

# Carbon-free & decentralized energy

June 2024



# SOMMAIRE

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NAAREA is a European sustainable nuclear energy company supporting the green energy transition by developing a fourth-generation nuclear reactor to produce and sell carbon-free, decentralized energy at competitive, affordable prices, in close proximity to industrial consumers and local communities.



**Jean-Luc  
ALEXANDRE**  
CEO & Founder

« Our planet is overheating. The scale and frequency of heat waves, the increase in extreme precipitation, the development of new droughts, the thawing of the cryosphere, and changes in the behaviours of numerous species are among the phenomena occurring before our eyes, to varying degrees in different locations. These are factual observations, that can no longer be dismissed as millenarian fears. It should come as no surprise that this situation leads to eco-anxiety. 'The era of global boiling has arrived', UN Secretary-General Antonio Guterres declared at the end of July 2023, the 'hottest month ever recorded in human history'. In March of the same year, the Sixth Assessment Report of the IPCC warned, once again, of the increasing risks to the planet, and to us along with it, in view of a level of global warming that has not slowed since 2014 – the date of the organization's last report. Experts predict that the increase in global surface temperature will reach 1.5°C by the early 2030s. Limiting warming to below 2°C would require immediate action to

reduce net global CO2 emissions to zero, as well as other greenhouse gas emissions (water vapour, methane, nitrous oxide, carbon tetrafluoride, etc.).

*In a word, without the slightest tendency to catastrophize, we are heading straight for disaster. In the face of such a climate emergency, if we fail to find a way to change our pathway, our planet will no longer be liveable for numerous species, including our own. Hence the expression of the energy transition which aptly sums up the new global imperative: energy is at the heart of all the issues we face.»*

Le nucléaire nouvelle generation (The New Generation of Nuclear Energy),  
Jean-Luc Alexandre, Preface, Éditions Hermann, 2024.

# OUR CONTEXT

## Growing energy challenges and urgent climate concerns

In a global context marked by growing energy challenges and urgent climate concerns, the search for sustainable, carbon-free solutions has become an absolute priority.

NAAREA estimates that the demand for electricity could quadruple by 2050, reaching 100,000 TWh per year. This increase is linked to the astronomic development of digital technology as well as population growth. Soon, eight billion people will aspire to the lifestyle currently led by the Western middle class.

In addition to growing energy challenges, the global context is also marked by pressing climate concerns. Today, the sustainability of our planet Earth calls for a carbon-free solution to produce this energy, as well as putting an end to the intensive consumption of natural resources.

Clean energy solutions exist, but whether due to their large size (conventional nuclear reactors), their dependence on energy transport networks or their intermittency (renewable energies), they offer only a partial response insufficient to meet the immense demand that only continues to grow.

## Renewed interest in nuclear energy

In this context, nuclear energy has attracted renewed interest for its potential to meet the needs of Europe and the rest of the world for reducing greenhouse gas emissions from human activities, while providing a stable green energy solution to compensate for the intermittency of renewable energies. Technological developments now enable reliable safety to be ensured throughout the entire nuclear sector. Major industrialized countries, mindful of the exponentially growing needs for electricity production, have quickly positioned themselves to take advantage.

In France, the report of the commission leading an inquiry into France's "loss of energy sovereignty", headed by Antoine Armand in 2023, emphasized the crucial role of the nuclear sector in the French energy mix and called for efforts to accelerate nuclear projects and modernize existing infrastructure. The France 2030 investment plan is also contributing to revitalizing the nuclear sector by boosting progress in innovation and training in nuclear professions. In February 2023, the French Minister of the Energy Transition at the time, Agnès Pannier-Runacher, launched a nuclear alliance in Europe in partnership with 12 EU countries and the European Commission with the aim of improving collaboration in areas such as skills, innovation and safety.

At international level, at COP28 in December 2023, nuclear energy was explicitly recognized, for the first time, as one of the key solutions for slowing the pace of climate change. Lastly, in March 2024 the European Commission launched the European Industrial Alliance on Small Modular Reactors (SMRs), which aims to strengthen industrial competitiveness and ensure a strong supply chain and qualified workforce in the European Union.



