



Energy

for a low-carbon world



ARTELIA



Energy

for a low-carbon world

Introduction: Transforming the energy system: a collective duty 6

PRODUCING LOW-CARBON ENERGY ON A MASSIVE SCALE

Quickly doubling the proportion of renewables in the electricity mix 12
Relying on nuclear power in a low-carbon energy mix 28
Decarbonising heating and cooling production by combining several sources 34
Realising the energy vector potential of hydrogen 42

DISTRIBUTING VITAL ENERGY TO EVERYONE

Reinforcing electricity networks by rethinking their role and functions 48
Deploying flexible, efficient heating and cooling networks 58
Securing natural gas and hydrogen supplies 64

REDUCING AND DECARBONISING OUR CONSUMPTION

Building optimal strategies via a systemic approach 72
Acting at city and regional level 80
Contributing to other forms of mobility 90
Moving towards sustainable buildings 96
Supporting the decarbonisation of industry 104

Looking forward: Energetically committed to the green transition! 110

*This book uses data and analyses produced and published by the International Energy Agency (IEA).
Artelia alone is responsible for this use, which has not been approved by the IEA in any form.*

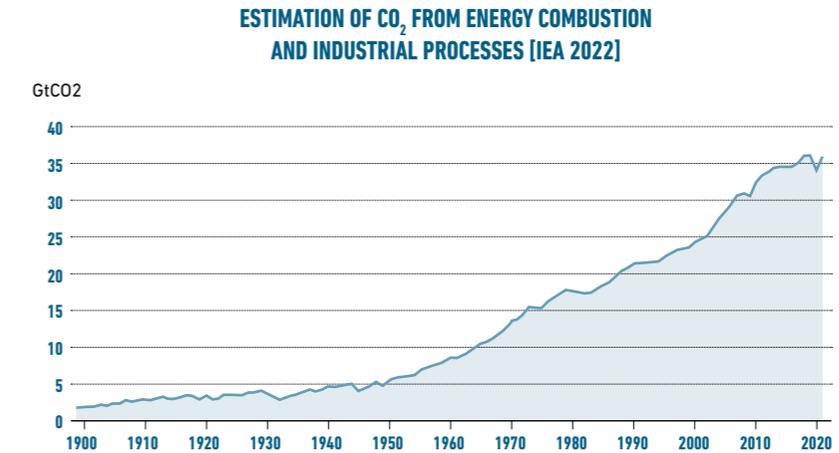


Transforming the energy system: a collective duty

Energy has played a critical role in the evolution of human civilisation. Our earliest ancestors counted on muscle power alone. Since then, humans have discovered fire, domesticated animals, harnessed the heat of the sun, and derived power from water and wind. Fairly recently - since the industrial revolution of the nineteenth century - they have also unleashed the energy contained in coal, oil and gas, and learned how to use energy from nuclear fission. The cumulative, large-scale use of these various energy sources - fossil fuels in particular - has vastly increased our ability to build, manufacture,

transport and communicate. Thanks to energy, much of humankind has been able to attain much safer and more comfortable living conditions. Energy has gradually become the lifeblood for all our societies. A vital component of all economic activities, contributing directly to the power and stability of nations and ubiquitous in our daily lives, energy now lies at the heart of some fundamental challenges.

The first challenge is to halt the ongoing, overly climate change, which is happening faster than expected and threatening to make parts of the earth



uninhabitable for animal species and human beings in the decades to come. Drawing on thousands of scientific papers, the Intergovernmental Panel on Climate Change (IPCC) has shown that this phenomenon is driven mainly by the carbon dioxide emissions generated by our use of fossil fuels, to meet our energy needs. Making the transition to a low-carbon energy system has hence become an urgent, vital, defining objective for humankind.

The other major challenge is supplying nations with energy. Given the central role this resource

plays in the workings of contemporary society, it is vital to secure supply and guarantee access to reliable, sustainable, affordable energy services for economic stakeholders and individuals alike. Recurring energy crises - most recently the one that hit Europe in 2022 - are putting entire countries under pressure and rekindling the debate on the energy independence of nations, particularly those where oil and gas are in short supply.

Artelia has been working for decades on these major issues of access to energy and decarbonising

the energy system. Over the years, as a consulting, engineering and project management company, we have participated in thousands of operations to these ends, across all continents. We are committed to supporting the boom in the various means of generating low-carbon energy. We are involved in the development of electricity and heat transmission and distribution networks. We are also helping governments, authorities, funding agencies, investors, industrial firms and manufacturers to design and implement energy efficiency and conservation strategies. Thanks to our multi-disciplinary nature we contribute to a vast array of developments relating to urban areas, building construction, transport, industry and the environment, giving us a complete overview of the energy system from the facilities used for generation

through to the issues inherent to final consumption. It is this experience, acquired gradually through our work in more than a hundred countries, which we have drawn upon to write this book.

It addresses a specific need. As independent players in the energy sector, we felt it was necessary to clarify our stance and our commitments in relation to the two major challenges facing our energy system today: decarbonisation and supply security. To do so, we adopted an approach that is both pragmatic and instructive. We called on the skills of our experts in order to gain a greater understanding of the key focus areas, the progress made and the difficulties currently faced, while also tapping into the many assessments and summaries produced by specialists in the field, including the International

Energy Agency (IEA). Throughout this book we have referred to the IEA's Net Zero Emissions by 2050 Scenario and used it as a benchmark for the efforts required to achieve a low-carbon energy system.

In addressing the issues of generation, distribution and consumption side-by-side, we wanted to express our conviction that meeting these challenges will require us to use all the levers available, through a process of continuous innovation. This will mean developing the production of renewable and low-carbon energy, improving transmission and distribution systems, enhancing energy efficiency, promoting energy conservation, while also perfecting and rolling out carbon capture, utilisation and storage technologies and implementing measures to offset the emissions that cannot be avoided. To this end,

Artelia has chosen to consider the energy system in its entirety and to support all stakeholders who seek to progress in the fight against climate change and improve access to energy.

At a time when many people are voicing concerns about the slow pace of change in face of the climate emergency, this book also aims to shed light on the complex nature of the energy system and use some of the projects to which Artelia is contributing to present all the efforts that are already being made to progress towards net zero by 2050.



roducing low-carbon energy on a massive scale

The need to drastically reduce the use of fossil fuels is now widely accepted by governments and international organisations.

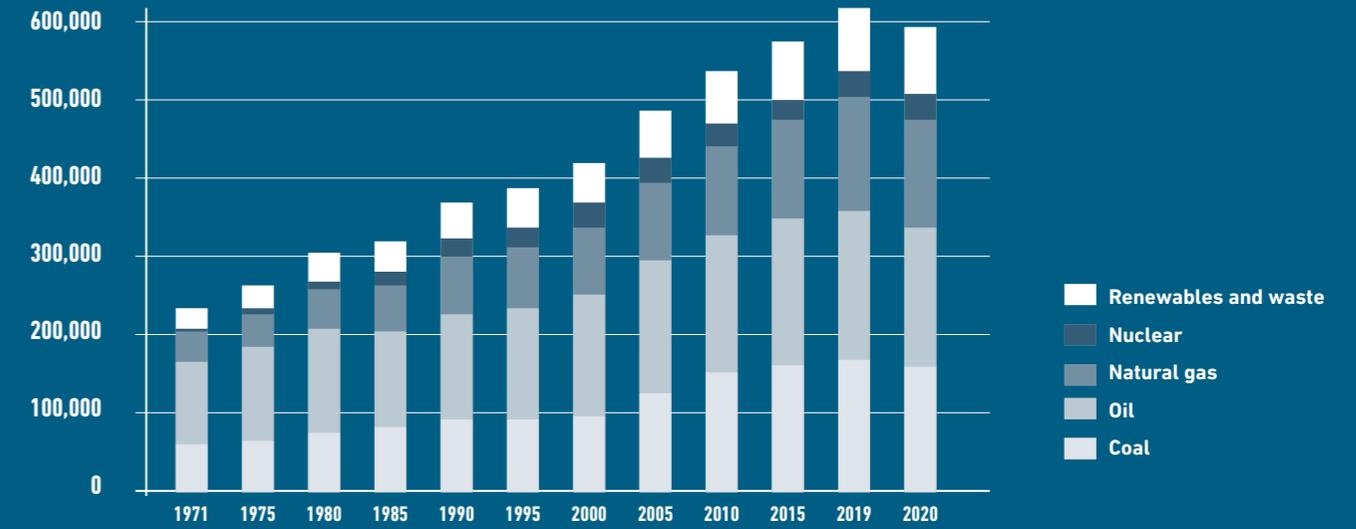
The goal is both to reduce atmospheric CO₂ emissions, the leading cause of climate change, and limit the geopolitical and socio-economic tensions related to the use of these fuels.

That may be easy to say, but in reality this transformation poses an unprecedented challenge. Coal, oil and gas underpin our current energy system, a legacy of a change that began in the nineteenth century with the industrial revolution. On a global scale they represent 80% of the primary energy sources mobilised and account for 60% of total electricity generation. The very idea of substituting one energy category for another is a first, because, over nearly 150 years of population growth and

industrialisation, humankind has been accumulating the energy sources it needs to continue functioning and developing.

Meeting this huge challenge of phasing out fossil fuels will first of all mean speeding up the development of all the low-carbon energy sources that we have already mastered. Supporting the boom in renewables (water, sun, wind, geothermal, biomass, etc.) is hence a key priority for the European Union and many governments. New investments are being made in nuclear power in order to provide low-carbon baseload electricity. Emphasis is also being placed on recovering energy from biomass in the form of heat, biogas and electricity. Within this

PRIMARY ENERGY GENERATION BY SOURCE WORLDWIDE (IN PETAJOULES) [IEA 2022]



shifting energy mix, fossil natural gas continues to play a major role as a transitional energy source, the priority being to remove coal and oil from the energy equation.

This transformation of the generation system relies to a great extent on electricity. The rapid growth in the consumption of energy in the form of electricity over the past few decades will accelerate inexorably, largely due to the rapid growth in electric vehicle use and the ongoing electrification of industrial processes. Hydrogen is also seen as a major energy vector for the decades to come.

Of course this shift in generation cannot be dissociated from the variation in demand, which depends directly on global demographics, the growth in consumption in developing

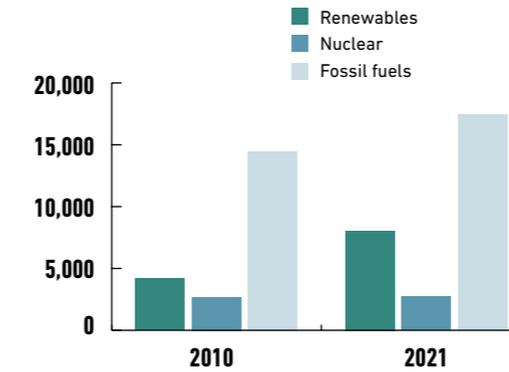
countries, and the progress made in achieving energy efficiency and conservation. The strategies and timelines also vary widely from one country to another, but the effort to be made everywhere is massive.

This is why Artelia is contributing to the roll-out of all low-carbon energy sources. We have long been pioneers in the field of hydropower, and have expanded our expertise over the decades to embrace the complete renewable electricity mix. We are also contributing actively to the revival of nuclear power, the decarbonisation of heat production, and the expansion of hydrogen as an energy vector.

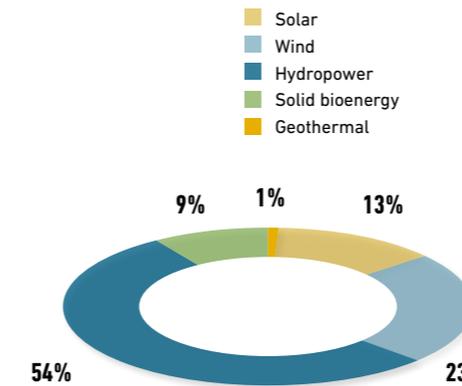


Quickly doubling the proportion of renewables in the electricity mix

Global electricity generation is still largely dominated by fossil fuels. Replacing these - especially coal and oil - with renewable energy sources that have a small carbon footprint is hence central to the Net Zero by 2050 strategies. Hydropower is the largest and most mature of these, and the aim is now to associate it with wind and solar photovoltaics, which have seen remarkable growth in the past ten years and must now be deployed at an even faster rate. According to the International Energy Agency (IEA), the share of renewables in the electricity mix must be increased from 30% to 60% by 2030 in order to achieve the goal of net zero by 2050. This increase will have to make allowance for the intermittent and variable nature of these sources, which can be substantial, as demonstrated by the droughts and the fluctuations in wind output that occurred in 2021 and 2022.



Global electricity generation by source in TWh [IEA 2022]



Breakdown by source of global electricity generation from renewable sources in 2021 [IEA 2022]

A SOLID HYDROELECTRIC BASE

Just over 15% of global electricity generation comes from hydropower, making it the largest renewable source currently harnessed to produce electricity. Approximately 70% of the total production capacity is shared by ten countries (China, Brazil, Canada, the United States, Russia, India, Norway, Turkey, Japan, France), and hydropower even predominates in the electricity mix in some of these (Norway 93.4%, Brazil 63.5%) [IRENA 2020]. Hydropower generation has tripled since the 1970s, with the construction of large schemes in South America, Africa and Asia. Moreover, in the latter two geographical areas there is still considerable potential for development which, if it were realised, would make some countries less dependent on fossil fuels.

Hydropower is mature sector that benefits from the lessons learned from more than a century of studies and innovations to optimise structures and facilities built in natural configurations that are never the same. Its developers were faced very early on with the issue of fluctuations in output, since seasonal and annual flow rates in mountain watercourses can vary significantly. A complete regulation system based on storage dams has hence been developed over the decades. This storage capacity, which provides a means of stabilising power generation, reducing flooding and safeguarding water supplies, has now made the sector highly flexible and robust.

Artelia has supported this development since the outset, participating in the construction of the first facilities in the French Alps more than a century ago, and gradually working on projects all over

the world in the intervening years. Today, efforts are concentrating on several areas. The first is the ongoing development of high-capacity hydropower schemes, which provide strategic power supplies for the regions where they are located. We are about to finish supervising the construction of the Nam Ngum 3 (480 MW) and Nam Ngum 4 (240 MW) power plants in Laos, a country which intends to make hydropower the cornerstone of its development. We are also involved in many projects in Africa, such as supervising the works on the Rusumo Falls hydropower scheme (90 MW) on the border between Rwanda and Tanzania, the Isimba scheme (183 MW) in Uganda, and Kingulé in Gabon (34 MW).

We are contributing to the studies for the Grand Inga dam on the Congo River, a colossal project with the potential to double the amount of hydropower generated on the African continent. Our teams of hydraulic, civil and environmental engineers are working in particular on the various phases of construction, which are likely to be spread over several decades, and on the damming of the Congo, a challenge dwarfing all those that have gone before, as the river's mean annual flow rate - one of the highest anywhere in the world - reaches almost 40,000 m³/s and it is up to a hundred metres in depth. At the same time we are also designing a scheme on the Saint Paul river in Liberia comprising a new hydropower project called SP2 (150 MW), a 44 MW extension of the existing Mount Coffee power plant (88 MW) and the creation of a 90 MW solar farm. We are also reviewing the studies for the huge Julius Nyerere scheme in Tanzania (2115 MW).



XAVIER DUCOS

Head of Dams, Hydropower & Infrastructure

Artelia has been contributing to the development of hydropower for more than a century. Over the decades we have perpetuated and honed this cutting-edge expertise. Today, our specialist teams are designing and overseeing the construction of some unique facilities. Our physical scale modelling laboratory, our numerical modelling skills, the calculation methods we have developed for large concrete structures, and our extensive knowledge of hydromechanical equipment are being called on for some of largest and most complex hydropower schemes in the world. We perform a broad range of assignments from due diligence for funding agencies to the design of schemes and the supervision of their construction.

The creation of pumped-storage schemes is another flourishing area of development, as it offers a means of boosting water storage capacities for power generation and, hence, of improving the stability of distribution networks. We are working on several schemes of this type such as Hatta (250 MW) in the United Arab Emirates, Abdelmoumen (350 MW) in Morocco, Nestor in Saudi Arabia (2100 MW), Attaqa in Egypt (2400 MW) and Ingham in Australia (3500 MW), one of the largest-capacity facilities of this kind anywhere in the world. Some mixed projects are now starting to emerge, combining solar and wind generation with pumped-storage facilities and harnessing the ability to store water to offset the intermittent nature of wind and solar power. Small-scale hydropower is also a solution being used in some countries, including France, where we contribute to the construction of low-capacity (less than 10 MW) power plants of this type. These are often operated as run-of-river schemes, without storage dams, and offer the benefit of being fairly simple to build.

