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INVITED PAPER

Do we have a chance for small-scale energy generation? The examples of technologies and devices for distributed energy systems in micro & small scale in Poland

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Abstract. This paper presents examples of technologies for distributed energy generation developed under the projects coordinated by the IFFM PAS in Gdańsk. These are CHP units (generating heat and electricity) for houses with a power from several to tens of kW and for municipalities in the form of the Municipal Energy Centers (with a capacity of several hundred kW up to several MW). A unique project, specializing in "energy-plus" technologies for residential houses and other buildings, which aims to build a Research Centre of PAS in Jabłonna is also presented,. These are key technologies for energy sector with respect to distributed generation.

Additionally, the article discusses the conditions and opportunities for the development of energy generation or more broadly: civic energy generation in our country. Civic energy generation is a great vision in which the citizen becomes an entity and do not subject to the energy market, and additionally has its virtual advisor in the form of smart grid and data processing technologies in a "digital cloud".

Key words: distributed energy generation, renewable energy sources, ecological power engineering, energy technologies..

1. Introductory remarks – legal framework

Following the recent actions of the European Union, it can be concluded that the previously approved strategic direction of the EU policy aimed at reduction of emissions, introduction of renewable energy sources and energy conservation in buildings will not only continue, but also will be strengthened. A framework activities in this area are defined by the Energy Road Map 2050 (ERM2050), which is currently under preparation, new support mechanisms in the form of the Framework Programme "Horizon 2020" (research and innovations) as well as by already functioning tools such as the "SET Plan" (implementations, cooperation with industry), which are currently being improved and broadened.

To adjust the Polish law to the requirements of the above activities and especially the requirements of the Directive 2009/28/EC regarding the development of renewable energy sources, the government team develops a package of Acts commonly called "energy three-pack". From the point of view of this article the Act on renewable energy sources (RES) is the most important. So far in the Polish legislation none of the documents concerning Renewable Energy Sources (RES) was ranked as a legal act.

One thing is certain: the above-mentioned EU legislation and national legislative initiatives clearly determine the path for the energy system development based on renewable energy sources, in particular small-scale and distributed.

In the light of the comments on these legislative initiatives, regardless of the pace of the works and the dangers arising from the lack of a stable law, one can expect a dynamic development of intelligent and distributed energy systems as well as significant improvement in energy efficiency. In this context, it is important to stimulate the development of activity of prosumers (producers who are simultaneously the consumers of energy), i.e. millions of small investors who are micro-scale producers of energy for their own use, selling the excess energy produced to the national power grid. This idea is a great opportunity for our power engineering, because the predicted lack of capacity in the period 2016–2017 cannot be so quickly replaced by large conventional units (new power units) entailing considerable investments.

Studies on the conversion of energy from renewable sources require a multidisciplinary approach. Hence the need for a systematic synergy of scientific achievements in the field of technical, biological and agricultural sciences , but first of all in the field of ecological power engineering.

Summarizing the above considerations it can be concluded that the distributed energy engineering based on renewable energy sources (DES / RES), "Smart Grid" and applications in the "digital cloud" will be a key element of national energy policy in Poland in the near future. This means that the hybrid systems integrating solar, biomass and wind technologies, heat pumps and energy storage for energy-plus residential houses, facilities and housing estates co-working in a smart grid are a challenge for the moment. In this context, the main task for national research centers, industry and self-government entities is to develop economically viable solutions for our market using multivariate synergies between the different technologies and the elaboration of the most useful applications for the processing in "digital cloud" [1–11].

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2. Small-scale eco-energy production – development opportunities

The development of distributed energy generation system DES is directly related to the implementation of intelligent energy management systems (SG – Smart Grid). Smart grids enable easier connection of distributed sources to the National Energy System, reduce the grid load and minimize the risk of blackout.

It is worth to emphasize that a smart grid itself in the electricity distribution system is only a certain technical layer. More important is that through the use of this grid, one can generate new services as well as new applications and as a result - simply make money. The grid itself is not able to trigger such changes but attractive applications are. It is worth noting that, for example Apple company succeeded predominantly thanks to applications rather than smartphones themselves.