## Modular reactors gaining increasing recognition

Like SMRs, AMRs (advanced modular reactors) belong to the category of small modular nuclear reactors. The term "modular" signifies that these reactors are designed for large-scale industrial production, which represents an initial revolution compared to traditional nuclear reactors. These small modular reactors are specifically created for distinct usage contexts, meeting local energy needs such as heat, vapour or electricity production.

They can be installed at energy-intensive industrial sites operating in sectors such as iron metallurgy, chemicals and steelworks, for example. Similarly, they can be suited to industrial clusters or groups of public buildings within the same geographic area, with energy needs that can be met with one or several small-sized reactors.

It is important to note that AMRs and SMRs have a lower power capacity than traditional nuclear reactors, and are designed to be mass-produced for large-scale use. This approach aims to decarbonize industrial sectors that are currently major sources of CO2 emissions.

It could therefore play a crucial role in powering the process of producing hydrogen or green fuels, further contributing to sustainable solutions.

# NAAREA's XAMR®

NAAREA is developing the XAMR®, a nuclear microreactor capable of producing electricity and high-temperature heat by burning long-lived nuclear waste recovered from spent fuel from traditional nuclear power plants. The XAMR® will be industrially mass-produced and designed to be installed in close proximity to electro-intensive industries.

Drawing on French expertise in fields including fast neutrons, molten salts and the management of long-lived spent fuel, NAAREA is paving the way for innovative, sustainable nuclear energy that contributes to energy independence, greater resilience and the circular economy. NAAREA is thus developing a complementary solution to intermittent renewable energies and will make the entire nuclear industry more sustainable by offering a solution for reprocessing spent fuel.



## A combination of proven technologies

The XAMR® combines, for the first time, several technologies that have been proven for decades. Firstly, it operates using a fast neutron spectrum, similarly to the Phénix and Superphénix reactors and the ASTRID project. This efficient method offers the ability to optimally burn long-lived components of spent fuel, using up to 98% of the fuel compared with 0.5% for current reactors. Fast neutron reactors can also generate energy from radioactive material such as plutonium and minor actinides, thus contributing to responsible nuclear waste management.

In addition, NAAREA's microreactor features a single molten salt reactor operating at atmospheric pressure, non-water-cooled, with an auto-regulated fission reaction taking place at high temperature (approximately 700° C), ensuring the intrinsic safety of the entire system.

Lastly, the reactor's compact design, the size of a 40-foot container, facilitates large-scale series production and easy transport thanks to its standardized dimensions. The modular reactors reduce on-site work, improving the effective containment of nuclear materials and their safety. The microreactor thus represents a trailblazing solution to meet energy needs while contributing to the

sustainable management of radioactive waste.

## Technology ensuring the highest level of safety and security

Since the 1950s, the evolution of nuclear reactors has been divided into four distinct generations. The first generation, developed in the 1950s and 1960s, includes prototypes and the first commercial reactors. The second generation of reactors, which emerged in the 1970s, remain predominantly used in current nuclear electricity production. The third generation, designed according to reinforced safety standards, takes into account the lessons learned from major accidents and terrorist threats.

Currently under development, the fourth generation represents a major technological step forward. These reactors incorporate advancements to meet criteria such as sustainability, safety, economic competitiveness and nuclear non-proliferation. Generation IV encompasses multiple technologies, including the molten salt fast neutron reactors developed by NAAREA, falling under the six reactor technologies of this new generation.

The molten salt fast microreactor offers inherent safety features, based on a design that uses a strong negative temperature coefficient of reactivity (as the temperature rises, reactivity decreases): the reaction is self-regulating, ensuring passive safety to protect against reactivity excursions. Conversely, as temperature decreases in the microreactor's core, density increases, increasing the probability of fission as well as the ability to generate heat.

These two effects provide the reactor with inherent stability. The equilibrium temperature is around 700°C. These effects also lend the reactor its flexibility in terms of power output, which can be controlled via the flow of the coolant salt through the heat exchanger.