Needs in terms of rehabilitating and monitoring existing dams and facilities are also increasing. After about fifty years in operation, some need to be refurbished in order to restore their optimal production levels. We have completed several operations of this type, including Buyo (165 MW) in Ivory Coast, and Grandes Chutes and Baneah in Guinea (106 MW). Simultaneously, Artelia has developed a range of dam monitoring tools which are used in a large number of facilities in France. Several clients including CNR and

SHEM have adopted our digital solution for monitoring dam and embankment behaviour, which is now an integral part of our online asset and facility management platform.

Over the decades Artelia has acquired state-of-the-art knowledge in dam construction and dam-related issues, including very tall concrete structures and risks in earthquake-prone areas. We have developed calculation methods which are now used all over the world. Our teams of environmentalists and sociologists are also performing studies in Asia and Africa focusing on ways to reduce the environmental and social impacts inherent to the construction of dams. All large-scale hydropower projects now have substantial budgets to take these objectives into account.

Hydropower may be a hundred years old, but it is clearly a thriving industry which is now being asked to make some additional efforts. As well as being used for baseload power generation, it is easy to mobilise during periods of peak demand on account of its storage capabilities. Many hydropower projects are coming into being today thanks to interest from private-sector players who help to finance them, alongside the public sector. More remains to be done, however, to reduce the carbon and environmental impact of large-scale schemes. Anticipating the effects of climate change on the water cycle and the flow conditions of watercourses is another area to which we are devoting a great deal of strategic thought, as it will probably be a prominent issue in the years to come.



Standing at a height of 210 m, Nan Ngum 3 in Laos is one of the world's tallest rockfill dams with an upstream facing. More than 2000 people have been mobilised on site by the works contractor, while a hundred or so others are overseeing the operation. Nearly thirty Artelia staff members have contributed to the studies and supervised the construction of this dam.

Located near the town of Hatta in the Emirate of Dubai, this power plant makes use of an existing downstream reservoir (6.5 Mm³) in conjunction with a newly-built upstream reservoir (5.5 Mm³) and a 300 MW powerhouse equipped with pump-turbine units. The principle consists in using excess electricity from the grid to transfer water from the downstream basin to the upstream basin, so it can drive the turbines once again to generate electricity during periods of peak demand. Our teams acted as designers for the civil engineering contractor in charge of constructing this scheme.





JEAN-MICHEL BILON

Development Director
Urban and Regional Development

The onshore wind power sector has now become more mature. At the outset, the aim was mainly to build high-performance wind farms and feed the electricity they produced into the grid. But now, we know how to build them quickly and produce low-carbon electricity at an attractive cost. So now we are looking at ways to store and optimise this additional energy, by associating wind with solar and hydropower, for instance. The question of rehabilitating the oldest wind farms also needs to be addressed.

THE INCREASING DEPLOYMENT OF WIND POWER

As with hydraulic energy, the first attempts to produce electricity using wind date back to the end of the nineteenth century. However, it took much longer to develop on a large scale because of the intermittent nature of the wind itself, the performance of the motors and competition from other sources (in particular fossil fuels). Wind power finally began to make inroads in some pioneering countries, such as Denmark, during the oil crises of the 1970s, but it was only in the early 2000s that it really began to be deployed on a global scale. With technological progress, the industrialisation of manufacturing processes and public support for renewable energy, the sector could then reduce its costs and offer increasingly competitive prices per kilowatt/hour compared with those for fossil fuels and nuclear energy.

Between 2002 and 2021, global output of wind-generated electricity thus rose from 50 to 1 TWh, making wind the second most important source of renewable electricity. China and the United States together possess about 50% of the total installed capacity, ahead of Germany, India, Spain, the United Kingdom, France, Brazil, Canada and Italy, which together account for around 30% [IRENA 2020]. Onshore facilities produce over 90% of this energy, with offshore wind power being concentrated mainly in Europe, even though more and more countries are starting to show interest in it. Much still remains to be done, as the International Energy Agency claims

that it would be necessary to produce nearly 8000 TWh of wind power by 2030 in order to achieve net zero emissions by 2050.

In light of this forecast, the public authorities in many countries are now encouraging the development of wind power. This is progressing onshore, where the technology for creating additional wind farms is fully mastered. The main obstacle to such projects is the frequent opposition from local residents on account of the visual and acoustic impacts of such facilities. This is one of the reasons why the European Union (EU) has made offshore wind power a central pillar of its strategy for promoting renewable energy. The coastal regions of the EU offer a combined installed capacity of 14.6 GW, and the objective is to reach 60 GW by 2030 and 300 GW by 2050. Though offshore facilities are usually more complex to build and maintain than onshore ones, they benefit from more regular winds and the turbines can be bigger and more powerful. The largest offshore turbines can now reach 250 m in height, with unit capacities of between 13 and 15 MW.

Artelia has constantly striven to expand its skills in order to take part in this expansion of onshore and offshore wind power. We are working with various developers, performing preliminary studies, proposing turnkey solutions, providing design services and supervising construction, or acting as



In France, Artelia has supervised the turnkey construction of several onshore wind farms, including "Energies entre Tille et Venelle", which comprises 16 turbines with a combined production capacity of 107 GWh/year.





YANN RENOUL
Project Director
Maritime Structures

We have gained solid experience in the field of submarine cables and landfalls for wind farms by working on most of the projects implemented by the French national operator RTE (Réseau de Transport d'Électricité). We are currently working on all connection aspects for the Leucate, Gruissan and Groix farms, and on the landfall for the Bretagne Sud project, the first commercial wind farm in France involving floating turbines, which includes three cables nearly 50 km long.

technical experts. We now offer services including site development and working design studies for turbine bases as well as the supervision of turbine erection and connection to the grid, while at the same time managing acoustic studies via our subsidiary Gantha. In less than 10 years, we have contributed to the installation of over 250 turbines with a total capacity of around 1 GW. Recently, we took part in the creation of the Tan Phu Dong 2 farm in Vietnam (12 turbines, 50 MW capacity) and in France we are currently completing the turnkey construction of the Bois des Sault farm (6 turbines, 18 MW capacity). Also in France, we are reaching the end of our design and construction supervision services for the Trois Cantons wind farm (6 turbines, 18 MW capacity), and are about to begin supervising a new farm of six turbines in the Champagne region.

We have also invested considerably in offshore wind power. Since the early 2000s, our maritime engineering specialists have worked on many issues that are crucial for the deployment of such facilities: environmental studies, physical and economic potential studies, the design of port infrastructure and offshore electrical substations, the stability and landfall of submarine cables, the protection of underwater foundations against scouring, preliminary studies of dismantling operations, etc.

With the arrival in our Group of the French and Norwegian companies Principia and Dr.techn. Olav Olsen, we have definitely taken a leap forward. Both experts in designing offshore structures, these companies create

and study the behaviour of different types of support (jackets, monopiles, floats) for offshore turbines. With their respective specialities (steel and concrete), each has become deeply involved in the development of floating wind turbines. In contrast to jackets and monopiles that are placed on the seabed, floating turbines are based on a semi-submersible structure held in place by anchor systems. This innovative technology means that turbines can be installed further away from the coast, at depths of more than 60 m, where the winds are more constant and the visual impact is minimised.

Through its various teams and subsidiaries, Artelia is increasingly involved in developing the wind power sector alongside developers, EPCI construction firms and equipment manufacturers on all types of technology, drawing on the wealth of experience its entities have acquired over the last decade and more. If the development forecasts are achieved, wind power could become the world's principal source of renewable electricity alongside solar power [AIE]. However, certain parameters must also be taken into account in this sector as well in order to safeguard it and make it completely virtuous. These are related to both the environment, with the expected increase in extreme climate events, and the availability of the materials required to make wind turbines with ever increasing capacities. Controlling their complete life cycle, right through to recycling their components, is one of the challenges the sector faces.



OO-STAR Wind Floater (patent), developed by Dr.techn. Olav Olsen AS, property of Bouygues Travaux Publics. Illustration: Dr.techn. Olav Olsen AS

OLAV WEIDER
Managing Director of Dr.techn. Olav Olsen

We have been involved in the development of floating wind power since 2004. We have assisted Equinor and participated in R&D projects supported by the European Union and Norwegian industry. That is how we came up with the concept for the OO-Star, an adaptable concrete floater capable of supporting large wind turbines in difficult sea environments with high waves and strong winds.



THIBAUT TRANCART
Chief Executive Officer of Principia

We have a decade of expertise in floating wind power, and our track record includes more than 120 multi-disciplinary engineering projects involving the design of floating foundations. For example, we are currently helping Marine Power Systems to develop a modular floating platform technology. This system is designed to keep the mass of the platform to a minimum and facilitate its maintenance. Its notable feature is that it can accommodate a wind turbine, a wave energy converter or both at the same time. An initial prototype equipped with a 2 MW wind turbine will soon be tested in real conditions in northern Spain.



On behalf of the developer Neoen, Artelia conducted a comprehensive owner's engineer assignment (technical assistance during the development, construction and commissioning phases) for the 200 MWp Altiplano Solar plant, the second largest in Argentina, at an altitude of 4000 m.

THE DRAMATIC RISE IN PHOTOVOLTAIC SOLAR POWER

The deployment of solar photovoltaics is relatively recent, even though the first cells were developed in the 1950s and operated in space in the decade that followed. With strong support from the public authorities as of the 2000s, the solar PV industry entered a phase of industrial development which has made it one of the fastest, most flexible and most economical renewable energy sources to implement. Back in 2010, solar photovoltaics only generated about 32 TWh of electricity worldwide, but in 2021 it supplied more than 1000, representing an annual growth rate of more than 40% for more than ten years. China owns nearly a third of the total installed capacity, followed by the United States, Japan, Germany, India, Italy, Australia, Vietnam, Korea and the United Kingdom, which account for 50% [IRENA 2020]. As is the case with wind power, considerable further development is needed if the Net Zero by 2050 targets are to be achieved, since it is hoped this sector will supply 7400 TWh of renewable electricity as early as 2030, representing a growth rate of about 25% per year over the decade 2020-2030.

Artelia has witnessed this expansion first-hand, having accompanied it since the end of the 1990s with teams who were already specialised in solar technologies.

Photovoltaic facilities were relatively costly at the outset, and initially reserved for areas that were not connected to power grids. An upscaling then began in the 2010s with construction of the first large-scale generating facilities connected to the grid.

We have contributed to the deployment of power plants of this type in France, Africa, Asia and Latin America. And we are still participating in flagship projects, including some currently underway in Vietnam, where solar photovoltaic output is now capable, at midday, of meeting the national demand for electricity. For our part, we have connected PV facilities totalling more than 3 GWp to the Vietnamese grid in the last few years. For almost 15 years we have been supporting project developers (Green Yellow, Neoen, EDF Renewables, Total Eren, etc.) in various countries by overseeing the construction of power plants with capacities that have increased from a few MWp to several hundred MWp. On behalf of Neoen we have just finished supervising the construction of the Altiplano Solar power plant (200 MWp) in Argentina, at an altitude of 4000 m.

The facilities we install are always isolated and often hybrid, particularly in Africa, to improve people's access to



MATHIEU VRINAT
Project Director
Solar energy

Nowadays, in most countries with sufficient sunshine, solar photovoltaics constitutes the cheapest source of energy, alongside wind. It is one of the fastest growing power generation sectors in the global energy mix. Today it represents between 3 and 4% of global electricity generation, but in ten years' time it is likely to account for between 10 and 20%, and probably 30 or 40% by 2050.



The Ninh Thuan solar farm (168 MWp), for which we provided complete construction management on behalf of the developer, Sunseap, illustrates the upscaling of this form of energy in Vietnam. Significant efforts are also being made in this country to develop rooftop solar power systems as a means of limiting land take. We have just finished commissioning a 26 MWp facility on the roofs of the Huafu site.

electricity. Another major aspect of our activity is introducing solar PV facilities into public spaces and integrating them in residential and commercial buildings. We are increasingly being appointed by industrial firms looking to develop solar PV generation to decarbonise the energy they consume, sometimes at difficult, isolated sites requiring high power ratings. For instance, we are considering ways to replace diesel generators at mines in Africa. All of these efforts count. Even though, in 2021, most of the global increase in PV generating capacities was related to large power plants connected to the grid coming on-stream (52%), the contribution from other facilities is far from insignificant (residential and commercial sectors 28%, industry 19%) [IEA].

Tremendous efforts must still be made if the highly ambitious Net Zero by 2050 targets are to be met, but the sector has a wealth of assets. Thanks to ongoing technological breakthroughs, solar cells are becoming ever more efficient and durable, as are the facilities used to convert and store electricity. A given area of solar panels generates twice as much power today as it did ten years ago, at a third of the cost. The architecture of solar installations, including their mechanical design aspects, is also becoming

increasingly optimised, for instance to improve wind resistance. Power plants have become modular, with components that are easy to replace, and can be quickly dismantled to return the space they occupy to its original purpose. The progress made in the field of batteries is also playing a key role by offering a means of smoothing out the often irregular daily production, simplifying injection into the grid. Storage also opens up the possibility of shifting part of the electricity supply until after sunset, thus delivering a host of system services such as frequency support.

The potential for installing solar photovoltaics on areas that have already been developed, such as carports for car parks and the large roofs of warehouses and industrial buildings, is another major source of growth for the sector. The development of solar projects in conjunction with other uses is also thriving, one such example being agrivoltaics, which involves combining photovoltaic panels and agriculture to produce energy while protecting crops from excessive heat or hail. Installing power plants on man-made water bodies is another growth area. We studied this type of facility for the European Bank for Reconstruction and Development (EBRD) and then produced a preliminary design



NICOLAS JALLADE
Head of the Energy & Environment Department
Artelia Vietnam

We began working in solar photovoltaics in 1996. We were among the pioneers in France and have gained a wealth of experience in its different applications. Our excellent knowledge of solar resources and electricity demand helps us make the right choices, optimise projects for our clients, and accompany them throughout the life cycle of their facilities. We have evolved along with the sector. It has changed a lot, and we are continuing to progress with it.



On behalf of the Italian electricity company Enel, Artelia designed the layout of a floating power plant on a 40 hectare reservoir in Anapo, Sicily. The brief was to create a platform of floating panels measuring about 600 x 200 m while overcoming several technical difficulties: widely fluctuating water levels, and the absence of any possibility for anchoring the platform in the bed (photo on left).

Having helped to build the Rance tidal power station in France, one of just two large facilities of this type in operation anywhere in the world, we are working on the preliminary studies for a newscheme in the United Kingdom (photo on right).



for a reservoir in Italy for the national electricity company Enel. We also installed a solar farm on disused basins at the Port of Marseille, and connected this electricity production to its internal grid. Floating solar farms are often tricky to implement on account of their anchoring systems, but they offer a number of advantages such as conservation of land, better cooling for the panels, and reduced evaporation of water reserves.

But the sector still has to overcome a number of challenges in order to continue growing. Most of these revolve around uncertainties concerning the future prices of materials such as silicon, aluminium and copper, and the difficulties of arbitrating between the uses of sites that would be suitable for

constructing large power plants. However, it is clear that this sector is set to play an increasing role in the decarbonisation of our energy system. Through the consultancy, due diligence and technical assistance services we provide to banks, investors and project developers, we estimate that we have helped to bring a total of almost 5 GWp of solar photovoltaic power generation capacity on-stream worldwide. We are continuing in this vein by building on our ability to work with all the players involved (local authorities, developers, construction firms, equipment suppliers, risk prevention organisations, etc.) and to mobilise in-house all the technical, environmental, economic, industrial risk management and other expertise required for this type of project.

THE STILL LARGELY UNTAPPED POTENTIAL OF MARINE ENERGY

Waves, currents, tides, and differences in temperature and salinity between the surface and bottom of the ocean are phenomena with considerable potential for electricity generation. It is, however, very difficult to harness this potential in an economically and environmentally acceptable way, because few settings on our planet are harsher and more demanding than the marine environment. The contribution of marine renewable energy sources to global electricity generation is hence still relatively small (1.6 TWh in 2021) [IEA] compared to the output from solar, wind and hydropower. With the exception of two large-capacity tidal power stations in France and South Korea, the sector is composed mainly of demonstrators or small-scale commercial projects

resulting from government-supported R&D activities. Financial assistance from various sources stimulated new interest in the sector in the early 2010s, but if the level of output envisaged in the Net Zero by 2050 strategy - 27 TWh by 2030 - is to be reached, it will be essential to move on from the current exploration phase and develop the most promising technologies on an industrial scale.

We began examining ways to harness marine energy back in the 1940s, focusing initially on tidal and wave power systems. It is these early studies that led to our involvement in the construction of the Rance tidal power station (240 MW) in France, which was inaugurated in 1966.



