NUWARD SMR's opportunities and socio-economic & environmental features

Report for

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Contents

Mandate and points of attention

Mandate

- Compass Lexecon has been mandated by EDF to **analyse the opportunities related to the development of a series of NUWARD SMRs in France,** as well as to **identify associated economic, social and environmental issues** in the context of the energy transition.

Points of attention

- This report **describes and assesses the opportunities associated with the use of the energy carriers produced by NUWARD SMR** (electricity and heat), with a particular focus on the uses of hybrid heat production.

- This report does **not explore the technical-economic aspects** of deploying a series of NUWARD SMRs in France, as the current stage of development of the project does not allow for sufficient detailed information to carry out this assessment. This report should be completed by a technical-economic study (particularly relating to the comparative costs and benefits of decarbonisation solutions) once the project has reached a sufficient degree of development.

- The analyses presented in this report are the sole responsibility of the authors and do not necessarily represent those of Compass Lexecon, its management, subsidiaries, affiliates, employees or customers (see disclaimer on slide 38).

Objectives and structure of the report

A fact-based study to inform discussions on the development of NUWARD SMR in the context of the energy transition

- Achieving carbon neutrality requires the **development of technologies** that can meet **evolving energy needs** for decades to come.
- In particular, many end users and industries are interested in **low-carbon solutions that provide sufficient energy** for their applications.
- This report focuses on the **potential contribution of the new nuclear small modular reactor technology, NUWARD SMR.**
- The report is structured in **three parts**.

Objectives and structure of the report

1. **Analysis of opportunities** related to the development of a **series of NUWARD SMRs in France**
2. **Identification of the socio-economic and environmental challenges** of NUWARD SMRs in France
3. **Conditions for success** for the development of a series of NUWARD SMRs in France

1

Introduction

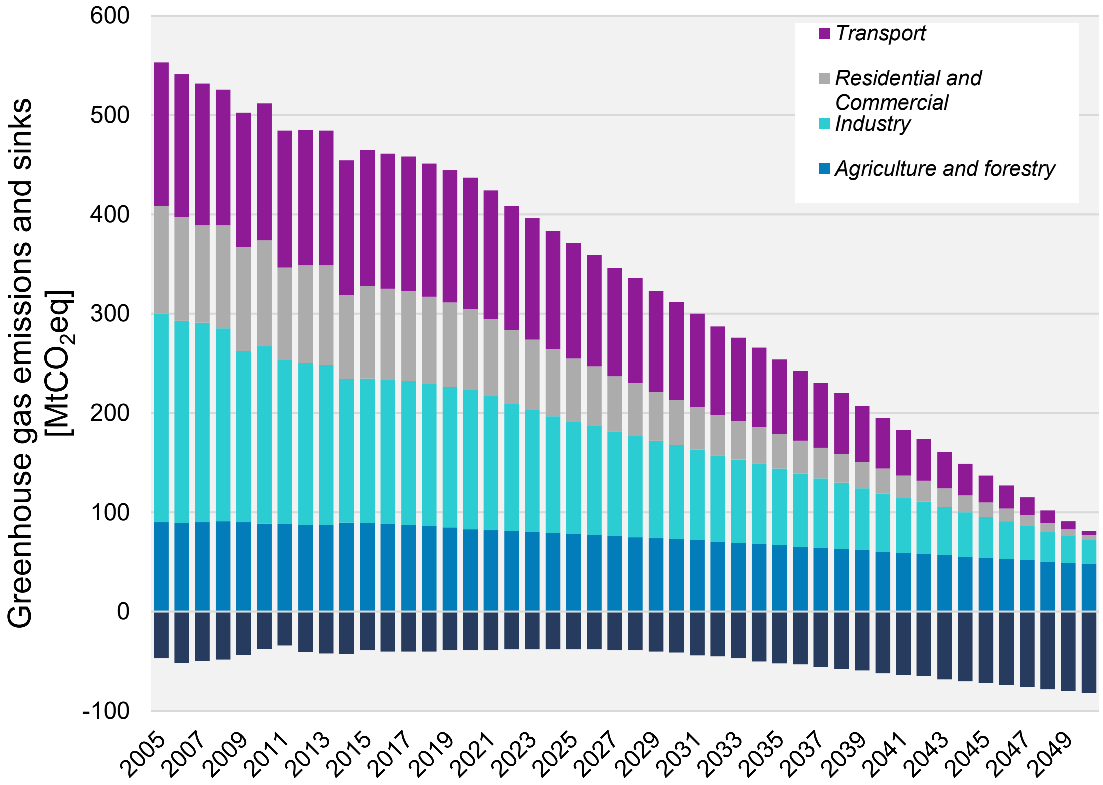
Background and presentation of NUWARD SMR

Context - A pivotal year for the French decarbonisation strategy

France's national low-carbon strategy (SNBC) will be updated in 2024

- In the wake of the Paris Agreement in 2015,[1] **France and the EU are aiming for Net Zero emissions by 2050** and have been developing a policy and regulatory framework to foster the energy transition.
- **France's decarbonisation strategy is due to be updated in 2023[3]** and will have to take account in particular the challenges associated with **energy independence,** as well as enhancing **competitiveness** and **economic / industrial sovereignty,** the necessity of which was highlighted by the Covid crisis and the war in Ukraine.
- To achieve Net Zero by 2050, we will not only need to **electrify energy usages,** but also **develop other low-carbon energy vectors such as heat and hydrogen.**
- **Different technologies** for **concurrently producing low-carbon electricity, heat and hydrogen** will be needed.

Emissions trajectories for the SNBC 2020 reference scenario, in $MtCO_2eq$[2][3]



Background - The challenges of decarbonising energy sources in France

Issues related to the development of different technologies for producing electricity, low-carbon heat and other low-carbon energy carriers such as hydrogen

Electricity generation	Heat production for industry	Heat and cooling production for buildings	H_2 Hydrogen production
The electrification of uses will require a **substantial increase in the production of low-carbon electricity,** in a complex environment due to: ▪ The challenge of **nuclear power plants' life** extension and refurbishing, ▪ Challenges linked to the expected increase in the **rate of deployment of low-carbon energies** and energy efficiency, • Growing **needs for flexibility.**	For heat-consuming industries, the decarbonization of **each process requires a case-by-case approach.** ▪ As such, the electrification of processes **needs to be considered on an industry-specific basis**. ▪ Some **industrial applications are not suited to total electrification** but will be able to rely on decarbonised heat.	Decarbonising the heating of residential and tertiary buildings will rely on: ▪ **Electrification**, and the efficiency gains made possible by **heat pumps**, ▪ **The development of district heating** and cooling, ▪ Fostering high-performance **thermal renovation.**	The **need to produce carbon-free hydrogen** will increase in the medium term, particularly for: ▪ Decarbonising **industrial processes,** ▪ The **production of e-fuels** in particular for aviation and maritime transport, ▪ Providing **flexibility and storage** for electric systems.

The decarbonisation of the economy must take place while **considering the specific needs of regions** and **under both ecological and socio-economic constraints**

Biodiversity and ecosystems	Soil artificialization	Preservation water resources	Industrial competitiveness and reindustrialisation	Preservation/ creation of jobs	Strategic independence

A range of complementary low-carbon solutions will be necessary.

Background - A new technological solution: NUWARD SMR

EDF is developing a model for a small modular reactor (SMR), which could complement other sources of low-carbon energy production from 2035 onwards

nuward SMR

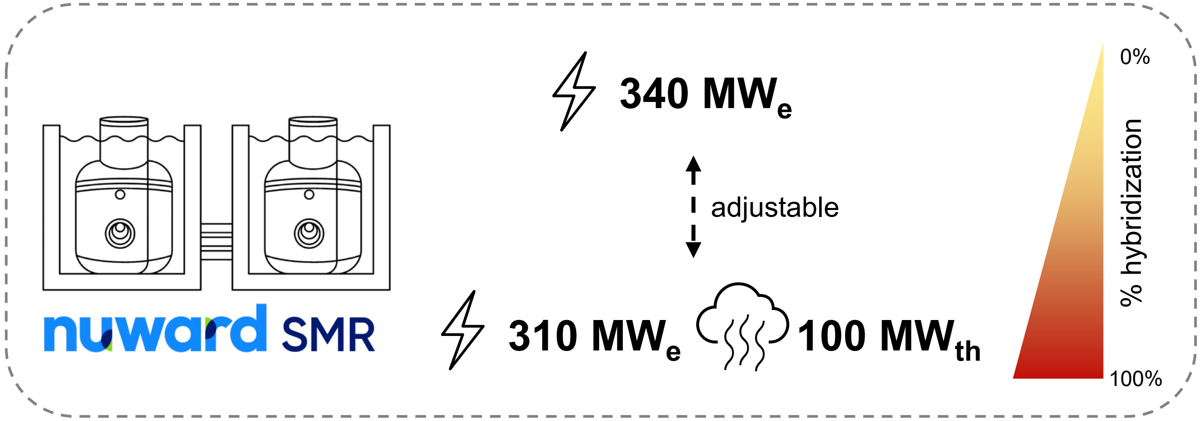
Two independent **170 MW_e** units

Generation III+ pressurized water reactor

Operational life of **60 years**

Designed to **recover up to 10% of the** thermal **energy** produced in the **form of heat**[1]

Production of heat and electricity adjustable to client's needs[2]



Main features of NUWARD SMR

- **Decarbonized energy**
- **Modular construction**
- **Hybridization option electricity and heat**
- **Controllable and flexible unit**
- **Limited land usage**
- **Reactor design with passive safety**

[1] Based on EDF's assumption of 90% availability, annual production of 0.8 TWh of heat and 2.4 TWh of electricity in 100% hybrid operation or 2.7 TWh of electricity in 100% electrical operation.
[2] Hybrid operation with a single unit is also possible, producing 50 MW of heat and providing close to 100% availability.
Sources: EDF data

One-page infographic - Presentation of NUWARD SMR

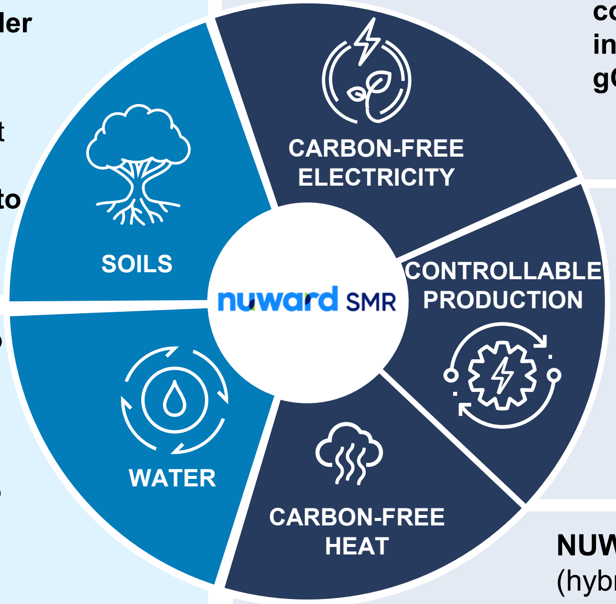
According to EDF, NUWARD SMR will target a high energy density

- The area taken to energy produced ratio of NUWARD SMR will be the **same order of magnitude as that of a large-scale nuclear power plant.** [1]
- This is likely to encourage development on former thermal sites or near energy-intensive industrial sites, **contributing to limited use of land**.

