the title “AD-WISE: a new tool to optimise the operation of Anaerobic Digestion plants”. The audience was scientific community and industry, with around 300 delegates mainly from EU countries.
- Envifood Meeting Point. In the framework of this fair, a Workshop on Innovation in energy efficiency and bioenergy in the agro-food sector was held on the 12th June 2014 in Madrid (Spain). AINIA presented the project in an oral presentation with the title “Optimisation of the yield of biogas plants through process control strategies: the AD-WISE system”. Attendants were mainly from the industrial sector.
- Cré Irish National Composting & Anaerobic Digestion conference “New directions and implications”. In this conference, celebrated on the 8th September 2014 in Naas, Kildare (Ireland) the AD-WISE project was presented by MAC with an oral presentation “AD-WISE optimises the operation of Anaerobic Digestion plants”. This conference was addressed to the scientific community, industry and policy makers.
- Jornada sobre valorización de residuos de la industria agroalimentaria (Seminar on agro-food industry waste valorisation). AINIA presented the AD-WISE project in the speech “Valorización de residuos orgánicos agroalimentarios en España. Nuevas tendencias y ejemplos (Valorisation of agro-food organic waste in Spain. New trends and examples)”. 19th November 2014.

Two workshops were carried out to inform the target market about the outcomes of the AD-WISE project: 18th September 2014 Valencia (Spain). AINIA organised a workshop in its premises to inform the target market and end-users about the outcomes of the AD-WISE project. 7th October 2014, Dresden (Germany). IPMS organised a workshop in its premises to inform the target market and end-users about the outcomes of the AD-WISE project.

Technical visits were organised in groups to the prototype installed in GSR, linked to the workshop celebrated in Spain.

A technology offer was published in the European Enterprise Network to perform a partner search for the future Innovation Pilot project foreseen in the business plan.

A video-clip was produced, and it is available in YouTube.

A Wikipedia entry named “AD-WISE project” has been submitted, indicating the project objectives and results, and including reference to the funds received from REA.

#### 4.5 Exploitation

A business and exploitation plan was carried out and finished at the end of the project. The exploitation and commercialisation strategy has been outlined. The potential market, product pricing, and knowledge sharing and protection are addressed in the plan.

As next immediate action, a joint project is being developed by the consortium of AD-WISE in order to expand the results to other industrial environments such as sewage sludge digesters in wastewater treatment plants, solid waste digesters in municipal waste treatment plants or food waste biogas plants, among others. This will allow an even more robust product ready to be installed in any operational anaerobic digester.

#### **ACKNOWLEDGEMENT**

*The AD-WISE project received funding from the European Union’s Seventh Framework Programme managed by the **REA – Research Executive Agency***  
<http://ec.europa.eu/research/rea> (FP7/2007\_2013) under Grant Agreement N.315115.