SÉBASTIEN LEDOUX

Project Director
Maritime and Port Engineering

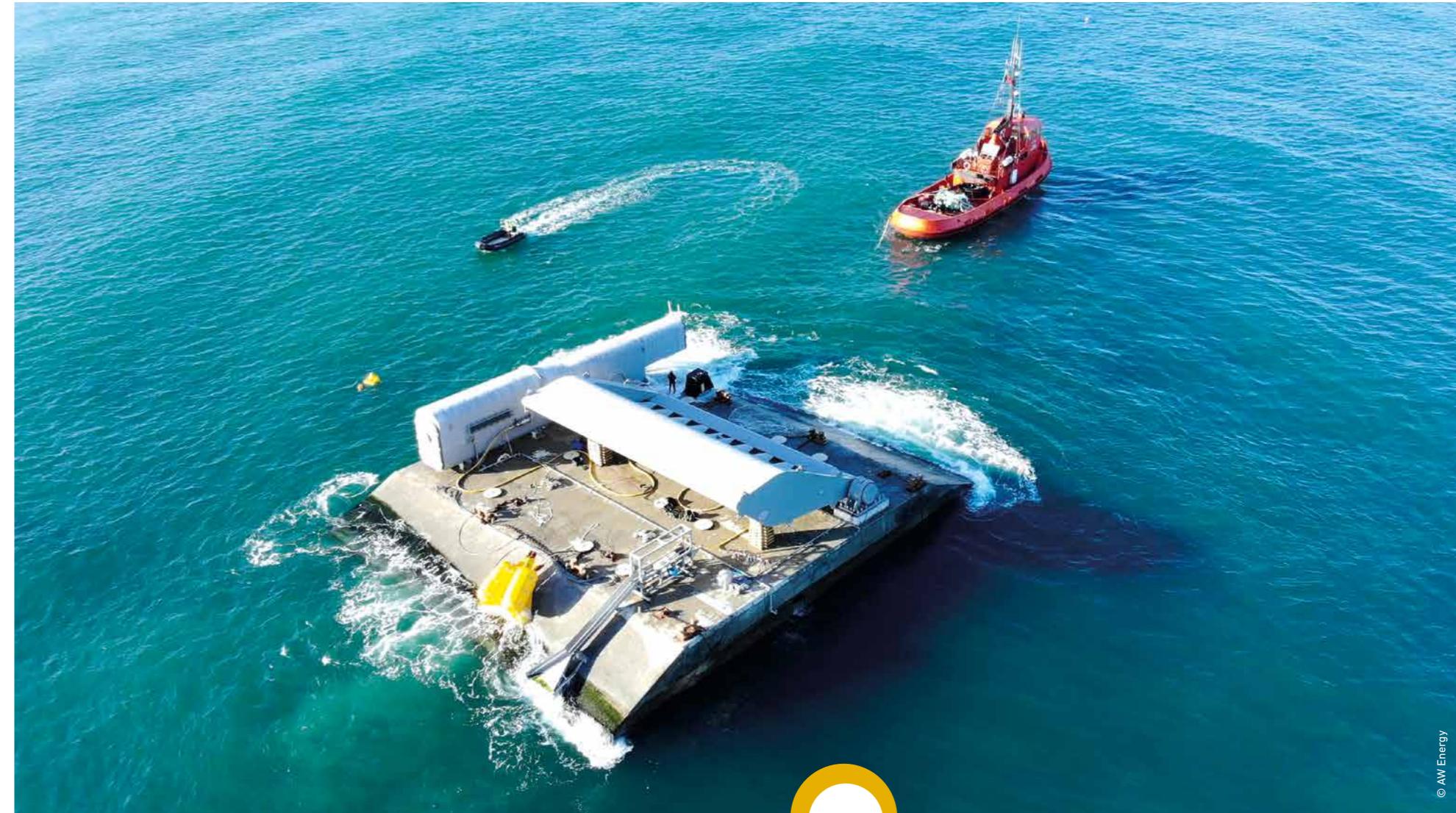
In parallel with offshore wind power, there was a lot of interest in the other forms of marine energy in France in the early 2010s. Continuing in our predecessors' footsteps, in the last few years we have carried out a large number of studies for tidal, wave and ocean thermal energy conversion projects. This work is continuing today, often in the context of European research programmes to which we are contributing our expertise in numerical modelling in particular.

Today we are participating in some new - and for the moment confidential - tidal power projects, in the United Kingdom in particular. These schemes are quite similar to conventional run-of-river hydropower plants, in that they involve closing an estuary with a dam housing a set of reversible motors that are capable of turbinating the flow of water during both rising and falling tides. These technologies have been well honed and their productivity is easy to forecast, but few projects have come to fruition because they require specific configurations, significant investments, and rigorous management of the environmental and social issues inherent to transforming estuaries.

The idea of harnessing wave energy also led us to develop a breakwater system capable of capturing water in a reservoir in order to drive turbines and generate electricity. We have perfected this principle and succeeded in patenting it. Our Norwegian subsidiary Dr.techn. Olav Olsen has been working on another technology and another prototype, the WaveRoller, which taps the back-and-forth movement of waves to generate electricity. The device consists of a hinged metal panel inserted into a mobile concrete barge that is placed on the sea bed. The WaveRoller is designed to be installed in near-shore areas, and was tested successfully in Portugal in 2019. Other technologies for harnessing ocean swell and waves, such as floating systems and oscillating water columns, are being developed around the world.

Ocean thermal energy conversion is another topic we studied in the 1970s and 1980s, and to which we returned in collaboration with Naval Group in the 2010s. Today, rather than depending on complex systems designed to produce electricity from differences in temperature across the water column, the trend is to use this energy directly via a seawater air conditioning system. We are currently working in Sète and on Réunion island (France) on projects of this type, involving drawing seawater through deep intakes in order to cool buildings. Lastly, a great deal of effort is being invested in developing tidal stream generators to transform the kinetic energy of marine currents into electricity. These operate very much like underwater wind turbines, and can be either fixed to the sea bed or installed on floating structures. We have performed a series of studies and simulations for tidal energy farms, and supported a number of developers such as Sabella and Hydroquest in France with the creation of pilot facilities.

We are continuing to collaborate on developing this sector, which still has many technical difficulties to overcome. Strong winds and powerful currents greatly complicate the implementation and maintenance of these facilities, which are also liable to corrode on account of the salinity and may be subject to clogging with silt and sand. The potential from marine energy sources is still as appealing as ever, but much remains to be done before we arrive at reliable, economical solutions to harness them.



Dr.techn. Olav Olsen designed the concrete unit for the WaveRoller, a system that converts ocean wave energy into electricity. The device can be recovered and moved, and is designed to be laid on the sea bed in shallow waters. A demonstrator has been tested on the coast of Portugal.



Relying on nuclear power in a low-carbon energy mix

Accounting for 5% of the total energy output and 10% of electricity generation worldwide [IEA 2022], nuclear plays an important role in the energy system. It is enabling many industrialised countries to limit their greenhouse gas emissions by providing them with a source of low-carbon energy as a complement to renewables. Nuclear energy has been given fresh lease of life amid today's decarbonisation targets and energy crisis, with a revival of programmes aiming to extend the working life of the existing fleet, anticipate its renewal, expand generation capacity and open the industry to newcomers, while consolidating the fuel sector.



After being closely involved in various post-Fukushima studies, we are now performing studies to determine the behaviour of mechanical components of reactors, fuel storage racks and nuclear island lifting equipment, in seismic loading conditions. Some of these studies tie in with programmes to prepare for ten-yearly inspections of the 900 and 1300 MW series.

EXTENDING THE WORKING LIFE OF EXISTING FACILITIES

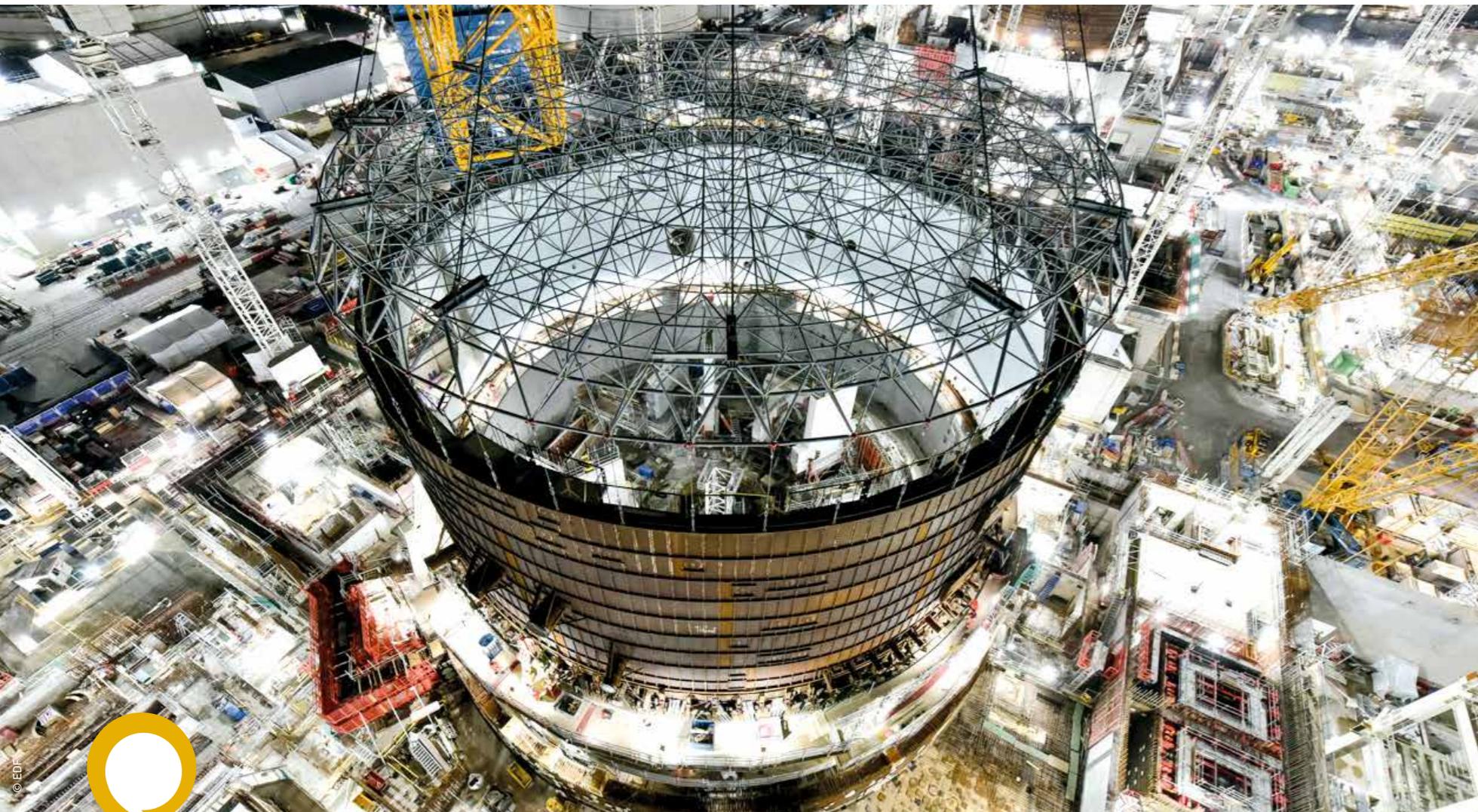
The first major programmes to build nuclear power plants began in the 1970s and 1980s, mainly in response to the oil crises and to enhance energy sovereignty. The United States, Canada, Russia, several European countries (France, Germany, Sweden, the United Kingdom) and a few Asian countries (South Korea, Japan) became major producers of nuclear power in the space of two to three decades. They were joined by other nations including China, which is now one of the world's frontrunners alongside the USA and France in terms of total installed capacity. France stands out with 68% of its energy mix being from nuclear sources, which is the highest percentage in the world [SDES 2021]. At the end of 2021, global nuclear power generation capacity stood at nearly 390 GW, from 437 reactors spread across 32 countries [AIEA].

The 2021 accident at Fukushima (Japan) triggered political decisions in several countries (including Germany, Belgium, Italy, Japan and South Korea) to scale down or stop the use of nuclear power. Having been unable to offset this production loss quickly enough by means of other renewable or low-carbon energy sources, some of these countries have decided to step up their use of fossil fuels such as gas or coal, or to import electricity from their neighbours. Today, the climate emergency and geopolitical tensions such as the Russia-Ukraine war are placing natural gas supplies under pressure and putting nuclear power back on the table as a major low-carbon component of the energy mix.

Although most of the nuclear power plants currently in operation are approaching the end of their working lives,

according to the initial design assumptions, specialists now view extending them to be a rational and profitable solution, even considering the investments required to keep them operating at the requisite levels of safety. Several plants have already been extended to 60 or even 80 years, and the prospect of extending some to 100 years is even being considered. Several countries have embarked on projects to extend the lifespans of their plants (the USA and France), postpone the shutdown of operational reactors (Belgium, Germany), restart many of their facilities (Japan) and reverse previous decisions to phase out nuclear power (South Korea).

For several years, Artelia and its subsidiary Principia have been providing engineering services for EDF's fleet in operation, working on their cold source hydraulics (liquid containment, water intake, outfall, etc.). We have performed several studies in this field for French nuclear power plants. We are also contributing our expertise in the numerical simulation of mechanical component behaviour, fluid flows and thermal atmospheres applied to a wide variety of situations. Most of these studies are carried out as part of preparations for forthcoming ten-yearly inspections for the 900 and 1300 MW series, and projects examining extreme heat and cold, ultimate water sources, liquid containment, and damage by external phenomena - including earthquakes. The studies comply with the requirements of nuclear safety and, in many cases, aim to increase the safety levels of facilities in line with the recommendations of the French nuclear safety authority (ASN).



Drawing on our previous experience of the Flamanville EPR unit, and after designing the liners and various components for the pools in the Hinkley Point C reactor building, we are currently supervising the construction works.

NEW INVESTMENT PROGRAMMES

In addition to extending the working lives of the current fleet, work is underway to expand generating capacities and anticipate the replacement of facilities that reach the end of their lifespans. To achieve net zero by 2050, the International Energy Agency estimates that global nuclear power generating capacity would have to be increased by 100 GW to reach a total of approximately 500 GW by 2030. Given that the replacement of the current fleet must be anticipated in parallel, creating about 300 GW in new capacity is now being considered. Meanwhile, the International Atomic Energy Agency (IAEA) is banking on the current nuclear electrical capacity being replaced identically as a minimum, and anticipates under its 'high case scenario' that this capacity will be doubled to almost 800 GW in the coming decades.

Asia is currently the region seeing the most intense development of nuclear power. Leading the pack, China is implementing an ambitious programme, with more than 50 reactors brought on stream in the past 30 years, 18 currently under construction and many more at the design stage. Investment programmes have also been announced in Europe (France, the UK, the Netherlands, the Czech Republic, etc.). Several countries which have only recently adopted nuclear energy have also instigated projects to convert part or all of their current fossil fuel-based generating capacity (e.g. Poland).

In France, the EPR2 programme being implemented by EDF entails building six new

reactors (or even eight) at three sites. Each reactor will deliver 1670 MW. The first phase of the programme, located in Penly in France (2 reactors) is currently at the public consultation stage. The goal is to bring them on stream by 2035-2037. Small Modular Reactors (SMR) are also being designed in several countries to complement these high-capacity reactors and offer, among other things, an alternative to fossil-fuel power stations. In a break from the usual practices in the sector, they are modular, built in factories, and assembled on-site. Their key advantages include a lower price, making them more accessible to new players, simpler integration into existing distribution networks, and shorter delivery times. The French nuclear industry is developing several SMR concepts including NUWARD™, spearheaded by EDF, which is consolidating lessons learned by the key players in the industry.

Having acquired a wealth of multi-disciplinary engineering expertise and a solid track record on many complex projects, we are capitalising on this to ensure that the French nuclear programme is a success. We are involved in EPR projects in France, Finland, China and more recently in the UK, in particular in the design and regulatory justification studies for pools (FA3, HPC, etc.) and we are also participating in both the civil and transport engineering aspects of the NUWARD™ project.



MICHEL ROCHON
Head of nuclear development

Energy sovereignty and reining in greenhouse gas emissions are two of the major challenges of our time. Nuclear power is one of our key assets in rising to these challenges. France is a great nuclear nation and EDF is one of the world's leading operators in terms of the size of its installed fleet and the wealth of expertise it has developed over several decades. The French nuclear industry, to which Artelia belongs, is contributing actively to the energy transition thanks to the experience it has acquired in the development, industrialisation and operation of a large number of reactors (energy, research, nuclear propulsion).



YANN HILTCHER
Site director
Artelia Industrial Facilities,
Pierrelatte

We are currently involved in dismantling the Phénix experimental reactor at the Marcoule site (France), which was cooled with liquid sodium. We are tapping into our nuclear chemistry expertise (general installation and processes involving liquids and gases) to design a sodium treatment loop with a resin filtration circuit that will trap the caesium. The nuclear safety requirements are so stringent that each proposal must be fully justified, as a result of which each calculation note is carefully checked following a graded approach, in the spirit of ISO 19443.

THE BACK END OF THE FUEL CYCLE AND DISMANTLING OF FACILITIES

Once it is no longer used in a reactor, the spent fuel remains highly radioactive and subject to a strict monitoring and traceability protocol in accordance with nuclear safety regulations. It is initially stored in a pool, thus benefiting from the radiation barrier provided by the water, before being processed and finally packed in suitable containers which are stored at secure sites and monitored continuously.

