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MICRO COGENERATION SYSTEMS USING NATURAL GAS : TOWARDS A SMART SOLUTION ?

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ABSTRACT

The micro cogeneration systems using natural gas allow to produce heat and electricity. There are a lot of advantages. These systems allow to reduce the primary energy consumption compared to a classical solution (boiler or electrical heating) . These systems of decentralized electricity production are a solution to relieve the electric grid which is more and more solicited during winter and summer because of the electrical consumption peaks.

The view of GDF SUEZ is that the micro cogeneration products have a high potential for the residential market in particular for individual houses. In this context, GDF SUEZ carries out many laboratory tests and field tests. Today, three technologies are tested : Stirling engine, Internal Combustion Engine (ICE) and fuel cell.

The Stirling mChp, combination of a Stirling module and a condensing boiler, is a mature technology. GDF SUEZ tested several products in his laboratory and has launched 30 field tests since 2011 with different manufacturers (De Dietrich, Baxi, Viessmann..). The obtained results meet the expectations in term of comfort and performances. This product is introduced in the new French thermal regulation 2012.

Currently, GDF SUEZ tests in his laboratory a Japanese ICE product and plans to install two field tests in 2014. These field tests will be a very good opportunity to evaluate the coupling between the ICE module and an existing boiler. Engine mCHP are already commercialized in Germany, where the energy tariffs are favorable to mCHP. Investment cost reduction or other subsidies are needed for a favorable context in France.

The fuel cell is considered as the highest potential micro cogeneration technology because of an excellent electrical efficiency (can reach 60%). GDF SUEZ tested several products in his laboratory (PEMFC and SOFC) and his objective is to launch quickly these products to the French market. Therefore GDF SUEZ decided to participate to the European project "ENE field which plans to install 1000 fuel cells in Europe. GDF SUEZ will install 28 field tests in France with different manufacturers (BAXI, HEXIS, RBZ, BOSCH, VAILLANT…). This field tests will allow to evaluate the performances, the reliability of the technology and to prepare the distribution chain (maintenance, installers, commercial offers..). GDF SUEZ does regulation lobby (installation and safety procedures, Ecodesign and new French thermal regulation 2012). The first French field test will be installed in January 2014.

Houses are becoming more and more insulated, so that the thermal load is increasing, whereas the specific electrical demand increases every year (computers, lighting, cell phones, TV..) : The electrical control is the tomorrow's challenge. GDF SUEZ is convinced that the micro cogeneration products are the solutions to reduce the primary energy consumption, to relieve the grid (peak shaving) and will be the solution to reach positive energy house.

In the future, these systems will be compatible with smart control and favor the development of advantageous offers, for example by using an aggregator.

The paper will present field test results on Stirling mCHP, lab test results on engine mCHP and fuel cells. Then, the paper will present the main challenges for mCHP in houses : preparation of the professional network, regulation issues, and economics issues.

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1 ENERGY TRANSITION AND FRENCH THERMAL REGULATION : A CONTEXT TO DEVELOP NEW GAS PRODUCTS

In Europe, new directives like the Energy Performance of Buildings Directive (EPBD) [1] and the Energy related Product Directive [2] push for energy efforts in the residential buildings sector, in order to achieve energy efficiency and renewable energy targets for 2020 and beyond. For new houses, each country adapts its regulation to apply the EPBD. For example in France, RT 2012 introduces a high level of requirements regarding new houses :

- An average level of energy consumption not exceeding 50 kWh of primary energy/m²/year (modulated depending on the geographic zone).
- A part of renewable energy of 5 kWh/m²/year or an equivalent. As equivalent, are considered : thermodynamic domestic hot water production (with COP higher than 2 according to EN 16 147) and micro-cogeneration system.

This is a important change for the buildings; heating and domestic hot water (DHW) products must be adapted.
To comply to the new regulations regarding energy efficiency, it is crucial to develop new gas systems. GDF SUEZ follow a roadmap for the products development, which can be summarize in three main axes :

- The adaptation of the boilers to the little heating needs of the new houses and to the retrofit applications.
- The association of the natural gas to renewable energies.
- The production of decentralized electricity combined with heat, i.e the micro CHP (Combined Heat and power).
- Develop smart controls.