A design that promotes resilience to water constraints

- According to EDF, NUWARD SMR's water consumption, in relation to the energy produced, will be **comparable to that of a large-scale nuclear plant.**
- Because of its size, **NUWARD SMR will require water consumption of around 0.2 m^3/s,**[1] which could allow for flexibility in the selection of site location and resilience during dry periods.

Possibility of open-circuit cooling, adapted to siting NUWARD SMR by the sea or in rivers with suitable flow rates[1]



NUWARD SMR will produce low-carbon electricity

According to EDF, **NUWARD SMR** will have **a carbon intensity comparable to that of the nuclear industry** as a whole, between **4-6 gCO_2eq per kWh_e** produced.[1][2]

According to EDF, **the simplified design and modularization** should help **speed up construction work** and contribute to controlling costs and emissions over the life cycle of NUWARD SMR.[1]

Controllable and flexible electricity generation

- Achieving carbon neutrality by 2050 requires **the penetration of decarbonized energies** such as nuclear and renewable energies.
- With load ramp-up and ramp-down capabilities, comparable to those of the EPR2,[1] **the flexibility of NUWARD SMRs** could also contribute to the integration of intermittent renewable energies.

NUWARD SMR will be able to supply decarbonized heat in addition to electricity (hybridization), at around a quarter of the cost of electricity according to EDF.

PROPERTIES OF HYBRID HEAT[1]

- Temperature: **between 150-250°C**
- Heating capacity: up to **100 MW_{th}**

POSSIBLE USES FOR HEAT

- Industrial applications
- Heating
- Production of H_2
- Desalination

The efficiency of these last two uses could be improved by hybridization.

The water in the cooling circuit, with a flow rate of around **0.3 m^3/s,** contains **residual heat that could be recovered** for low-temperature heating purposes.[1]

Environmental impact | Product characteristics

RE: renewable energies
Sources: [1] EDF data [2] ADEME

2

Market and opportunity analysis

A series of NUWARD SMRs in France could contribute to the energy transition by producing low-carbon electricity and heat

Introduction: Methodology

We explore the challenges related to opportunities for heat and electricity (including coupled opportunities) and illustrate the most promising uses through examples of potential NUWARD SMR applications

Energy vectors | *Opportunity analysis* | *Examples of potential applications*

Heat

Context and perspectives

Electricity

Hydrogen production

Desalination

Opportunity 1

Opportunity 2

Opportunity 3

Potential application of nuward SMR

Methodological approach

For each energy carrier, we describe the **context and outlook,** and explore the challenges associated with **each of the key opportunities** for each energy carrier produced by NUWARD SMR.

Given the particular interest in the coupled use of electricity and heat for **hydrogen and desalination**, we explore these opportunities individually.

To illustrate certain opportunities in concrete terms, we present **examples of potential applications** for NUWARD SMR.

Electricity - Challenges of decarbonising the electricity system

France is meant to increase further its electricity demand and step up its decarbonisation efforts during the next decades. This requires the development of new low-carbon electricity production capacity, of which a part should be controllable

Increasing electricity consumption to decarbonize energy uses requires the deployment of new low-carbon production capacity

- France has set a target of **Net Zero emissions by 2050.**[1] Achieving this goal will require not only efforts in terms of energy efficiency and sobriety, but also the electrification of uses and processes.
- The increase in electricity consumption will require **a swift development in low-carbon electricity production capacity.** However, uncertainties remain as to the achievable pace of deployment.[2]
- In this context, **a wide range of solutions are needed**: SMRs can complement renewable energies and large-scale nuclear power, helping to **diversify sources of** low-carbon energy and **securing energy supplies**.
- This section focuses on **some of the key issues** associated with the decarbonisation of the electricity system, presented on the right.

Key issues for electricity system decarbonisation

1. Development of **clean electricity production capacity** and **integration** of variable renewable energies
2. **Congestion and network constraints**
3. **Land use and project acceptability**
4. **Resilience to water stress in a context of climate change**

Sources: [1] Paris Agreements, [2] RTE, Energy Futures 2050

Electricity - The challenge of controllability to support renewable energies

NUWARD SMR could complement other sources of low carbon electricity and help with the management of network constraints

1 Complementarity with variable renewable sources of electricity

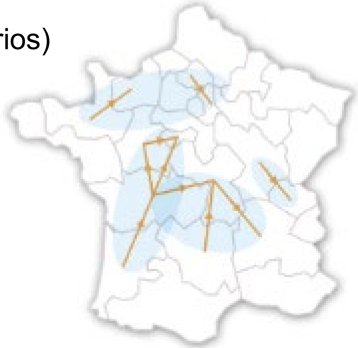
- The **load ramp-up and ramp-down capacities** (5% of rated power/min)[1] targeted by EDF for NUWARD SMR will be comparable to those of large and medium-scale reactors.
- As a result, NUWARD SMR will be **compatible and complement the strong deployment of renewable energies** on the grid, which will be necessary to achieve carbon neutrality.
- NUWARD SMR would complement the EPR2 and other controllable sources by **diversifying the range of controllable low carbon technologies available**.

2 Contribution to managing network constraints

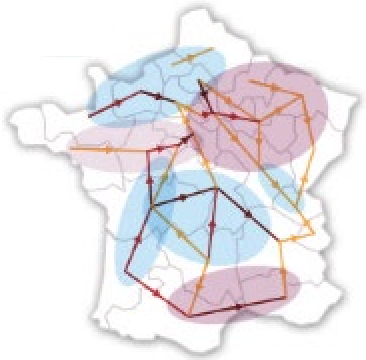
- RTE's *Energy Futures 2050* scenarios[2] show that **structural constraints on the** transmission network are likely to emerge by 2050.
- The size of NUWARD SMR will open up a broad range **of possible locations**.
- Siting NUWARD SMR in appropriate locations, coupled with the plant operational flexibility, could help to **alleviate network constraints**.

Estimation of structural constraints on the transmission network in 2035 and 2050[2]

2035 (all scenarios)



2050



RE + nuclear scenario (N02)

Annual overload frequency: Moderate Average Strong

Electricity - Issues of grid integration and land use

According to EDF, NUWARD SMR will require limited water consumption and could be installed on existing industrial sites

3 Possibility of reusing industrial sites, contributing to a limited use of land

- The reuse of former sites would **contribute to the limited use of land** and facilitate access to the necessary resources (water, transport infrastructure, network connections).
- It could also **facilitate the acceptability** of projects locally.

4 Resilience to water stress in a context of climate change

- According to EDF, the NUWARD SMR plants will require **limited net water consumption** requirements (through evaporation) **of around 0.2 m³/s,** withdrawing around 0.5 m³/s and returning 0.3 m³/s to the watercourse.[1]
- NUWARD SMR will thus benefit from a degree of **flexibility in terms of location** to adapt to water resource constraints.
- Its features could contribute to the **resiliency of water resources** in a context of climate change.

Estimating variations in river flows by 2046-2065[2]

Variation in mean flow between 1961-1990 and 2046-2065

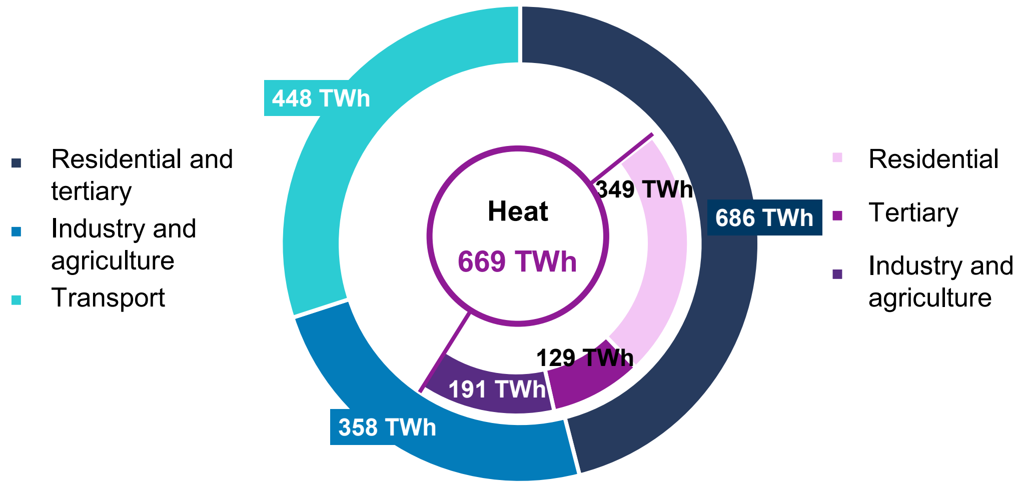
+10% | 0% | -10% | -20% | -30% | -40% | -50%

