Smart Gas Meters & Middleware for Energy Efficient Embedded Services

M.Piovano,
R&D Projects, Italgas SpA (Italy)

T.Carretero, R.Jane
Technology & Engineering Division, Gas Natural Fenosa (Spain)

A.Wankelmuth, A.Lofti
Gas Residential Segment, Itron (Germany)

C.Lorentz, K.Landwehr
AMR/AMM Systems & Projects, Elster GmbH (Germany)

Keywords: smart gas meters, electronic index, communication module, middleware, energy efficiency.

1. INTRODUCTION

The ME³gas Project

ME³gas (acronym for "Smart Gas Meters & Middleware for Energy Efficient Embedded Services") is a three year project, whose final goal is the integration of a smart gas metering system to improve energy efficiency at home. The objective of ME³gas is to put consumers in control of their energy efficiency and appliances at home as a result of that European Directives[1] is imposing information on energy consumption as a clear measure for energy-saving usage without compromising comfort or convenience.

In this context, the ME³gas project addresses the development of a **new generation of smart gas meters**, based on embedded electronics, communications and the remote management of a shut-off valve, which shall offer a whole range of added values: management of multiple tariffs and payment modalities, remote gas cut off, security alarms, absolute index, temperature correction, and so on. Specification, implementation and dissemination of an open architecture for wireless communication is also addressed in the project.

[1] For example Directive 2006/32/EC (Energy-Use Efficiency and Energy Services) supports smart metering and the need of new developments for encouraging energy efficiency and CO2 reduction in households and commercial buildings

Additionally ME³gas makes use of the **service-oriented middleware for embedded systems** developed in the Hydra project and use its huge potential to create services and applications across heterogeneous devices to develop an energy-aware middleware platform.

ME³gas project is coordinated by Gas Natural Fenosa and includes several partners roles in a wide consortium: manufacturers, software developers, technology research institutes and gas utilities.

Partner classification

- **Industry/Services**: Sensing and Control, Kromschroeder, Itron, Elster, Sistemas Avanzados de Control and Thya Tehnologije.
- **Software developers**: Cnet, ResourceKraft and Communications Reseach Labs.
- **Technology research**: Tyndall National Institute, Arup, Steinbeiss and Swedish institute of Computer Science.
- **End user**: GasNatural and Italgas.

Figure 1 - ME³gas Consortium

ARTEMIS Programme

The ME³gas project is co-funded by the European Commission (ARTEMIS JU) and by the national Governments. The vision of ARTEMIS is that embedded systems will realise the dream of ambient intelligence in which intelligent support for people will be embedded in everyday objects. Large-scale application will increase our quality of life. The result will be to help make life healthier and more secure. And to provide more comfort for Europe's ageing population. ARTEMIS nurtures the ambition to strengthen Europe's position in embedded intelligence and systems and to attain world-class leadership.

The ARTEMIS European Technology Platform was established in June 2004 to bring together key players in the Embedded Computing arena across the entire spectrum of industrial sectors by 17 major companies. One of its core tasks was to define a common Strategic Research Agenda (SRA) which acts as a reference for the Embedded Computing domain to attract investment from the stakeholders. The activities of the ARTEMIS Technology Platform have now been continued by ARTEMISIA, the ARTEMIS Industrial Association who represents the interests of industry and the research community within the Joint Undertaking.

The ARTEMIS Joint Undertaking (JU) was established in February 2008 as a Community body based in Brussels by means of a Council Regulation. The ARTEMIS JU will implement significant parts of the Strategic Research Agenda co-funded by industry, research organisations, participating Member States and the Commission's own ICT programme. The ARTEMIS JU manages and co-ordinate research activities through open calls for proposals. The ME³gas project was selected in the ARTEMIS JU call 2009.

The Regulatory Context in Europe

During the last years the European Union is promoting and regulating the adoption of energy efficient systems. One of the main objectives of the EU regulations is to provide accurate information to the customers in order to make them aware of their energy consumption. A key Directive in this direction is the already cited 2006/32/EC on the energy end-use efficiency and energy service.

At the same time, the European Union has been pushing for the deployment of Smart Metering systems within the framework of the Internal Energy Market Package, including systems for gas. This Directive requests that the Member States prepare a study of costs and benefits, and put forward a proposal for the implementation of Automated Meter Management (AMM) in the residential sector. This analysis should be finished before September 2012.

Beyond this, some countries like Italy and the UK have already regulated the deployment of Smart Metering systems for residential gas meters. Many othercountries are already on their way to following this example.

Nevertheless regarding this issue there is a lack of standards that is slowing the deployment of these systems. EU is investing important efforts to this aim through Mandate 441 of March 12 2009. The ultimate goal of M441 is the creation of a European standard to enable interoperability of utility meters (water, gas, electricity and heating). Its application should allow promoting and standardizing the sector through the development of new meters with open architectures, enabling providers to better control demand and provide consumers with new tools to better control their consumption. The development of the European standard is asked to the European Standardization Organizations, CEN, CENELEC and ETSI.

In the context of the M441, standardization does not mean imposing a single solution for all metering projects in the Member States. The aim is that potential needs to develop smart metering can be satisfied by a set of standards known and available. Thus, each State can have its own space to define their measurement systems and management of electricity, gas, water and heating according to their own priorities, but within the framework established by common standards.

The Regulatory Context in Italy

In ME³gas project, Italy was given a major emphasis because it is the country where the National Regulator already issued quite precise requirements and defined a time schedule for the implementation of smart metering in the gas industry. As a matter of fact, in year 2008 the Italian Regulatory Authority for Electricity and Gas (*Autorità per l'energia elettrica e il gas*) issued Resolution ARG/gas 155/08 concerning smart metering. It applies to all consumers connected to distribution networks (not to transmission networks).

Resolution 155/08 aims at easing the development of gas market in Italy, by:

1) enhancing efficiency in gas utilisation through a more accurate measurement of gas;
2) promoting technological innovation in measurement devices and measuring process quality;
3) improving quality of sales and distribution services.

It provides a minimum set of functional requirements all new metering devices will have to fulfil. It also defines a roadmap to replace the existing metering devices with the new ones. Requirements sets will be divided in two classes according to the maximum flow rate of the device, <G10 and ≥G10.

The resolution is integrated and completed by the technical specifications listed in UNI/TS 11291 series, which establish the minimum requirements and performance of all aspects of the smart metering system and network (device requirements, communication protocol, central data centre structure, data security). This technical specification is not completed yet and some issued like the definition of the point-multipoint communication are still pending.