In order to take advantage of all its benefits, the smart grid must be provided with appropriate IT interface layer enabling prosumers' communication in the so-called "cloud computing" – Figs. 1, 2. The term "cloud computing" is here quite contractual. Although it is used in the literature in rather different contexts, its main features find applications in relation to the distributed eco-energy generation. There is a place for different kinds of virtual installations, business models or even advisory systems applying artificial intelligence methods. The "cloud", defined and understood as above mentioned, is in fact a virtual platform for the exchange of information for prosumers, their data and knowledge bank as well as their system of professional advice. This is undoubtedly the future of this sector of energy engineering and a targeted vision of civic energy generation, where prosumers and consumers feel independent and free.

Similarly to the rapid development of ICT, which resulted in freedom of communication among citizens, one can expect that the development of distributed technologies (DES/RES) in combination with the smart grids and virtual communication platform for prosumers will make the citizens free also from the energy point of view. It's a great vision, which shall be given more attention – Fig. 1.

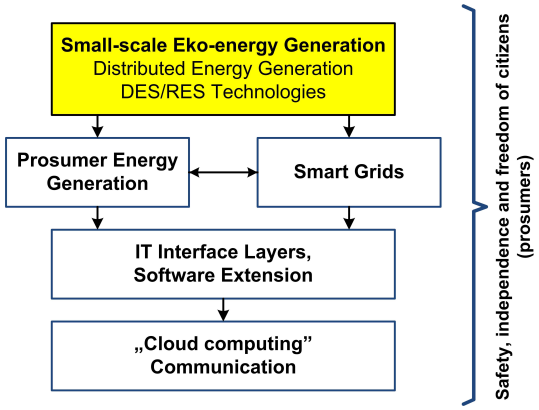

Fig. 1. The development of small-scale eco-energy production as a vision of civic energy generation: from RES/RES technologies to processing in the "cloud". The vision of safety, independence and energy related freedom of the citizens

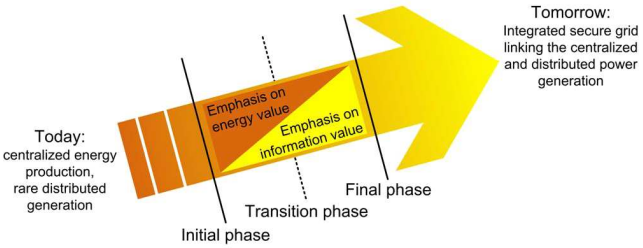

Fig. 2. The role of information in the development of energy systems

Figure 3 shows the advantages of small-scale distributed cogeneration in comparison with a classic, large-scale power system.

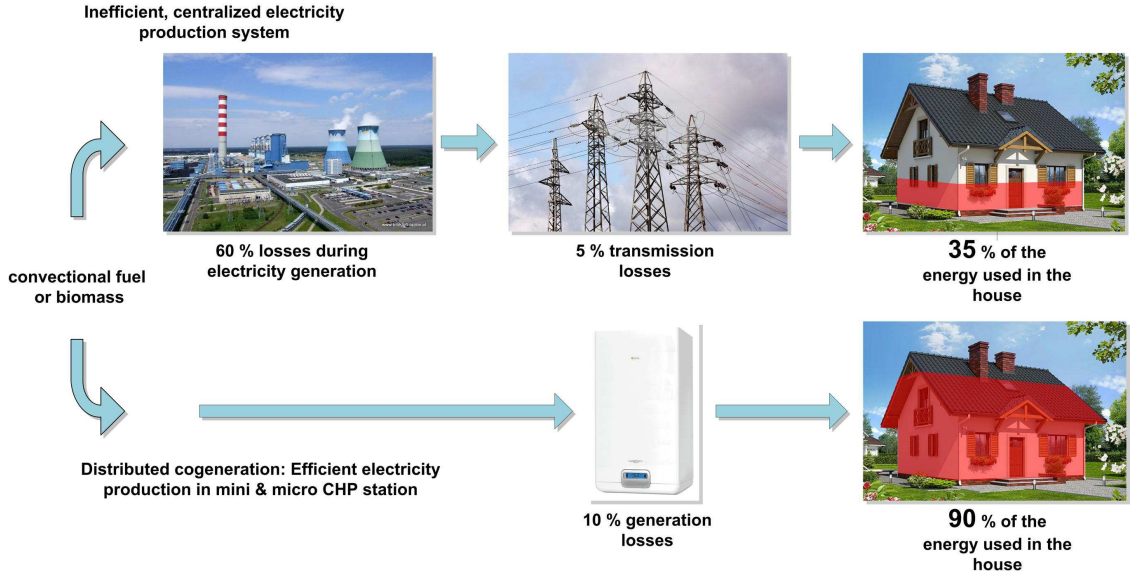

Fig. 3. The advantages of distributed cogeneration in comparison with centralized power generation