Some countries, including France through the Orano company, use a reprocessing technology which produces usable fuel from part of the spent fuel (MOX) and reprocesses the waste in order to minimise the proportion referred to as ultimate waste. Although this long-lived high-level radioactive waste (HLW) accounts for only relatively small volumes, its long-term storage is an area of special attention and extensive study. Deep geological disposal is now forming the focus of a number of international studies (Yucca Mountain in the USA, Cigeo in France, Olkiluoto in Finland, Östhammar in Sweden, Gansu in China).

The decommissioning of nuclear power facilities also involves deconstructing and treating the structures, equipment and materials that have been exposed to radiation during their operating lives. The treatment protocol is specific to each component and its radioactivity level. Automated or remotely-operated systems are used extensively

for these operations, and the teams involved are protected and subject to strict dosimetry monitoring rules. Decommissioning a nuclear facility is a long process.

More and more nuclear reactors will move into the decommissioning phases in the near or more distant future. In France, various dismantling activities are already underway at the Marcoule and Cadarache sites. The Fessenheim power plant, which has recently been shut down, is about to become a pilot site for the dismantling of pressurised water reactors (PWR), which are used in most of the plants currently in operation around the world. The site will be used to industrialise processes, and to test and accredit equipment. It will also have facilities for recovering very low-level activity metal materials in order to bolster the circular economy.

Artelia has participated for many years in major fuel-related projects, from general installation to transport and handling systems and the complete design of buildings and facilities containing hot cells. The experience we have gained through contributing to this wide variety of projects will be invaluable for decommissioning high-capacity reactors in the future.



We are supporting the ITER project by helping to design mechanical components and thermal systems for the vacuum chamber.

FUTURE TECHNOLOGIES AND EMERGING APPLICATIONS

A variety of research projects are currently underway in the field of nuclear energy, requiring the construction of dedicated reactors and facilities. Several international projects are focusing on developing and industrialising fast neutron (fast breeder) reactors, using so-called "spent" fuel as their energy source. On reaching the end of its operating cycle in a nuclear reactor, the fuel still contains a large amount of energy that can potentially be harnessed. The major benefit of fast-neutron reactors is hence that they significantly reduce the quantities of ultimate waste, while limiting the need to use natural uranium resources.

Looking beyond nuclear fission, the source of energy used today, nuclear fusion is also the focus of a great deal of research, seeking to replicate the processes that occur inside the sun. The challenge is so colossal that 35 countries have joined forces in the ITER scientific programme, pooling expertise, industrial resources and funding with a view to designing a large-scale demonstrator. While fusion has great



CYRIL HAUER
Head of Industrial and Nuclear Facilities

We have solid know-how in the design of nuclear buildings and facilities, including areas such as ventilation, power, lighting and data cabling. In France and Denmark we are currently designing facilities for storing components dismantled from research reactors. On the strength of this experience, as well as what we have learned through overseeing a wide variety of complex large-scale projects, we are now involved in the area of 'new' nuclear power, with an ambition to contribute to meeting the challenge of the energy transition.

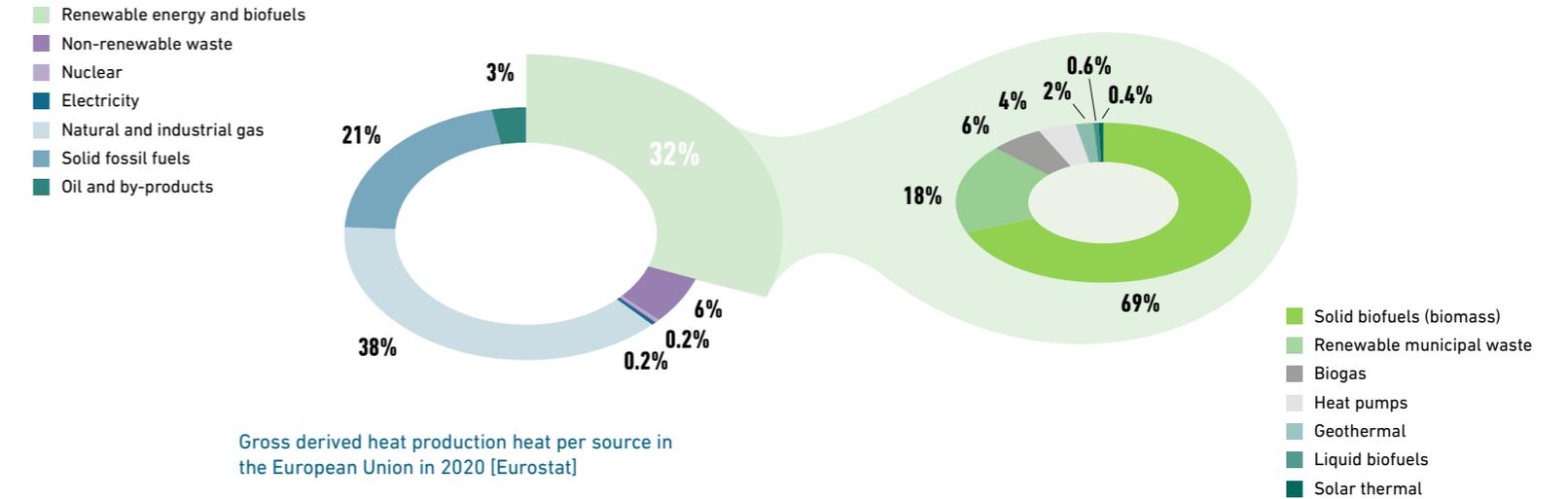
potential (little ultimate waste, very high level of nuclear safety), several decades of research and experimentation will probably still be required before facilities can be developed to generate, control and exploit this highly complex process and then deploy it at an industrial scale.

As one of the industrial partners in the ITER programme, we are contributing our expertise in lifting systems and in modelling the thermomechanical behaviour of components interfacing directly with the Tokamak experimental machine and the thermal conditions in the cryostat for various operating configurations.



Decarbonising heating and cooling production by combining several sources

Approximately 50% of the energy consumed worldwide is in the form of heat. Whether it be for cooking food, heating spaces and water, or industrial manufacturing operations, heat is still produced mainly by using fossil fuels, and in particular gas. In addition, there is growing demand for cooling systems, which are also major consumers of energy. Successfully decarbonising heating and cooling production is therefore a major area for progress in the Net Zero by 2050 scenarios. As with electricity, the first goal is to prioritise low-carbon sources by aiming for sustainable biomass usage, and greater reliance on geothermal and solar thermal energy.



FOCUSING ON WOOD AND BIOMASS COMBUSTION

For a long time, burning wood or animal excrement was the commonest way of producing heat for warmth and cooking. Such traditional use of biomass, generally involving burning on an open fire with a mediocre level of energy efficiency, is still widespread throughout the world, even though it has largely been replaced by the use of coal, oil and gas in developed countries. In parallel with low-power individual or collective boilers, large thermal power plants that exploit these fossil fuels have been created everywhere over the years in order to produce heat and electricity for distribution networks and industrial sites. In recent years, however, the climate emergency and the rising price of hydrocarbons have begun to reverse this development.

Once again, the trend is to rely on wood and biomass as low-carbon and renewable energy sources. Since plants capture atmospheric carbon through the process of photosynthesis as they grow, burning them is theoretically a neutral operation from the point of view of CO₂ emissions. However, in order to guarantee

the sustainable nature of this process, the renewal of the biomass used must be managed intelligently, while minimising the impacts of its use on biodiversity and avoiding jeopardising food production. By using more energy-efficient boilers, power plants that operate with fossil fuels have thus begun converting to biomass (wood, straw, wood waste and pellets, etc.). This movement is now gathering impetus.

Artelia is assisting with these changes in a number of countries, especially in Denmark, which has traditionally relied on thermal energy and has extensively developed its heat distribution networks. Having successively used coal, oil and gas, the country is now aiming to dispense completely with these fossil fuels by 2050 in order to produce its heat and electricity. For about 15 years now, Danish power plants have been converting their facilities to operate with wood, wood chips and pellets, and straw, a material that feeds many boilers in the farming regions of Denmark. We have contributed to many of these transformations,



JACOB STEN PETERSEN
Business Development Director,
Energy & Industry
Artelia Denmark, Sealand

As consulting engineers, we are involved in the entire process, from initial planning up to the point where the end customer can turn on their radiator. We help Danish town councils and heating companies to make the best choices in terms of production and network, budget and schedule, using different sources (biomass, solar thermal, recycled waste, etc.) and technologies (production, recovery, waste-to-energy, storage).

including the heating networks of Funen and Studstrup, two 150 MW plants which have been converted from coal to wood chips and pellets respectively. In Copenhagen, we have recently completed the installation of a fourth biomass combustion unit at the Amager plant, one of the largest facilities of its type in the world.

In France too, biomass is considered to be a substitute for fossil fuels in heat production. The government is encouraging conversion schemes via subsidies and increasingly stringent regulations (such as the banning of fuel-burning boilers in new housing as of 2022). Over the past ten years or so the country's main heat production facilities have started to convert, and we are involved in this movement at various levels.

We work at the institutional level by conducting technical and economic analyses of biomass cogeneration for Ademe, the French Agency for Ecological Transition. We work on behalf of local authorities, for example when new business parks are being created, with a view to installing biomass power plants and creating heat networks, as is the case at present in Lorient and on the Paris-Saclay plateau. We are also involved in similar operations on behalf of industrial companies that wish to decarbonise their heat and steam production facilities. At the same time we are taking part in a number of innovative operations. We have incorporated a pilot biomass gasification unit

For several years we have been helping the Amager production plant that provides district heating and electricity for more than 500,000 residents in Copenhagen (Denmark) to convert from fossil fuels to biomass. We have recently finished designing and managing the construction of a new block, BIO4 (rated output 550 MW), which operates with wood chips.

at the TotalEnergies site in Mardyck, in France. This process helps to improve combustion efficiency and reduce emissions.

Lastly, our French and Danish teams regularly work on the modernisation of fume treatment systems, a field in which considerable progress has been made in recent years.

Alongside this renewable sector of "clean" wood and biomass, the combustion of end-of-life wood derived from the furniture and construction industries, is another means of producing heat. Similarly, the practice of creating RDF (refuse-derived fuel) from non-hazardous waste is currently spreading. These two processes are converging with practices that have been commonplace for a long time and on a large scale in the household waste treatment sector, where the heat produced by incineration is now almost always recovered. However, the logic behind these usages based on waste-to-energy and waste heat recovery is slightly different and will be discussed in the third part of this book.



FROM HOT TO COLD

Cooling production has become increasingly important over the years as air conditioning for homes and workplaces has expanded, and as industrial facilities requiring powerful cooling units, such as data centres, have become more common. Here too, creating large collective cooling production and distribution facilities, sometimes combined with heat production, offers numerous benefits in terms of energy efficiency and emissions control. We are working on several such facilities (Paris-Saclay business park, university hospitals in Denmark) that involve virtually the same issues of decarbonisation as those connected with heat production. We are also building seawater-powered facilities that aim to use cold water from the seabed to supply air conditioning (SWAC) networks.



MICHEL GALAS
Technical Director for Energy
Urban & Regional Development

Sustainable wood and the stewardship of forest resources are subjects receiving attention at European level. The aim is to use first of all the leftovers from timber cut for construction and carpentry, and to use green waste, sawdust and wood chippings in order to avoid cutting down trees just to burn them. The aim is also to prioritise supplies from areas close to where the wood is consumed.

In times when gas was very cheap, biomass was not competitive. But with the current crisis and the steep rise in the price of gas, biomass solutions may become so with little or no subsidies. Everything will also depend on the level of carbon taxes applied to encourage the use of virtuous energy sources. In any case, it is necessary to find solutions for producing renewable energy on a massive scale, and I believe that biomass has its place in this movement today.



KENNETH GRAA
Business Development Director,
Energy & Industry
Artelia Denmark, Aarhus

Several of our clients have commissioned us to improve their heat production by installing solar thermal facilities. We carry out initial studies to determine whether the investment is worthwhile, and then design the facility and supervise project implementation through to commissioning of the solar farm.

THE ADDITIONAL CONTRIBUTION OF GEOTHERMAL AND SOLAR THERMAL ENERGY

Exploiting solar radiation and the differences in temperature between the surface and subsoil are other ways of producing low-carbon heat and helping regions to become autonomous from the energy standpoint. These sources are unevenly used throughout the world and still account for a relatively small proportion of global energy production. They are, however, becoming more commonly used for both individual facilities (solar water heaters, geothermal heat pumps) and for much more extensive collective facilities intended to supply large buildings and heating networks.

With regard to solar thermal energy, there are several large power plants of the so-called concentrating type, consisting of mirrors that focus solar radiation in order to heat a fluid to very high temperatures. The other, more common, solution involves using panels that capture and transmit solar heat via a water circuit. The temperatures reached are generally lower (up to 60°C), but this type of facility is much easier to build. This solution is currently deployed to supply some heating networks, as an addition to other energy sources. Artelia's teams in Denmark have worked on a large number of facilities of this type, sizing the solar panel arrays and calculating their orientation in order to optimise heat production. Today, our French and Danish teams are studying the implementation of solutions of this type for the Lille urban area in France, which wishes to increase the proportion of renewable energy used in producing heat for its municipal network.

In the field of geothermal energy as well, several types of facility are implemented in order to

exploit heat from the subsoil, which increases with depth and can vary depending on the geological configuration of the site in question. Deep geothermal systems involve tapping water from aquifers situated several hundreds of metres below the surface, removing the heat it contains and then returning it to its original location. Such facilities are relatively expensive and require complex drilling operations, equivalent to those needed to extract hydrocarbons. The water obtained by such operations can be at temperatures of more than 100°C, in particular in active volcanic regions. Surface, or very low-temperature, geothermal systems are more accessible. These involve tapping heat from the subsoil or shallow aquifers and delivering it via a heat pump. In most cases the facilities are located at depths of less than 200 m and at average operating temperatures of between 10°C and 30°. Several technologies can be used. Either, as in the case of deep geothermal systems, they involve tapping water from aquifers, when they exist, by creating one well to abstract the water and another to return it. Or heat is tapped directly from the soil using a vertical probe or array of probes through which a heat transfer fluid flows. In some cases, the tapping system can even be incorporated directly into the foundation of the building.

Artelia has gained extensive know-how in the design and construction of such surface facilities by mobilising its hydrogeology specialists, so that today they have several decades of experience. With our experts and modelling systems, we are able to offer services right from the preliminary study stage in order to evaluate the resources and technologies that can be exploited. We analyse



We assisted the Stege Fjernvarme district heating plant in Denmark with its project to create a solar thermal facility, which today covers 20% of its heat requirements. We acted as consultants from the initial profitability analysis stage through to commissioning of the facility (photo on the left).

In Grenoble (France), to simulate the impact of each new geothermal facility, we built a hydrogeological model covering an entire peninsula area measuring 265 ha. This enables SEM Innovia, the company responsible for developing the area, to make rational decisions concerning the management of projects submitted to it involving the use of groundwater (photo on the right).



