# NUWARD SMR COGENERATION SERVICES

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**Abstract**

Since the creation of the French nuclear fleet, the question of adding a cogeneration option (also known as Combined Heat and Power CHP) has arisen in connection with the different crises on the price of fossil fuels. Leveraging the direct utilization of nuclear heat for industrial applications emerges as a compelling alternative to relying on fossil fuels, showcasing superior efficiency compared to generating heat through electricity. Given Europe's current objective to decarbonize energy consumption, the CHP appears to be an interesting option for the new generation of Nuclear Power Plants (NPPs), especially for Small Modular Reactors (SMRs) and is part of NUWARD SMR features. The pressure/temperature characteristics of NUWARD SMR are suitable for supplying a range of industrial applications such as hydrogen production with high temperature electrolysis, desalination, district heating, industrial heating or direct air capture. Besides they are easier to build and can be placed close to industrial or urban areas where needs are. Depending on the specific industrial application, the steam extraction location can be adapted to find a compromise between electricity production and the required steam characteristics. Integrating the CHP options also requires design specific analyses: hazard assessments, operating impact, plot plan integration and design of new equipment such as steam transformers. These development and analyses ensure a seamless integration and operation of CHP systems, as a service provided by NUWARD SMR.

## 1. NUWARD SMR SOLUTION

NUWARD is developing a Small Modular Pressurized Water Reactor as a solution to achieve transition to a Net Zero economy. NUWARD SMR is being designed and optimized to produce low carbon electricity, offering an alternative to fossil-fired power plants. It also includes a Combined Heat and Power (CHP) feature to deliver thermal power complementary to electrical power.

A first stream of development entered a basic design phase in March 2023 during which the engineering teams were able to progress on the plant's design. They carried out in-depth studies regarding technological innovations and refined their impact in terms of time schedule and costs. At the same time, EDF had extensive discussions with potential customers, particularly owner-operators, who expressed their confidence in NUWARD and the EDF Group, and their expectations about technological innovations. This led EDF to adapt its product development strategy for SMR.

Given the changing dynamics of the SMR market and the lessons learned from the development of NUWARD SMR, EDF proactively decided in decided June 2024 to reorient its product design and focus its development on proven and existing generation 3+ technology bricks. The aim of this approach is to create better conditions for success by providing a solution fitting market needs and client expectations.

The NUWARD SMR will target electricity production and will address multipurpose applications thanks to a combined heat and power service. It is being developed with a fast and efficient build process thanks to its simple, modular and standardised design.

## 2. COMBINED HEAT AND POWER SUPPLY (CHP)

### 2.1. Heat supply decarbonisation opportunity

Complementary to electricity supply, steam produced by the nuclear reactor is an interesting heating source that can cover many uses. This ability to provide a heating supply is a response to very important thermal power needs and an efficiency lever for decarbonization.

#### *2.1.1. Heat energy needs projection*

Heat is currently the largest energy end-use, accounting for 50% of global final energy consumption in 2018 and contributing to about 40% of global carbon dioxide emissions [1]. The transition toward a net zero economy implies decarbonizing the heat supply.
Projection of EU energy needs confirms the huge heat generation needs and introduces hydrogen as an important new need (see Figure 1). Figures for hydrogen on Figure 1 are projections from REPower EU plan set in 2022 and could be revised in projection updates. Hydrogen production processes can be fully electrical or require heating means (high temperature electrolysis).

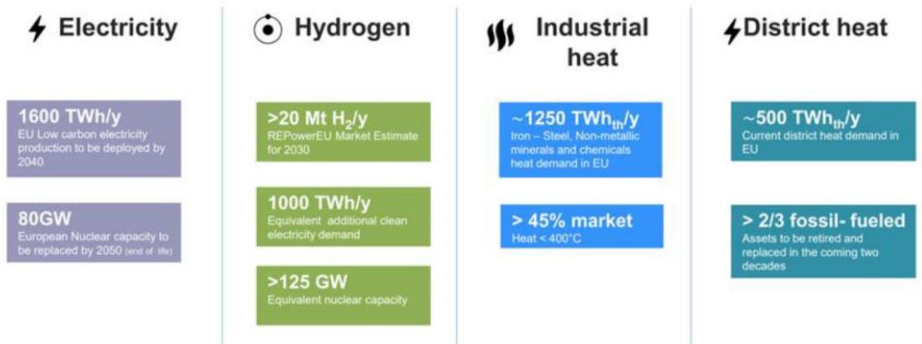


Figure 1 : EU energy market needs – source [2]