2. APPROACH & GOALS FOR SMART GAS METERS

The development of a new generation of smart gas meters and the design and specification of an overall smart gas metering system are ME³gas objectives. An example of the proposed system is shown in the picture of the next page and includes:

- The smart gas meter and an associated communication network allowing the installed gas meter(s) to communicate with a data concentrator associated to that area, as well as with an indoor display providing the customer with updated feedback information on his own gas (and electricity) consumption.
- The local consumer display to give information to the end user about its gas (and electricity) consumption.
- The data concentrator, which would also be able to communicate with a back-end system through a Wide Area Network (WAN)

The main task to deal with for the successful execution of the project consists on the design, specification and development of a new generation of smart gas meters providing the wished functionalities, namely their communication features and the ability to be remotely managed (including the control of the newly developed smart valve). It should be noticed that the goal of ME³gas is to achieve an open solution that can be adapted to the standardisation requirements, which are not yet completely defined. As a matter of fact such solution should be flexible so as to be used with different communications means and to be in line with the requirements of different countries.

The new ME³gas smart meters will be based on the diaphragm gas meter (called Bellows meter), which uses a measurement principle discovered 150 years ago, but is reliable, accurate, consumes no-power and is a low cost solution for residential meters. The use of this well-known meter will reduce in ME³gas the risk to develop a new fully electronic meter. The new smart meter will incorporate embedded electronics providing its communication and control capabilities.

In addition, suitable data concentrators will be developed so as to be able to register the gas consumption measurements and to forward them to the appropriate databases within the utility's premises. The electricity metering field will be specifically taken into account in the development of these data concentrators, so that they comply with the needs and communication and application protocols used in this field. One of the objectives of the project is to prove the practical viability of integrating the remote metering of electrical and gas meters through a unique data concentrator device.
As it can be observed from Figure 2, the system includes an interoperable multiutility local display (in-home display) that will enable the disclosing of not only gas consumption information, but also electrical consumption information. This will contribute to the reduction

of the energetic consumption within European homes thanks to the process of making customers aware of their expenses. Possibly disclosed information may span from simple consumption figures to the identification of individual consumption patterns, even considering the comparison with standard or more rational energy consumption models, or the displaying of sustainability recommendations. Other functionalities to be provided to the display will be those given by the possibility of interaction between the utility and the customer for the management of services provided by the utility, as well as the management of the shut-off valve of the meter.

In-home displays are interoperable devices, and fully compatible with the newly developed smart gas meters, as well as with the required electrical consumption meters. In order to optimize the system development time, the displays included as in-house components of the ME³gas system have been based on already existing and commercialized displays.

The system has to be indispensably complemented by the setting out of an open communication infrastructure providing the required communication functionalities according to the foreseen operation of the system, which means that data connection links shall be able to be set from the different gas meters in a certain environment to the data concentrator in that area, from the data concentrator to the corresponding utility, but also backwards to the display (providing consumption information) and finally also from the utility to the meter, enabling the secure management of the meters (including the smart valve included within the smart meters). The network in all its paths has to assure efficient and secure communication features, so that high-quality performance of the network connections is achieved.

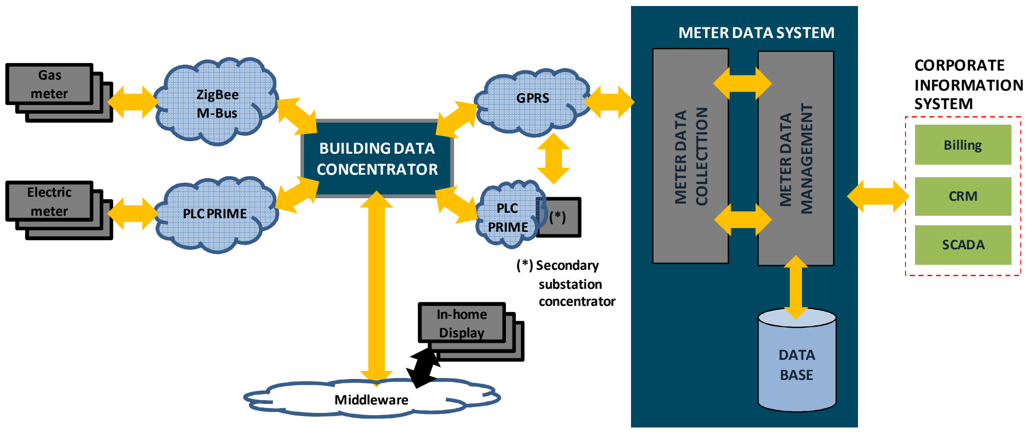

Figure 2 – Smart meter & system architecture

3. APPROACH & GOALS FOR MIDDLEWARE

One of the main objectives of the project has been the development of an energy-aware middleware platform, making it possible to network heterogeneous physical devices into a service-oriented architecture.

The goals that have been set for the middleware platform are:

- Monitoring energy consumption at home, to create a middleware platform that will make it easy for developers to provide energy monitoring functionality in both home automation systems and commercial buildings.
- User-driven planning and controlling of devices while optimising energy consumption. (Energy efficiency at home can only be successful if the same level of comforts can be maintained for the home owner)
- Connecting user behaviour/external information sources with energy consumption. (Our approach is based on the premise that true improvement in energy efficiency at home can only be achieved if users and their behaviour is taken into account)
- Context Aware combination of different energy sources and profiles to achieve user defined goals.
- Learning and sharing energy consumption patterns. An innovative feature of ME³gas is a P2P architecture that provides means for devices in different local networks to communicate and access each other without compromising security and privacy. We intend to make use of this so that different house networks can share and exchange energy consumption patterns. This also opens up for energy efficiency solutions that are not only based on one household but try to optimise the energy use in the entire neighbourhood.

The ME³gas project builds on the architecture developed in the FP6 project Hydra for embedded heterogeneous physical devices and use its huge potential to create services and applications across heterogeneous devices to develop an energy-aware open source middleware platform. This middleware hides the complexity of the underlying device and communications technologies for application developers, so that in any application that needs to integrate physical devices or appliances, energy efficiency aspects can be included.