The lack of pressure in the circuits provides another advantage. The molten salt reactor operates at near atmospheric pressure since the fuel salt and coolant salt remain liquid at high temperatures.

Furthermore, the molten salts used have very high boiling points (1300°C), which means that even a temporary temperature rise of several hundred degrees will not lead to a significant pressure increase. Lastly, the XAMR does not use water, which eliminates the risk of the release of hydrogen in the reactor, thereby limiting the risk of explosion.

### An affordable model enabling control of the overall cost structure

NAAREA's business model is that of an energy provider with a performance contract. NAAREA will retain ownership of its microreactors under all circumstances to ensure their security, safety, maintenance and flawless operation.

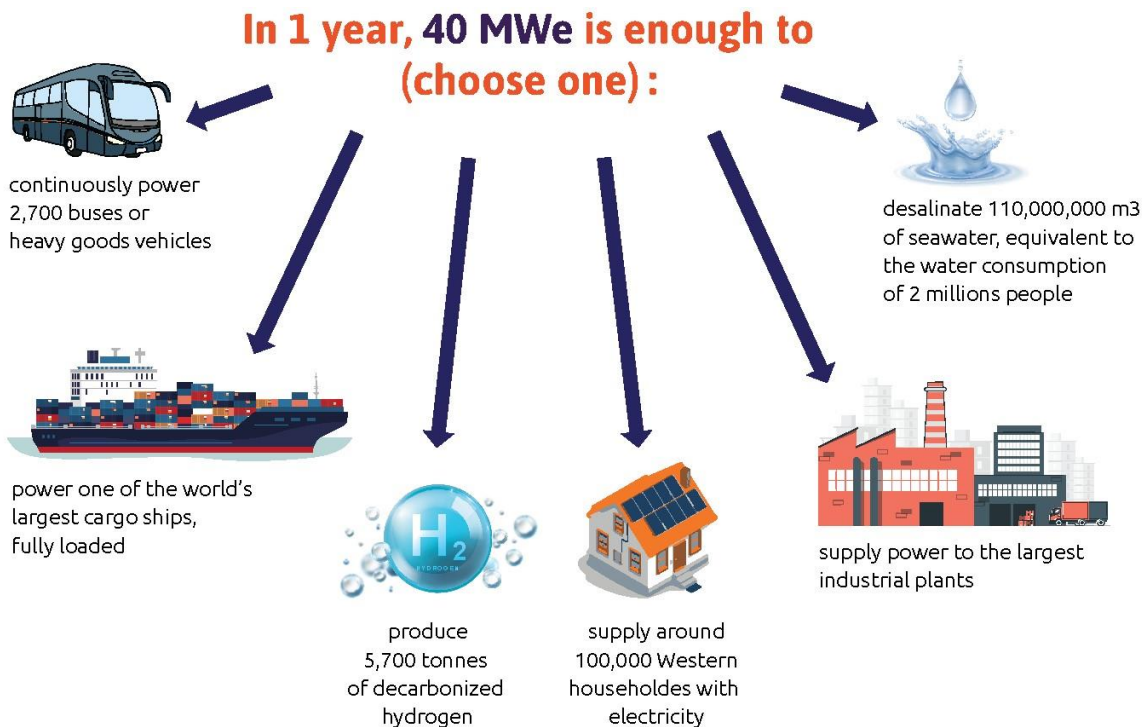
The range of activities covered by NAAREA will include manufacturing, transport and on-site delivery, installation, connection, security, insurance, operations and maintenance, emergency services including shutting down or deactivating microreactors, and end-of-life management. The electricity and heat produced by XAMR® reactors will either be consumed by local users, or fed back into the power distribution grid. NAAREA will cover all fixed and variable manufacturing, maintenance, operating and fuel costs. Customers will be billed only for their power usage.

By choosing the role of operator, energy provider and designer, NAAREA is securing the entire value chain, which ensures predictability in terms of prices and costs and makes it a competitive player.