#### *2.1.2. Efficiency opportunity*

The use of steam from power plant secondary circuit for heating usages is potentially a more efficient way to use thermal power from nuclear reactors as it avoids heat conversion to electricity and energy losses associated to this thermodynamic cycle. Secondary circuit of Pressurized Water Reactor has an efficiency of about 34 to 38%. Energy that is not converted into mechanical energy in the turbine is evacuated and lost in the condenser. Thus, the use of steam for heating applications can limit this loss. The real gain highly depends on the ability of downstream customer process to extract all the energy from steam and return it at temperature and pressure conditions close to feedwater extracted from the condenser. A simplified scheme of secondary circuit is given on Figure 2. It outlines main secondary circuit pieces of equipment and potential usages (electricity generation, steam extraction and heat services). P0, P1, … $P_N$ represents the potential steam extraction points from main steam line. P0 has the maximum available pressure and temperature. P1, P2, …, $P_N$ are extraction points along turbine stages and have a gradually lower pressure. The choice of extraction points is at the core of CHP system design and adaptation of secondary circuit to cogeneration uses (see section 3).

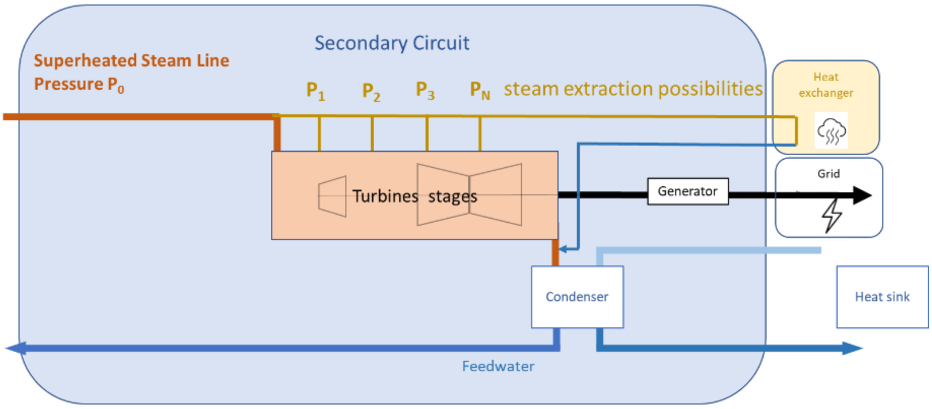

Figure 2 : Simplified scheme of secondary circuit and energy usages (electricity, heat)

## 2.2. Processes that can be addressed by NUWARD

An analysis of coupling opportunities between NUWARD SMR and electrical or heat applications has been carried out in the framework of study [4]. This study analyses the opportunities associated with the use of the energy carriers produced by NUWARD SMR on the basis of French energy transition. In this study a temperature of 250°C is taken as an input of NUWARD SMR heat exchanger supplying thermal power to customer. The different possible coupling and applications are described hereafter. The analysis below as well as study [4] are focused on physical feasibility of heat coupling. They are being completed with an economical assessment of heat services to provide a full vision on coupling opportunities. Beyond French scope of [4], studies [5] and [6] give an overview of the European global market potential for SMR for both electrical and heat applications.

### *2.2.1. Industrial heat*

Coupling opportunities in [4] are analyzed considering quantities of heat consumed, required temperatures and sustainability of the needs on a long-term basis, in consistency with NUWARD SMR lifespan.

The first output of the study is that coupling compatibility is not limited to industry with temperature needs below 250°C. Indeed, for industrial applications with very high temperatures, preheating needs are important and NUWARD SMR is a competitive solution to address them. As a complement to heat supply, thermal-electric means can ensure heating beyond 250°C. These means can be SMR-powered electrified means or hydrogen [5]. Thus energy and high temperature needs can be met thanks to both electrical and heat services provided by CHP solutions such as  NUWARD SMR.