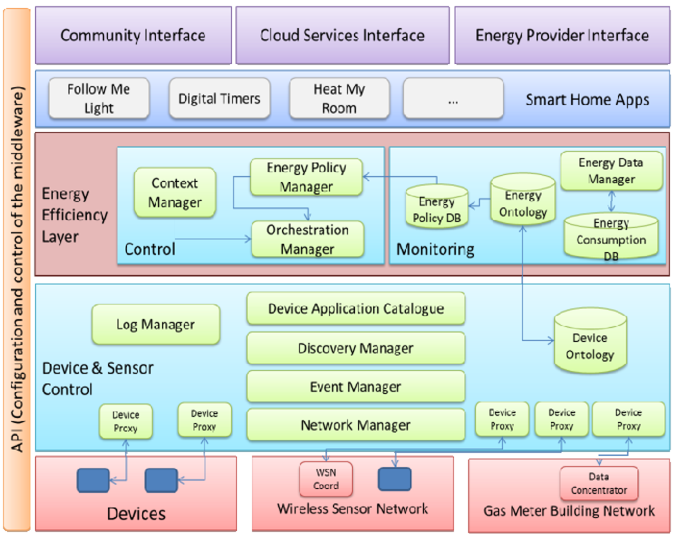

Figure 3 –Middleware Layers and Components

One main feature of the middleware platform is that it can handle many different physical device and communication protocols and automatically create a web service for a device. This provides application developers with an easy to use high level interface for integrating and using devices and home appliances in their applications such as home automation and personal health monitoring. The figure below shows its basic architecture:

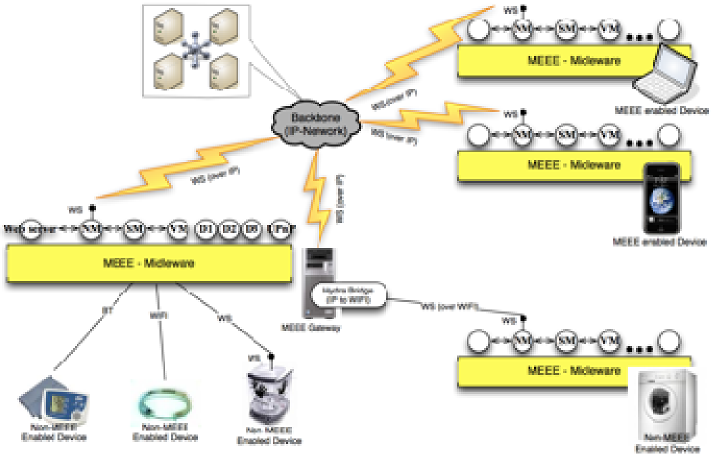

Figure 4 – Middleware platform multi-device architecture

4. DEVELOPMENT OF SMART METER COMPONENTS

The general design approach for the Smart Gas Meter is to maximise flexibility and reliability. Cost reduction is the aim of a second step, once markets are more stable and the meter requirements are static and understood. The design and development provides electronic control to the gas meters, where previously there was only electro-mechanical control. Moreover, the integration of embedded electronics has never been done before in Bellows type meters, and this integration opens a lot of possibilities to provide new functionalities. The block diagram of the new generation meters and associated embedded electronics to be developed and integrated in ME³gas is the following:

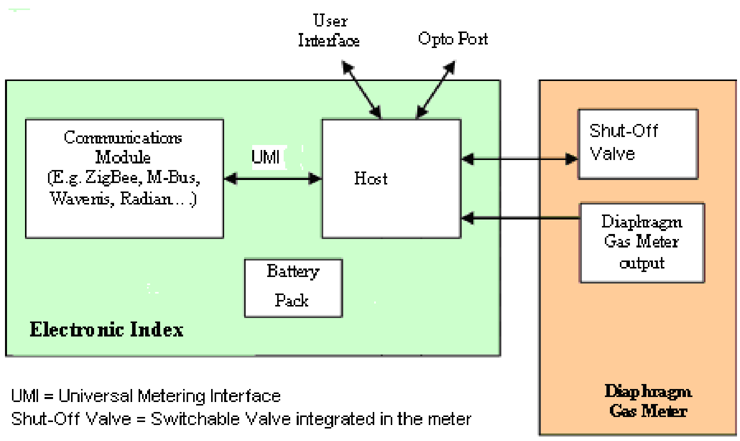

Figure 5 – Smart Meter blocks diagram

Main blocks of the meter and the functional innovation provided by each of the blocks will be:

- **Electronic index:** It is the element giving the intelligence and new capabilities to the new generation meters. Among many others, it is capable of:
    - Encoding and sending the gas readout values to the data management centre by the use of different communication means
    - Capable of activating the Smart Valve

- Performing the overall control of the meter: communications, clock, alarms, messages…

- **Smart valve**: New meters incorporate a remotely controlled shut-off valve. One of its main characteristics is that it includes all the necessary safety features to make this functionality completely safe. The remote opening and closing provides the meter with a wide range of benefits:
  - Reduce time and costs to supply gas to new customers, simplifying gas switching in the residential market
  - Give the possibility of charging flexible tariffs and integrating functions of prepayment meters, which are not available nowadays
  - Allow to stop the gas supply in case of leakage or any other security problem
  - Allow new strategies with bad payers.

- **Communication module:** Able to integrate different communication technologies. In normal operation a single Communications Module (short range) is located within the Electronic Index. Optionally further Modules can be connected externally. The Electronic Index will function without any Communications Modules being fitted to allow also the installation of "Smart Ready Meters". The Battery Pack and Communications Modules will be in-field replaceable by a technician with appropriate tools and without requiring access to the metrology.

Following all these key components (Electronic Index, Smart Valve and Communication Module) are described in detail.

Electronic Index

The Electronic Index pursues the development of the embedded electronics, hardware, and firmware to meet all the functionalities to be provided by the new generation of smart meters and covers the following main characteristics:

- MID compliant (Class 1,5)
- Supports time and volume
- Configurable to perform temperature compensation of the volume
- Optimised for long battery life time
- In-field replaceable Battery Pack
- Smart gas valve could have add, local acknowledgement
- Support Universal Meter Interface for in-field replaceable communication modules (modular concept)
- Service Interface
- Aimed to be used in a variety of European markets with only changes to the software (without requiring metrological re-approval by a notified body)

In addition, this development undertakes the integration of the several modules of the new meter (smart valve, electronic index, communication module, batteries), and the development of a standard housing to be attached on the meter face, so that the first complete ME³gas smart meter prototypes are obtained. The adaptation/testing of an existing display for customer information have been also performed.

A first major outcome was the *Specification of the electronic index and interfaces with related modules* (communication/battery) by mid of 2011. The specification is in line with the project requirements and in line with European requirements, such as e.g. Italian UNI-TS 11291.

Figure 6 – Smart Meter prototype

In the beginning of 2012 the design of the diaphragm gas meter with electronic index was finished and the part lists are available. First small batches of prototypes have been produced supporting the validation and testing of this new type of gas meter which includes pressure absorption test, temperature and chemical resistance tests. Accelerated life time and ageing tests shall ensure a lifetime for the electronic index as for the meter asset itself.