3. The examples of DES/RES devices and technologies

The following examples refer only to the three selected research projects coordinated by the IFFM PAS in Gdańsk. However, these are the largest research projects in the country regarding the field of RES-based eco-energetics. They can therefore be treated as representative ones for this energy sector.

This article focuses on the results of the work related to so-called "energy-plus" technologies and small & micro-combined heat and power units. These results are the effect of research conducted at the institute and in cooperation with industrial partners (mainly the Capital Group ENERGA) and more than a dozen research teams from different research centers across the country. These study focuses on the future implementation and is addressed to individual and municipal consumers.

The other results of the work carried out by our fellow-workers (regarding, for example, micro bio-gas works, gasifiers, biorefineries, fuel cells, etc.) are not discussed in this paper. This stems from the obvious fact that the volume of this article is limited.

It is not the intention of the author of this article to present any other DES/RES technologies known in the country even in the field of combined heat and power units. It is just not possible within a single article.

However, we present below some of the results of the country's top three research projects in the field of renewable energy sources, namely [12–15]:

- The "Key" project from the indicative list of Innovative Economy Operational Programme "Model agro-energy complexes (...)".
- The "Strategic" program/project "Advanced Technologies for Energy Generation"; Task 4. "Production of energy from biomass (. . .)"
- The Research Center of PAS in Jabłonna "Energy Conversion and Renewable Sources" project.

When it comes to the so-called "Key" project, the construction of the CHP ORC plant is planned (the blocks consisting of a boiler and a microturbine operating with a low-boiling agent using an ORC) with the electric power of several kW and tens of kW of thermal power. Whereas in the framework of the "Strategic" project it is planned to build CHP ORC units of higher power (hundreds of kW of electrical power, thermal power up to several MW).

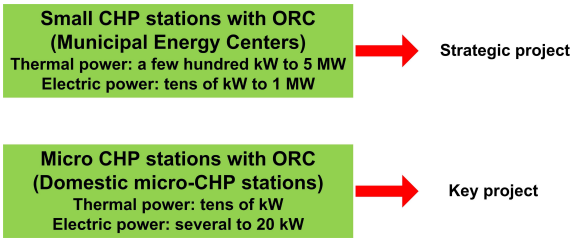

Fig. 4. CHP ORC stations in small & micro scale as suggested in the framework of the IFFM PASci projects

The results of the "Key" project are thus addressed to individual customers in the form of domestic CHP units, and of the "Strategic" project to the municipal customer as Municipal Energy Centers. Figure 4 shows this pictorially.

3.1. Domestic CHP ORC units. The "Key" project (under the Innovative Economy Operational Programme) entitled: "Model agro-energy complexes (...)" is realized by the scientific consortium composed of: IFFM group (Gdańsk University of Technology, Łódź University of Technology, University of Warmia and Mazury – Faculty of Technical Sciences), Wrocław University of Technology group, Institute of Power Engineering group and University of Warmia and Mazury group. The main task of IFFM group is to elaborate several prototypes of the so-called Domestic CHP stations, which include biomass and multi-fuel fired boilers with a capacity of tens of kW coupled with micro-turbine with a capacity of a few kW – operating with a low-boiling agents using an ORC (Organic Rankine Cycle). The concept of Domestic Cogeneration Units i.e. small plants that produce heat and electricity, may be attractive to thousands of individual customers, especially if the micro-CHP units will be integrated with other systems (solar/wind/water energy, heat pumps and energy storage), creating the so-called hybrid systems with greater mutual synergy – Fig. 5. Such micro-CHP units could create a new and powerful market and play a key role in the concept of civic and prosument energy generation.

