# development Challenges of

# SMR cogeneration moduleS

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**Abstract**

Orlen Synthos Green Energy (OSGE) is a Polish company that plans to deploy a fleet of Small Modular Reactors (SMRs) in Poland with use of BWRX-300 technology by GE Hitachi Nuclear Energy (GEH). Originally, BWRX-300 has been designed to produce only electricity, whereas, the waste heat is discharged to the atmosphere via cooling towers, as most of existing large-scale nuclear power plants do. However, the production process can be optimized to decrease waste heat and to produce instead useful heat that can be used to supply district heating networks (DHNs) and industrial facilities, therefore making the SMR a cogeneration plant. Cogeneration is widely applied in Poland for coal and gas fired plants, however it has been only a niche area for the nuclear industry. OSGE is determined to use nuclear technology as a key solution for decarbonizing the Polish and European energy sector and nuclear cogeneration can only enhance its effect. Moreover, cogeneration SMR could be used in a wider range of applications compared to large-scale nuclear cogeneration. Therefore, BWRX-300 with a cogeneration module perfectly fits to address the decarbonization needs for Polish DHNs and the Polish industry. The paper describes different challenges faced in development of a cogeneration module for existing SMR technology taking into account international, technical, business and regulatory aspects.

## INTRODUCTION

ORLEN Synthos Green Energy (OSGE) is a Polish company that is involved in development in Small Modular Reactors (SMR) in Poland. Our vision is to develop sustainable energy generation using innovative nuclear technologies, which will ensure steady economic growth and clean environment for our communities and the next generations. Our mission is to have a leading role in deployment of a fleet of SMR as an essential component of the efficient transition of energy generation towards Net Zero by 2050.

Currently in Poland there are no commercial nuclear power plants. However, there are several ongoing projects aiming at construction of the first ones. OSGE is conducting one of those projects and the selected technology is BWRX-300 by General Electric Hitachi (GEH). OSGE plans to deploy a fleet of SMRs, which would work in an electricity-only or a cogeneration mode of operation. The cogeneration module for SMR would allow to produce hot water to supply district heating networks and to produce steam for industry. BWRX-300 with the cogeneration module allows OSGE to fulfill its vision and mission, which are the clean environment and achieving the goal of Net Zero by 2050.

OSGE has obtained 6 Decisions in Principle for deployment of BWRX-300. Decision in Principle is the first major milestone for the nuclear project in Poland. It is issued by the Ministry of Climate and Environment. Projects with Decision in Principle are authorized by the Polish government to apply for a decision on determining the location for the construction of a nuclear power plant and other decisions necessary for the preparation, implementation and use of an investment in the construction of a nuclear power plant. Each of the locations shown on Fig. 1 can have up to 4 units. Moreover, Fig. 1 shows the mode of operation of those units: electricity only, cogeneration for district heating, and cogeneration for industry.

BWRX-300 with the cogeneration module perfectly fits to address the decarbonization needs for Polish DHNs and the Polish industry. The paper describes the important role of cogeneration and challenges related to its development.



*FIG. 1 Map presenting locations with Decision in Principle obtained by OSGE.*

## What is cogeneration and why IT is important?

Cogeneration, also known as Combined Heat and Power (CHP), is a production of electricity and useful heat at the same time. Most of nuclear power plants around the world produce only electricity with an average thermodynamical efficiency around 30%. The rest of the energy is treated as a waste heat which is discharged to the environment: to the atmosphere via cooling towers or to water reservoirs via heat exchangers. Currently, there are 416 operable nuclear power reactors in the world with total of 374 GWe installed capacity [1]. If we assume the average efficiency of 30% and the average Unit Capacity Factor of 79,2% for all those reactors [2], then roughly estimated 6 054 492 GWh/year (21,8 EJ/year) of thermal energy are emitted to the environment. This amount of thermal energy is higher than the total heat demand for residential and service sector in European Union from year 2010, which was 15,5 EJ/year [3]. Utilization of a fraction of this energy would help in decarbonization efforts. Fig. 2 compares efficiency of cogeneration versus separate production of electricity and heat. The same amount of heat and electricity are produced, however, cogeneration allows to generate much lower losses. The values are typical for a cogeneration plant fired with fossil fuel. In case of nuclear cogeneration the values will be slightly different, however, the general idea is the same – cogeneration creates primary energy savings. In decarbonization efforts the energy that is not consumed is the best kind of energy, as it allows not only to save fuel but it also allows to build lower installed capacity of power plants, thus decreasing the capital cost of decarbonization.