Communication module

The aim of the “Communication Solution” activity is to develop the communication solution for the new gas smart meters. This comprises the communication of the meter with the network (data concentrators) and also the communication link with a remote customer display unit. The communication concept to be developed is completely modular, this means, the design have been done in such a way that the meters are able to adopt different modular communication solutions, depending on the situation of the meter and associated network. This future proof design reduces the risk of stranded assets. Even if the communication technology is changing, the main part of the meter asset can stay in the field. The communication module can be replaced on field – e.g. together with the battery exchange procedure. Combined with the over the air firmware upgrade, a maximum asset lifetime is ensured. In the picture below a block diagram illustrates that idea. Main board and communication board are separated and communicate via a mechanically and electronically defined interface supporting a standard set of commands.

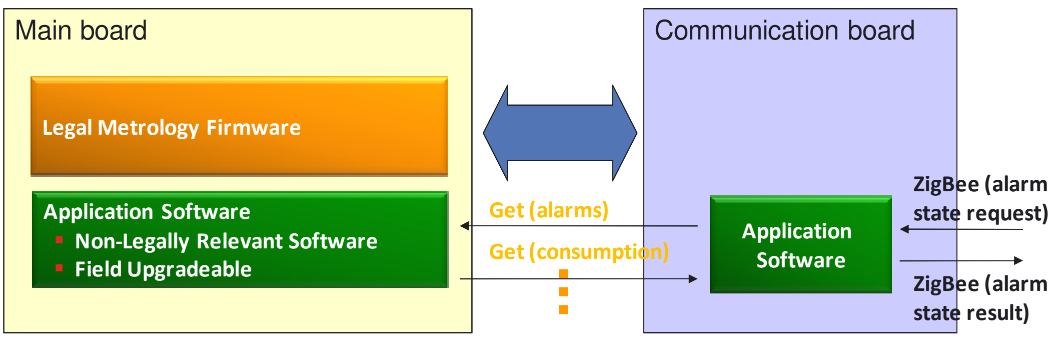

Figure 7 –Communications modular design

This ensures that new communication boards can be designed in the future complying to this interface. It becomes obvious that the aim was to define a universal communication interface independent of communication. This allows a complete flexibility to the ME³gas meters, as there is no communication solution that satisfies all the requirements issued by the energy utilities in a context where the communications standards are evolving probably for many years. Main requirements that have been taken in account are:

- Hardware independency versus communication standard.
- Installation or replacement on the field of the communication module.
- Ultra low consumption suitable with 15 years battery powered meter.
- Low economic impact on price of the standard meters.
- Security and reliability.

Furthermore in the scope of the communication technology work package is to make a technology assessment on communication technologies suitable for the communication of the meters with the data concentrators and the remote home display unit. Taking the general requirements specification, the following key parameters are assessed for different available and future communication technologies:

- Services: Reading, Remote valve management, billing, on-demand reading
- Performances: Propagation (range), Response time, Quality of service
- Constraints: Meter battery life, regulatory environment, ATEX certification
- Security and confidentiality
- Topologies and location of the meter
- Others: Commissioning / Decommissioning / Maintenance

The analysis is carried out according to the different functional layers defined by the OSI segmentation of the communication requirements (and will be complemented by the results of the field pilots):

- Physical and MAC layers
- Networking and network management protocols
- Application protocols

There are some keys assumptions that have been taken into account during the study:

- Protocols should be open and based on up-to-date technologies,
- Suitability on existing or upcoming hardware and software components or platform,
- Technical and economic impacts on the meter mainly.

The openness of the protocols will guarantee that future market requirements are met and that utilities' investment and user needs are future proof. Protocols should also be open for the integration of other metering tasks, i.e. they should allow multi-utility meter integration. Protocols should also be open for the integration of other metering tasks, i.e. they should allow multi-utility meter integration. This approach holds the promise for the integration of gas, electricity, heat and water meters through a unique communication infrastructure. Protocols should provide bidirectional communication. I.e. they should include a back-channel for communication from the control centre to the meters. This is of key importance for prepaid energy and for the control of the smart valve, but could also be used as entrance card towards closed-loop control of energy provision.

A particular attention is paid to the security features of the whole protocol stack. The AMI system will require a high level of reliability and security on exchanged data or services in order to avoid malfunctioning, to preserve the customers' data integrity and prevent attacks from hackers.

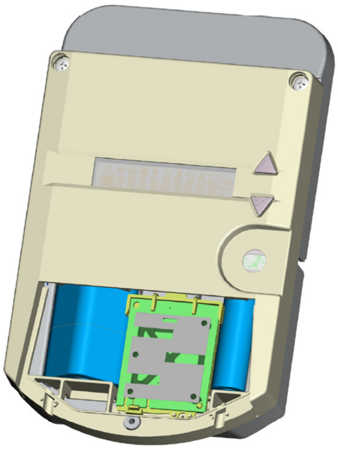

Figure 8 –Communications module design

Looking on the achieved results as of first quarter 2012, the design of the communication module according submitted specification is finished for Zigbee and GPRS, part lists are available and the validation is ongoing. MID approval for meter including the valve is available and some first small batches of prototypes have been produced.

Specification of the ME³gas communication solution based on analysis about communication technologies, work started on the detailed specification of the communication solution derived from requirements defined within the project for a suitable HAN solution. ZigBee modules are already available; GPRS modules are also available for field testing and considered to be a good solution at least for hard to reach rural locations. Other communication solutions are under development like e.g. wireless M-Bus over 868 MHz or 169 MHz.

The available communication technologies ZigBee and GPRS (and also the ones under development) were designed in accordance to the requirements mentioned in the ARG155 and UNI/TS documents and the requirements mentioned in the requirements specification and support the following features:

- Remote Transactions
- Support a method to read the current and logged totalizer registers
- Support a method to activate and control of the time of use totalizers
- Support a method to perform a synchronization of the clock and calendar
- Support a method to issue alarms
- Support a method to read the meter status register
- Support a method to execute a software update
- Support a method to close the valve
- Support a method to enable the opening valve
- Configure tariff
- Retrieve tariff base consumption data
- Functionality for reconfiguration of the network (HAN)
- Provision of meter status information

Smart Valve

With the introduction of the **smart valve**, further value adding features for the end consumer and the utility can be implemented. For example in the change of tenancy use case, the utility can disable the gas supply and ensure a proper settlement of the customer leaving the property. On the other hand the consumer can be sure that after his account was settled, nobody else can use gas in the meantime reducing potential billing disputes.