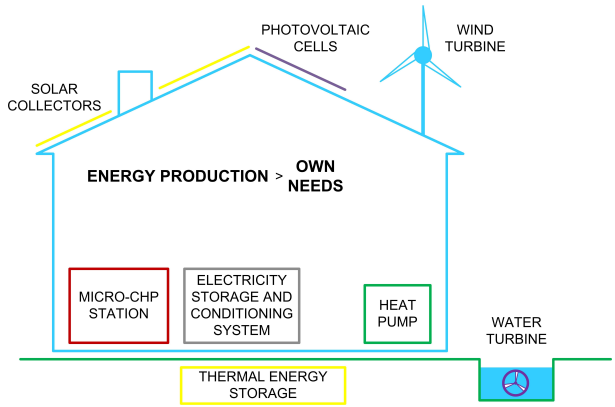

Fig. 5. Domestic CHP units – an example of the hybrid system with a much greater mutual synergy. The attractive vision of civic or prosumer energy generation for thousands of individual customers

The IFFM group developed two concepts of microturbines with a capacity of 3 kW (axial-flow and radial-flow) coupled with multi-fuel boiler with a capacity of 20 kW (biomass or gas fired). As far as microturbines are concerned, the essential idea was to use the low-boiling agent (turbine's working medium) for bearing lubrication, which ensures tight and hermetic construction. Figure 6 shows this idea, while drawings and photographs of micro-turbines are presented in Figs. 7 and 8. Figure 9 shows the photo of test stand in the micro-turbine laboratory (located at the IFFM PAS in Gdańsk) and the photo of multi-fuel fired boiler.

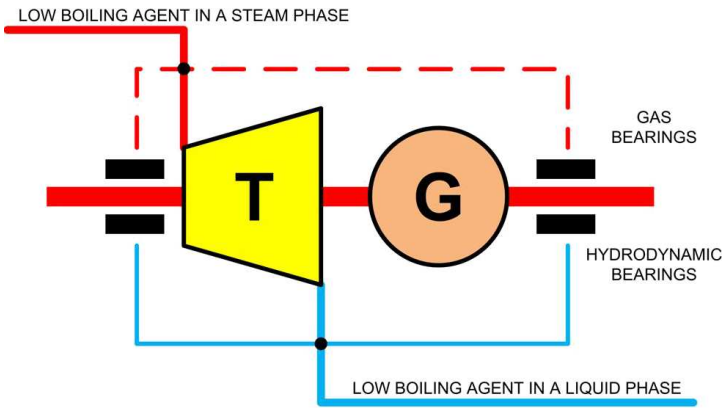

Fig. 6. The possibility of utilization of a microturbine's working medium in the liquid and gas phases as a bearing lubricant. The concept of hermetic construction of a turbine and a generator to facilitate the integration with a boiler

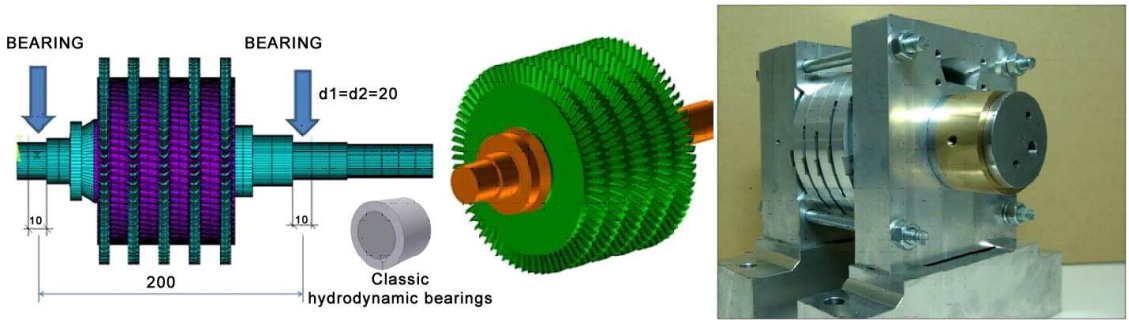

Fig. 7. The axial-flow micro-turbine, 5 stages, with a capacity of 3 kW and rotational speed 8000 rpm developed within the "Key" project. Tests are currently underway in the laboratory of the IFFM PASci (developed by a research group of the Technical University of Gdańsk)