### A solution with a valuable place in the energy mix

The innovative technology NAAREA is developing positions it to play a complementary role in the energy landscape, as a counterpart to the traditional nuclear sector and renewable energies. Contributing to closing the nuclear fuel cycle, NAAREA aims to produce energy for industries located throughout France and Europe.

NAAREA also provides a complement to renewable energies, enriching the French and European energy mix. The fundamental objective is to lower the energy bills of industries and consumers. NAAREA's solution stands out for its effectiveness as a response to the intermittency of renewable energies, by offering a stable energy source that is geographically close to users and can be adapted to meet demand.





## NAAREA selected as the first french winner of the france 2030 “innovative nuclear reactors” call for projects

NAAREA is a winner of the “Innovative Nuclear Reactors” call for proposals under the France 2030 investment plan. This key government funding reflects the increasingly strong support on the part of public authorities for the development of Generation IV molten salt fast reactors.

This distinction was granted following an independent evaluation and selection process that attests to the trust placed by public authorities in NAAREA’s solution to help meet France’s objectives for energy sovereignty, decarbonization and improving the energy mix by 2050. The sum awarded for this initial call for proposals phase, added to the private capital NAAREA already raised, will allow the company to accelerate its execution of the design phase and related testing, and to continue increasing its personnel, from 140 employees in May 2023 to 200 by the end of 2024.

NAAREA awarded the “french tech 2030” label

After being selected as a winner of the “Innovative Nuclear Reactors” call for projects under the France 2030 investment plan, NAAREA was also awarded the “French Tech 2030” label as a beneficiary of the support programme created by the French Tech Mission, the General Secretariat for Investment and Bpifrance.

Created to support the emergence of innovations in key strategic sectors, this label allows NAAREA to receive specific support (related to regulatory, customs or industrial property issues, business intelligence, cybersecurity, administrative authorizations, visibility, international delegations, etc.) from all government and regional services, coordinated by the French Tech Mission.



# DEVELOPMENT PHASES

## From conception to materialization

NAAREA will develop, design, build, install, operate and maintain its microreactors, and ensure their recycling, reprocessing and dismantling. To achieve this, NAAREA is pursuing an ambitious development plan with the aim of launching series production by 2030. Two major steps of this development plan have already been implemented: the digital twin and the first technical tests to qualify the materials for the future XAMR®.

## First significant steps in the microreactor's development

### Technological progress

NAAREA achieved a crucial milestone in its development plan by creating the first version of the digital twin of its microreactor, thanks to the technology and expertise of Dassault Systèmes and Assystem. This 3D representation of the reactor, subject to the laws of physics, makes it possible to visualize the interactions of the different physical aspects impacting the functioning of the reactor system (mechanics, neutronics, thermodynamics, etc.) The digital twin also serves as a demonstration tool with regard to safety and security. It can be used to anticipate phenomena such as the ageing of materials, their resistance to corrosion and wear on the overall system. Completed in 18 months, the digital twin is an indispensable tool to facilitate the design of the microreactor and accelerate its development.

### Scientific progress

In parallel, NAAREA also launched its first materials tests, another key step in the microreactor's development. NAAREA notably worked with the Mersen Group, a global expert in advanced materials for high-tech industries. This collaboration has already resulted in the design of the first silicon carbide loop, in operation since August 2023. The chloride salt test loop, which operates using natural convection and at a temperature of 600°C under inert atmosphere, will enable study of the dynamic corrosion behaviour of silicon carbide and salt-gas interaction phenomena.

These tests will contribute to analysis of the impact of chlorine-based salts on silicon carbide and confirming this material's capacity to resist corrosion while meeting the safety and security requirements for fourth-generation reactors.

In operation since August 2023 in the French materials engineering laboratory ICAR-CM2T, which specializes in the thermo-mechanical characterization of high-temperature materials, this loop is the first milestone in an ambitious testing programme planned over several years with a view to qualifying the materials for the future XAMR®. The primary objective is to ensure compliance with current safety and security standards.

In March 2024, NAAREA announced that it was developing

online analytical tools to provide real-time data on the composition of molten salts and inerting gases in its future reactor. Known as ALIS, the joint project involving NAAREA, CNRS-IJCLAB and iUMTEK aims to develop online tools to analyse the composition of radioactive molten salts and inerting gases. The online analysis of these elements will notably help ensure the highest level of safety and optimized control of the future microreactor.