Other benefits of a possible remote disconnection of a gas supply to be mentioned cover a wide range of applications and reasons as non-payment of bill, prepayment operation, change of occupancy, management of special network events, or for environmental reasons (high temperature, earthquake). These features help to improve the utilities' operational efficiency and protect its revenue collection, in order to pay back the investments that have to be done when introducing smart meters. Regardless of above mentioned possibilities it has to be highlighted, that an integrated smart valve is not a safety device.

Security and safety are nevertheless critical requirements to be considered. It has to be ensured that the smart meter cannot be hacked to prevent unintended operation of the valve in one or several meters. Also a safe re-opening procedure has to be implemented to avoid gas flows e.g. by still open appliances. Hence the possibility to detect any potential uncontrolled gas flows for remotely opened valves is necessary resulting in automatic re-closure of the valve. Depending of utility approach or national laws this remote opening may be bound to a local activation permission, e.g. through the push of a meter button.

The scope of the "Smart Valve" work package is to develop a "smart" valve and its control / command circuit for the new smart gas meters. The smart valve will allow some benefits for the meters like reducing time and costs to supply gas, stopping the gas supply in case of leakage, or prepayment strategies or others for bad payers.

Different potential architectures for the valve have been looked at and will be finally assessed with their advantages and disadvantages after the field pilot in order to recommend one or several choices for the final design. More in detail, the "smart valve" consequently covers the following main features (not exhaustive list):

- **Valve position**: The valve is not intended to be used to control the flow rate of gas delivery to the gas consumer. The valve has 2 stable positions (open or closed), which are the results of a switching request remotely or manually for opening. When the valve is in a transient state, the switching must be not affected by tampering issue or a depleted battery (bi-stable behaviour).
- **MID compliance, and metrological behaviour:** Even being "smart", the meter has to be compliant with the metrological standards relevant to gas meters essentially EN 1359 and OIML R137 recognized by the MID for diaphragm meters. The influence of this device on the metrological behaviour of the basic credit meters has to be evaluated, and the principal standards still fulfilled. Among others, pressure absorption test, temperature resistance, chemical resistance and a particular caution has been paid on ageing tests which is key for this part, as contrary to communication module, the valve will stay the whole life of the meter.
- **Tampering:** The use of the valve in each meter requires high levels of protection and detection of fraud and tamper attempts. For example, the smart valve operation must be immune to magnetic fields from commercially easily available magnets.
- **Reliability:** The valve shall be reliable and shall operate without any interaction or maintenance during all the meter life of the product: 15 years typically. The valve

shall be able to perform a sufficient number of switching operations according to the specifications.

- **Safety:** The valve shall be safe as it is located inside the meter and in permanent contact with natural gas. In order to ensure the protection of the final consumer using the meter, the valve as well as the control circuit have to be ATEX compliant in reference of EU directive 94/9/EC about equipment and protective systems intended for use in potentially explosive atmospheres.
- **Leakage flow rate:** When the gas is switched on, some gas equipment like a cooker can be turned and may cause a leakage of gas if they are not designed to handle the risk. A leak test is conducted every time the gas valve opens. When the valve is closed, the maximum leakage flow rate must be far below the leak detection capability of the meter. The measurement of tightness must be made at the maximum operation pressure of the meter and depending of ageing of the meter.
- **Response time of the valve:** The response time corresponds to the duration necessary to close and open the valve after receiving the command remotely or not by the Electronic Index. The response time may vary significantly depending of technology used to drive the valve: stepper motor or solenoid.
- **Energy consumption:** The meter is battery powered. For economic and environmental reasons, the size of the battery must be minimized. The valves using in existing prepaid meters have usually a high current load and affect drastically the battery life depending of amount of switching operation. Particular attention has been paid to reduce as much as possible the power consumption of the valve.
- **Integration inside the meter case:** The size of valve must be compliant with the targeted meters for each manufacturer assuming that the G4 range is the main target. The location of the valve at the inlet or outlet has to be selected as a preference. The drawing shows on example of integration of a valve driven by a stepper motor.

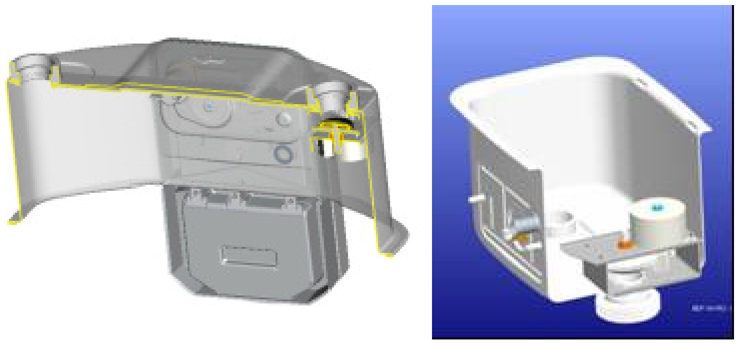

Figure 9 – Integration design of a valve driven by a stepper motor

- **Integration with Electronic Index:** The smart valve is controlled by the Electronic index through the control / command circuit. So the characteristics of the smart valve, and its command circuit have to be compatible with the Electronic index to allow in particular the remote control of the device. Also the communication between these two components has not to be 1-way (just the index controlling the valve) but a 2-way as the valve has to be able, for instance, to “send” information about its state (opened closed) to the Electronic Index

Figure 10 –Smart valve prototype

Looking on the achieved results as of first quarter 2012, the design of the valve according submitted specification is finished, part lists are available and the validation is ongoing with first results very positive results. MID approval for meter including the valve is available and some first small batches of prototypes have been produced.

A detailed specification of the smart valve has been worked out and agreed between the partners that specifies in detail above mentioned requirements like response time of the valve, temperature range, leakage and more. Potential architectures for the valve and design choices for its elements are discussed with their advantages and drawbacks. Slightly different architecture options have been tested in the field in order to evaluate the valve performance. All the parts composing the valve and the control/command circuit have been designed. Respective materials and parts have been chosen and potential suppliers for the parts of the valve have been identified. Integration into the meter casing and the design of the command / control circuit have been finished and tested. First prototypes of the valve have been produced supporting the validation task, which includes pressure absorption test, temperature resistance and chemical resistance tests. Accelerated life time / ageing tests shall ensure a lifetime as for the meter asset itself.

Validation activities

Activities planned to ensure that the proposed solution is feasible and adequate have included the definition of tests and test facilities, execution of compliance tests, laboratory testing, metrology approvals and interoperability field testing. The three main activities and their objectives are:

- Development of an Electronic Index for the Diaphragm Gas Meters;
  - give an overview about Smart Metering Systems based on actual requirements and the involvement of Diaphragm Gas Meters with Electronic Index;
  - define basic requirements for an Electronic Index for Diaphragm Gas Meters;
  - describe the architecture for a new generation of Electronic Index for Diaphragm Gas Meters;
  - describe the benefits for End Users as well as Utilities by using Gas Meters with advanced functionalities.