Figure 3 illustrates such a coupling between NUWARD SMR and a ethylene steam cracker process. The ethylene cracking process operates at 1000°C, following a preheating stage. Preheating stage by NUWARD SMR could avoid the emission of 190 kt$CO_2$/year for a total ethylene production in France of approximately 400-500 ktons per year.

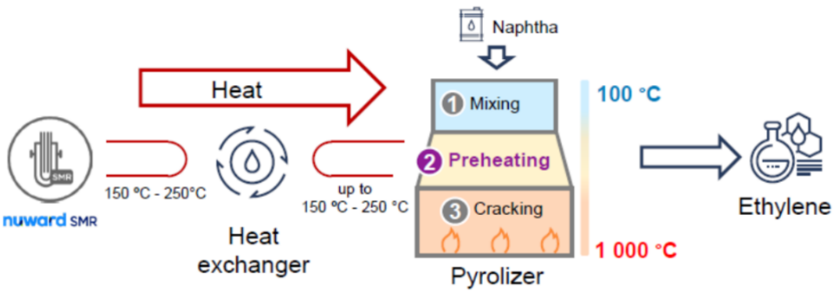

Figure 3 : Industrial pre-heating use – source [4]

The second output of the study is that industrial heat applications compatible with a NUWARD SMR represent high energy needs. Figure 4, illustrates French industry needs that would be compatible with a NUWARD SMR. It has to be underlined that there is an opportunity for industries with lower energy needs to gather into clusters and mutualize their heat power supply.

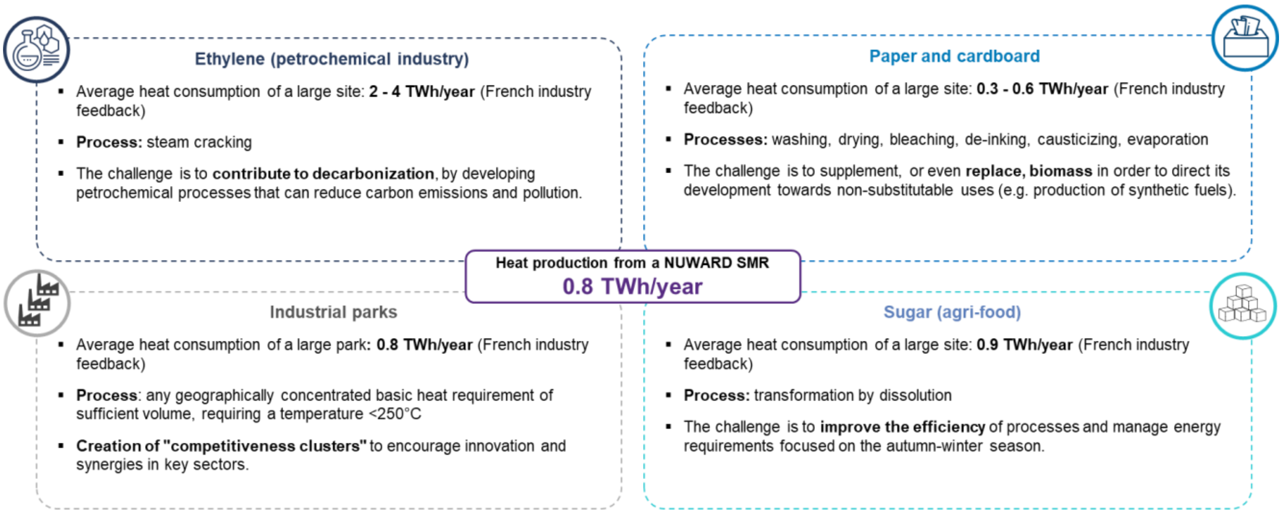


Figure 4 : Industrial heat applications that can be met by NUWARD SMR (opportunities in France) – source [4]

#### 2.2.2. *District heating*

Transition to net-zero implies a decarbonization of existing district heating networks and a higher penetration in countries with low one, such as France [4]. The temperatures are compatible with NUWARD SMR supply. The main challenges lie in the seasonality of the needs and consumption needs that can highly vary in time. This leads to very important peaks on limited durations. In this context, NUWARD SMR could be a baseload energy source for the heat network and could operate in electric-only mode in summer. Both heat and electrical supply is thus an asset to adapt to variations in consumption needs.