In June 2024, NAAREA, the CNRS and Université Paris-Saclay launched a joint laboratory dedicated to molten salt chemistry research. Known as Innovation Molten Salt Lab (IMS Lab), this laboratory will draw on the expertise of NAAREA and ICJLab1 (Laboratoire de Physique des 2 Infinis Irène Joliot-Curie). Its aim is to become the European leader in the field of molten salts R&D for both nuclear (molten salt reactors) and non-nuclear applications.

Under joint governance, Innovation Molten Salt Lab (IMS Lab) will follow a roadmap for research and innovation. This roadmap will aim to foster collaborative work and capitalize on the concepts and innovations developed at NAAREA to the benefit of the European molten salt reactor sector, in particular in the context of the strategic partnerships it recently formed.

### Industrial progress

In 2023, NAAREA also took several key steps in the pursuit of its strategic development. On the occasion of the 2023 World Nuclear Exhibition, NAAREA signed a partnership agreement with ACC (Automotive Cells Company), a European high-tech leader in the development and manufacturing of electric vehicle batteries. ACC aims to study how NAAREA's XAMR® solution can help meet carbon neutrality objectives and the energy supply needs of its future gigafactories.

NAAREA and Pôlénergie, an energy cluster organization in the Hauts-de-France region specialized in the energy transition and decarbonization, also entered into a partnership to identify and pre-qualify regions and industries that would be suitable candidates for the deployment of XAMR® technology to supply electricity and/or heat. Concretely, this partnership agreement involves the identification of regions whose needs are well-matched to NAAREA's solution, conducting feasibility studies assessing electrical and/or thermal energy demand, and sharing input data necessary to qualify projects to install an XAMR®.

# THE NEXT KEY STEPS

To move forward in its application process to obtain authorization from the French Nuclear Safety Authority (ASN), NAAREA will continue its dialogue with the ASN, based on the recent changes to the licensing method in France. The conventional licensing procedure in stages (DOS safety report, environmental studies, authorization for commissioning, etc.) has changed for new applicants, evolving into an ongoing exchange with the ASN in the form of “seminars”. This method is perfectly suited to innovative projects for which limited feedback from operating the installations is available, requiring the ASN to redefine a demonstration of safety.

As part of its roadmap, NAAREA also plans to create a testing facility to conduct inactive tests (without nuclear materials) which will contribute to creating a “cold” demonstrator, a significant step before moving to the nuclear phase. This stage will be followed by an observation and operation phase, with the aim of acquiring feedback for the technology’s development.

NAAREA also plans to build a molten salt reactor prototype to validate the design of its reactors for series production through irradiation tests on materials and salts as well as nuclear safety testing.

The last phase of the development plan will involve building the production facility, which will be a basic nuclear installation (BNI) equipped with robotics. This site will include two modules: a manufacturing facility and a decommissioning/reprocessing facility for recycling the microreactors.

## In 2024, two strategic and industrial partnerships

In response to the specific needs of the fourth-generation reactors currently under development, NAAREA formed two strategic and industrial partnerships to pool research and development efforts in the specific fields of fast microreactors and molten salts. These partnerships are part of an approach complementary to the vital Industrial alliance on Small Modular Reactors (SMRs) launched by the European Commission.

The first partnership, signed with *newcleo*, is intended to be opened up to all players involved in the industrial design and deployment of fourth-generation fast reactors, in the following areas of cooperation:

**The fuel cycle:** access to spent nuclear fuel (in particular the separation of transuranic elements – plutonium and minor actinides), and the development and implementation of a supply chain for the reprocessing of spent fuel.

**Financing fuel cycle infrastructure:** through the development of public-private partnerships.

**Research:** the development of a joint research and development platform (heat exchangers, materials, etc.) and facilitating funding at European level.

**Industrial development:** through optimizing and supporting procedures with the safety and security authorities, providing access to scientific computing tools in particular for safety demonstrations, providing the use of testing centres for future prototypes (including partner laboratories), and developing and implementing shared testing facilities.