- Meter System Validation
  - the integration of the several smart meter components (e.g. the shut-off valve) into the final ME³gas smart gas meter;

o the integration of the rest of the system components in order to design, engineer, build, and operate the ME³GAS Smart Metering System.

- Lab testing and metrology approvals
  - o To carry out the laboratory testing of the new gas smart meters to check their compliance according to the technical specifications & functional requirements, including the reliability tests of all components;
  - o To carry out the laboratory testing of communication and interoperability issues;
  - o To carry out the identification and description of the required metrological & non metrological approvals. Metrology testing in recognised laboratories.

5. AMI & HAN INFRASTRUCTURE

AMI Infrastructure

In addition to the Smart Meters, the system is also composed by other key devices or elements that complete the AMI Architecture and have been developed within the present project.

- **Building Data Concentrator (BDC):** The BDC is the key element in the AMM system network, because, aside from managing the reading data and AMM information from the meters, it is also responsible for organising the network, facilitating the creation of operational groups of all the AMM meters of a community (principally buildings or horizontal properties).
  Each BDC have the capacity to manage up to 200 smart gas/electric meters. Some of the developed functionalities are:
  - o *Dual fuel communications*: for Gas Meters trough RF and for Electricity Meters trough PLC-PRIME
  - o *Information management:* Data reading, data storage
  - o *Smart meters management: Meters discovery and network management*
  - o *Configuration and management of the unit*
  - o *Alarms and events management*

Figure 11 –Building Data Concentrator (BDC) prototype

- **Meter Data System***:* The meter data system acts as a management platform for all the elements of the AMM system (concentrators and smart meters). At the same time, it shall manage the readings carried out by the smart meters in a database for its subsequent treatment and integration with other corporate information systems from the Utility.

The meter data management provide an efficient platform for managing data from smart meters and make available this data to multiple utility applications, such as billing and CRM. Some of the key functionalities developed are:

- *Smart meter management*
- *Technical management*
- *Data Storage*
- *Reporting*
- *System administration*

AMI-HAN Integration

A key aspect in the communication architecture for the Global system of the ME³gas project, is the integration model of the two environments for development (HAN environment, associated to ESCOs or Retailers, and Smart Metering-AMI environment, associated to DSO). Main challenges of this integration came from three different sides:

- **Regulation constraints**. Roles and relations among different players of the energy market are fully regulated. This point is important in order to set the different information fluxes to be considered in the project.
- **Service challenges.** The system must be able to provide service in all situations and for all customers (meaning that all communication systems used must reach the customer in all cases).
- **Privacy challenges:** In an international context where the privacy issues are becoming more and more important (since energy infrastructure is an strategic asset and metering information are also confidential) privacy use of the data is also must. Main objectives to be fulfilled with respect privacy are:
  - Guaranty the privacy of the transmitted data
  - Guaranty the quality of the transmitted data (meaning that the data has not been changed or manipulated during the transmission process).

With these objectives, several scenarios and architectures have been analyzed and discussed in the framework of the project. Finally, the model defined and detailed is the following:

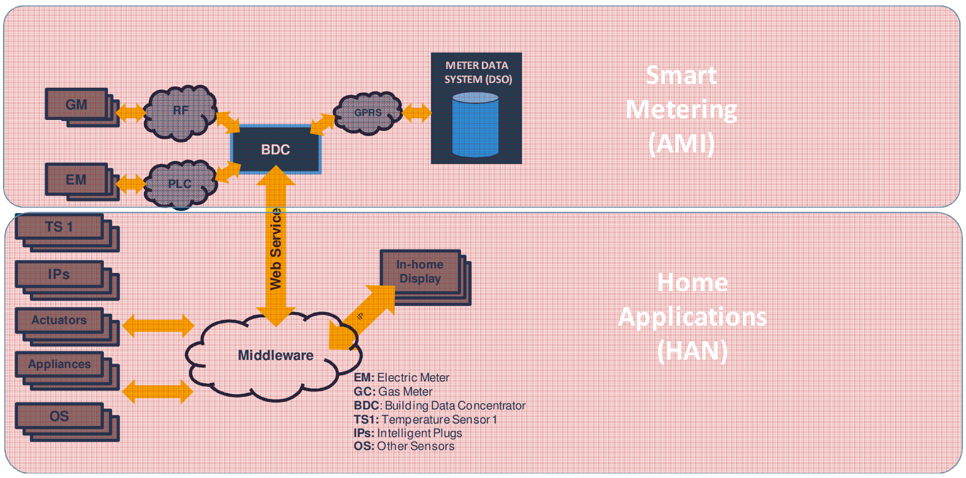

Figure 12 – AMI & HAN Integration architecture

The communication among AMI and Middleware is done through the Building Data Concentrator, allowing that each middleware access to the BDC to extract the information to boost the Energy-Efficiency Services designed. Some key points of this architecture are:

- **Web Services integration**. A complete WS interface has been defined in order to organize the access to the information. Main WSs allow to:
    - *sdbReadData*. Read a single point from DB (Data Base).
    - *sdbReadMultData*. Read multiple points from DB.
    - *sdbKrunchData*. Write a point to SDB
    - *webAsynchRequest*, to obtain reports

  The usage of WS for integration carries an important level of flexibility in terms of communication technologies that can be used since the physical media is independent from the application. In firsts trials xDSL technologies have been used nevertheless it’s easy to move to any kind of mobile technologies (for example).

- **Security**. The ME³gas project relies on high levels of protection and security for its AMI system, so to guarantee the confidentiality of the transmitted data and the security against change or manipulation during the transmission process. Some alternatives have been analyzed for key authentication (i.e.: asymmetric keys for IP communications and others). Also the management of the keys has been defined to guarantee a secure generation and exchange.

  A key reference for the integration has been the recently adopted German Model for the gateway, and the recommendations included in:
    - Protection Profile for the Gateway of a Smart Metering System (v1.1.1, BSI, August 2011)
    - Protection Profile for the Security Module of a Smart Metering System (v0.8.3, BSI, November 2011)

- **In Home Display**. The role of the IHD is crucial to inform the customer and to provide the Energy aware services. Once again, since the customer may have different preferences, the flexibility for using different devices and communication technologies is a must. With this objective the final architecture allows IHD to communicate with Middleware through a wide set of technologies locally (for example with WiFi) or remotely (for example with GPRS) and the usage of commercial displays (or even tablets or PCs).

As a result of the design, the model defined fulfils the objectives targeted for the integration and, most important, allows important synergies among both development areas (AMI-HAN) and the development of energy aware services based on real consumption data.