Sources: [1] EDF data, [2] Veolia and Explore 2070 project

Heat - Challenges of decarbonisation

In 2020, almost 45% of the final energy consumed in France went to heating, of which almost 60% is still to be decarbonized

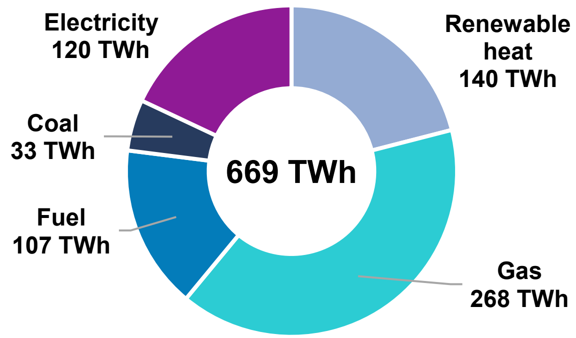
Share of uses in final energy consumption in France in 2020, in TWh[1]



45% of final energy is consumed as heat in France

- In 2020, final energy consumption in France is of **1 492 TWh**, of which **45% of heat, i.e., 669 TWh,** considering all sectors (residential, tertiary, industrial and agricultural).
- Heating for residential and tertiary buildings account for 478 TWh in 2020.[1]

Breakdown of heat sources in France in 2020, in TWh[1]



60% of the heat consumed in France is produced from fossil fuels

Sources: [1] Compass Lexecon analysis based on Carbone4. Renewable heat includes solar, geothermal, heat pumps, biomass (including household wood consumption), UVE (Unité de Valorisation Énergétique, unit for measuring the energy produced by waste incineration), biogas and biofuels excluding transport.

Industrial heat - Decarbonized heat can complement electrification

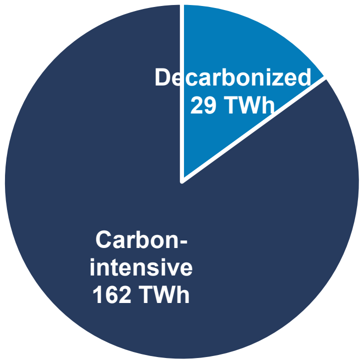
To date, around 85% of industrial heating needs are covered by carbon-intensive sources. Going forward, decarbonised heat could complement electrification efforts

In 2020, industrial processes mainly used carbon-intensive heat

- **In 2020**, only **15% of the 191 TWh of heat** consumed by industry was decarbonized.
- **By 2030**, **up to 45% of industrial heat** could be **decarbonized.**[1]

Final heat production in French industries in 2020 by type of source, in TWh[2]

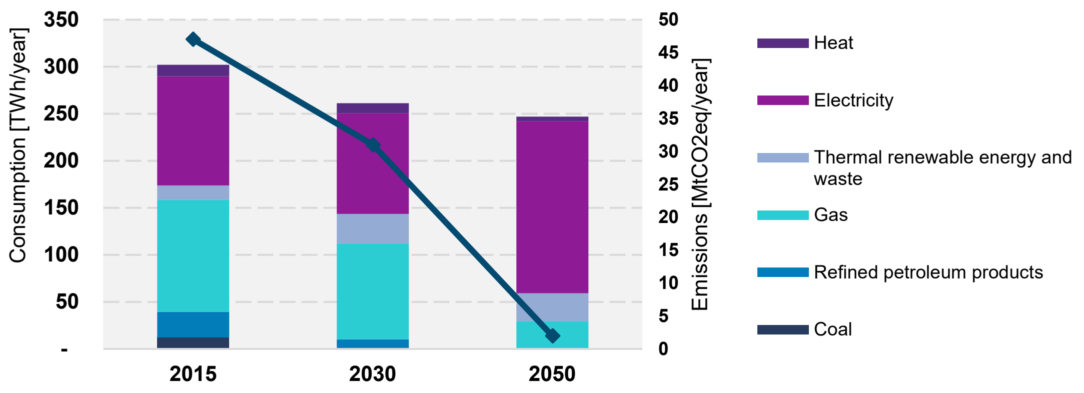
Industrial heat
191 TWh



By 2050, while the SNBC is focusing on electrification, decarbonised heat can complement these efforts for specific industrial applications, with gains in energy efficiency

- **Electrification is at the heart of the current decarbonization strategy.** The SNBC favors decarbonization through electrification, with a limited role for decarbonized heat.
- However, decarbonized heat could make a significant contribution to the energy transition.

Energy consumption and GHG emissions in industry in 2015, 2030 and 2050, in TWh and $MtCO_2eq$ per year[7]



[1] CL estimate based on the SNBC reference scenario and assuming a constant need for industrial heat compared with 2020 (economic growth offset by gains in energy efficiency).
[2] Volume of industrial heat from [3], carbon content calculated from [4], [5] and carbon content of electricity in France from [6].
Sources: [3] Carbone4 [4] Bilan énergétique 2020, MTE , [5] INSEE [6] Bilan électrique 2020, RTE [7] Stratégie Nationale Bas Carbone (SNBC)

Industrial heat - Sectors whose needs are compatible with the SMR (1/2)

The chemical, paper and food industries offer opportunities for the heat produced by the hybridisation of NUWARD SMR, given the quantities of heat consumed, the temperatures required and the long-term heat needs in these sectors

Features of NUWARD SMR[1]	Heat production of a NUWARD SMR **0.8 TWh_{th} per year**	Temperature of heat produced by NUWARD SMR **150-250°C**	Operational life of NUWARD SMR series **2035-2105**
Screening criteria	**Heat consumption**	**Temperature requirements**	**Continuity of needs of industrial heat**

Heat consumption

- **Chemicals and petrochemicals:** 1st steam and natural gas demand in 2020 (12 - 34 TWh)[2]
- **Agri-food:** 2nd natural gas demand in 2020 (around 26 TWh)[2]
- **Glass:** 3rd natural gas demand in 2020 (17 TWh)[2]
- **Paper:** 2nd steam demand in 2020 (11-17 TWh heat)[2][3]
- **Metallurgy:** 4th steam demand in 2020 (12 TWh)[2]

Temperature requirements

- **Chemical and petrochemical:** <250°C, used for chemical processes[4]
- **Paper:** <250°C, used for drying, bleaching, de-inking, etc.[4]
- **Food industry:** <250°C, used for dissolving, pasteurizing, cooking, etc.[4]

Continuity of needs of industrial heat

- **Chemicals and petrochemicals:** outlook for moderate growth (+1.6%/year between 2019 and 2030)[5]
- **Paper:** moderate growth outlook (+ 1.8%/year between 2021-2030)[3]
- **Sugar:** stable outlook (+0.3%/year between 2020-2030)[6]

Sources: [1] Source EDF [2] Insee [3] COPACEL [4] ECEEE [5] CEFIC [6] OECD/FAO

Industrial heat - Sectors with needs compatible with SMR (2/2)

Three key industries have individual sites with heat requirements that are compatible with the annual output of a NUWARD SMR, with industrial clusters also offering complementary opportunities to be explored

Ethylene (petrochemical industry)

- Average heat consumption of a large site: **2 - 4 TWh/year**[1]
- **Process:** steam cracking
- Demand is expected to remain stable up to 2030.[2]
- The challenge is to **contribute to decarbonization**, by developing petrochemical processes that can reduce carbon emissions and pollution.

Paper and cardboard

- Average heat consumption of a large site: **0.3 - 0.6 TWh/year**
- **Processes:** washing, drying, bleaching, de-inking, causticizing, evaporation
- **Estimated stable heat demand** by 2030 (around 26 TWh/year).[3]
- The challenge is to supplement, or even **replace, biomass** in order to direct its development towards non-substitutable uses (e.g. production of synthetic fuels).

Heat production from a NUWARD SMR

0.8 TWh/year

Industrial parks

- Average heat consumption of a large park**: 0.8 TWh/year**
- **Process**: any geographically concentrated basic heat requirement of sufficient volume, requiring a temperature <250°C
- **Creation of "competitiveness clusters"** to encourage innovation and synergies in key sectors.

Sugar (agri-food)

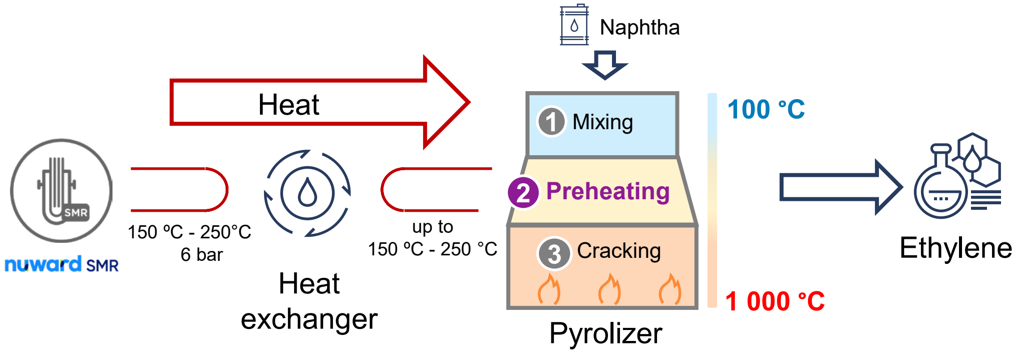
- Average heat consumption of a large site: **0.9 TWh/year**[4]
- **Process:** transformation by dissolution
- **Heat demand estimated to be stable** between now and 2030 at around 7 TWh/year.[2]
- The challenge is to **improve the efficiency** of processes and manage energy requirements focused on the autumn-winter season.

Sources: [1] Compass Lexecon analysis based on L'Elementarium and MTE [2] RTE [3] COPACEL [4] Compass Lexecon analysis based on Cristal Union, SNFS, Bodija, Y. et. al.