A second partnership was formed with Thorizon, a Dutch startup developing reactor cores using molten salt cartridges. The two companies will pool their resources in terms of technology development knowledge to develop a roadmap for research and the development of shared testing facilities. The partnership between NAAREA and Thorizon aims to create the best conditions for:

1. Pooling resources for safety and security demonstrations as well as chemical, industrial and strategic knowledge in molten salt technology.
2. Developing shared laboratories and test facilities.
3. Securing access to reprocessed fuel needed for molten salt synthesis.
4. Bringing to market a range of complementary solutions with a common technological base.
5. Broadening political and government support for molten salt reactor technology.

# FOUNDERS

Since 2005, the two founders of the project, Jean-Luc Alexandre and Ivan Gavriloff, have been successfully collaborating to explore creative ways for different professional fields to work together.



## Jean-Luc ALEXANDRE

Jean-Luc Alexandre is a graduate of the École Technique Préparatoire pour l'Armement military engineering school and an engineer with a degree from Centrale-Supélec (class of '92) as well as INSEAD business school. He began his career at Spie Batignolles working on the engineering and construction of complex rail systems. He became Vice President, Infrastructure at Alstom Transport in 2007. In 2013, he was named managing director of Degrémont. He was also Chief Technical Officer of the Suez group for infrastructure until 2019. His fifteen years spent abroad have provided him with a keen understanding of international challenges. This international field experience made him deeply aware of social inequalities, the daily hardships experienced in developing countries and the devastating effects of climate disruption on their populations.

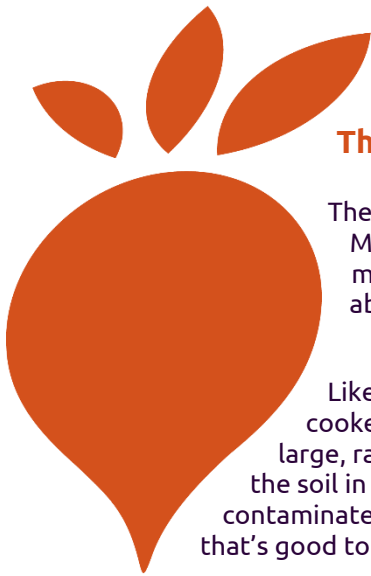
## Ivan GAVRILOFF

Ivan Gavriloff, a graduate of the École Polytechnique (class of '81), is an entrepreneur and founder of KAOS Consulting. An expert in creativity and innovation, since 2012 he has taught "Thinking Differently" at French military institutions including CHEM, École de Guerre and EMSST and the Management Training Centre of the Ministry of Defence (CFMD). He also provided support services to the general officer responsible for the digital transformation of the armed forces (OGTDA) for 18 months (2017-2018), and is a colonel in the French citizen reserves (ADER air force network). He leads creativity groups ranging in size from ten to several hundred people. His expertise brings out innovative solutions from seemingly disparate groups, thanks to collective intelligence methods that have delivered proven results for 1,000 clients, including from CAC 40 companies.



Inspired by and professionally committed to the achievement of the 17 sustainable development goals (SDGs) adopted in Paris in September 2015 by 193 countries, Jean-Luc Alexandre and Ivan Gavriloff published a book, *Oui, c'est (encore) possible* [Yes, It's (Still) Possible], in December 2019, the fruit of their analysis and observations on the subject. "Protecting our planet and our family of living things" leads to the idea that the climate is our heritage for which we bear a responsibility toward future generations. NAAREA is led by Jean-Luc Alexandre, its Chief Executive Officer, and Ivan Gavriloff, who chairs its supervisory board.

# THE NAAREA LOGO



## The radish, a symbol of innocuousness and safety

The radish is an element of nature found throughout the world, from China and India to Mexico, Africa and Europe. As a food, the radish offers an abundant energy source, rich in minerals and micronutrients. Affordable and accessible to all, it symbolizes the shared abundance that represents NAAREA's ambition.