6. PILOT TESTS

Proof-of-concept Tests

In the first year of the ME³gas project, a middleware pilot was developed and deployed in Crossleigh house, a two storey building in Cork, Ireland, used as an office building by the School of Applied Social Studies, the University College Cork (UCC).

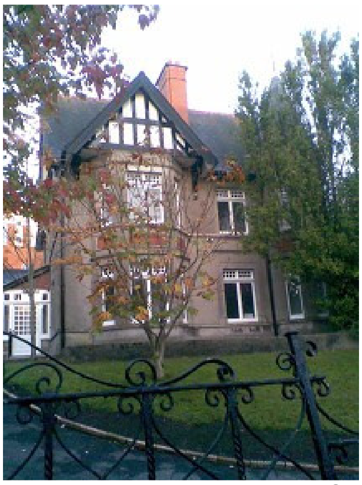

Figure 13 – Middleware pilot site at the University College Cork (Ireland)

First stage of the Cork Pilot (started in beginning 2011) was focus on metering (gas, electricity, thermal energy, etc), with the first objective of successfully integrate a muti-service and multi-device environment in a real environment and start to test the energy services. With this in mind, the following installation was performed:

Figure 14 – Middleware and sensors pilot deployment in Cork (Ireland)

Currently, the pilot has improved this work, updating the nodes of the sensor network to a newer more capable platform, and provides the middleware with exterior data. The installation in Crossleigh also incorporates a data concentrator in order to exhibit the convergence of gas technologies into the middleware platform.

The second part of the pilot initiates a migration of the technologies developed for the Crossleigh house into a domestic environment. This part targets a prototype pilot, in order to be able to experiment with more advanced logic. The prototype pilot will target the combined production of hot water and heating and, more specifically, their control over time. It will build upon results from successful deployment of smart electricity grids for deciding when to start producing hot water, conducting a number of experiments seeking to reduce the CO2 footprint and to attain energy savings as compared to present logic. The pilot is also extended to two pilot sites Cork and Stockholm in order to have different systems to be tested.

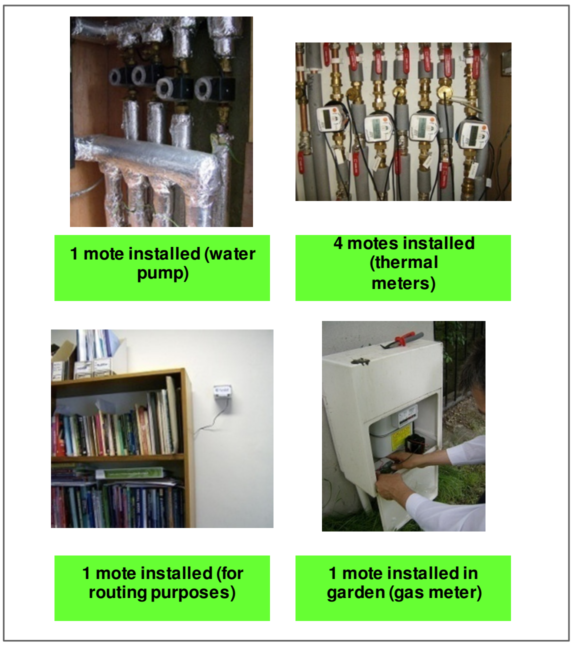

Figure 15 – Detail of some of the sensors (motes) installed

Figure 16 – Multi-device (IHD) energy viewer

Current status will be reported to the user through a user interface, providing ways to override self-learned decisions whenever necessary. As part of this newly created interaction medium between the hot water and heating production system and the end used, and since long-term measurements and diagnostics are made possible, the prototype pilot will be able to provide some reporting over the health of the system. The project sees this type of relationship as a future development that could lead to better products, able to build a long-term relationship between the manufacturer of, e.g. a hot water tank or a heating pump, and users.

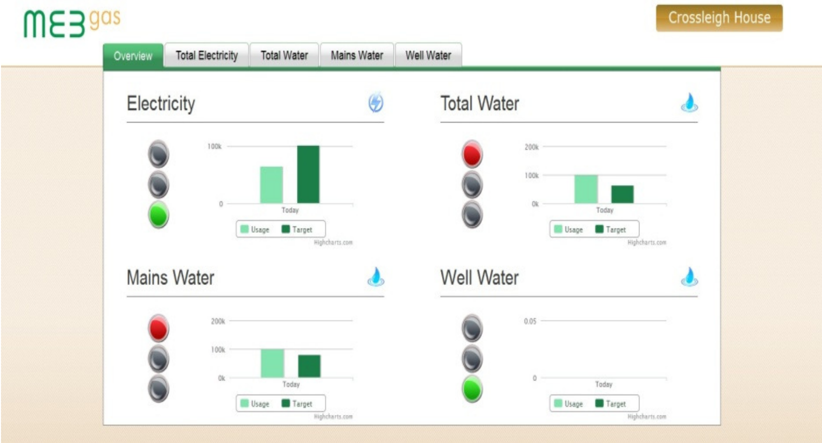

Figure 17 – In Home Energy viewer application

In this pilot also some potential scenarios have been identified which could be implemented using the technologies from this project, such as:

- Collaborative Hot Water Production, by redistributing electricity production sites (i.e. a nationwide green electricity cooperative)
- Energy Competitive Office Buildings, or developing competitions between buildings to save energy using the daily energy consumption measured data.
- Heating Surveillance, detecting daily deviations from "normal" Gas/electricity winter consumption to detect equipment malfunctions which increase consumption.
- Smart Boiler, or services to provide to consumers warning them of "Strange Boiler Consumption Performances" or "Strange Pressure Boiler's Levels" by a close monitoring of their boilers,

Field Tests

Field tests are planned in order to make the validation of the features and the reliability of the smart gas meters and of the associated system infrastructure under real operation conditions. Field tests that are currently being developed have been designed in order to be statistically representative, covering different user types (residential and commercial), and different deployment areas (high and low density). With that objective the trials have been sized with a total of 500 customers. The selected roll out site is Italy since it's one of the current countries with a regulated deployment requirement.

The stages considered for the field test have been the following:

- **Field test specifications** in order to define the scope and goals as well as all the technical details concerning such tests. In particular all the necessary parameters for trials implementation will be defined (e.g. location, total amount of equipment, number and location of users, number and location of places to test, topologies, total duration of the trials, etc.). Moreover it is important to clearly specify the evaluation methods and give detailed instructions about the testing criteria, which will include explanation of different scenarios, stress conditions and network load, priorities and grid topologies.