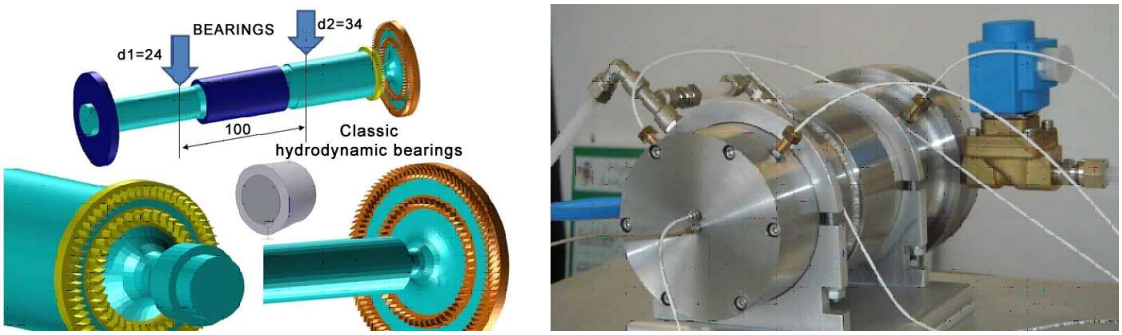

Fig. 8. Radial-flow micro-turbine, 4 stages, with a capacity of 3 kW and rotational speed 23000 rpm developed within the "key" project. Tests are underway in the laboratory of the IFFM PASci in Gdańsk (developed by a research group of the Lodz University of Technology)

Fig. 9. The laboratory of the IFFM PASci in Gdańsk: Pictures of micro-turbine test stand (on the left) and multi-fuel fred boiler (on the right)

Currently, laboratory investigations are carried out and as a result the boiler and both versions of micro-turbines are being tested. After completion of tests, the development of a target version (and perhaps commercial one) of an entire micro-CHP unit is planned. The brief foredesign and initial documentation of such micro-CHP station have already been elaborated – Fig. 10. If this undertakings are successful, it will be the first national construction of this type.

Fig. 10. Target design of Domestic Micro-CHP Unit with ORC after all examinations and tests in the laboratory of the IFFM PASci in Gdansk. Highly possible commercial version of the installation

As part of the "Key" project, an attempt was made to develop a "software upgrade" for the Smart Grid systems. These are the origins of an advisory system which cooperates with an individual user in the virtual space. The system, called SoftRol was developed by a group of the Faculty of Technical Sciences, University of Warmia and Mazury in Olsztyn – Fig. 11. Currently the database (data on technology, type of crops, the size of an acreage) and also the knowledge base (simple business models) are being built along with testing of the entire system.

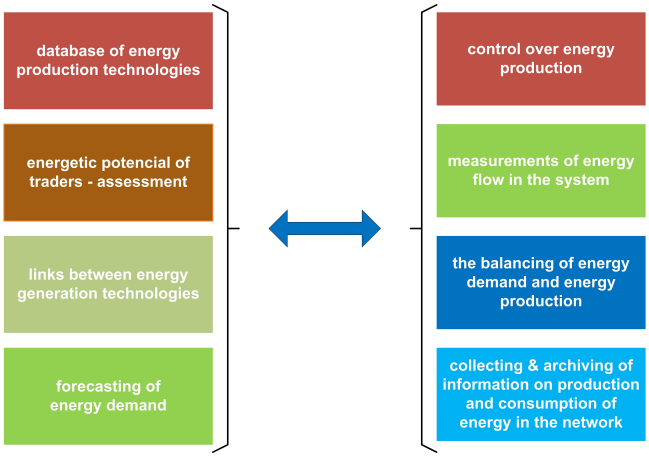

Fig. 11. SoftRol system, developed within the "key" project as an example of data & knowledge base ("software upgrade" for the Smart Grid systems). SoftRol functions (on the left), Smart Grid functions (on the right). Developed by a group from the Faculty of Technical Sciences, University of Warmia and Mazury, in Olsztyn. The system currently undergoes a test phase

3.2. Municipal Energy Centers (MEC). Concept, assumptions for building of the Municipal Energy Center is one of the tasks of the "Strategic" project. This high-budget project is being realized by scientific-industrial partnership between IFFM and ENERGA SA (the largest energy company in northern Poland) with the co-participation of many partners (University of Warmia and Mazury in Olsztyn, Institute of Power Engineering in Warsaw, Institute for Chemical Processing of Coal in Zabrze, Gdańsk University of Technology). This is one of the few examples of co-operation between science and industry on this scale (in one project) in our country.