Like NAAREA, the radish generates little waste, since the entire plant can be eaten, raw or cooked: microgreens, root, greens, flowers, seed pods and seeds (oil and sprouts). Small or large, radishes grow quickly, in around three to four weeks, and are an indicator of the health of the soil in which they grow. Radishes are particularly sensitive to radiation. If they grow in contaminated soil or air, they may decontaminate them by extracting toxic heavy metals. A crop that's good to eat is evidence of the absence of radiation.

That's why the radish was chosen for NAAREA's logo as a symbol of innocuousness and safety.

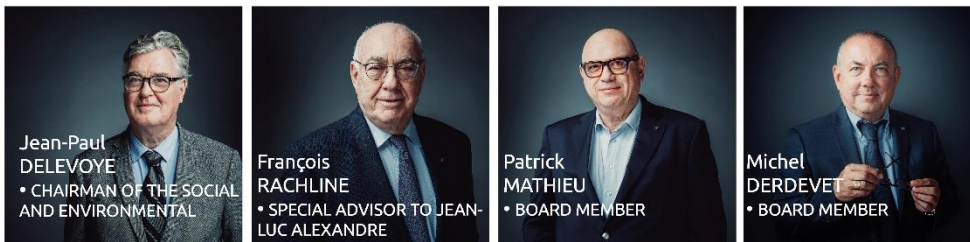
# EQUIPE

NAAREA brings together the top experts in the French nuclear sector, as well as professionals with a background of working with industrial companies. Currently, 220 professionals are working on a daily basis to roll out our XAMRs by 2030.

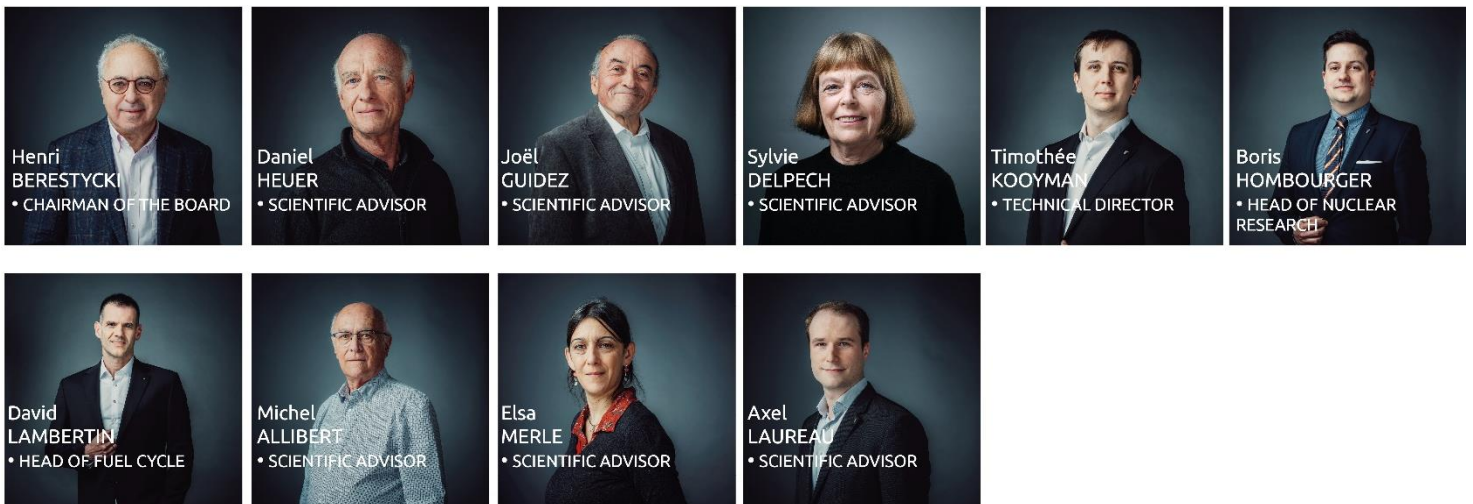
## Executive committee



## Social and environmental advisory board



## Scientific board



## Industry associations and labels





*naarea*

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