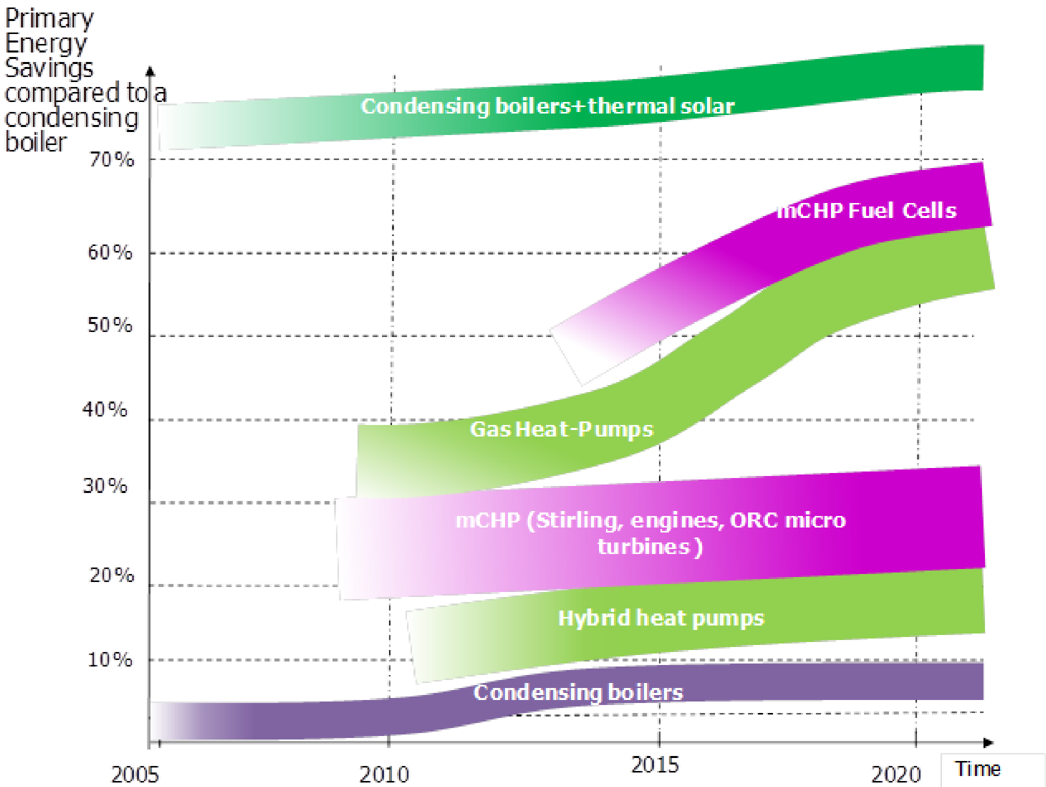

*Figure 1: Among GDF SUEZ roadmap for products development, the association of natural gas and renewable energies and **mCHP** are pillars.*

Houses are becoming more and more insulated, so that the thermal load is decreasing, whereas the specific electrical demand increases every year (computers, lighting, cell phones, TV..) : the electrical control is the tomorrow's challenge. Micro-cogeneration products are solutions to reduce the primary energy consumption, to relieve the grid (peak shaving) and will be a solution to reach positive energy house. In the future, these systems will be compatible with smart control and favor the development of advantageous offers, for example by using an aggregator.

Several micro-CHP product exist based on different technologies : Stirling engine, Internal Combustion Engine (ICE), Organic Rankine Cycle (ORC), Fuel cell. GDF SUEZ aims to develop the best technologies in collaboration with manufacturers. GDF SUEZ mainly takes part in these steps of development :

- Definition of the product specifications, adapted to the market,
- Laboratory Test of the first prototype,
- Field test,
- Regulation integration.

The following paragraph will focus on the current deployment of Stirling mCHP, fuel Cells mCHP and smart grid and energy management integration.

2 STIRLING MCHP AND INTERNAL COMBUSTION ENGINES MCHP : PRODUCTS ALREADY COMMERCIALIZED

GDF SUEZ carried out laboratory tests and field tests on two products :

- Hybris power : product developed by De Dietrich
- Vitotwin : product developed by Viessmann

The characteristics of these products are presented as below in figure 2.