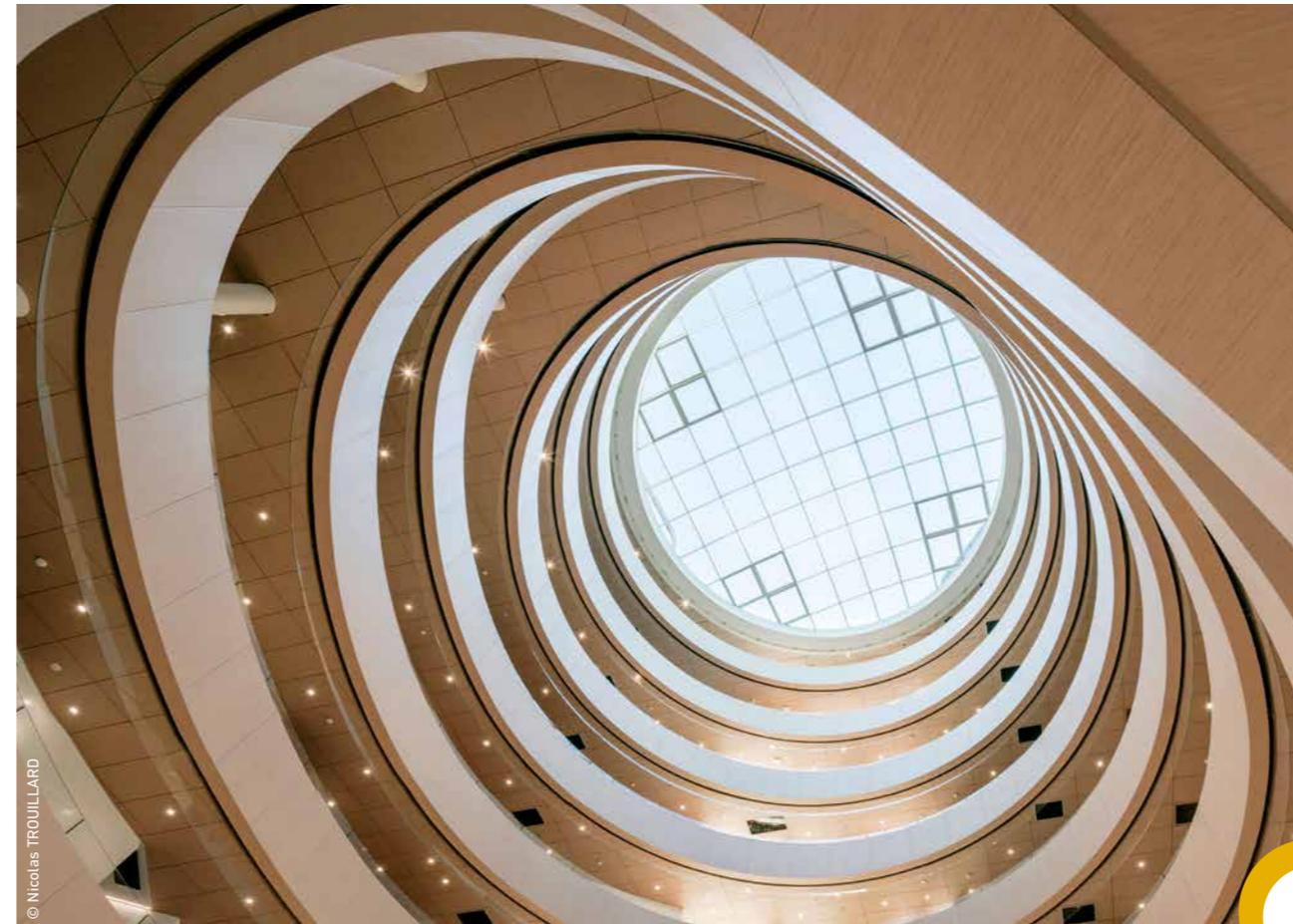
CHRISTELLE TARCHALSKI

Manager of the Groundwater area of expertise

Throughout the Group, we draw up turnkey projects for shallow geothermal facilities beginning with the heating requirements of the building in question. We work with local authorities, private developers, industrial companies, EPC firms, investors, architects, etc. Our team has solid expertise in the field of hydrogeology and takes charge of all the subsoil geothermal aspects. Our colleagues in the building construction and industrial facilities sectors manage the surface facility aspects.

all the geological, hydrogeological and environmental aspects in order to define the most appropriate tapping facility and perform preliminary field tests. Based on the results obtained, we design the facility and supervise the works, draw up the statutory documents and submit any funding applications. We have several accreditations in France awarded by engineering qualification organisations (OPQIBI) and the Ministry of Ecology, Sustainable Development and Energy. We hold "GMI" accreditation to install very low-temperature geothermal energy systems across the whole of France, and conduct a range of expert appraisals relating to shallow geothermal energy in addition to installing complete facilities.

In France, geothermal solutions are strongly encouraged, studied and increasingly implemented, in conjunction with other sources. Experience shows that they have a very small carbon footprint and offer relatively fast returns on investment. In some French cities, such as Strasbourg, Lyon and Grenoble, a very large number of buildings (offices, shopping centres, public services) use a geothermal facility for heating and air conditioning purposes. Indeed, groundwater heat pump systems have been so successful that in some cases they have caused variations in aquifer temperature affecting the optimum operation of the facilities (too much hot water discharged into the aquifer in summer and too much cold water in winter). We are therefore assisting several local authorities in performing overall studies of the impacts of geothermal operations in order to design decision-support tools for managing the resources sustainably.



© Nicolas TROUILLARD



As part of the project to build the Origine property complex in Nanterre (France), we carried out the feasibility studies and provided design and construction supervision services on behalf of developer Icade for a facility providing heating and cooling for 80,000 m² of offices, housing and commercial property, using a shallow geothermal system (photo on the left).

Our team studied, designed and tested the creation of a probe array geothermal facility for the new nursing home in Manois (France), consisting of 34 probes descending to a depth of 130 m (photo on the right).



SÉBASTIEN CAPPY

Hydrogeologist in the Environment unit

In the case of shallow geothermal systems, we look for underground water at a temperature of 12°, for example, and use it to produce heat or cold by means of a heat pump. Such simple exchanges of calories can be implemented anywhere using probe array technology or via an aquifer, if there is one. The geological configuration determines the technologies that can be used and the cost of the project.



Realising the energy vector potential of hydrogen

Hydrogen, an industrial gas currently used in a variety of manufacturing processes, especially in the petrochemicals sector, is now also widely seen as an energy vector capable of contributing to the decarbonisation targets contained in the Net Zero by 2050 scenarios. More specifically, it could replace conventional fuels in the heavy goods transport sector (ships, trucks, trains) and be a substitute for coal and gas in some industrial production processes (e.g. steel and cement). Combined with CO₂ or recycled carbon recovery, it could also be used to produce synthetic methane and electrofuels (e-fuels). The ability to integrate it into the energy system as a means of storing electricity is another advantage. This promising sector is still in its industrialisation phase, however, and must overcome several challenges before it can become fully operational, including implementing the large-scale production of low-carbon hydrogen and optimising the processes used to capture CO₂ and produce e-fuels.

ASSOCIATING STEAM METHANE REFORMING WITH CO₂ CAPTURE

Hydrogen does not exist on earth as an isolated element, and is extremely rare in the form of dihydrogen (natural H₂), a molecule which is extremely light and very difficult to contain. It is, however, found in many other molecules, associated with oxygen (water - H₂O), carbon (hydrocarbons - C_nH_n) or nitrogen (ammonia - NH₃). To isolate it, and produce dihydrogen (H₂), it is hence necessary to break down these molecules using various thermochemical processes, and then to develop equipment for storing and distributing it at very low temperature (liquid state) or very high pressure (gaseous state) to increase its density.

At present, more than 90% of the hydrogen produced worldwide is derived from steam methane reforming (SMR). Economically speaking this is the most advantageous means of meeting industry's demand for hydrogen, but it emits large quantities of CO₂ and is hence incompatible with the decarbonisation targets. One technique being explored to overcome this problem consists in developing CO₂ capture systems and associating them with SMR-based hydrogen production facilities. It is also possible to recover and reuse so-called "coproduced" hydrogen (from other petrochemical production processes), but this is rarely in a pure form and has to be reprocessed.

Artelia is assisting industrial firms in the petrochemicals sector on this issue of hydrogen and boosting low-carbon

production. In doing this we draw on our long experience of designing, integrating and revamping industrial facilities, during which we have covered a wide range of nitrogen, hydrogen and oxygen production, storage and distribution projects at a number of industrial sites across Europe. We have worked with some major players (e.g. TotalEnergies, Air Liquide, Messer) on this type of operation. We are currently contributing to a number of coproduced hydrogen recovery and reprocessing projects. We also provided engineering designs for Air Liquide's Cryocap facility, intended to capture the CO₂ emitted during hydrogen production. This is an issue on which we will continue to work in the future. We have just finished supervising the construction of a pilot CO₂ capture facility (DMX) in the steel-making field for Axens, in partnership with TotalEnergies, ArcelorMittal and IFP Énergies Nouvelles.



PASCAL THÉVENET

International Development Director

We perform detailed design studies for facilities related to the production and distribution of nitrogen, hydrogen and oxygen. Starting from a given procedure, we develop the complete facility: the layout of the equipment, the earthworks, civil works, structures, piping, electricity, and instrumentation. We also have specialists in risk assessment, because hydrogen has a very wide flammable and explosive range requiring strictly managed safety measures right from the facility design stage.



CHRISTIAN AVERT

Manager, Decarbonisation
Solutions Development

Hydrogen is a highly promising subject, even though it is not yet financially profitable. We are at the start of a development process.

The key is having access to cheap, decarbonised electricity. There are several projects in France, such as Normand'Hy for Air Liquide, H2V in Dunkirk, Massylia for TotalEnergies/Engie, and Hyd'Occ with Ey in Port-La-Nouvelle, but many investors are turning to countries where electricity is cheap. The huge Inga hydropower project in the Democratic Republic of the Congo could offer a means of producing ammonia, which would then be exported to consumer countries for transformation back into hydrogen.

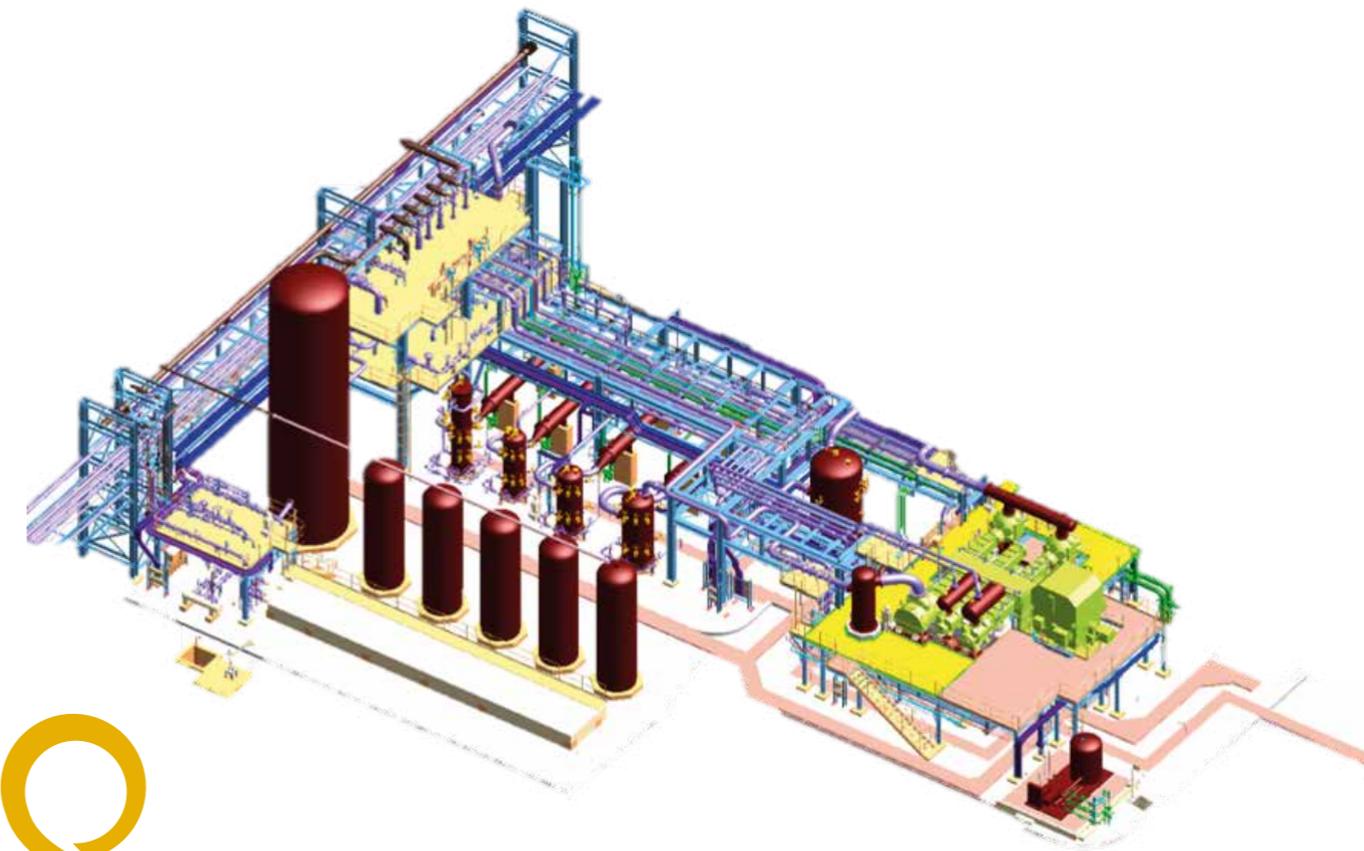
WATER ELECTROLYSIS AS A MAJOR AVENUE

Hydrogen can also be produced through water electrolysis, a well-established principle that uses an electric current to break down H₂O molecules into hydrogen and oxygen. Several systems can be used to carry out this operation, including alkaline water electrolysis, the Proton Exchange Membrane (PEM), the Solid Oxide Electrolysis Cell (SOEC), and the Anion Exchange Membrane (AEM). This method is currently more expensive than steam methane reforming but is considered promising nevertheless, as it does not depend on hydrocarbons or emit CO₂ and can be implemented anywhere, provided that plentiful supplies of water and decarbonised electricity are available at relatively low prices.

This sector is currently being developed with support from the European Union and many states. Industrial demonstrators are gradually being deployed to explore facilities in various configurations and test equipment and systems which are still lacking in feedback. One key aspect of this development consists in coupling electrolysers with controllable (hydropower) and intermittent (solar,

wind) renewable electricity production. This would make hydrogen a means of storing electricity as a complement to storage reservoirs and electrochemical batteries. Several projects of this type are currently being deployed around the world. Other methods for producing hydrogen are also being explored, such as high-temperature electrolysis processes which could be supplied with heat from small modular nuclear reactors.

We have been contributing to the expansion of these new low-carbon hydrogen production techniques for a number of years. We have designed and built research centres dedicated to these fields, such as the one operated by Air Liquide in Le Blanc-Mesnil (France). We are currently working for the Fraunhofer IWES (Institute for Wind Energy Systems) in Germany, on the construction of a testing centre dedicated to electrolysers and hybrid power plants. We are also contributing to a confidential project to produce hydrogen from biomass for transport, and audited a large facility in French Guiana intended to couple a solar power plant with a hydrogen



In the context of the Synergie H2 project, on behalf of TotalEnergies, Artelia performed the design and integration studies for a hydrogen compression unit, its related auxiliaries, and a pipeline connecting it with petrochemical facilities in the surrounding area. We were also involved in supervising construction of this facility, at Gonfreville-l'Orcher (France).

production unit. Our experience in industrial integration also equips us to work on the layouts of electrolysers, as units of this type have been used for many years in industry to produce chlorine and we have completed several projects in this field. We participated recently in the construction of a unit of this type in France, comprising an electrolyser, the electrical power supply, and all the related facilities.

In view of the various projects currently being rolled out around the world, the International Energy Agency recently estimated that hydrogen

production capacity, which stood at about 94 Mt in 2021, could increase to 175 Mt by 2030. Most of this increase would result from the deployment of electrolytic production and, to a lesser extent, from the steam reforming of hydrocarbons in conjunction with CO₂ capture processes.



Distributing vital energy to everyone

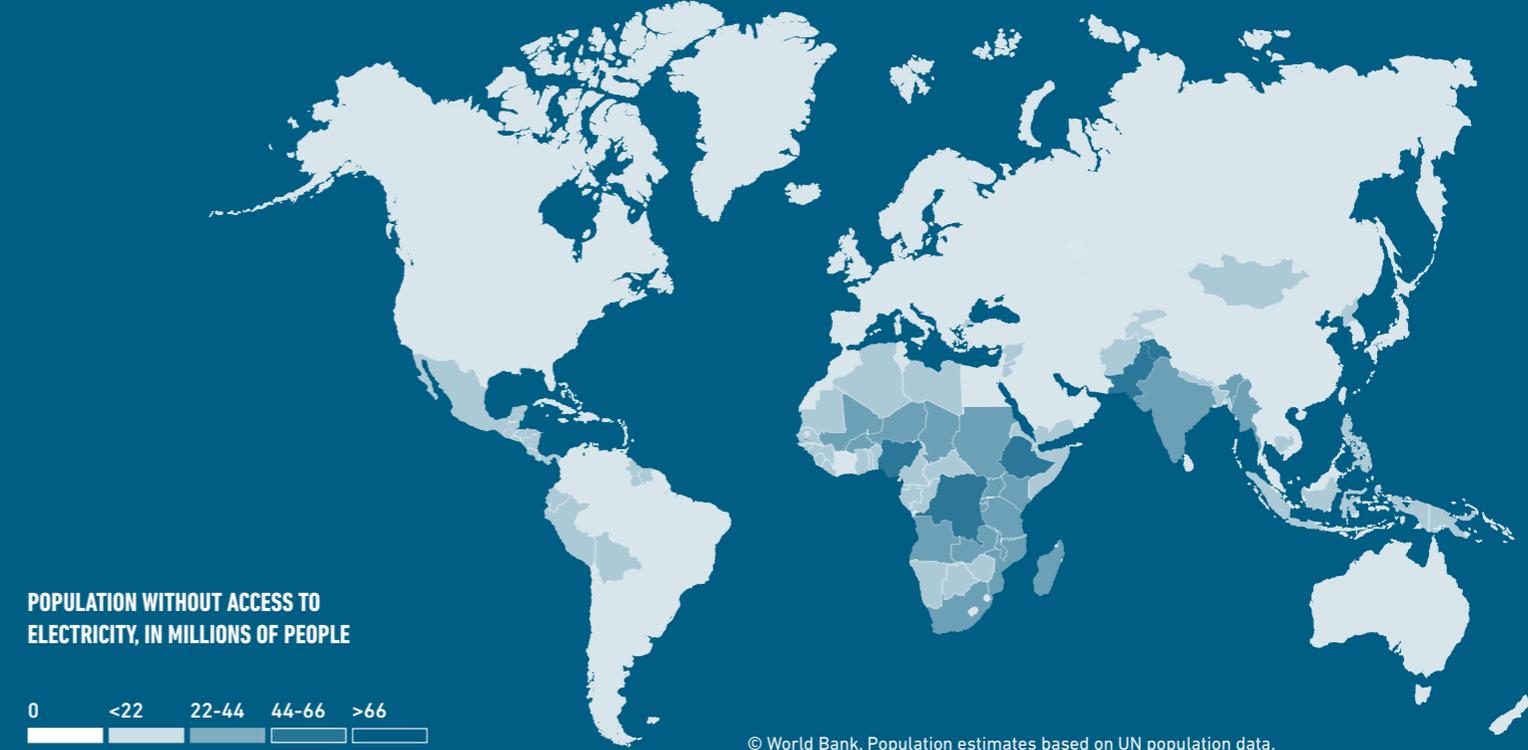
Guaranteeing access for all to reliable, sustainable and modern energy services at an affordable cost is one of the 17 sustainable development goals selected under the United Nations Global Compact, an initiative that encourages corporate social responsibility and to which Artelia has signed up.