Figure 12 schematically shows the main objectives of the "Strategic" project. The significant feature of this project is the number of innovative, prototype installations that are to be built upon its completion in 2015. Over a dozen of these installations will be created, with two flagship ones inselected municipalities in Poland. For obvious reasons we do not discuss these systems in this article. We mention only the installation, because it can serve as an example of a modern Municipal Energy Center (MEC) playing a key role (along with Domestic CHP Units) in the concept of distributed and civic energy generation. Centers like these are also referred to as Autonomous Energy Regions (AER). Leaving aside the issue of terminology, the essence of the matter remains the same.

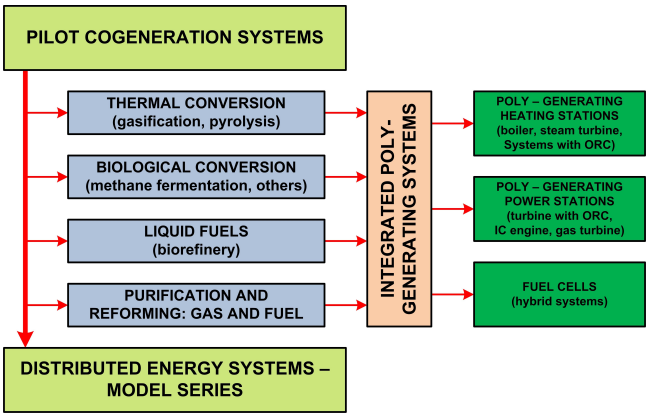

Fig. 12. The main objectives of the "Strategic" project

The Municipal Energy Centers (MECs) or Autonomous Energy Regions (AER), equipped with new technologies and CHP systems, become the project that creates a great opportunity for economic development of the Polish countryside. AER is a concept that should direct Poland into the path of changes that are already occurring around the world. Currently, in Europe and in North America, as well as in China "green" villages, housing estates, districts and even cities are being developed, (where "green" means emission-free, zero-energy or energy-plus).

The installation which is currently being built in one of the communities in Poland will serve as a role model of a small-scale CHP plant. In place of the old fashioned heat only generating, modern cogeneration units will be built, which include – Fig. 13:

- ORC system with an electric capacity of 0.143 MWe and the heating capacity of 0.83 MWt,
- CHP system with two combustion engines powered by natural gas with a total electric capacity of 3.1 MWe and the heat capacity of 3.4 MWt,

- biomass-fired steam block with the electric capacity of 2.7 MWe and heating capacity of 5.2 MWt,
- supplemented with an upgraded exhaust gas extraction system and backup boilers: WRp12, WR3.5.

The solution shown in Fig. 13 exhibits the unquestionable technological progress in the field of energy solutions in the Polish municipalities.

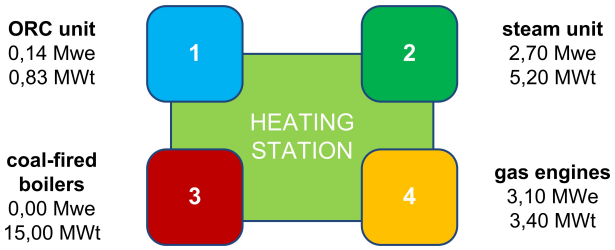

Fig. 13. The clue of the concept of modernization of the heating station in selected municipalities: several flexible CHP modules, including the module with ORC working all year round

The essence of the proposed solution in MEC/AER. The biomass CHP system with ORC – designed to cover the summer demand for domestic hot water – be working continuously throughout the whole year, while other systems will be started in response to the heat demand (this limitation is particularly important for combustion engines, for which the income from electricity production does not cover operating costs and is balanced by the income from heat generation). The steam block is planned to be operated all year round. During the heating season it will work in a heating mode (with steam bleeding), and then in condensing mode with maximum efficiency in electricity production. When the heat demand increases then reserve, coal-fired boilers will be switched on.looseness1

This technology has been awarded the Prize of the Prime Minister of first- degree for the year 2012.

The above idea solves an extremely difficult problem of this type of heating stations in the country: i.e. what to do with excess heat during summer?