Brands		Stirling technology	Power (kW)	Performances (% LHV) Source : Manufacturer'sdata	Specificities
Viessmann		Stirling Microgen Engine Corporation (MEC)	Stirling engine: 1kWe Main boiler: 6 kW Back up boiler: 18k	Electrical efficiency: 16% Global efficiency: Up to 107%	Installed together with a water buffer tank (packaged or separated
BDR Thermea (De Dietrich)		Stirling Microgen Engine Corporation (MEC)	Stirling engine: 1kWe Main boiler: 6 kW Back up boiler: 18k	Electrical efficiency: 16% Global efficiency: Up to 107%	-

Figure 2 : Two Sirling mCHP tested by GDF SUEZ

<u>Laboratory tests</u>

Different kinds of tests have been undertaken:

- Safety tests allowing checking the decoupling device essential for the French regulation,

- Heating tests allowing to evaluate the electrical and thermal efficiency at different levels of temperature and part loads,
- Domestic hot water tests.

The results obtained are in accordance with the manufacturer's performances.

Field tests in individual houses

40 field tests equipped with sensors have been undertaken in individual houses. The sensors installed [Figure 3] have allowed to evaluate :

- self consumption's rate
- electricity exported in the grid
- electrical efficiency of Stirling engine
- thermal efficiency
- global efficiency

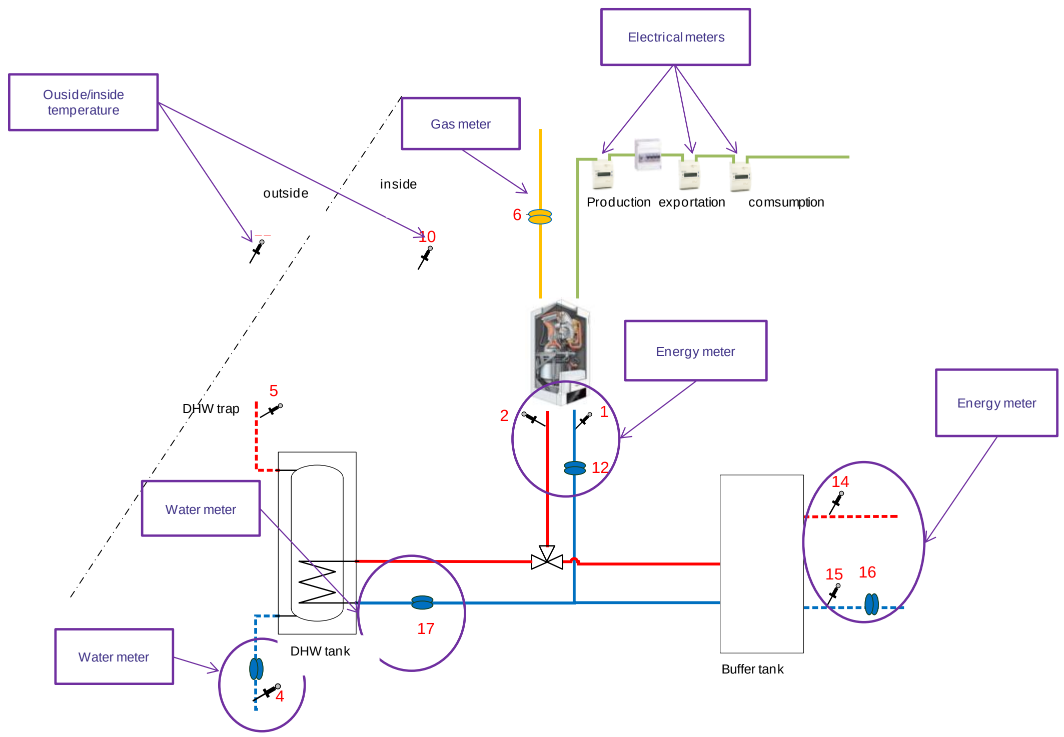

Figure 3 : Field test measurement

The performances obtained are :

- Average electrical efficiency : 14%
- Average self consumption : 70%
- Global efficiency : up to 102%

These performances are satisfactory. It has been observed that the reliability of the Stirling depends on quality of water. The manufacturers have therefore integrated in the accessories an appropriate filter.

Field test in collective housing

A Hybris power combined with a condensing boiler has been installed in a boiler room. This association is used to heat 13 new apartments.

13 apartments mCHP + condensing boiler

Figure 4 : Stirling mCHP Field test in a collective dwelling

In this configuration, the electricity produced is consumed by the common parts (lighting, auxiliary pumps) or exported to the grid.

The results obtained are satisfactory. The annual self consumption is about 80% and 75% of common electric demand is covered by the electricity selfconsumed.