According to this organisation, even if significant progress has been made in recent years, nearly 750 million people around the world still did not have access to electricity in 2021, three quarters of whom live in Africa. Similarly, 2.4 billion individuals lacked non-polluting methods of cooking [IEA 2022]. Reducing disparities in terms of access to sustainable energy naturally involves deploying additional generation facilities, but also extending transmission and distribution infrastructure.

In the electricity sector, considerable effort is still necessary in developing countries, where improving grid access and strengthening interconnections are key

objectives of development policies. In addition, in all countries around the world, the stability and flexibility of these networks must be guaranteed by improving their architecture, their management and their transmission and storage capacity, enabling them to adapt to fluctuating demand and accommodate the intermittent nature of renewable energy sources.

Increasing the density of heating and cooling networks is also encouraged, because pooling these services enables efficient, durable individual heating and air conditioning solutions to be offered at a reasonable cost.



Safeguarding natural gas supplies and developing new infrastructure related to hydrogen are other challenges requiring the deployment of dedicated transmission and distribution facilities.

Artelia has been at the forefront of electrification in African countries for decades, and in doing so has accumulated solid expertise in the design and implementation of electricity networks at the scale of countries, regions and cities. Heat distribution is another key area of activity.

Having supported the boom in this type of infrastructure in countries such as Denmark, which is highly advanced in this field, our teams have acquired cutting-edge expertise in these subjects for the benefit of all our clients. As a large international player in maritime engineering, we also work on underwater electrical networks and the creation of conditioning and transmission facilities for natural gas and hydrogen.



Reinforcing electricity networks by rethinking their role and functions

Electricity networks are essential infrastructure systems that criss-cross our planet, and their organisation and operation must be rethought in the context of shifting the energy system towards low-carbon sources. Today, they are under growing pressure due to the continuous rise in electricity use (for communications, electric vehicles, industry, etc.) and the increasing integration of intermittent renewables from production sites. Similarly, the expansion of self-consumption, “demand-side management” and the diversification of storage possibilities are transformations requiring network architecture and management to be reconsidered to enable them to manage complex flows and functions.

INCREASING NETWORK TRANSMISSION AND INTERCONNECTION CAPABILITIES

Since its beginnings in the 1880s, the installation of electricity transmission and distribution infrastructure has required decades of innovation and development. High-voltage lines had to be constructed to convey electricity over long distances with minimal losses, transformer substations and medium- and low-voltage lines installed to carry current to industrial or individual consumers, and management entities created as networks were extended and branches were added. Networks were initially local, then regional and national, and were eventually connected internationally to encourage energy exchanges and the emergence of electricity markets. Transmission, distribution and real-time management of the balance between supply and demand are still the basic functions of the grids operating today on all continents, some significantly more advanced than others.

The most developed countries, which were electrified many years ago, now have efficient transmission and distribution infrastructure, with high voltage levels, densely interwoven regions, and well-maintained facilities that undergo regular upgrades and deliver a stable current to consumers at an accessible price wherever they are. Highly experienced companies or organisations manage these grids and oversee their

structural transformations (extension, reinforcement, automation, etc.). Artelia works with some of them, in particular RTE, which operates the French national electricity transmission system, in regard to the connection of new generation sites, particularly offshore wind farms. We also participate in creating transformer substations and distribution systems at the scale of industrial and hospital sites. For example, at Purpan hospital, near Toulouse (France), we are finishing a study of a medium-voltage substation and the design of all the power and lighting distribution systems inside the establishment.

However, in recent years our activity in this area has focused primarily on developing countries, in Sub-Saharan Africa in particular, where needs are greatest. As explained by the World Bank and the French Development Agency (AFD), Africa still needs to extend its networks and modernise its ageing infrastructure, reduce the gap between cities and the countryside, and increase regional and continental interconnections. Artelia is participating actively in these development actions in several African countries. In close partnership with authorities and energy management organisations, we draw up national master plans to adapt electricity generation, transmission and distribution to the



VIRGINIE GAILLAT

Director, International Energy
Water, Energy, Environment & Africa
Middle East Business Unit

In developing countries, such as in Africa where we are involved in many structural projects, networks are still often fragmented with insufficiently high voltage. Whereas supplies are more or less adequate in areas of dense economic activity and large cities, this is not the case in rural areas. One of our objectives is to supply electricity to the greatest possible number of people, and the network of interconnection lines between countries contributes to this: some are operational, while others are under development or being doubled. This must continue, with construction of an increasingly dense mesh allowing countries to exchange electricity, because this greatly facilitates grid balancing.

populations' changing needs. We have recently deployed this type of strategic approach in Burkina Faso, Ivory Coast, Mali, Madagascar, Mauritania and Togo. On the basis of these studies, development scenarios can then be proposed and priorities identified. In this context, we produce comprehensive transmission plans to convey electricity correctly from the place of production to the place of consumption. We define the storage or compensation needs to keep the network stable at each stage of its development. Our projects also include distribution, at scales varying from cities to rural communities, right up to the end consumers.

The main objective is to create transmission infrastructure with sufficiently high voltages to meet the rising demand and create a mesh that is dense enough to provide a secure supply across all locations. Installation of modern, automated, connected equipment is also essential to then be able to use high-performance grid management technologies. Depending on the needs of our clients, who are public authorities or private promoters, we become involved from initial conception to commissioning of the facilities, and sometimes continue to provide advice during the operational phase.

For Cameroon's national electricity transmission company, Sonatrel, we have just finished the complete engineering design to upgrade the transmission network in the northern regions of the country. This operation strengthened the capacities, efficiency and reliability of this network. In Bamako, the capital of Mali, we constructed a 225 kV high-voltage loop around the city to improve the distribution of current in its northern districts. We have also participated in several structural projects involving transnational interconnection between countries or groups of African countries (Cameroon, Chad, Kenya, Uganda, etc.). We are currently contributing to the interconnection of the Mauritanian and Malian grids (1500 km of 225 kV line), and the Malian and Guinean grids (774 km of 225 kV line). In addition to energy exchanges between countries, these operations offer opportunities to develop the secondary grid and expand rural electrification from high-voltage lines, thus overcoming some of the physical barriers preventing access to electricity.



We are performing various design and technical assistance assignments to strengthen the 225kV network in Bamako. These include the construction of approximately 20 km of lines (overhead and underground), and the creation or modification of several high-voltage substations. These operations will allow 25,000 new customers to be connected. We are also working on the city's north loop (approximately 100 km of overhead lines, 1 km of underground lines and 5 transformer substations).



In Mali, in the context of the SHER project, supported financially by the World Bank, and the PHARE project, funded by the French Development Agency (AFD), we are participating alongside the Malian office for energy development in the rollout of hybrid solutions and mini-grids to bring electricity to more than 100 localities in the country.

THE FUNDAMENTAL IMPORTANCE OF MINI-GRIDS AND HYBRID ENERGY SYSTEMS FOR ISOLATED SITES

In countries where financial resources are lacking, simultaneously developing power generation capacities and transmission and distribution infrastructure in line with requirements is often very difficult to do within reasonable time frames. Some zones, generally those which are the least densely populated and the most difficult to access, hence remain off-grid and their inhabitants deprived of electricity. Significant socio-economic imbalances between cities and countryside arise from this situation that national authorities, international development organisations, and some NGOs are attempting to resolve by supporting rural electrification projects in isolated areas.

For a long time, in the African and Asian countries where electrification was the least advanced, the simplest and most financially accessible solution for very precarious rural communities in unconnected regions consisted in installing generators and therefore relying on oil to produce electricity. However, volatile oil prices have caused some mini-grids to malfunction and fail. Concomitantly, the issue of climate change and the arrival on the market of more advanced, economical solar solutions (despite a greater initial investment) have

encouraged authorities to pursue other options. Over the past few years, with support from international institutional funding bodies, rural electrification of isolated zones has come to rely more and more on solar power, via individual equipment (solar kits) or mini-grids. These include hybrid production (solar, oil, more rarely wind), battery storage capacities, distribution infrastructure, and monitoring, management and payment systems tapping into the boom in e-banking.

Artelia has designed and supervised hundreds of facilities of this type in recent years, in various African and Asian countries including Burkina Faso, Cambodia, Cameroon, Chad, Democratic Republic of the Congo, Guinea, Ivory Coast, Kenya, Madagascar, Mali, Mauritania, Mozambique, Nigeria, Senegal, Tanzania and Vietnam. These projects generally require careful attention and long periods of time in order to coordinate the various players, reach viable compromises and start the works. We assist funding agencies, national and regional public players, and private developers throughout entire projects or with specific phases, depending on the scope of our assignments. Our projects



ADRIEN NAMUR
Project Director
Solar energy

Although it is not as vital as water, electricity has become essential and those who cannot access it often find themselves at the margins of society. In some countries, there can be large disparities even within the same family, between those who live in cities and those who live in the countryside. This leads to significant tensions and a strong sense of social downgrading amongst those who do not have sufficient lighting or who cannot use professional or domestic electrical appliances, telephones, internet, etc. Our work consists in creating possibilities for accessing electricity in areas that are deprived of it, by implementing stand-alone generation and distribution infrastructure.



The Economic Community of West African States (ECOWAS) is working on interconnecting the electricity grids of its 15 member states. On behalf of one of its offices, “West African electrical energy exchanges”, Artelia participated in the study and supervised construction of a 774 km (225 kV) line between Guinea and Mali, and managed creation of the new associated source substations.



generally benefit small cities and rural communities, and are carried out with local partners. The first stage consists in studying the requirements and evaluating how they are likely to change. Society as a whole has to be taken into account, including households and their financial capacities, businesses, craftspeople and other economic activities, and community buildings such as schools, health centres and town halls. We then produce the dimensional design for the facility, ensuring that we strike the best economic and environmental balance. Maintaining a certain degree of hybridisation is generally inevitable, because 100% solar generation requires large battery storage capacities, which greatly increases investment costs. We then supervise construction of the facilities.

Amongst the operations for which we are currently providing assistance at each stage of deployment, two projects, in Kenya

and in Mali, are highly representative of these efforts to improve access to electricity in unconnected zones by adopting low-carbon solutions. We are assisting the company Kenya Power, which manages most of the national grid, with its project to hybridise mini-grids with renewable energy sources (23 are being studied). The aim is to simultaneously contribute to the transition to a low energy mix, increase the rate of access to energy in rural areas, and reduce operating costs to drive down the cost of electricity for the end user. We are performing a similar operation in Mali for Amader (the Malian agency for the development of domestic energy and rural electrification) relating to the creation of hybrid power plants incorporating storage and of mini-grids in approximately fifty localities.

STABILITY, STORAGE AND MANAGEMENT: TOWARDS “SMART”, MORE FLEXIBLE GRIDS

A traditional electricity grid is a system that balances supply and demand, relying strongly on concentrated flexible generation (coal, fuel oil, gas, nuclear, hydropower). It manages downward energy flows from these generation sites to multiple, geographically dispersed consumers. This dominant model, constructed over the course of several decades, is currently being called into question by the transition to a low-carbon energy system.

The increasing introduction of electricity from intermittent sources (e.g. solar or wind) is the first challenge for grid managers. Dependent on wind strength and solar radiation, they are subject to wide variations which can decrease or put a stop to their output at the very moment when electricity demand is increasing. Conversely, they can produce a lot of electricity during periods of low demand. To inject this intermittent energy into a grid efficiently and on a massive scale, storage capacities must

hence be increased and the increasingly tricky balance between intermittent production, manageable production and storage must be managed.

Similarly, the dispersed nature of the generation sites (e.g. small wind farms, roof-mounted solar panels) and the expansion of self-consumption make flow management more complex. For example, the manager of a building that is equipped with solar panels, consumes all or part of the energy it generates, and relies on back-up from the grid if needed, is required to handle multiple irregular upward and downward flows. Other practices related to decarbonisation objectives, such as “demand-side management”, which consists in encouraging users to shift some of their energy usage to a different time of day in order to relieve pressure on the grid, are also contributing to the changes in the manager’s role. From a technical point of view, guaranteeing a stable electricity supply therefore becomes a



ADRIEN PORET

Manager, photovoltaic production and storage

The boom in the use of electrochemical batteries to store electricity is linked to the growth of renewable energy, but is more generally a way of reducing the constraints on transmission and distribution networks. It forms part of the grid equipment, in the same way as a transmission line or transformer, and can provide useful flexibility at reasonable cost. It is integral to the development of modern grids.



more delicate operation requiring more sophisticated management tools involving a high level of automation, data collection and digital data processing ("smart" grids).

Artelia is increasingly being asked to contribute to these stability, storage and grid management issues. Naturally we work on these subjects from the initial infrastructure design stage, calling on our experts and deploying our modelling, grid simulation and dynamic management tools. Our excellent technical and economic expertise in electrical systems and our knowledge of how grids must function, be

planned and operated, enable us to manage their implementation in detail and ensure that they remain dynamically and statically stable.

Inextricably linked to this stability objective is electricity storage, which has become a prominent issue. One of the oldest and most mature solutions, in which Artelia excels, consists in using dams and pumped storage hydropower facilities. According to the International Energy Agency, pumped hydropower storage represented approximately 90% of electricity storage capacities around the world in 2020.

In Mauritania, we are drawing up a roadmap for the development of electrical storage systems, by studying the feasibility of various solutions. As a basis, we are using an analysis of variations in the country's electricity mix and demand on several time scales (2025/2030/2040).

In West Africa, we are assisting a private client with the technical and financial aspects of creating a Li-ion battery storage facility (160 MWh/40 MW). We are also managing the definition and implementation of the management system.

The other solution is electrochemical battery storage, which has made significant progress in recent years in terms of performance and cost with the development of electric vehicles. Today, Lithium-ion (Li-ion) technology, developed for mobility, is also used within electrical grids. However, other avenues are also being explored to find solutions better suited to static storage, based in particular on materials that are more abundant and accessible than lithium. The use of batteries is set to expand very rapidly in the next few years.

Looking for stability and flexibility, a growing number of countries are asking Artelia to draw up electricity storage optimisation plans. In Africa in particular, networks are often hampered by stability issues resulting in frequent power cuts. This is also a continent with tremendous potential for renewable energy, which can rapidly destabilise the as yet sparsely-meshed networks. This type of issue is now also beginning to present itself in European countries with the highest levels of solar and wind power integration, even if their transmission and distribution infrastructure is generally more robust.

We are working with distribution authorities in a number of countries including Burkina Faso, Ivory Coast, Mali, Senegal and Togo. We have developed electrical system planning tools that take into account the high penetration of renewable energy sources and we perform detailed stability analyses incorporating possibilities for battery storage. In France, we are participating in the

considerations being undertaken by Ademe, the French Agency for Ecological Transition, on the creation of stand-alone energy systems in island areas, relying on a large contribution from intermittent energy sources and the associated storage facilities. We are also studying and managing the construction of battery storage facilities for various renewable power generation developers. We are currently assisting three of them with implementation of around 200 MW of storage capacity. We are also continuing R&D work on battery wear and recycling issues so that we can provide our clients with the best possible advice on these topics. The question has become much more pressing since the European Union made it compulsory to at least partly recycle this type of equipment.

At the same time, we are contributing to initiatives that aim to use hydrogen as a means of storing electricity. Still at the industrial demonstrator stage, the principle consists in combining electrolysers with the grid or with specific production facilities to transform surplus electricity into hydrogen, given that this can later be converted back into electricity via a fuel cell.