Industrial heat - Example of potential application for nuward SMR

Using the heat generated by a NUWARD SMR plant to preheat a steam cracker used to produce ethylene would avoid the emission of around 190 ktCO_2/year

Simplified diagram of the hybridisation of a NUWARD SMR to feed the pyrolysis of an ethylene steam cracker[1]



Dimensions of the steam cracker pyroliser and calculation of avoided emissions[2]

	Levels	Comments
Annual consumption	3 TWh_{th}/year	Corresponding to a production of approximately 400-500 ktonnes per year of ethylene
Current carbon content	100% gas	Methane emanating from the naphtha used to sustain combustion
CO2 emissions avoided with a NUWARD SMR[2]	188 ktCO_2/year	Carbon intensity of 240 gCO_2/kWh_{th}[3] for gas compared to 1-2 gCO_2/kWh_{th} for heat produced by NUWARD SMR

Industry opportunities for NUWARD SMR

- NUWARD SMR could supply **base load** heat **to a large site or industrial park.**
- It would be **particularly suitable in a context of decarbonization of industries,** for certain energy-intensive thermal uses.

Points of attention for hybridisation with industrial applications

- If the load needs to be reduced (e.g. to balance electricity supply and demand), the **heat supplied by the SMR could be supplemented by** thermoelectric means.
- NUWARD SMR could supply heat up to 250ºC and use decarbonized electricity to **supplement thermal requirements up to cracking temperature**, by means of resistors (or heat pumps in the future).

[1] The steam cracker requires other high-temperature heat sources which are not shown in the diagram.
[2] Methodology: sizing of the steam cracker according to [4] so that it can absorb at all times all the heat production capacity in the temperature range accessible to NUWARD SMR (assumption of base production profile), then calculation of the replacement of an equivalent quantity of energy produced with gas using the carbon intensities of [3].
Sources: [3] ADEME [4] Properties of hydrocarbons

District heating - Growing demand for low-carbon heat by 2050

By 2050, 35 TWh/year of low-carbon heat would be needed to supplement the needs identified by the PPE, assuming a growing development of district heating

Today

In 2020, urban networks will supply **6% of residential and tertiary heating in France,** or 30 TWh.[1]

In urban networks, **38% of the total** remain to be decarbonized (11 TWh).

2028 - PPE objectives

- **10% penetration of district heating**
- -1.15%/year heating requirement 2020-28

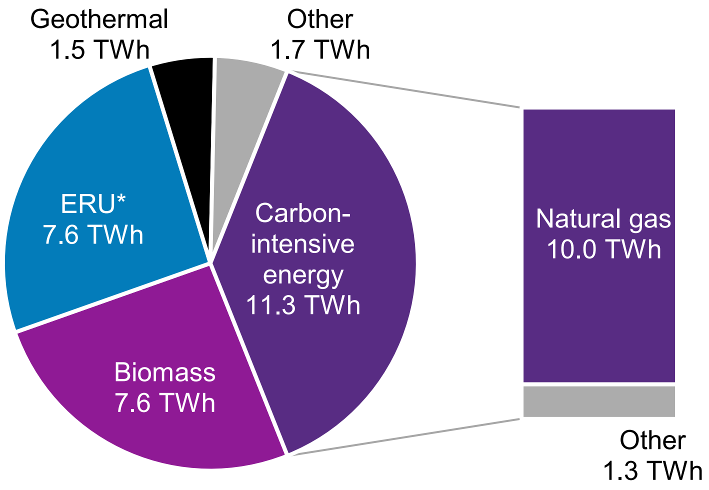
→ **Between 31 and 36 TWh/year** of decarbonized heat delivered

2050 - Compass Lexecon scenario

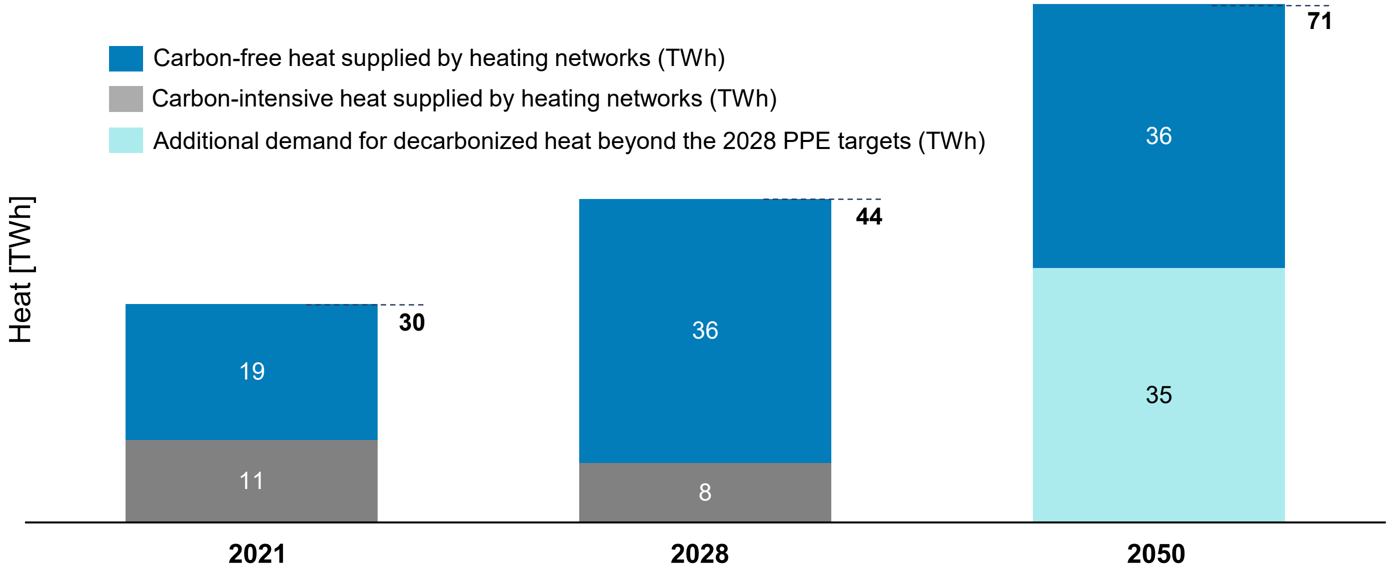
- **20% penetration of district heating** (x2)
- -1%/year heating requirement 2028-50

→ **+35 TWh/year** of decarbonized heat beyond the PPE targets for 2028**

Energy mix of French heating networks in 2020, in TWh[1]



Estimated growth in heating networks and decarbonized heating needs by 2050 based on ADEME scenarios, in TWh**



** ERU: Energy Recovery Units, considered here as decarbonized. ** Methodology: Compass Lexecon assumption of a 1%/year decrease in heating demand, based on the trend [2] and an increase in the penetration of district heating to 20% of residential and tertiary demand by 2050. This CL assumption corresponds to a conservative increase in the penetration rate of district heating (from around 13% in 2028 according to the figures in the PPE to 20% in 2050). The total need for heat delivered to the networks is established at 71TWh in 2050, which is the average value between the 'Regulatory' and 'Alternative' ADEME scenarios, which forecast an acceleration in the deployment of district heating (see ADEME, Figure 15).*

Source: [1] FEDENE, [2] Residential energy consumption by use, 1990 to 2021, SDES

District heating - SMR would be suitable for large-scale networks

NUWARD SMRs could contribute to the decarbonization of certain district heating networks with needs of the same order of magnitude as the heat production capacity of a NUWARD SMR

Criteria for screening district heating networks suitable for NUWARD SMR production

Large network and/or planned expansion

- NUWARD SMR's level of production will be **particularly well suited to large-scale district heating networks**, maximizing the value of the low-carbon heat produced by the plant.
- A NUWARD SMR **could supply several district heating networks in nearby towns,** through boiler plants close enough to the SMR.

High proportion of carbon sources

- Achieving the decarbonization targets for district heating networks implies a **need for decarbonized production**, for those networks still largely powered by fossil fuels.
- NUWARD SMR will be able to **contribute to efforts to replace fossil fuels** in district heating from 2035.

NUWARD SMR heat production during the heating period[1]

440 GWh_{th} in 6 months

(equivalent to the heating needs of 110 to 150 thousand inhabitants)

Limited geothermal potential nearby

- The production profile and low-carbon nature of geothermal energy make it a **suitable energy source for supplying district heating**, provided it is available locally.[2]
- NUWARD SMR would be **suitable for areas with no identified geothermal potential** and would complement geothermal energy where the potential is not sufficient to cover needs.

Opportunities for industrial heat recovery

- **Synergies within the local industrial cluster** can be a source of **heat recovery from a NUWARD SMR** in smaller district heating networks.
- As demand for district heating is seasonal, the use of hybrid heat by industrial consumers would enable the **heat produced by NUWARD SMR to be used throughout the year.**

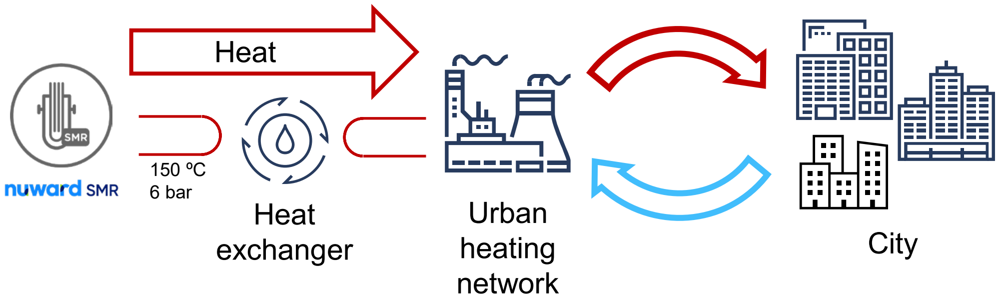
Note: As shutdowns of SMR plants are traditionally scheduled outside the building's heating periods, we have assumed 100% availability over 6 months. Availability for process heat, calculated over the year, takes into account shutdowns for maintenance.

Source: [1] ADEME; SDES [2] Compass Lexecon analysis based on Bureau de Recherches Géologiques et Minières

District heating - Example of potential application for nuward SMR

A NUWARD SMR would produce 440 GWh_{th} over the heating period, which would correspond to almost three quarters of the heating needs of a district heating network supplying 150 000 to 200 000 inhabitants.