Commercialization of the mCHP Stirling

BAXI commercializes their Stirling mCHP in Europe : Germany, UK and France. Viessmann commercializes the Vitotwin in Germany and plans to launch it for the French market in 2015.

GDF SUEZ has also performed laboratory tests of an Internal Combsution Engine (ICE) dedicated to individual houses. GDF SUEZ is evaluating their potential for European market. The laboratory tests have confirmed the efficiency announced by the manufacturer (Electricity efficiency of 26% on Net Calorific Value). The evaluation continues to study the possible association with an existing boiler. This product could be of interest for the European market, if they offer a lower investment cost than other mCHP products and if the maintenance stays compatible with a good profitability for the customer. Today, the good market conditions are present in Germany, where but not yet in France.

3 FUEL CELLS MCHP : FIELD TESTS IN EUROPE

Fuel cells using natural gas are commercialized in Japan for the residential market. 50 000 products are sold per year. The development of fuel cells for the European market is in progress. There are European development and also partnership between European boiler manufacturers and Japanese fuel cells manufacturers. A European project, ENE.FIELD, has started in 2012 for 5 years with the main objective to deploy up 1000 fuel cells for the residential market.

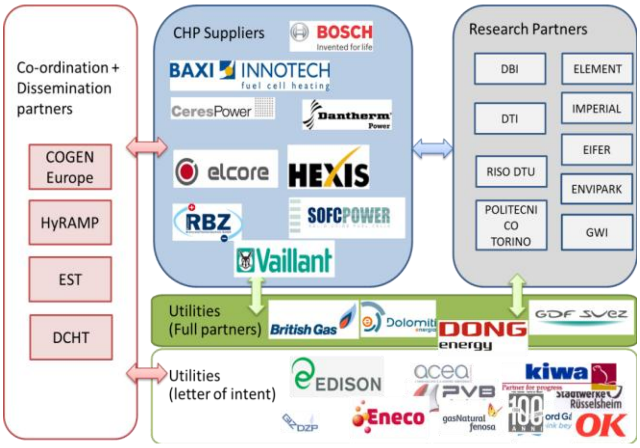

Figure 5 : Enefield consortium : 9 manufacturers, 4 utilities whose GDF SUEZ, 12 countries

The other objectives are to establish well-developed supply chains, support networks and evaluate the performance and reliability of mCHP fuel cell technologies. The objective of GDF SUEZ is to install 28 fuel cells in France, from different manufacturers and different kinds of products (PEMFC[1] and SOFC[2]).

In April 2014, GDF SUEZ Research and Technology Division installed two first individual fuel cells, developed by Baxi Innotech from BDR Thermea Group, in two existing houses located in the cities Haguenau and Munschhausen , in Alsace region , in East of France.

 Build in 2000, 120 m², 4 persons	 Build in 1969, 130 m², 4 persons
	

Figure 6 :Two fuel cells installed in France for a measurement field test within Enefield

[1] PEMFC : Proton Exchange Membrane Fuel Cell

[2] SOFC : Solid Oxyde Fuel Cell

These fuel cells have been installed by De Dietrich Thermique, a French branch of BDR Thermea Group, nearby their manufacturing premises in Alsace.

De Dietrich Thermique has selected volunteer householders whose houses were heated by natural gas or oil boiler, and these equipments have been replaced by pre-commercial micro-CHP fuel cell boilers. These fuel cells produce locally from natural gas heat and electricity for the dwelling, reducing the household primary energy, CO2 and pollutants footprints.

Three other GAMMA PREMIO and one Galileo have been installed in June 2014.

The next steps will be the analysis of the results.

4 NATURAL GAS TECHNOLOGY : TOWARDS AN ELECTRIC GRID FLEXIBILITY

Through the European Union's energy performance policy, the **development and the integration of distributed energy production within the European electricity network is already initiated**. We can already see significant market and technology evolutions, mainly through the expansion of the renewable energies (wind energy, photovoltaic panels) which can already answer to half of the electricity needs of some countries such as Denmark.

In parallel, the electrical demand in residential buildings is increasing from the appearance of new usages (computers, lighting, cell phones, TV..) and the growth of electrical heating in such countries such as France. One of the consequences is the amplification of the phenomenon of electricity demand peaks (both from seasonal and daily points of view).