#### 2.2.3. *Desalination*

Adaptation to more frequent droughts due to climate change could require the development of seawater desalination capacities. Two kinds of technologies are used to desalinate water:

- Reverse osmosis.
  This is the most efficient and widespread solution. It uses only electricity as energy source.
  A pre-heating of the incoming water to around 30°C improves the process efficiency. Given the target temperature, there's an opportunity to develop cogeneration on the power plant tertiary circuit (heat sink loop of Figure 2). This enables to value residual heat, improving the overall efficiency of the combined systems: SMR and desalination process.
- Multi-stage distillation.
  This process uses heat only. It has the advantage of producing a high-quality water with a high level of reliability. Temperature needs are compatible with NUWARD SMR.

#### 2.2.4. *Hydrogen production*

Hydrogen needs are expected to grow with a projection of about 20 Mt a year in Europe by REPowerEU plan [2] [3]. There are two kinds of decarbonized ways to produce hydrogen, as an alternative to steam-reforming of methane:

- Low temperature electrolysis.
  This technology only uses electricity as energy source. A 100% electrical NUWARD SMR configuration can address this use.
- High temperature electrolysis.

This technology is developed to produce hydrogen with a greater efficiency than alkaline technology. In high temperature electrolysis incoming water is heated at about 700°C. This pre-heating improves the process energy efficiency with gain up to 30% when compared to low temperature electrolysis (alkaline, or proton exchange membrane). To cover the heating needs of this technology, a coupling with an input heat source at temperatures above 150°C is required. This need can be covered by NUWARD SMR as illustrated on Figure 5.

Document [7] describes the different processes to produce hydrogen and their level of maturity. It also highlights the potential and interest of deploying nuclear means to produce hydrogen: reliability, low carbon intensity, high-capacity factors, energy density that leads to a low land area consumption compared to other low carbon solutions.

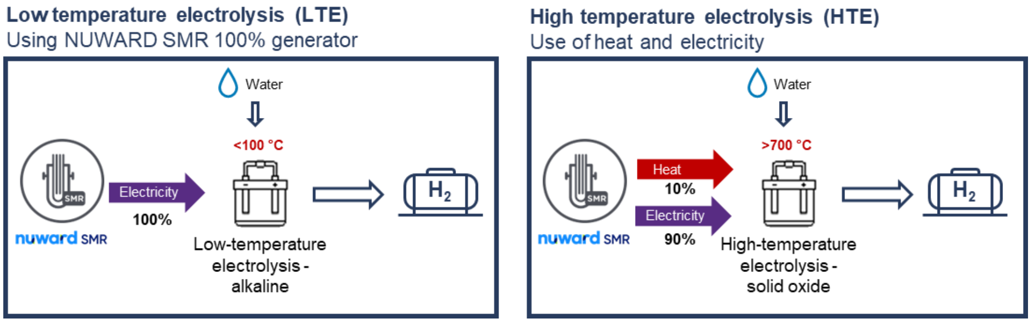


Figure 5 : Hydrogen use – source [4]

#### 2.2.5. *Direct Air Capture*

Direct air capture solutions are also a potential cogeneration application for NUWARD SMR. Direct air capture technologies are under development and their energy needs include electricity and heat at medium temperature (around 90°C).

It can also be mentioned that the production of low carbon e-fuels involves hydrogen and carbon dioxide capture. They thus have cogeneration needs described in section 2.2.4 and 2.2.5.

#### 2.2.6. *Synthesis*

The different services provided by NUWARD SMR making it a key component of an overall low-carbon energy network complementary to high nuclear power plants and renewable energies as it can supply electricity services as well as heat services.

## 3. INTEGRATION OF CHP IN NUWARD SMR DESIGN

The integration of CHP service implies dedicated design activities. These activities aim at developing the underlying technologies and systems. They also aim at fully integrating CHP feature into the design of the whole plant with the objective that the plant and CHP feature meet the targeted level of performances regarding economic optimization, plant operability and safety.