It is estimated that in Poland there exist over 300 heating stations of a similar, old-fashioned type! If the idea is successful (and success is highly probable due to the scale of involvement of a large industrial partner), suggested solutions can be copied across the country in municipalities and housing estates.

Cogeneration Units Laboratory is currently constructed in the IFFM PAS in Gdańsk. This modern and largest laboratory in the country is financed from the "Strategic" project. In the future, this laboratory will also serve as a back-up research facility for devices and technologies to be applied in MECs.

4. Research center of PAS in Jabłonna

Trends related to the development of distributed energy generation were the basis of decision made by the Polish Academy of Sciences and the Office of the Marshal of Mazowieckie Voivodship to build, a new and unique in the country, Research Center – Figs. 14 and 15. This Center will be dedicated to the investigation of aspects of renewable energy conversion. The Center, (to be located in the municipality of Jabłonna, about 20 km from Warsaw), is planned to serve as a complex of modern research/testing laboratories with a unique apparatus and a set of demonstration facilities concerning distributed energy systems (DES) as well as technologies for the so-called energy-plus houses and facilities – Fig. 16. The beneficiary is the Institute of Fluid-Flow Machinery PAS in Gdańsk, who developed the concept of the Center and coordinates its implementation. The completion of the investment is scheduled for December 2014 but activities related to design & legislative work, planning of research and consolidation of scientific and industrial centers are ongoing since 2012.

The Center will be equipped with a local intelligent "Smart Grid" system which makes it possible not only to manage energy sources and the way energy is stored, but also remote archiving, transmission and processing of the experimental data obtained from research laboratories. The set of conference rooms, guest rooms, recreational areas and "RES" Education Path will enable Center to fulfill also the important educational and training functions.

The energy systems installed at the Center – in the power range from a few to several hundred kW (biomass and gas boilers, combustion engines, gas and wind turbines, heat pumps, solar collectors, PV cells and several types of energy storage), thanks to the possibility to create multiple variants and operational modules as well as the original hybrid associations, offer unique research opportunities for testing and certification of these devices. This is particularly important given the fact that all these devices are concentrated in one place and work within a single system of energy/information management (expanded BMS). The achievement of the so-called "synergy effect" in these conditions is certainly facilitated.

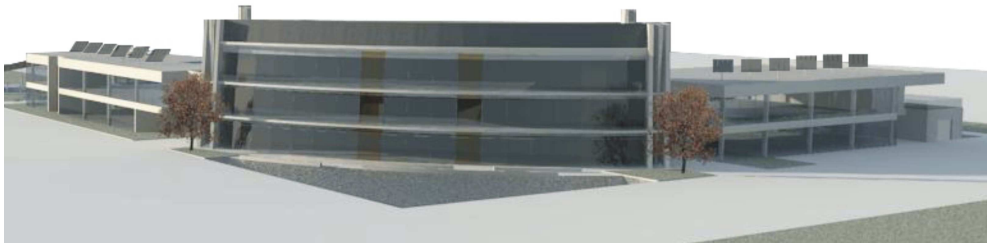

Fig. 14. The view of the Research Center in Jabłonna from the south (after completion of the project in December 2014)