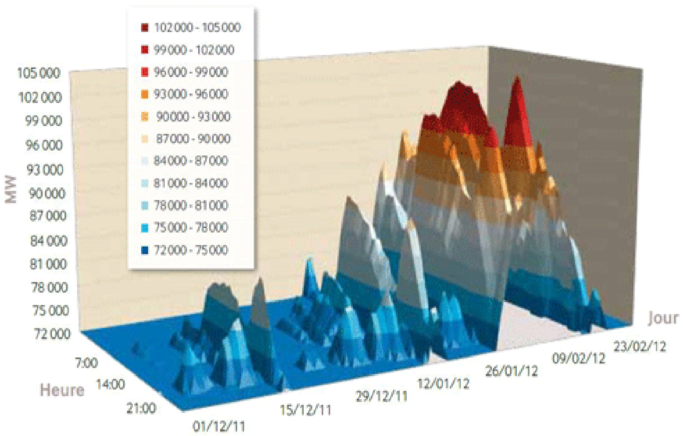

Figure 7: Electricity peak demand during the 2011/2012 Winter in France (Source : RTE)

The implications for distribution and transportation electricity networks are numerous: infrastructures must adapt to the new decentralized production while assuming the same levels of safety and quality of the grid. The following aspects must be taken into account:

- ✓ The impact on the network is higher when production and consumptions aren't correlated (issue of renewable energy's intermittently production);
- ✓ The needs of investments are higher when development happens in lower density areas where networks are sized at a minimum;
- ✓ The number of network adaptations depends on the number and concentration of decentralized production units.

Investments are therefore necessary but they must be planned carefully (optimization of costs) and should be able to embark the aspects linked to peak consumption issues. N**ew approaches of grid management, through the "smart grid" concept and network flexibility are therefore needed**.

Cogeneration units (using the gas network to produce locally heat and electricity) **are of course integrated in such a concept** since they allow decentralized electricity production with the main advantage of not being intermittent such as renewable energies. Indeed, electricity production happens during heat demand periods, that is to say periods of major electricity peak demands : **micro-cogenerations are products perfectly suited for giving flexibility to the electricity grid** (peak shaving).

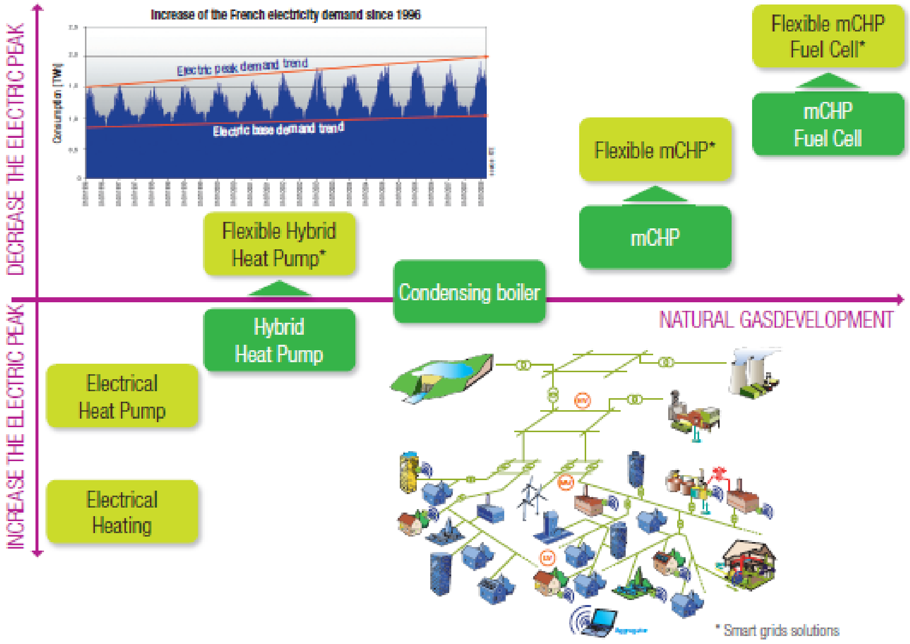

Figure 8: GDF SUEZ firmly believes that natural gas technologies are one of the main options to reduce electricity peak consumption and bring flexibility through natural gas existing networks.