- **Selection of locations and apartment buildings** where the field trials are going to be carried out as well as the communication and participation acceptance from the customers' side, and the selection and training of the installers. Regarding the customers, they are selected from the customers of the utilities taking part in the project; of these the utilities already have historical data about their consumption and satisfaction levels (to be used during the project results assessment).

- **Data collection head-end and the MDMS (Meter Data Management System)** including their data repositories, applications, and GUIs to satisfy and support the documented business rules and customizations previously defined. At the completion of this subtask, the smart meter data collection head-end and the MDMS is fully integrated in the trial in order to support activation and management of any installed smart meters and the collection and processing of meter reads from the smart meters.

- **Installation process** with the collaboration of the utilities preferred and certified meter operators. The utilities consider to perform at least the following functions:
    - set the appointments for the meter installation;
    - installation of the gas smart meters and recording of all the relevant installation information and distribution of this information (in the form of meter replacement reports or similar documentation);
    - receiving meters, dispatching to the field and tracking the process;
    - receiving and dispatching the removed meters back to the Utility;
    - quality assurance, controls and validation of all newly installed meters.

  The gas meter installation follows all established industry norms and practices. Subsequently it is necessary to ensure that the communications facilities are available and functioning at each meter/customer location.

  The **data collection system commissioning** is also carried out at this stage: configuration of the system to address the data collection and integration needs of the smart meter solution. The completion of every smart meter and communications commissioning allows the activation process to begin. Each installed device has to be configured to deliver the data as required for utility business process (e.g., billing). Upon detection, each meter is activated accordingly via the Meter Data Management System (MDMS) and the smart meter data collection head-end.

  As soon as the meters/devices are provisioned the end-to-end system testing is carried out: the MDMS begins to monitor data provided by the data collection head-end to verify that each device has been discovered by the communications network and is delivering the required data, at the required frequency. This process also identifies any exceptions that may occur due to failed devices, incorrect configurations, or other field-related or system problems.

- **Field trial operation** starts when all the AMI devices have been installed, provisioned, and activated, and partially verified,. This comprises the process to collect all available data from the smart meter system, perform the validation, processing, and data analysis. It is important to note that the field trials operation is being carried out during one year in each of the locations.
  The smart meter system collects meter reading data and diagnostics information on a scheduled basis and makes this raw data available to the MDMS. The MDMS captures this information with as little delay as possible. For unscheduled meter readings or meter status requests (e.g., to support the off-cycle read process, ad hoc

requests, etc.), the MDMS initiates the read request through the smart meter data collection head-end system interface adapter. All meter readings (scheduled and unscheduled), flags, meter status and meter events are validated for correctness and converted to a common format for processing by internal MDMS processes and applications.

During the field trials operation phase, customer satisfaction surveys will be carried out in order to assess the customer satisfaction levels with the new smart metering systems.

Field trial experiences and results will be evaluated in order to get conclusions so as to reach some key points to deploy smart meters in different countries, build business cases and give recommendations for improving present smart meter design for next generation (pre-series) mass production. Among others, the following points will be dealt with:

- Assessment of the reliability of the new smart meters and of the associated communication infrastructure. In addition to the reliability of the different components of the gas meter (smart valve, battery…) it will be particularly important to validate the reliability and vulnerability of the communications chain to external interventions intending to interfere with the remote control of the system in critical aspects such as, for instance, the closing of the smart valve.
- Assessment of the aspects that have been critical in the process of installation and starting up of the smart meter and associated system. The results obtained will be important in view of the optimization of the smart meter design prior to its mass production, and also in order to conceive the most effective topology of the communications network.
- Assessment of the gas consumption rationalization and customers satisfaction.
- Assessment of the viability of the integration of the electrical smart metering and gas smart metering data and infrastructure.
- Proposal of new value-added services based on the features of the smart meter and assessment of their hypothetical impact on gas and overall energy consumption in the European domestic market according to geographical customer typologies.

7. CONCLUSIONS & NEXT STEPS

In spite of European Standardization Mandate 441 and many other initiatives launched by European Union to promote energy efficiency at residential apartment buildings through the roll out of smart meters, for both electricity and gas energy distribution networks, several relevant barriers arising from legal and technology issues makes that benefits are still unclear. Energy Deregulation in Europe makes necessary that network operation and commercialization and value-added services are legally separated and, furthermore collaboration for technology validation or standardization activities between companies as DSO (Distribution System Operators) and ESCOS (Energy Service Companies) and Retailers are running currently in separate frameworks.

From this perspective ME3gas is taking advantage of merging of two previous proposals and consortiums to address this challenge of interconnecting both worlds of Smart Metering (DSO) and Home Area Network (ESCO's) in order to reach a more rational use energy (gas and electricity) at home. In our project we have solved this challenge demonstrating that the best way to exchange data for implementing energy efficiency applications and services is using BDC (Building Data Concentrator) and web services approach. This solution means a good balance to keep the common infrastructure for AMI and HAN at a minimum level as well as for reaching an open and flexible perspective that can be implemented by different Utilities in most of European Countries. Middleware platform also plays a very important role to guarantee interoperability between different products-applications at home environment and several manufacturers has shown their interest to implement his tool in the development of energy oriented HAN solutions to customers.

Smart gas meter development has been a unique milestone in order to provide a future-proof and reliable solution, considering the participation of the two leading meter manufacturers, based on:

- Advanced features solution that is able to face the requirements of the industry from all countries (from Italy-UNI requirements to UK, to put an example).
- Flexible communications approach. Based on the modular design of the communications module allows to easily adapt the communications to the requirements/protocols that might appear in the future.
- Based on standards. All interfaces and communications systems have been developed considering the current standard or, when standards are not still available, with the aim to become an open standard to be adopted by the industry in order to guarantee the interoperability of the systems and also to contribute to the UE's objective of promoting standards in order to facilitate the adoption of Smart Metering.

Security issues are currently a hot topic across Europe in order to assure the privacy of the information that is being transmitted within the Smart Metering / Smart Grid Systems. The study of the security mechanisms for the whole Smart Grid is not still completed but some important requirements have been already issued. In the project a secure system has been designed from both perspectives: from one side considering the Smart Metering System, but also considering the integration with the HAN/Middleware platform.

In the current stage of the project, the laboratory and proof of concept tests have been successfully conducted and the field tests are being started and as next steps we can point the following:

- Complete the trial tests and extract the technical and strategic conclusions in order to validate the design trough a real field test
- Promote the trials with other international gas utilities in order to validate the system and also to promote its adoption.
- Contribution of ME³gas project to the standardisation works being carried out currently in Europe, thanks to the position and involvement of partners in these standardisation initiatives and Committees.