Deploying flexible, efficient heating and cooling networks

Though they are less common and extensive than networks devoted to electricity, district heating networks occupy an important position in some countries and are now being reconsidered on account of the role they can play in decarbonising energy systems. As they can be supplied by different types of renewable and recovered energy (biomass, geothermal, recycled waste), authorities are taking an increasing interest in them and encouraging their extension and modernisation. In this area too, progress made over the years in terms of lower temperatures, storage, supervision, cooling networks, etc. is offering a wider range of prospects.

STRONG INCENTIVES FOR EXTENDING DISTRICT HEATING NETWORKS

The development of contemporary heat distribution networks began at the end of the nineteenth century with a view to meeting the needs of industry and heating buildings. Such infrastructure was subsequently deployed in phases in large cities, to an extent and using methods that varied significantly from one country to another. In Denmark, heating and electrical systems developed hand in hand. The two types of network were thus widely deployed throughout the country based on thermal CHP plants. In France, electric and individual heating systems were generally preferred to collective networks, even though some towns installed this type of infrastructure as early as the 1920s and 1930s, or later in response to the baby boom and the various oil crises.

Today, this type of collective distribution, which continued to increase in 2021, meets approximately 8% of global heating needs for buildings and industry. It is in China, Russia and Europe (especially northern Europe) that such networks are the most developed (accounting for

90% of global production for district heating). Worldwide, however, they are still mainly supplied by heat produced from fossil fuels, and in particular coal and gas. Europe has, however, made considerable progress in incorporating renewable energy, as in some countries (Sweden, Denmark, Austria, Estonia, Lithuania, Latvia, Iceland, France, etc.) the proportion exceeds 50% [AIE 2021]. The ability to generate heat while producing few CO₂ emissions, by prioritising the use of local resources and offering the end user a reasonable price, is now a powerful argument in favour of developing such district heating networks. Various international bodies including the UN and the International Energy Agency are calling on governments to take action in this respect, as is the European Union, which wishes to increase the coverage of heating requirements by such networks in the member states to 10 or 12% on average.

Such political determination is evident in some countries in which Artelia works. In France, since 2010, the authorities have



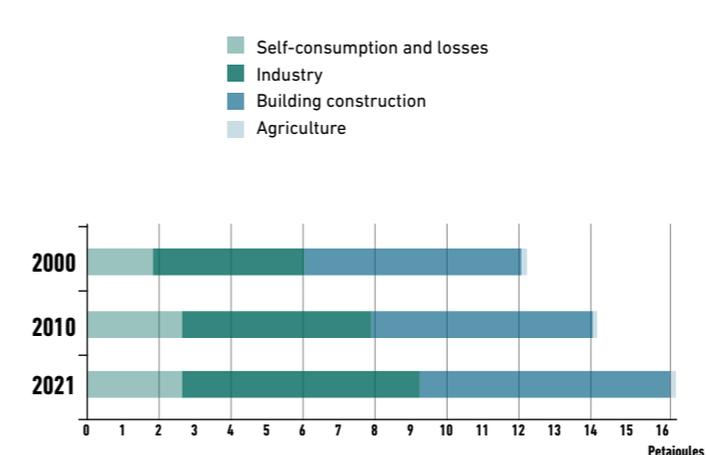
KNUD ERIK NIELSEN

Energy & Industry project director,
Artelia Denmark, Aalborg

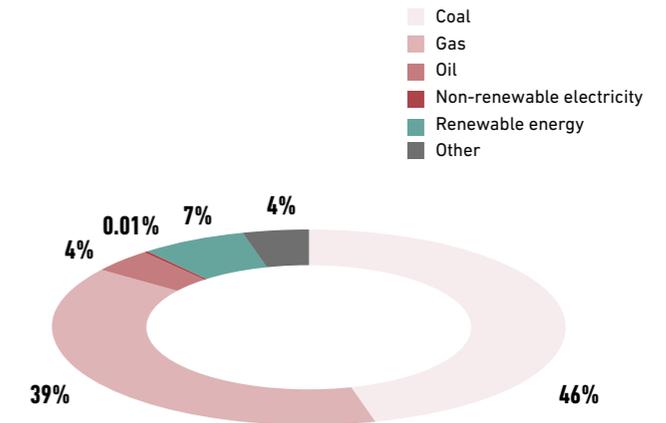
At the moment, the Danish government is promising in the media that all citizens living in the country's major cities will receive an e-mail from the authorities by the end of the year informing them whether there is a plan to connect them to the district heating network and when they can expect to be connected. In the present context, with the cost of energy rising, it is a major political goal to offer access to collective district heating to as many people as possible. Each town council and each district heating company in Denmark therefore has a lot of planning to do and we are helping them with this work.



With a view to renewing the operating licence for the district heating network in Lille (France), Artelia performed a technical and financial audit and an in-depth prospective study concerning the future of the network. The study examined possibilities for extending it and creating a cooling network, and for greening its sources of supply by developing solar power generation and recovering waste heat.



Annual deliveries of heat worldwide to end use sectors via district heating networks



Categories of energy used to supply heating networks worldwide in 2021 [IEA]

once again been strongly encouraging the deployment of heating networks, in particular by offering considerable financial assistance to support such initiatives. More recently, new regulations have even been implemented to encourage property developers to connect their buildings to existing collective networks rather than install individual heating facilities. In Denmark, where networks already cover nearly 60% of the country's heating requirements, new government incentives are pushing all players in the sector to take steps to offer all residents who are not connected the possibility of doing so. We are taking part in these different programmes by assisting municipal authorities, heating companies and construction companies with their projects to create or extend networks.

Ideally, we become involved right from the design and planning stage, whether this be with a view to reorganising existing neighbourhoods or creating new urban spaces. When we assist local authorities with this kind of operation, we propose heating networks among the possible range of solutions, studying their technical and economic relevance and planning their potential deployment. We are providing services of this kind in France in Nice (creation of the Nice-Meridia district), Lille (extension of the municipal network) and Lorient ("ZAC de Bodélio" mixed development zone). We are also helping numerous local authorities in Denmark with the new efforts they are having to make.



CLAIRE DEMAIRÉ
Design engineer, Energy

Heating networks are relatively flexible systems that can absorb different sources of energy and adapt to their development. In several European countries, including France, the current aim is to eliminate fossil fuels as much as possible. No networks rely completely on renewable and recovered energy but some of them are close to the 80% mark. They are topped up when the weather is particularly cold, often using gas. The goal is to dispense with this gas. In reality, the entire production and distribution chain is being steadily optimised by ensuring better management of how the heat is used, and of what happens in real time at consumer level.

TOWARDS A NEW GENERATION OF HEATING AND COOLING NETWORKS

The first district heating networks were relatively simple. An oil-fired boiler produced steam that was sent via pipes under pressure to consumption sites - generally close by and not very large - often with significant loss of heat. These facilities were gradually grouped together, connected and modernised to form larger, more complex and efficient infrastructure. The sources of heat began to be diversified. Steam was replaced by hot water (<100°C). The infrastructure took on its contemporary form: a closed system of two-way pipes, pumps, substations and distribution/transformation equipment linking up with the end user. More recently, as decarbonisation targets have become more stringent, a new generation of networks has begun to be deployed in the more developed countries. Artelia is playing an active part in this transition via its various design, construction and project management assignments for district heating networks.

As in the case of electricity networks, the first step in this change is to incorporate an increasingly wide range of renewable energy sources (biomass, geothermal, solar, etc.), while exploiting the heat generated by incinerating household

waste. Today, major efforts are also being made with a view to recovering the waste heat emitted by different sources and activities (industry, data centres, waste water, etc.). Recovering this unwanted and often wasted heat is a major avenue for achieving substantial savings in terms of production infrastructure.

Another strong trend is to improve the energy efficiency of conveyance and distribution facilities by generalising the use of moderate pressures and temperatures (50-60°C), by insulating pipes more effectively and by combating leakage. All these measures help to keep losses to a minimum. To improve flexibility and avoid having to resort to hydrocarbons as much as possible during peak consumption periods, modern networks must also include greater storage capacities. Other requirements include automating facilities, taking more careful account of user behaviour, and digitising management of the infrastructure, which is now essential for overall system supervision. Cooling networks, which may be associated with heating networks, are also enjoying considerable development in several countries. In France, there are 833



The Paris-Saclay network is based on the use of geothermal energy and the recovery of waste heat. Artelia is providing supervision services for the entire extension project while studying the installation of a biomass boiler. The project will eventually supply a huge complex of buildings (2.15 Mm² floor area) with a coverage rate of 63% for renewable and recovered energy.

heating networks (net capacity 25.4 TWh) and 32 cooling networks (net capacity 0.81 TWh) [Ademe 2020].

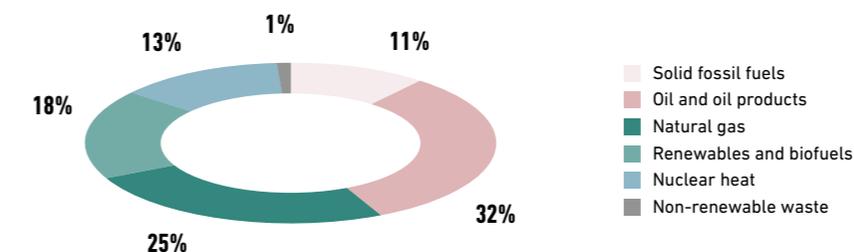
Artelia's work on the Paris-Saclay network, one of the largest in France, is symbolic of the changes taking place (extensive incorporation of renewables, automated supervision, management of heating and cooling, etc.). We are also working on superheated water networks (160° at 16-20 bar), which call for specific capabilities in flexibility and expansion calculations. An example is Mulhouse, where we are

currently supervising the rerouting of a network of this type. Our expertise and resources for modelling and designing heating and cooling networks are underpinned by our multi-disciplinary nature and our experience in urban engineering, drinking water networks, the environment and sustainable buildings. This comprehensive approach enables us to grasp the full complexity of a project and to contribute effectively to the modernisation and extension of a heating and cooling system. Much effort will still be needed in this field if the goals of the Net Zero by 2050 scenarios are to be met.



Securing natural gas and hydrogen supplies

Fossil gas, known as natural gas, is currently used extensively as an energy source for both electricity and heat generation. Releasing lower carbon dioxide emissions during combustion than coal and oil, it is considered in the Net Zero by 2050 scenarios as an essential transition energy source, at least until 2030 when the expansion of renewables and the switch to hydrogen may enable its use to be reduced. The recent cessation of pipeline natural gas exports from Russia to Europe has placed high pressure on this resource and driven several countries to reinforce their maritime import and export facilities to adapt to the market upheaval.



Total energy supply of the European Union (27 countries) by energy source in 2020 [Eurostat]. Total: 1322 million tonnes of oil equivalent



ALAIN DEFORCHE

Deputy Director, Water, Energy, Environment & Africa Middle-East Business Unit

Gas must be liquefied before it can be transported by sea. For exports, an onshore or floating plant must be constructed, with access to water for the process of cooling and converting the gas into LNG, and a specialised wharf must be developed for berthing and filling the LNG carriers. For imports, there are equivalent facilities that take in this LNG and convert it back to a gaseous state. Our projects encompass all of these maritime facilities, the water intake structures and the plant pumping stations.

NEW LNG TERMINALS AND LIQUEFACTION/GASIFICATION PLANTS

Natural gas accounts for 25% of global electricity generation, and also plays a decisive role in the production of heat for industry, homes and commercial buildings. Worldwide, gas is the main fuel used to supply nearly 40% of all district heating networks, and is also used to heat 40% of buildings all taken together [IEA 2021]. Gas is also a leading energy source at the scale of the European Union, representing approximately 25% of all energy supplied. This figure even exceeds 33% in several countries of the continent such as Georgia, the Netherlands, Italy, Ireland and Hungary [Eurostat 2020].

Simultaneously reducing the use of coal, oil and gas in the next ten years has been considered by energy specialists and political leaders to be an unrealistic objective. Many countries, including those in the European Union, have hence accepted gas as a transition energy source that will continue to be used until sufficient progress has been made in renewable energy production, hydrogen, and energy efficiency and conservation to allow its use to be reduced. In its Net Zero by 2050 scenario, the International Energy Agency therefore predicts a slight increase in gas use for electricity generation until at



TotalEnergies commissioned Artelia to perform complete engineering design studies (maritime, environmental, industrial and safety aspects) for the creation, on the Le Havre LNG site, of an FSRU capable of handling the equivalent of 10% of the gas consumed by France.

Morocco's national ports authority selected Artelia to design a gas terminal and an FSRU that will be installed in the port of Mohamedia.

Engie, through its subsidiary Elengy, also commissioned Artelia to perform the technical studies for an extension of its LNG terminal in Fos in order to increase the imported gas capacity and accommodate a broader range of LNG carriers.

least 2030, followed by a sharp reduction over the following decades to achieve low carbon targets.

In this context, with many countries selecting gas as a manageable transition energy, the cessation of Russian gas supplies to Europe in 2022 as a consequence of the Ukraine conflict has had a considerable impact, including volatile prices, fear of shortages and their consequences for heating homes, a slowdown in some industrial production processes, and a rise in manufacturing costs. As an emergency measure, importing countries have therefore sought alternative sources of supply by approaching the primary producing countries (Qatar, United States, Algeria, Nigeria, Malaysia, etc.) and beginning the construction of new maritime facilities to take in this gas, transported by ship in the form of liquefied natural gas (LNG).

Artelia, having been designing and supervising gas terminal projects for many years, was ready to meet the requirements of players in the sector in both importing and exporting countries.

The objective is to rapidly develop new port infrastructure and industrial facilities so that these supply flows can be redirected. In France, we provided design services and technical assistance for construction of the LNG terminal in Dunkirk, commissioned in 2017, and we are in charge of studies for a Floating Storage Regasification Unit (FSRU) for Le Havre GNL. These floating units are a solution that is relatively flexible and quick to implement. They are generally created by converting an LNG carrier into a regasification plant. We are also participating in the deployment of a similar facility in Morocco for the Mohamedia project. We also have several ongoing assignments in exporting countries, in particular the United Arab Emirates on behalf of ADNOC (Abu Dhabi National Oil Company), where we have performed comprehensive studies on artificial islands in the Hail & Ghasha gas field.

DEPLOYING SOLUTIONS FOR STORING, TRANSPORTING AND DISTRIBUTING HYDROGEN

Today, hydrogen is considered an energy vector that could at least partly replace natural gas in future decades. It could be a suitable substitute as a manageable energy source for electricity and heat production. Several experiments are in progress in the field of transport, and some applications are being tested as a means of decarbonising industry. Hydrogen production on a large scale, at economic and environmental costs that are compatible with the Net Zero by 2050 scenarios, is still in the demonstration phase, but at the same time a great deal of effort is being invested on a global scale in implementing infrastructure for storing, transporting and distributing it.

Hydrogen is not an easy gas to handle. A small, extremely volatile and highly flammable molecule, dihydrogen (H₂) requires appropriate secure facilities to avoid issues with leaks and corrosion,

which are more significant than with methane. Currently, for storage or transport, it is compressed and then injected into pipes, tanks or bottles. However, several other procedures are being studied and tested. It can be liquefied at -253°C but this consumes large quantities of energy. It can also be transported in the form of ammonia or methanol, since there are fewer constraints associated with these molecules, in particular for transport by sea. But this option requires an industrial and logistical chain to produce these chemicals, transport them and (re)transform them at their place of consumption. Other experiments involve injecting a small proportion of hydrogen (<20%) into the natural gas network, but this requires specific equipment to separate the two substances again on reaching their destination. In recent years, there have also been significant developments in the implementation of final distribution facilities for hydrogen fuel in the



Artelia is assisting Shell with the deployment of hydrogen distribution systems in service stations in Germany and the United Kingdom.

We have been working with Air Liquide for several years on the design, engineering and management of projects relating to the compression, storage, transport and distribution of hydrogen.

transport sector. The first hydrogen service stations are now operational.

We are working on all these hydrogen transport and distribution issues for a variety of industrial players. We are particularly involved in creating compression units and piping networks at production sites. We have recently designed hydrogen and oxygen compression and cooling facilities for Air Liquide in Germany and Bulgaria.

We have also been very actively involved in the field of alternative fuel distribution for several years. It has hence been quite natural for us to assist our clients with the installation of their first service stations dedicated to hydrogen distribution, in countries including Germany, the UK,

France, the Netherlands, Italy, and the Czech Republic. In Germany, which is highly advanced in the deployment of hydrogen fuel, we have already completed nearly a hundred feasibility studies and commissioned around twenty stations in the context of the H2 Mobility network, which is spearheaded by a number of industrial players (Shell, TotalEnergies, OMV, Linde, Air Liquide, Mercedes). In the United Kingdom, we are providing assistance to Shell, with more than a dozen stations already in our portfolio. In Italy, we performed the design and engineering services and then coordinated the construction of Eni's first hydrogen station. We are also involved in designing the distribution infrastructure for two hydrogen-powered train projects, in Germany and in Italy.