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5 HOME ENERGY MANAGEMENT SYSTEM AND ELECTRIC AUNTONOMY

Smart homes have the capacity of independent actions with economical or environmental aspects in mind. The aim is to create a global control of the different heat and electricity production means of a house and use the consumption posts, energy production possibilities, storage units and also external incentives to design **the most efficient control strategy for the end-user.**

The two main approaches are Demand Side Management (adaptation of the end-user's consumption) and production management, mainly through utilization of energy storages. Some commercialized products are already available on the market, mainly in link with the photovoltaic aspects: the principle is to add a battery storage and a management system to photovoltaic panels in order to optimize electricity utilization.

GDF SUEZ is studying the opportunity to adapt this logic to micro-cogeneration products : the advantage is to be able to use a non intermittent electricity production (from natural gas) to optimize electricity self-consumption, energy bills and environmental aspects. But the parallel production of heat implies a more complex installation (addition of a heat storage, for instance) and control algorithms.

A specific platform has been developed to test different energy related products combinations (photovoltaic panels, micro-cogenerations, energy storage) in relation with tomorrow's house (end-user's consumption, integration of an electrical vehicle…). **The objective is to define new strategies to improve self-consumption, minimize environmental impact, improve reliability and services to the end-user.**

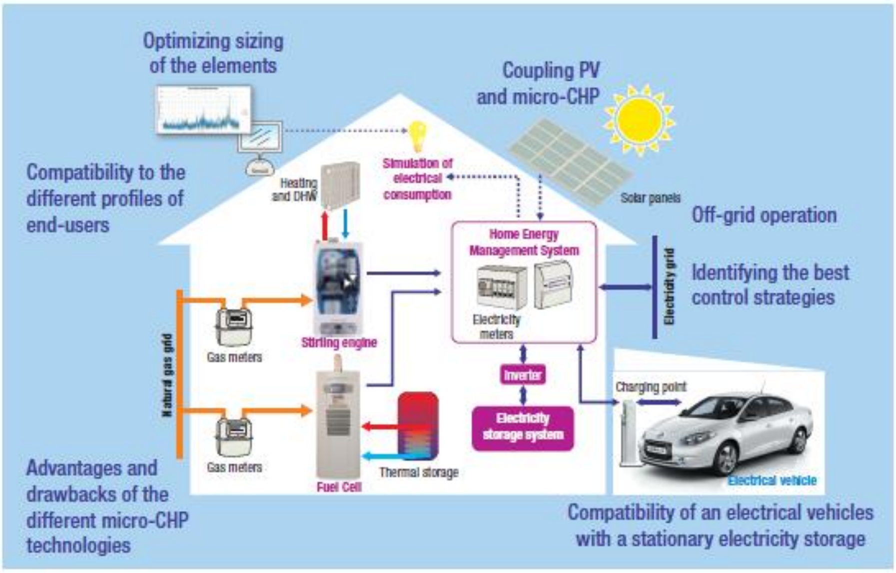

Figure 9: GDF SUEZ's (CRIGEN) test platform.

This installation also enables the creation of an islanding situation : the house can disconnect from the main grid (during a grid failure, for example) and operate autonomously, supplying its own loads from internal power sources for some period of time. Such an installation gives to the end-user the assurance of an off-grid operation and therefore an increased comfort and independence from events on the electricity grid (back to the notion of flexibility). Micro-grids can range from a neighborhood to a small town. Without a connection to the central grid, it is said to be islanded (during a grid failure, for example), which generally means the integration of an electricity storage (to ensure a proper demand/production balancing). The micro-grid controller must take into account the load profiles and capacities of the different electricity production plants and heating or cooling needs (if it integrates a cogeneration) as well as the storage's capacity.

6 CONCLUSIONS

GDF SUEZ is involved in the development of mCHP systems in collaboration with manufacturers. Several technologies exist and have potential : Stirling engines, internal combustion engines, fuel cells…GDF SUEZ contributes to perform laboratory test and field tests. These steps are important to evaluate to the potential of the product, to optimize it and adapt to the specificity of the markets. These tests also give the data to evaluate the safety in order to have the good input to propose to the public authorities the good installations rules. Furthermore, they are also necessary to integrate these new products to the regulations and incentives.

mCHP has a very interesting potential in terms of efficiency, but also presents opportunities to decrease the electricity peak demand, and to go towards the electricity autonomy. GDF SUEZ (CRIGEN) is doing research to develop appropriated installations.

REFERENCES

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings.

[2] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of Ecodesign requirements for energy-related products.

LIST OF FIGURES