Diagram of the hybridisation of a NUWARD SMR to supply a district heating network[1]



Main characteristics of a suitable heating network[2]

	Levels	Comments
Annual consumption	600 GWh_{th}/y	Coverage of 15-20% of the population of a city of one million inhabitants
Carbon content	75% Gas	
CO2 emissions avoided with a NUWARD SMR[2]	104 $ktCO_2$/y	Avoids 440 GWh of gas consumption feeding a boiler with a carbon intensity of 240 gCO_2/kWh_{th}[3]

Coupling opportunities

- NUWARD SMR could be the **baseload energy source for a large-scale heating network,** extending/replacing existing resources and adapted to sites with no geothermal or renewable potential.
- In summer, NUWARD SMR could **power cooling production** or operate in electric-only mode.

Points of attention for hybridization in heating networks

- NUWARD SMR can be **supplemented by thermal peak load sources** to meet consumption peaks during periods of intense cold.
- The 4th generation of heating networks[4] will see a **drop in operating temperatures, broadening the range of possible solutions**, including NUWARD SMR.

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[1] Other possible sources of heat are not shown in the diagram.
[2] Methodology: Assumption of operation of the heating network from October to March, substitution of the energy produced by combustion of natural gas with heat by hybridisation of a NUWARD SMR.
Sources: [3] ADEME [4] CEREMA

Desalination - The challenges on water resources for 2050

By 2050, adapting to more frequent droughts in France could require seawater desalination capacity

Several challenges relating to the sustainable use of water have already been identified in the South of France

- France has **large theoretical water reserves** but is dependent on rainfall to replenish its aquifers.[1]
- By 2050, **adapting to climate change could require seawater desalination capacity**. For example, according to studies on the hydrology of the Garonne and Rhône rivers, water stress is set to increase between now and 2050.[2][3]
- **Desalination can contribute to resilience during water stress situations**, contributing to securing drinking water supplies.[5]
- However, desalination plants **are not exempt from environmental impacts,** in particular with the issue of treating the brine produced by desalination.

Climate change exacerbates droughts[4]

Increase in the number of droughts per decade over the period 2041-70, compared with the period 1981-2010

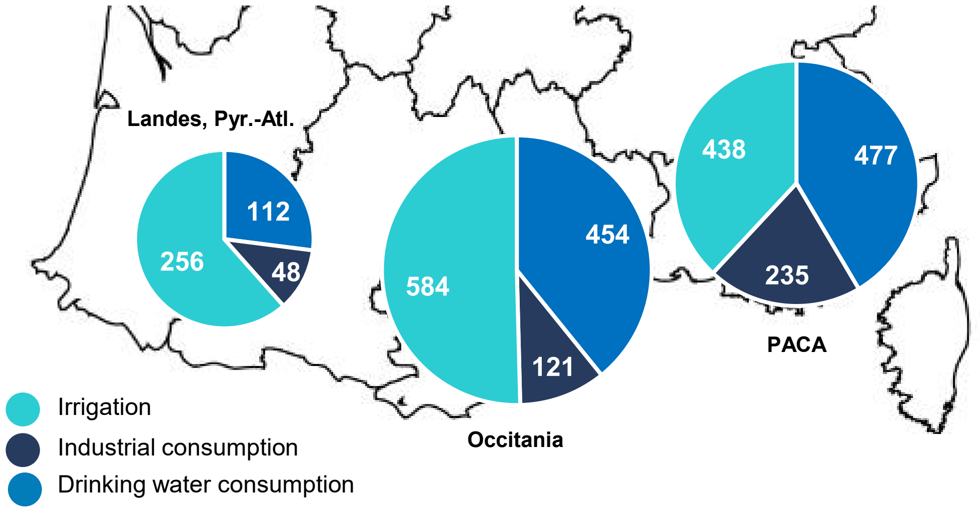
- Droughts **could become more frequent in the** decades to come, which is likely to contribute to increasing water stress in the regions.
- For metropolitan France, this increase will probably be more marked in certain parts of the South.

Sources: [1] AFP, [2] Agence de l'eau Adour-Garonne [3] BRL ingénierie, [4] European Environment Agency [5] International Atomic Energy Agency (IAEA)

Desalination - Example of potential application for nuward SMR

Coupling NUWARD SMR with a desalination plant would make it possible to produce drinking water

Water consumption in the south of France in 2020, in million m³/year [1]



The hybridization of NUWARD SMR with a desalination plant could help to increase the security of drinking water supply

- **By 2050,** the Adour-Garonne Agency predicts that the **volume of water consumed** in the south of France will increase by around 8%, mainly as a result of increased irrigation needs due to climate change,[2] while river flows could decrease.
- In this context, desalination can provide an **insurance value to the drinking water supply** by reducing the pressure on low-water flows,* in addition to the adaptation efforts implemented by public authorities.
- According to EDF, NUWARD SMR would display an adequate size to **supply electricity and heat to the desalination industry**, which can require significant amounts of energy. In addition, NUWARD SMR can operate in an **open circuit using seawater as a cooling source,** with minor adaptations.

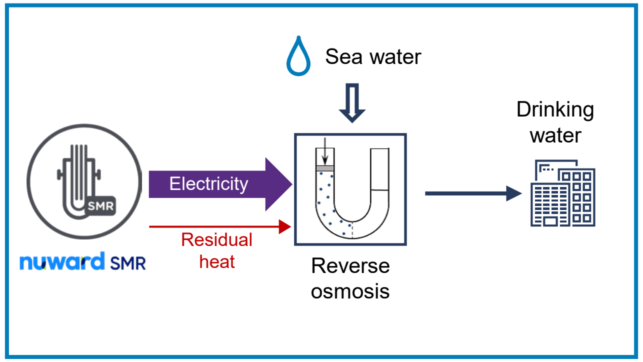
** Value below which the river decreases for a maximum of 10 days a year, used to assess the minimum flow of a river.*
Sources: [1] Eaufrance [2] Adour-Garonne Water Agency

Desalination - Example of potential application for nuward SMR

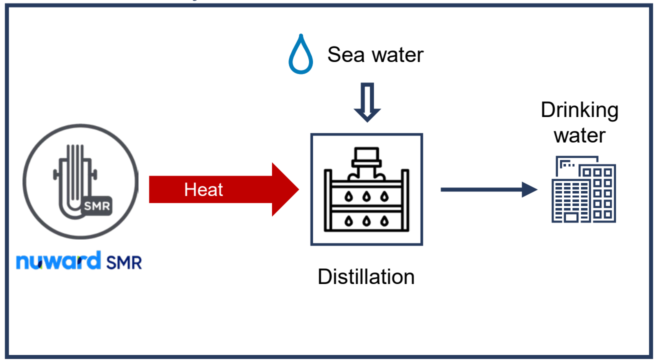
10% of the energy produced by a NUWARD SMR in the form of heat supplied to a distillation plant would cover the annual drinking water consumption of around 180 000 citizens

Diagram of possible combinations of NUWARD SMR with desalination plants

Reverse osmosis
Use of electricity and residual heat



Multi-stage distillation (MSF)
Use of heat only



Sizing of the desalination plant*

10% of a NUWARD SMR
(100 MW_{th} ≈ 25 MW_e)
of hybrid heat
in MSF distillation

→ **10 Mm^3/year** drinking water

→ Drinking water for **around 180 000 inhabitants**

Reverse osmosis, **4.3 MW_e** of electricity required for the same volume

Coupling opportunities

- Reverse osmosis efficiency is improved by preheating the incoming water to around 30°C. **Waste heat from the NUWARD SMR cooling circuit** could be used for this function, **improving process efficiency** by up to 20%.[3]
- Distillation is renowned for its robustness and the quality of the water produced, while **reverse osmosis is more efficient.**

Points of attention for hybridization with desalination

- **Reverse osmosis requires occasional shutdowns to clean** the membranes used to filter the salt from the water.
- The sizing of desalination plants depends on **projected demand, losses in the network** and **environmental constraints,** particularly with regard to brine treatment.

** Methodology: estimate based on conservative figures for reverse osmosis and distillation efficiency [1] and [2], distillation mechanical energy consumption not included in the sizing (taken from the electrical energy produced by NUWARD SMR). For reverse osmosis, an efficiency factor is applied to take account of water temperature as per [3], brine treatment taken into account as per [4]. Equivalent consumption of drinking water by residents according to [5].*
Sources: [1] Kim et al, [2] Shahzad et al, [3] Al-Mutaz et al, [4] Navarro et al, [5] EauFrance

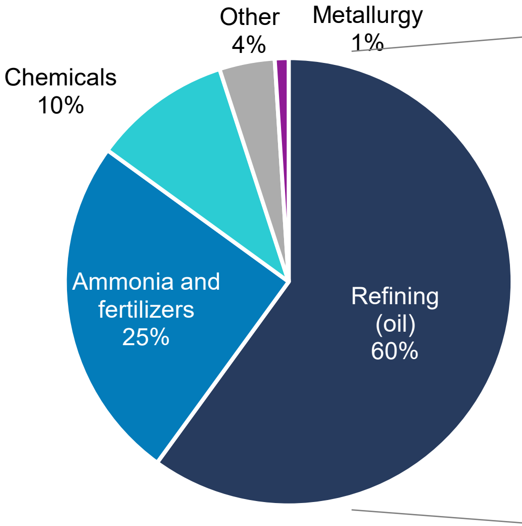
Hydrogen - Challenges of developing decarbonised H_2 production

In 2020, 95% of the H_2 consumed in France was produced from fossil sources. RTE anticipates a 50% increase in demand between now and 2050, which will require the deployment of new decarbonised H_2 production capacity

Developing the production of carbon-free hydrogen is a key challenge for the energy transition

- The French **industrial hydrogen** market is **around 1 million tonnes*** a year.[1]
- Today, the main **energy sources used to produce hydrogen in France are fossil fuels,** in particular natural gas, which accounts for almost 95% of hydrogen production.[1]
- In 2020, hydrogen production was responsible for 11.5 Mt of CO_2 emissions in France, or around **3% of national emissions**.[1]
- In its reference scenario, based on the SNBC trajectories, RTE expects **hydrogen consumption to grow by around 50% between** now and 2050, compared with 2020.[2]