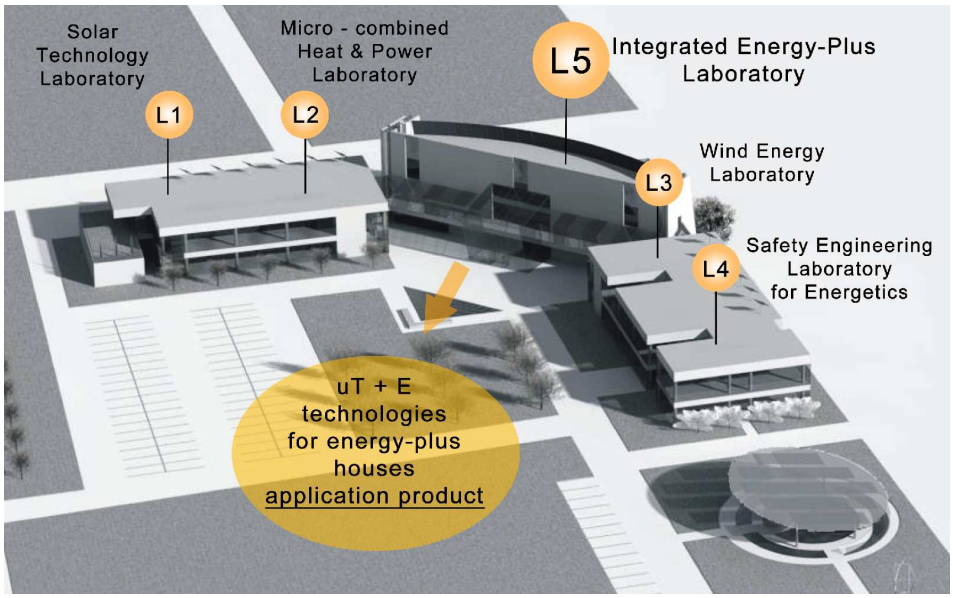

Fig. 15. The view of the Research Center in Jabłonna from the north – location of laboratories

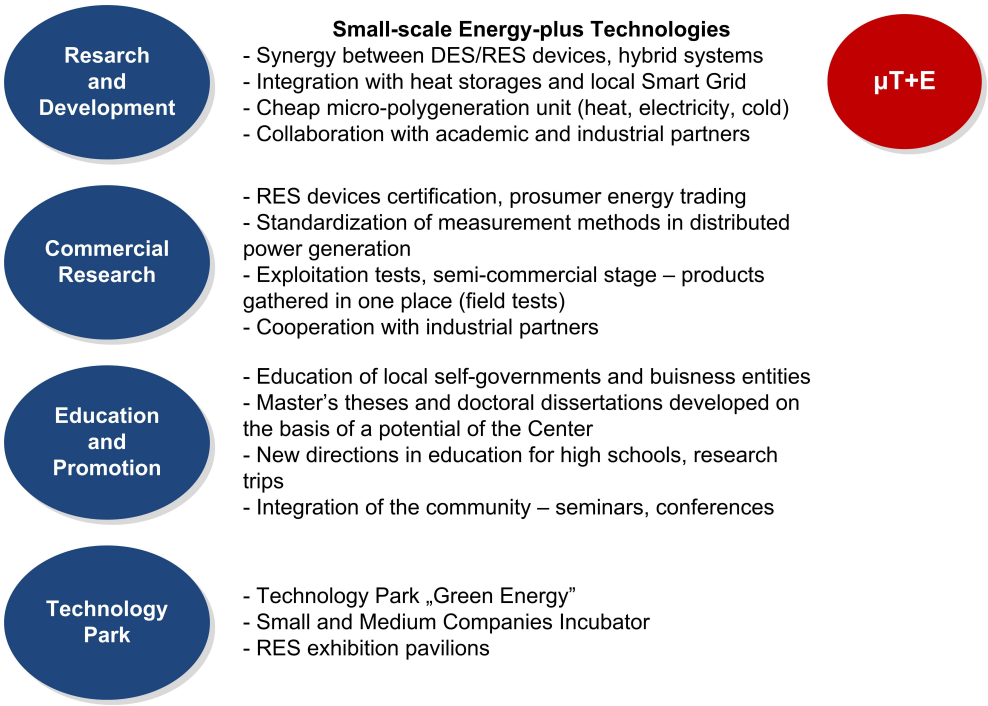

Fig. 16. The Research Center's offer for local scientific community, self-government and industrial entities. "Business card of the center" – Energy-plus Technologies for houses, facilities and housing estates (uT+E)

5. Concluding remarks

This article presents only two examples of specific devices for distributed power generation from renewable energy sources (DES/RES), developed within two selected research projects. These are:

- Domestic CHP Units,
- Role Model of the CHP Plant in selected municipalities as an example of a Municipal Energy Center.

The unique project to build a Research Centre in Jabłonna was also presented. It might play an important role in the development of small-scale distributed power generation in our country.

The question whether these devices and the offer of the Research Center in Jabłonna will become an important element of the concept of prosumer energy generation or (more broadly) civic energy generation depends on many factors. The most important are:

- stable legislation supporting concepts and installations of this type,
- stable and favorable legislation for consumers and companies,
- sufficient development of intelligent "Smart Grid" system,
- development of cost-effective DES/RES technologies.

These are the key factors directly determining the development of this energy sector in Poland.

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