*FIG. 2 Comparison of cogeneration vs separate production of heat and electricity for plants fired with fossil fuels*

While it may not be possible to apply cogeneration for each of existing nuclear power plants, however, nuclear power plants that will be built in the future, especially SMRs and MMRs (Micro Modular Reactors), should consider cogeneration. The cogeneration module for BWRX-300 is feasible to address the district heating networks and industry requirements.

## Existing nuclear cogeneration plants

According to “Opportunities for Cogeneration with Nuclear Energy” by IAEA [4], 20 nuclear power plants in the world have been constructed in cogeneration mode of operation. 16 of them produce heat for district heating networks:

* 1 in Bulgaria (WWER);
* 1 in Hungary (WWER);
* 9 in Russian Federation (RBMK or WWER or LMFR);
* 1 in Slovakia (WWER);
* 1 in Switzerland (PWR);
* 2 in Ukraine (WWER);
* 1 in Romania (HWR).

4 of them produce heat for industry:

* 1 in Canada (HWR);
* 1 in Germany (PWR);
* 1 in Switzerland (PWR);
* 1 in India (HWR).

Moreover, an existing nuclear power plant in Czech Republic in Dukovany shall supply district heating network in Brno. A 42 kilometer pipeline is planned to be built in years 2027-2031 [5] send the heat from the NPP to the DHN.

As we may observe, most of those nuclear power plants are located in Eastern European countries. There are only a few western countries and USA is not among them. What is more, none of those nuclear plants use Boiling Water Reactor (BWR) technology. It shows that BWRX-300 with the cogeneration module is the first of its kind. OSGE and GEH are looking forward to expanding the abovementioned list of nuclear cogeneration plants with the whole newly deployed fleet.

## Heat Market and Business challenges

In Poland there are 387 licensed companies which supply heat to the customers and district heating networks supply heat to 50% of population [5]. The amount of energy supplied to the district heating networks in Poland in 2020 was 257 TJ. The Polish industry consumed additional 200 TJ [5].

At the first glance at those number it seems that there are plenty of opportunities for nuclear cogeneration to be used in district heating and industry. In case of OSGE 5 out of 6 locations with Decision in Principle are planned to operate in cogeneration. However, a more detailed investigation is also needed.

First of all, almost a half of Polish district heating networks have installed capacity up to 50 MWth [5]. Whereas, estimated heating output of the BWRX-300 operating in cogeneration for district heating is about 350 MWth.

Secondly, the heat demand for district heating networks varies within a year. During a winter the demand is close to the installed capacity of existing heat sources. However, during a summer the heat demand is about 5-10% of that capacity.

Those two factors impact the potential scope of applying nuclear cogeneration for district heating while keeping the economically feasible operation. For sure, the biggest Polish cities with district heating networks are most attractive for nuclear cogeneration as they have a heat demand big enough to allow high and steady install capacity utilization.

What is more, Polish district heating networks have already installed or plan to install in near future some renewable heat sources that would need to be integrated with nuclear cogeneration in the energy mix.

Therefore, a detailed market analysis is needed in order to assess how many additional BWRX-300 with cogeneration module for district heating could be constructed in Poland. This information is crucial in order to prepare a long-term deployment strategy.

The situation seems to be simpler for the industrial application of the nuclear cogeneration. Industrial sites can have a high and steady steam demand. Building a dedicated BWRX-300 unit to supply particular factory with electricity and steam is one of OSGE’s business models that can help to decarbonize the industry. However, for such a business model there is a risk that the factory may be shut down in the future, leaving a lot of installed heat capacity without the demand for it. In such a case, it would be safe to have a backup industrial clients for heat that are located in vicinity.

Once again, a comprehensive market analysis is needed to assess the full market potential for BWRX-300 with cogeneration module for process heat.

As highlighted above, heat demand depends on localization and may vary over the years. Therefore, the implemented solution shall be flexible to cope with these challenges. Again, the cogeneration module for BWRX-300 is flexible enough to work in the pure condensing mode and in the cogeneration mode, thus this technology has been selected by OSGE for its deployment program.

However, Poland in not the only country that would benefit from nuclear cogeneration. Similar market analysis should be done in next step for other European countries.