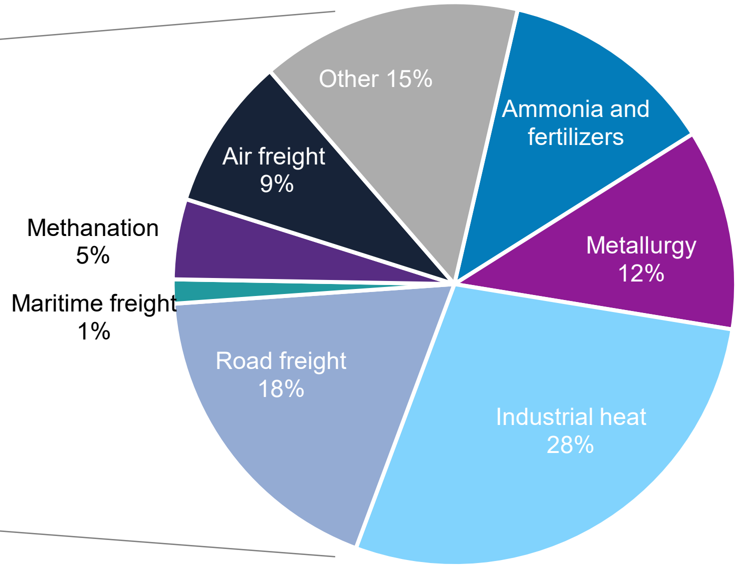
Breakdown of H_2 consumption in France by use in 2020[3]



H_2 consumption in France in 2020

29 TWh

Breakdown of consumption in 2050 according to RTE's Reference scenario[2]



Estimated H_2 consumption in 2050[2]

43 TWh

[1 million tonnes H2 ~ 33 TWh in net calorific value (NCV).
Sources: [1] MTE [2] RTE [3] RTE

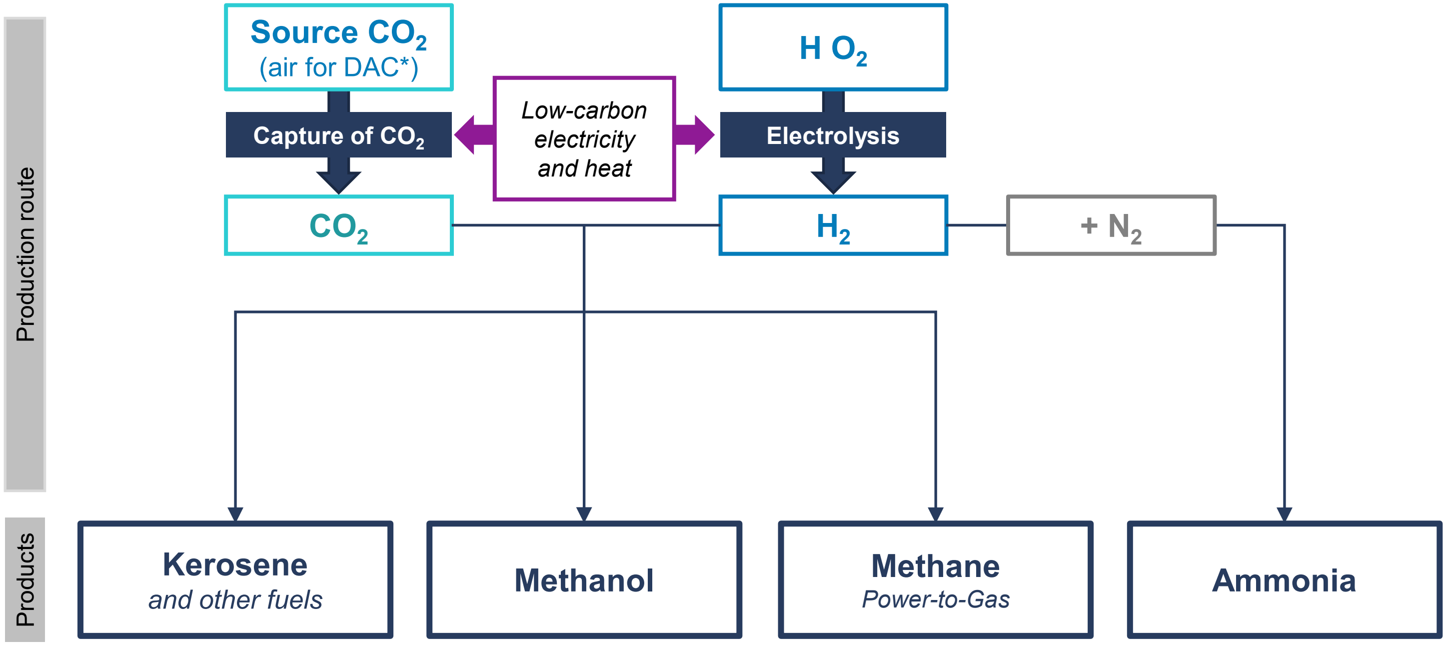
Hydrogen - Issues related to the production of e-Fuels

The production of H_2 and the capture of CO_2 are necessary to produce low-carbon e-Fuels (synthetic fuels) and require both electricity and decarbonised heat

E-Fuels can help reduce carbon emissions from transport energy needs that are difficult to electrify

- To date, certain modes of transport, particularly aviation, have few technological alternatives to fossil fuels. Given the imperative of the energy transition, **e-Fuels,** produced with decarbonized and/or renewable inputs**, could be decisive in decarbonizing certain sectors**[2] (particularly the aviation sector).
- The production of inputs for these e-Fuels, through CO_2 capture and electrolysis, will require not only decarbonized electricity but also **decarbonised heat sources, such as NUWARD SMR.**
- **Coupling electrolysis with the direct air capture of CO2** (using low-carbon energy sources) would theoretically make it possible to **close the carbon cycle**.*

Main chemical processes for synthesizing fuels from CO_2 , H_2 and N_2[1]



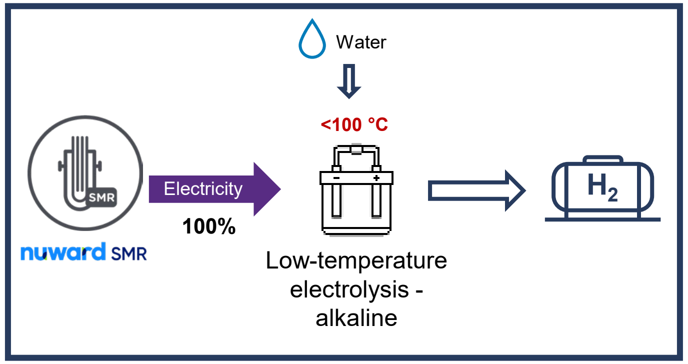
* DAC: Direct Air Capture, direct capture of CO_2 from the air.
Sources: [1] IFPEN [2] IEA; HIF Global

Hydrogen - Example of potential application for nuward SMR

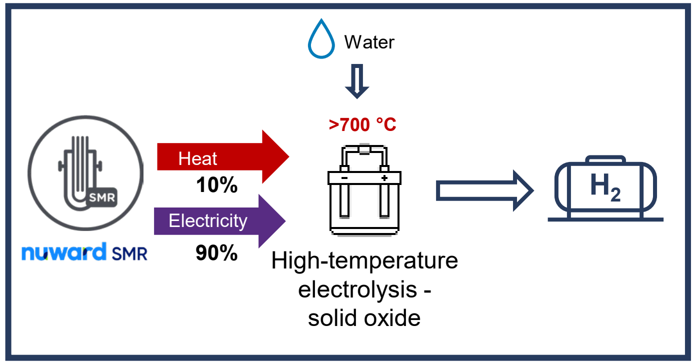
Once high-temperature electrolysers are commercially available, the hybridisation of a NUWARD SMR could avoid up to 600 ktCO_2/year by replacing steam reforming, and improving the efficiency of the process

Diagram of a NUWARD SMR connected to an electrolyser, by technology

Low temperature electrolysis (LTE)
Using NUWARD SMR 100% generator



High temperature electrolysis (HTE)
Use of heat and electricity



Sizing of the electrolyser and calculation of emissions avoided compared with the steam reforming of H_2

	LTE	HTE	Comments
Power consumption	**Electricity: 340 MW_e**	**Electricity: 310 MW_e Heat: 100 MW_{th}**	For HTE, the heat from the SMR heats the water entering the electrolyzer.
Hydrogen production[1]	**60** kt H_2/year	**69** kt H_2/year	
CO2 emissions avoided by electrolysis with NUWARD SMR vs. steam reforming of natural gas[2][3]	**0.51** MtCO_2/year	**0.6** MtCO_2/year	

Coupling opportunities

- Coupled with electrolysis, **hydrogen** can be **decarbonised,** replacing the steam-reforming of methane.
- According to EDF, the **hybrid heat produced by NUWARD SMR will be able to vaporise the water** at the inlet to HTE electrolysers, reducing the need for electrical energy for electrolysis.

Points of attention for hybridisation with electrolysis

- LTE electrolysis consumes only electricity, while **HTE combines heat and electricity to achieve greater efficiency**.[1]
- While currently in the technology demonstration phase, high-temperature electrolysis **could reach technical and commercial maturity around 2030-2040,** which would be compatible with the deployment of the NUWARD SMR series.