### 3.3. Design drivers

The development of NUWARD SMR CHP feature is led with the objective to address a wide range of heat applications while maintaining the high level of performance of the product. Thus, the steam extractions are developed with an attention on:

— Design standardization;

Electrical power generation is the basis of NUWARD SMR service. For standardization purpose, which is at the core of NUWARD business model, the turbine designed for a 100% electrical power configuration shall also operate in a CHP configuration. Steam extraction positions and power extraction are thus developed to be compatible with both configurations.

— Frequency regulation;
NUWARD SMR provides frequency regulation services. It can modulate its power by +/- 10% to participate in the frequency regulation of the electrical network. This service shall also be supplied in CHP configuration.

— Energy efficiency optimization.
Steam extraction impacts differently electrical efficiency of the unit depending on the extraction location. One thermal MW extracted at $P_0$ (see Figure 2) has a different impact on electrical production of the unit than at another extraction point ($P_1$, $P_2$ or $P_N$). An extraction downstream the high-pressure steam turbine stage lowers electrical power loss of about 45% compared to an extraction at $P_0$.
It is thus essential to create extraction points that make it possible to select, for every application, the extraction points that optimize thermal application and electrical production. The design of extraction is carried out in collaboration with turbine manufacturers.

### 3.4. Design specific analysis

CHP feature is based on new systems that interface NUWARD SMR secondary circuit to customer process. This interface is made through a heat exchanger, as pictured on Figure 2. This exchanger enables NUWARD SMR secondary circuit to remain a closed loop and limit interactions with customer process (water consumption, steam quality…).

The development of a CHP feature requires design activities dedicated to these new systems:

- Design of steam line extractions;
  The extraction points are designed in collaboration with turbine manufacturers. Several extraction points along turbine stages are required for the design to be able to cover a range of applications as wide as possible and limit mechanical impact on turbine components. Besides, the location of extraction points has an influence on the dynamic of the coupling between the two processes. The intensity of the coupling is studied through plant operability analysis (see below).
- Steam exchanger at the interface between NUWARD SMR and the customer process.

Besides, the additional systems can have an impact on other systems regarding process interaction, plant operability and additional safety load cases. These impacts are assessed and integrated into the whole plant design with the objective to maintain plant performance and safety.
From a safety point of view, the fact that the plant is supplying industrial activities, such as the one quoted in section 2.2, implies that risks associated to the industrial environment have to be taken into account. These industrial risks are thus to be included in external hazards safety design assessment of the plant. For instance, $H_2$ production is an application of interest and $H_2$ explosion risk has to be included into external hazard safety analysis. Such design assessment is necessary to maintain fundamental safety objectives of the plant and is a prerequisite in the development of CHP services [7].
Then these new systems have to be fully integrated into the plant operability analysis. It requires to model the systems into the plant simulator as well as the behavior of the customer process (normal operations and bounding evolutions). This is an important analysis that allows to characterize the kinetics and operation impact of heat process on NUWARD SMR operation. These kinetics and impacts are to be taken into account into the design of system regulations and, if necessary, as initial conditions for safety transients.
Eventually, the CHP feature is to be integrated into the plot plan. The challenge of this activity is to optimize the locations of heat supply systems. This location is highly dependent on available surface and location of the customer facility.

All these analyses aim at ensuring safety and plant performances are not impacted by the CHP feature.

## 4. CONCLUSION

The Small Modular Reactor NUWARD SMR is developed to address a variety of low carbon energy needs. It includes a Combined Heat and Power (CHP) feature that can deliver thermal power and electrical power.
The CHP feature delivered by NUWARD SMR makes it a flexible decarbonized energy supplier and a relevant solution to energy needs projections that combine high electrical and heat needs. The heat service is ensured by steam extractions on NUWARD SMR secondary circuit and a heat exchanger that interfaces this secondary circuit to the customer process. Heat provided by NUWARD SMR can cover a wide range of applications (industrial heat, district heating, desalination, hydrogen production, direct air capture).
The development of this feature is fully integrated into the design activities of the whole plant. It leads to the design of specific systems: extraction points on the steam line, steam exchanger. It also leads to integrate these systems into safety analysis, plant operability analysis and plot plan. These developments and analyses ensure a seamless integration and operation of CHP systems, as a service provided by NUWARD SMR.

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