## Technological challenges

Nuclear power plants usually work in condensing mode of operation. On Fig. 3 a diagram of condensing mode of operation is shown. In this mode of operation the temperature of the waste heat is usually around 20-30 Celsius degrees, which is not useful for supplying district heating networks neither supplying industry. Typically, district heating networks need around 120 Celsius degrees during the winter and around 90 Celsius degree during the summer, whereas, industry needs saturated or superheated steam. BWRX-300 in its original design also uses condensing turbine. Therefore, in order to apply cogeneration to BWRX-300 some design changes had to be done.



FIG. 3 Diagram of a fragment of a power plant system with a condensing turbine

Usually, the fosil-fuelled cogeneration plants use back-pressure steam turbine. The steam is not fully expanded and has higher enthalpy. The steam can be supplied to the industrial facility or used to produce hot water for district heating. Fig.4 presents this process. However, this solution requires a different turbine (back-pressure turbine instead of condensing turbine) than it is used in BWRX-300.



FIG. 4 Diagram of a fragment of a power plant system with a back-pressure turbine

The other solution, is to extract some steam from turbine extractions, add heat exchangers, and use it to supply heat to the district heating network with use of intermediate circuit, as shown on Fig. 5. The intermediate circuit is used to add a safety barrier between primary circuit and DHN / process steam circuit. This way the condensing steam turbine is kept in the design and the changes are limited to the turbine extractions and added heat exchangers. Moreover, in case of producing process heat for the industry, in order to produce saturated[[1]](#footnote-2) or superheated steam an electric boiler is needed to increase the temperature of the steam, thus decreasing the electricity sales.



FIG. 5 Diagram of a fragment of a power plant system with heat exchangers used for a production of heat for DHN or process steam

Both solutions (back-pressure turbine and steam extractions for a condensing turbine) allow to produce useful heat, however, the drawback is a thermodynamical efficiency i.e. decreased electricity production. Either the steam is not full expanded or some of the steam is drawn from the turbine, thus generating lower mechanical power by the turbine, therefore, generating less electricity. This impact has to be taken into account for the business plan of the nuclear cogeneration module development.

## Regulatory challenges

Nowadays, the biggest regulatory challenge in developing nuclear cogeneration in Poland is the current wording of the Energy Efficiency Directive of the European Union [6]. The Directive defines allowed energy mix for district heating networks that is required to follow in order to have a status of an “efficient district heating system”. This status is important for Polish district heating operators as it is required in order to connect new clients to the network. The table 1 below shows the details of criteria from the Directive. The most important criteria is that starting from year 2050 district heating networks are required to be supplied 100% from renewable energy and/or waste heat. Heat from nuclear reactor is barely mentioned in the Directive and totally omitted in the criteria. However, the European Parliament [7] and the Council of EU [8] voted to treat the nuclear energy generation equally to renewable energy generation. Therefore, the Directive should be updated to reflect this decision.

TABLE 1. EFFICIENT DISTRICT HEATING CRITERIA FOR ENERGY MIX

|  |  |  |  |
| --- | --- | --- | --- |
| Date | Renewable energy and/ or waste heat | Cogeneration only | Mix (renewable energy + waste heat + cogeneration) |
| Until 31.12.2027 | 50% | 75% | 50% |
| From 01.01.2028 | 50% | 80%\*  | 50% (min 5% renewable) |
| From 01.01.2035 | 50% | N/A | 80% (min 35% renewable or waste heat) |
| From 01.01.2040 | 75% | N/A | 95% (min 35% renewable or waste heat)  |
| From 01.01.2045 | 75% | N/A | N/A |
| From 01.01.2050 | 100% | N/A | N/A |

\*high-efficiency cogeneration (defined in details in the Directive)

## Summary

SMRs are being rapidly developed nowadays. There are multiple designs from vendors that are on different maturity level. First of a kind BWRX-300 power plant is currently being developed in Canada by Ontario Power Generation (OPG) in Darlington (vicinity of Toronto). OSGE plans to quickly follow OPG and construct next of a kind BWRX-300 power plant in Poland and later on deploy a whole fleet of them. The project in Canada aims at constructing BWRX-300 working in electric-only mode of operation, whereas, OSGE is undertaking a construction of BWRX-300 which would produce hot water for district heating and steam for the industry.

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1. As an example, the temperature of saturated steam at 12 barG is 191,66 Celsius degrees. [↑](#footnote-ref-2)