Methodology: assumption that all the electricity from an SMR is used for electrolysis, electrolysis efficiencies based on estimates for 2050 from [1]. Avoided emissions calculated based on CO2 emissions from steam reforming from [2], the carbon intensity of nuclear power from [3] and the efficiency of LTE electrolysis.
Sources: [1] IRENA [2] IEA [3] ADEME

3

Socio-economic and environmental impact

NUWARD SMR aims for an environmental impact comparable to that of the French nuclear industry as a whole, with possible positive impacts for employment and industry

Introduction: Methodology

We identify the environmental and socio-economic externalities associated with the development of a series of NUWARD SMRs in France*

Environmental externalities		Socio-economic externalities
Carbon intensity	Consumption of critical mineral resources	Effects on employment
Polluting emissions (NOx, SOx, PM...)	Waste management	Development industrial
Land use	Nuclear fuel cycle	Contribution to the reindustrialization
Water consumption	Impact on human health	Opportunities for the titanium industry

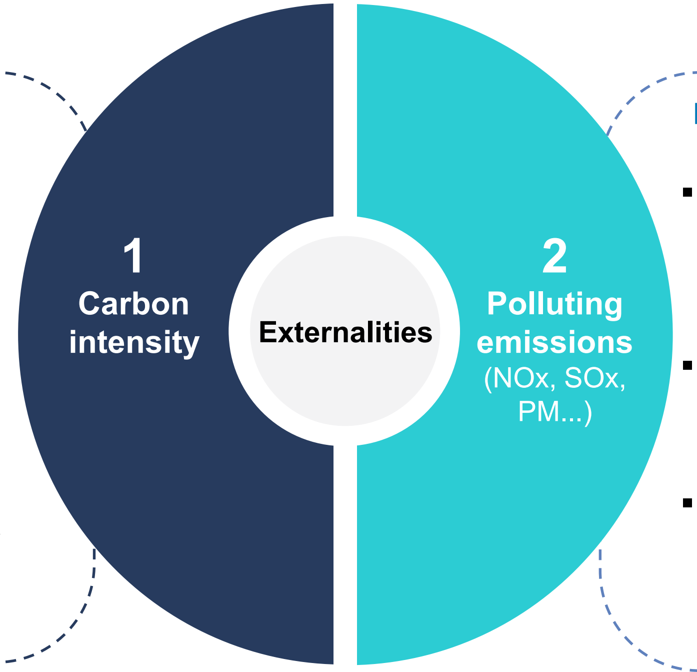
The information in this section is based on data and estimates provided by EDF. Some items correspond to targets or objectives for NUWARD SMR and will need to be confirmed in subsequent stages of development of the project.

Environmental impact - CO_2 and air pollutants

NUWARD SMR will produce low-carbon, low-emission, electricity and heat, in line with the nuclear industry

Nuclear power produces low-carbon energy

- According to EDF, NUWARD SMR will have a **carbon intensity comparable to that of the nuclear industry** as a whole, between **4-6 gCO_2eq per kWh_e** produced.[2]
- Similarly, **the heat produced by NUWARD SMR will have a footprint of around 1-2 gCO_2/kWh_{th}** thanks to the efficiency of hybridisation (around a quarter of the emissions of electricity[1] with respect to the energy produced).
- SMRs **will provide an additional low-carbon option** for the energy transition, complementing the development of intermittent renewable energies and large-scale nuclear.



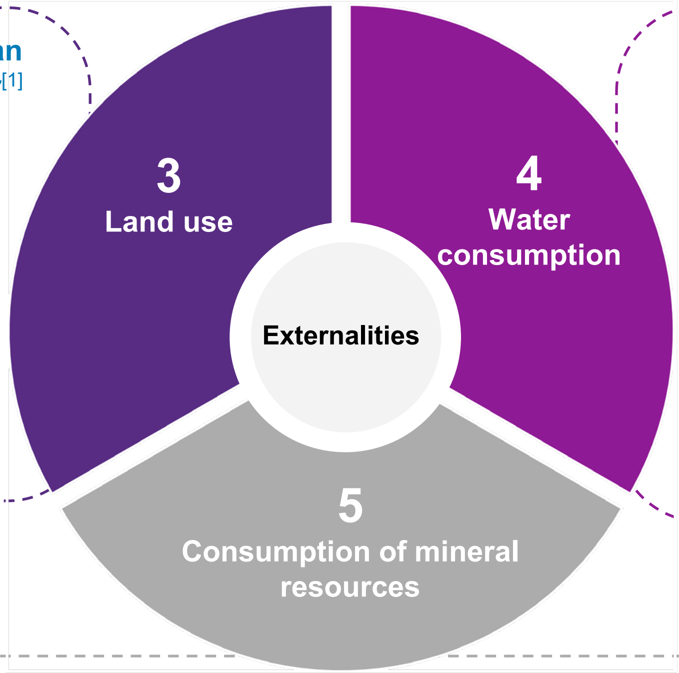
Nuclear power emits few atmospheric pollutants

- According to EDF, NUWARD SMR will produce electricity and heat **with very low life-cycle emissions** of NOx, SOx, fine particles and mercury, **comparable to the nuclear industry as a whole.**[3]
- The heat produced by NUWARD SMR could replace the **use of oil or coal-fired industrial boilers**, which emit high levels of SOx and NOx.
- *Santé Publique France* points out that long-term exposure to air pollutants can lead to numerous chronic respiratory and cardiovascular diseases.[4]

Sources:
[1] Source EDF [2] ADEME [3] UNECE [4] Santé Publique France

Environmental impact - Footprint on land and resources

Because of its small size, NUWARD SMR will have a limited land footprint, cooling water requirements and consumption of critical mineral resources[1]



In terms of land usage, NUWARD SMR will aim for an energy density similar to that of large-scale nuclear[1]

- NUWARD SMR will target a high energy density, requiring **a land area per unit of energy produced of the same order of magnitude as large-scale nuclear power,**[2] and contributing to limited pressure on terrestrial ecosystems.
- It could be built on dismantled former thermal power stations or near energy-intensive industrial sites, thereby helping to **limit the use of land**.

A design that aims for resilience to water constraints[1]

- According to EDF, an SMR will pump a flow of **around 0.5 m^3/s, of which 0.2 m^3/s will be consumed by evaporation,** in a closed circuit, and 0.3 m^3/s will be returned to the water stream.*
- This level of water consumption, along with other possible configurations (e.g. open circuit), would allow **flexibility in the choice of location** and could contribute to resilience in the context of the multiplication of dry periods.
- According to EDF, the **environmental impact of** NUWARD SMR in terms of liquid discharge will be **similar to that of the existing nuclear industry**.

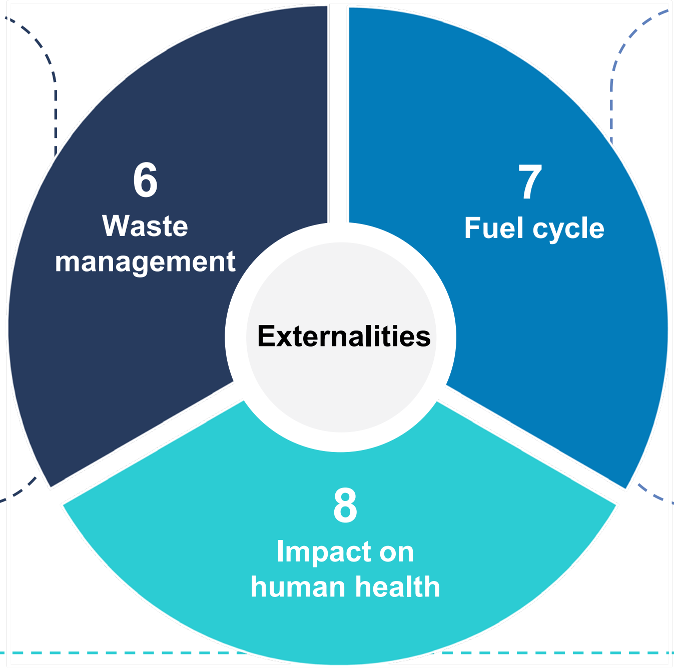
NUWARD SMR will consume resources comparable to the nuclear industry as a whole[1]

- In line with the needs of the nuclear industry, the construction of the **NUWARD SMRs will require significant quantities of steel and titanium**,[1] metals whose supply chain is not at high risk of disruption.[3]
- According to EDF, NUWARD SMR will require **quantities of critical materials** (in relation to the energy produced) **comparable to the French nuclear industry** as a whole,[1] including metals under stress such as copper, nickel and rare metals.

** Flow rate and water consumption values for NUWARD SMR closed-cycle configuration.*
Sources: [1] EDF data, [2] UNECE, [3] IEA

Environmental impact - Risks and waste management

According to EDF, NUWARD SMR will be able to draw on the French nuclear industry's experience in waste and life cycle management, and implementation of high radiological protection standards*



Waste from NUWARD SMR will be treated in a similar way to existing nuclear waste*[3]

- The types of waste produced by NUWARD SMR will be **similar to those produced by reactors operating** in France.[1]
- NUWARD SMR will be able to draw **on the expertise and industrial facilities** for waste management of the French nuclear industry.
- According to EDF, the current industrial system **safely manages all waste produced** by the pressurized water reactor fleet in dedicated facilities.

The fuel cycle for NUWARD SMR will be based on that of high-power nuclear power*[2]

- According to EDF, the fuels used by NUWARD SMR will not require any significant changes to the fuel processing plants and will benefit from the **French nuclear industry's experience on managing the fuel cycle.**
- NUWARD SMR will **have an in-core fuel management period of around two years**, with half the core replaced at each shutdown, according to EDF.
- According to EDF, security of uranium supply will be guaranteed in the same way for NUWARD SMR as for the high-power nuclear fleet.

NUWARD SMR will meet the highest standards in the French nuclear industry in terms of radiological impact*

- **The safety objective for NUWARD SMR will be the same as for high power**, but the path to achieving it is different and could lead to higher societal acceptability.
- According to EDF, NUWARD SMR will meet the highest **3rd generation** standards in terms of safety and radiological protection.**

** The elements related to technical design and safety of the nuclear power plant are based directly on information provided by EDF.*
*** 3rd Generation nuclear reactors incorporate safety, fuel utilization and waste reduction systems that meet the highest standards.*
Sources: [1] EDF data [2] Ministry of Energy Transition [3] ASN

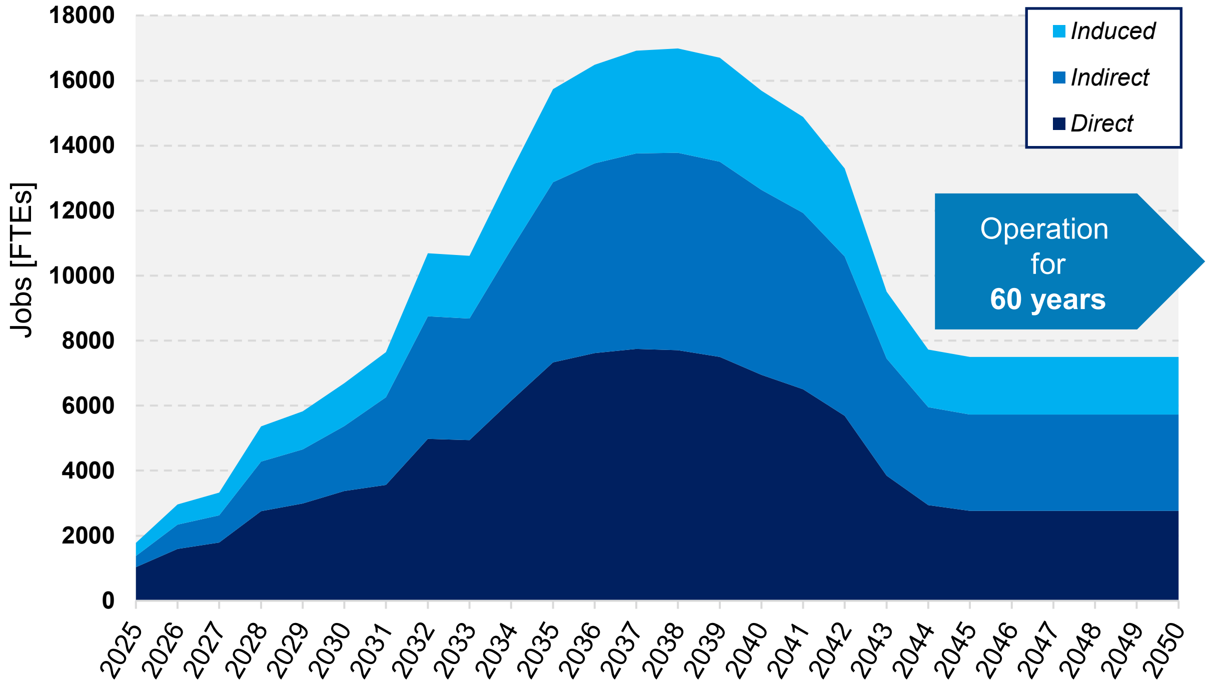
Socio-economic impact - Effects on employment

According to data provided by EDF, a series of NUWARD SMRs could create an average of 12 500 jobs per year during construction

The NUWARD SMR project could generate around 12 500 jobs per year during the construction of a series of plants in France[1]

- Assuming the commissioning of one NUWARD SMR plant per year from 2035 to 2044 and based on the data provided by EDF on the jobs generated in the various years and development phases of a plant, the construction of a series of ten NUWARD SMR plants **would employ around 5 500 people (FTE*) per year on** average from 2030 to 2045 within the EDF Group.
- In addition, the construction of a series of SMRs **would create jobs at EDF's suppliers** (known as *indirect* jobs), and all the direct and indirect jobs will have an effect on consumption, leading to the **creation of *induced* jobs**.
- Based on EDF data for the New French Nuclear Plan and the SMR Jobs study by EDF R&D, all these jobs would represent an average of **around 7 000 people (FTE) per year** from 2030 to 2045, for a total of around 12 500 jobs per year created by the NUWARD SMR project.[3][4]
- The operation of a series of NUWARD SMRs **would create stable jobs over the 60-year** operational life of these plants, with a total of **around 7 500 people employed (FTEs) per year**, including direct, indirect and induced jobs.

Estimated jobs created per year by a series of 10 SMRs in France[1]



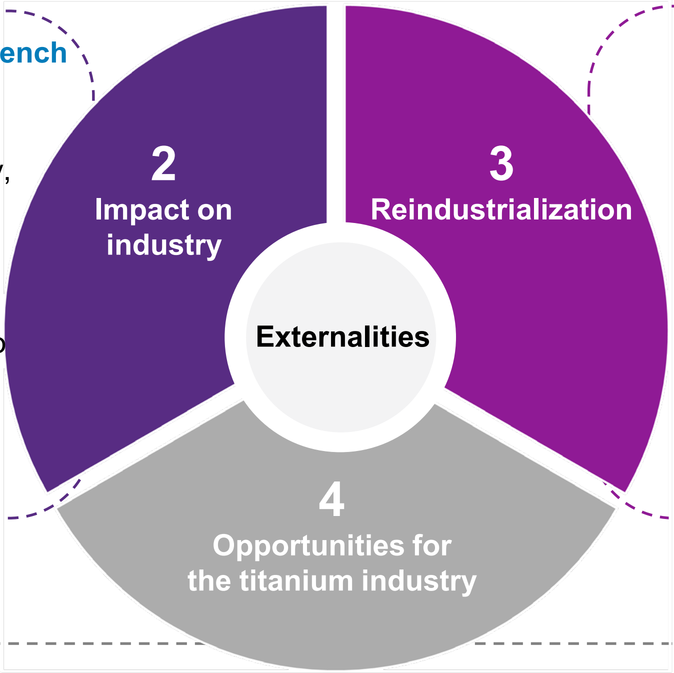
*Methodology: Visualization based on data provided by EDF [2] on direct jobs for an SMR (first-of-a-kind and series model) per year, per phase of project development and per segment in the construction phase, indirect job data based on import-export analyses from [3], data on induced effects based on [4]. * FTE: Full-time equivalent*
[1] According to EDF, these jobs could be spread over several European countries depending on the NUWARD SMR supply chain strategy.
Sources: [2] EDF data [3] SMR Jobs Study, EDF R&D, 2023 (confidential) [4] Ratios calculated by PwC for EDF's New French Nuclear Plan, 2021 (confidential)

Socio-economic impact - Effects on industry

A series of NUWARD SMRs will have positive economic and industrial effects for France and its regions, according to EDF

NUWARD SMR's modular design could benefit the French industry, including in local clusters

- **NUWARD SMR will be based on a modular design:**[1] major parts of the plant could be assembled in the factory, which **could reduce construction times**.
- The development of a series of NUWARD SMRs would provide **visibility on industrial activity**.
- According to EDF, the NUWARD SMR plant could help to **revitalise some regional industrial clusters** and **strengthen European industrial sovereignty.**



NUWARD SMR could contribute to reindustrialisation

- According to EDF, a significant part of the **NUWARD SMR supply chain** for the construction of a series of SMRs **will be located in France,** thus contributing to the **country's efforts to reindustrialise in a low-carbon economy.**
- According to EDF, NUWARD SMR could produce decarbonized heat by hybridization and at a competitive cost, which would enable the development of **new industries using competitive decarbonized heat** and create **opportunities for adapting industrial processes** (including the production of H_2).

NUWARD SMR could contribute to the consolidation of a titanium value chain

- The **innovative design of the NUWARD SMR steam generator** will require around 200 tonnes of titanium per power plant, according to EDF.
- According to the EESC and the *Royal Society of Chemistry*, titanium is a **strategic but abundant metal, with growing industrial uses,** and whose supply chain is not at high risk of disruption in France and Europe.[2] NUWARD SMR could contribute to the **consolidation of the titanium industry in France,** covering the entire life cycle and exploiting synergies with the aerospace industry in particular.[3]

4

Conditions for success

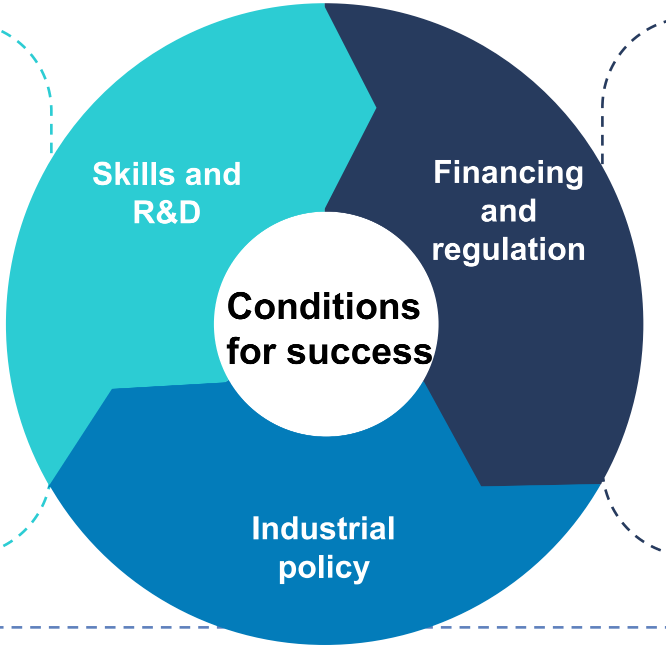
The development of NUWARD SMR project will require favorable financial, institutional and regulatory conditions

Conditions for success of nuward SMR

The development of the know-how of the nuclear industry, an adequate regulatory framework, and supportive public policies could foster the development of NUWARD SMR

Developing and enhancing industrial skills and know-how

- Increase resources **for research and development in state-of-the-art nuclear power.**[1]
- Developing **training in key nuclear construction skills**, in particular welding and high-performance steelworking,[2] in order to optimize the pace of deployment and the creation of high value-added jobs.
- **Develop industrial expertise** in modularisation and in manufacture of complex titanium components, **based on synergies** with other industrial sectors, including aerospace.[3]



A regulatory framework providing long-term predictability for major nuclear projects

- Consider the **opportunities offered by low-carbon heat** in the updated French decarbonisation policies.
- Facilitate the **creation of new sites**, as well as the re-use of former thermal and industrial sites, to speed up deployment.
- Implement **appropriate contractual and financial mechanisms** to provide long term predictability.

Public policies to promote industrial development and reindustrialisation in France and Europe

- Launch a **specific industrial strategy for the NUWARD SMR** to anticipate the implementation of the value chain.
- Share the opportunities offered by low-carbon heat and NUWARD SMR **with local stakeholders**, in line with their development projects.
- Consolidate a **titanium value chain** in France, given its importance for high-tech products.
- Develop a **framework for the international commercial promotion** of NUWARD SMR.

Sources [1] MTE [2] MEF [3] MTE

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