Reducing and decarbonising our consumption

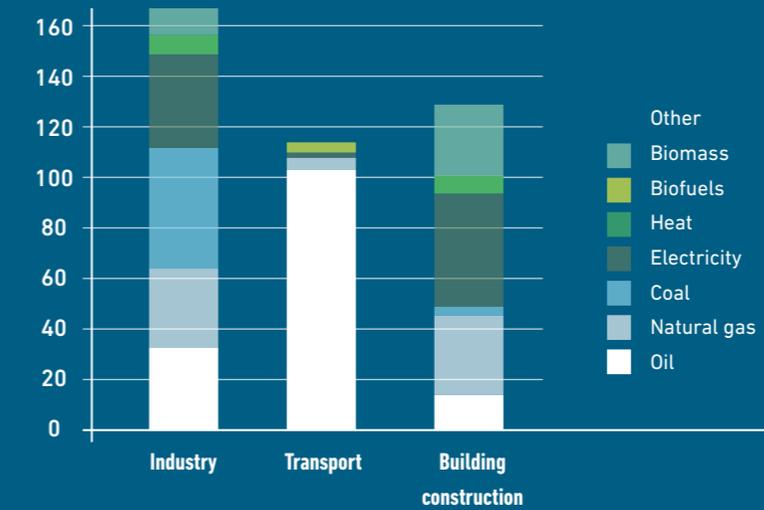
The various scenarios aiming to achieve net zero by 2050, such as that drawn up by the International Energy Agency, agree that this target cannot be reached without the “rapid and large-scale adoption of measures to limit the growth in energy demand” [AIE 2022].

It is indeed the case that, considering the growing global population and the number of people aspiring to access a satisfactory level of electricity services, even a massive increase in low-carbon generation will not, alone, be sufficient to meet demand in full without using fossil fuels. Bolstered by the current energy crisis, it is now widely accepted that factors such as energy efficiency, behavioural changes to conserve energy, electrification, and changes in fuels, must be leveraged on a large scale to rein in our consumption and ensure a successful low-carbon energy transition.

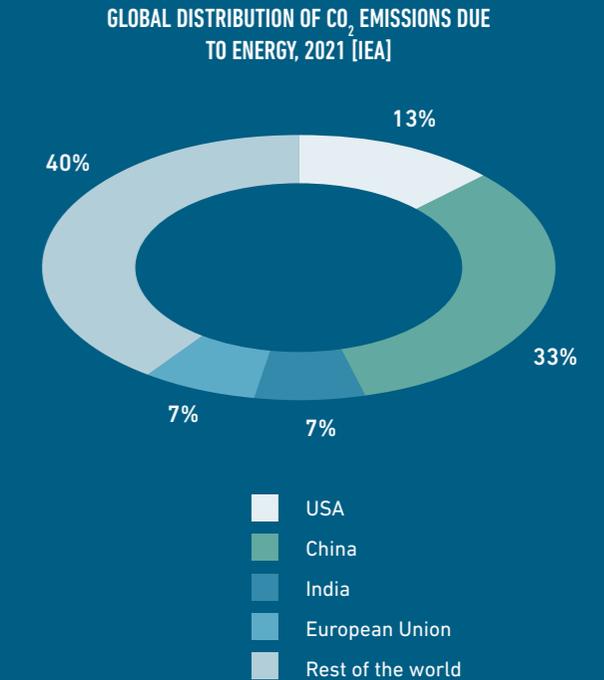
Energy efficiency measures (to maintain the same service whilst expending less energy) are now broadly

accepted, even though the lengthy returns on investment on some projects can often be a barrier. Instead, the aim today is to accelerate and expand the changes that have already begun in terms of infrastructure, buildings and equipment. Similarly, the electrification of many previously carbon-based uses (mobility, industry, etc.) has already been partly initiated and must be escalated further.

Conservation, on the other hand - in other words, reducing energy consumption by adjusting practices and behaviours (the ways in which we build, manufacture, travel, heat, use lighting, communicate, etc.) - involves collective and individual political and societal choices



FINAL ENERGY CONSUMPTION BY SECTOR AND BY SOURCE WORLDWIDE IN EXAJOULES), 2021 [IEA]



which are profoundly challenging our lifestyles and our development models. This is particularly acute in the richest countries which have enjoyed uninterrupted growth in affordable energy services in recent decades, and which are now being held to account for their high energy consumption.

Over the years, Artelia has accompanied these growing requirements to reduce and decarbonise energy consumption. As a multidisciplinary consulting and engineering group, actively involved in sectors where demand is greatest (building construction, industry, transport), we help governments, local authorities, contractors, industrial firms, property asset owners and operators to meet their commitments in terms of the transition to net zero and clean energy. As independent

consultants, our comprehensive view of energy allows us to adopt a systemic approach, which is essential in understanding the complexity of the issues involved and in planning actions effectively. Drawing on our experience in the field, we design and implement an array of solutions adapted to each specific situation. From sustainable buildings to urban lighting, and electricity-based mobility to the recovery of waste heat, the challenges are immense.



Building optimal strategies via a systemic approach

Today, all the players involved in development schemes are faced with low carbon and energy savings targets that vary in urgency from one activity sector and country to another. A comprehensive understanding of the energy system as a whole is necessary in order to draw up effective and sustainable strategies in these matters. A clear grasp of all the interactions involved in generation, distribution and consumption is essential, along with a detailed analysis of the specific technical, social, economic and environmental issues and constraints applying to each situation.

ACTION PLANNING AT GOVERNMENT AND LOCAL AUTHORITY LEVEL

Successfully building a low-carbon world involves designing energy systems that are capable of avoiding additional greenhouse gas emissions or offsetting those that cannot be avoided. Various prospective models and scenarios (IPCC, IEA, EU, etc.) have been drawn up to act as a framework and create an overall plan for this transformation to net zero by 2050. However, these plans have yet to be confirmed at national or local authority scale, and some very real obstacles remain, such as limited investment capacities, sometimes unsuitable organisations, contradictory economic interests, limits of the technologies currently available, and reticence or resistance from citizens faced with a need to reduce energy use that conflicts directly with today's consumer society. This new prism of decarbonisation hence requires a more cross-disciplinary approach and actions that are more advanced and more difficult to implement than the objectives of saving energy or increasing renewable generation that have been the focus of many projects in recent years.

We must now correctly identify, for each use and consumption, the types of energy involved and the emissions generated, and then estimate how this consumption will

change in the future in order to determine the most suitable actions to meet the goal of net zero. This means understanding the full spectrum of available techniques, so that the best combinations can be selected: implementing renewables on a self-consumption basis or via a collective network, improving the energy efficiency of buildings and facilities, introducing advanced measurement and management systems, interacting with users to bring about changes in behaviour, and more.

We think in terms of energy flows, looking at how energy is generated, consumed, and conveyed from point A to point B. We look at the entire system, repositioning it within each specific environment. We are able to adopt this approach thanks to Artelia's detailed knowledge of the many components of the energy system, our personnel with a wealth of experience in energy efficiency studies (assessments, consumption studies, etc.), and our vast array of technical expertise covering all the solutions for generating, transmitting, storing and managing energy.



EYMERIC LEFORT
Head of Energy activity
Water, Energy, Environment &
Africa Middle East Business Unit



For the authorities in Madagascar, Artelia drew up a least-cost energy development plan placing the priority on renewables and network upgrading. This document sets out an economically, politically and socially viable strategy, based on a detailed study of existing infrastructure and changes in requirements up to 2035.

Artelia possesses the objective multi-disciplinary expertise required to envision this transformation and assist public authorities with their analysis, planning and scheduling tasks. We are therefore working with several African countries (Burkina Faso, Ivory Coast, Mali, Madagascar, Togo) on drawing up their energy master plans. These plans analyse growth and consumption forecasts for the next 10, 20 or 30 years, identify ongoing projects and propose new developments to meet demand. Cooperating with many stakeholders, we draw up various scenarios that are analysed in collaboration with the authorities. These essential planning documents answer fundamental questions about the low-carbon energy mix, access to energy and socio-economic development.

We provide assistance to other public actors in a number of countries. We recently helped Italian authorities implement schemes such as the green 'Superbonus' and the 'Conto

Termico' which aim to boost renewable energy use and promote energy efficiency improvement. We also perform this type of study on a very regular basis in France, particularly on behalf of Ademe, the French Agency for Ecological Transition, for which we completed a large-scale prospective study of the technical, organisational and economic implications of an electricity mix comprising a high proportion of renewables within French island systems.

We are also assisting a number of French local authorities, such as the Toulon urban area in the preparation of its energy master plan, and the South Province of New Caledonia with a study for the integration of electric vehicles on the Isle of Pines, potentially using the cutting-edge vehicle-to-grid technology enabling energy to be fed into the power grid from vehicle batteries at certain times of the day.



JÉRÔME MERCIER

Manager of the Energy and Carbon Optimisation area of expertise

Drawing up an action plan requires a participatory, co-constructive approach. We contribute our methodology and our technical, economic and legal expertise in energy and decarbonisation. But to identify the needs, issues, implications and all the factors that could impede the transition, we work with the client's financial, legal, technical and operations departments. This is essential to guarantee long-term overall performance and ensure that the approach followed is truly responsible.

FACILITATING THE TRANSFORMATION OF COMPLEX ASSETS AND HISTORIC BUILDINGS

Economic players in both public and private sectors are gradually becoming more aware of the scale of the energy and decarbonisation challenges they face, in terms of both managing their assets (Capex) and operating them (Opex). There are multiple reasons for this. They may be motivated by increasingly strong legislative pressure. They may be compelled to act due to the forthcoming ban on the sale of combustion engine vehicles in the European Union, or under the new regulations in several countries targeting the real estate sector. Economic risks are other major incentives. The explosion of energy prices in 2022 is thus a powerful stimulus for conserving energy, boosting efficiency, securing supplies and abandoning fossil fuels, even though this crisis is also diminishing the financial capacities of companies and the most at-risk members of society. In the medium term, some players are also concerned about an increase in carbon taxation, fearing this will devalue their industrial or real-estate assets, or are wondering about the role "green finance" will play in shaping future investments. A desire to contribute to building a low-carbon world - to 'do one's bit' - is also a strong

incentive for transformation. Many economic players have hence expressed their intentions through CSR (corporate social responsibility) policies or strategies based on ESG (environmental, social and governance) criteria that they then strive to implement under the watchful eye of the public and their own personnel, both of which are increasingly well-informed, sensitive and critical in regard to these issues.

Artelia addresses a vast array of situations and projects in the context of its international assignments. Our methodology consists firstly in objectively analysing the condition of an asset and its capacity to meet the estimated future needs. Through this combination of asset-based and energy-oriented considerations, we are able to determine the type and scale of the actions required, from simple renovation to complete restructuring, in accordance with the overall investment budget. We then work on the possibilities for reducing energy demand and consumption. Significant technical progress has been made in recent years in terms of thermal insulation for buildings, more efficient heating systems, and low-consumption



PAOLO ALBERTI

Executive Director, Energy
Artelia Italia

We have completed hundreds of energy audits in recent years, whilst also managing improvement works. For some clients, we act as external manager for energy issues. In this situation, we install measurement and monitoring systems in order to analyse the energy consumed on a continuous basis.

In the context of a vast operation to modernise the real-estate assets of the Monte dei Paschi di Siena bank, Artelia Italia designed a unified system for gathering and managing energy data at the scale of a fairly disparate office complex.



DAVID CHOTARD
Energy systems and forecasting expert

Energy efficiency is still often approached from the point of view of immediate economic savings, namely "How can I reduce my energy bills?". But energy efficiency actually means investing today to avoid expenditure tomorrow. You have to think in terms of overall cost, in the long-term, with a complete overview of energy flows, uses and related practices. And in light of our low-carbon ambitions we need to go even further, seeking to improve overall project economics with regard to energy-related issues.



equipment. The last stage consists in looking for substitution opportunities (potential for generating low-carbon energy locally, using renewable sources, changing the energy vector).

Nowadays, many of our assignments are related to the tightening of legislation in the building sector, so we work with a very large number of public- and private-sector clients to assess and adapt their real-estate assets. In France, in the context of modernising 10,000 housing units managed by the French armed forces ministry, we performed a risk assessment

and are currently assisting the lenders in ensuring the operation is completed smoothly. The Provence-Alpes-Côte d'Azur regional authority has asked us to revise its plan for reducing the energy consumption of high schools in its remit by 30 to 40%. Given that energy efficiency has become a mandatory criterion in the context of a sale, we also perform various due diligence assignments for investors and private real-estate asset owners. For the Crédit Mutuel Arkéa group we are contributing to an audit and energy master plan for 31 office buildings (250,000 m²) spread across the whole of

France. In Italy, where energy audits are compulsory, we also assist a wide variety of players in assessing their real-estate assets (banks, hotels, sports centres, hospitals, etc.), in some cases also managing the subsequent refurbishment programmes.

Our assignments also call us to work on assets of many other types. For the Grand Arena energy-positive district in Nice, we analysed the energy-related issues and variations in consumption, and then proposed development solutions. We are working with the south-east



Artelia is contributing to the project instigated by Marseille Provence Airport aiming to achieve net zero carbon emissions by 2030. We analysed all the energy consumption items (heat/cold production, electricity, back-up generators, runways and servicing equipment, etc.) and proposed modifications to decarbonise them.

Toulouse urban area authority (Sicoval) on its project to create the region's first positive-energy business park, by drawing up the technical, legal and economic strategy for the operation. We also contribute to defining action plans for transport infrastructure transformation. Examples include the Pointe des Grives harbour (Martinique), which wishes to decarbonise the electricity it supplies to berthed vessels, and Marseille Provence airport, which is aiming to achieve net zero by 2030. We also perform studies on decarbonising energy use in a variety of industrial assets.



JULIEN SAINT
Head of Artelia Consulting

Awareness of ecological, energy and decarbonisation issues is becoming predominant in the technical audit and due diligence assignments that we perform for investors and asset owners. Consequently, we are now providing new services, such as helping our clients analyse their activities and assess the requirements they must meet under the EU green taxonomy that will gradually come into force across all economic sectors.



Acting at city and regional level

Local authorities are key players in urban development, and are naturally engaged in implementing decarbonisation strategies. A growing number of them are today focusing their efforts on reducing energy consumption and greenhouse gas emissions. To achieve the structural goals that they have set themselves, they need to use all of the available levers: urban ecodesign, promotion of renewable energy and energy recovery, optimisation of public lighting, refurbishment of public buildings, development of soft mobility and electric transport, public transport, etc.

DESIGNING LOW-CARBON AND ENERGY-NEUTRAL PUBLIC SPACES

Cities house a very large number of inhabitants and a wide range of activities and services, meaning that they consume a lot of resources and form areas with high greenhouse gas emissions. Improving this scorecard has become a concern, among many others, which is forcing them to reconsider land-use planning by developing infrastructure which is aligned with the goals of the Paris Agreement.

For several years now, thoughts have increasingly turned to urban sprawl, the functional mix of neighbourhoods, active travel and even the greening of public spaces, all levers which can be used to reduce or offset consumption and emissions. For example, reducing urban sprawl and creating mixed neighbourhoods (combining housing, businesses and services) have a direct impact on the reduction of travel and the associated energy usage. Similarly, the creation of high-performance public transport infrastructure, combined with urban design which facilitates active travel (walking, cycling), offers residents the chance to reduce their energy and carbon footprints, two factors which are very closely intertwined in urban planning thinking.

Artelia has been involved in urban planning for decades and is a stakeholder

in this change, by adopting an ecodesign approach in many of its projects. In France, mixed usage is at the heart of most of the redevelopment projects and work to create new neighbourhoods to which we are contributing in cities such as Paris, Lyon, Bordeaux, Nice, Lille, and Nantes. Combining shops, green spaces and public services with housing and office buildings to provide more coherent and self-contained living areas is now standard practice. Increasing urban density is also a key step which involves reinvesting in areas of the city which up until now have been neglected to create neighbourhoods where people live, go for a walk and meet, allowing for short and simple journeys between destinations. By re-concentrating these activities, urban sprawl can be controlled.

We are hence supporting the Nantes metropolitan area authority with a number of projects focussed on “renewing, connecting and extending” the city centre to contribute to the “closer city”. We are assisting the Bordeaux and Toulouse urban areas, which are being redesigned to combine increased urban density with an improved living environment. In Bordeaux, for example, we are contributing to the Bastide Niel project which involves creating a city centre neighbourhood which is “dense, mixed, light, green, and welcoming”.



BÉATRICE ARBELOT

Executive director
Urban and Regional Development
Business Unit

The best energy is the energy we don't consume. The news reminds us of that every day. Much of our work therefore focuses on ecodesign for urban projects, mixed-use neighbourhoods, soft mobility, etc. - all of which helps to reduce consumption. Where energy use cannot be avoided, we support local authorities in the roll-out of renewable energy generation and energy recovery, and in transitioning away from fossil fuels.



GUILLAUME RUFFIN

Head of the Energy Department
Urban and Regional Development

These days, local authorities are looking closely at ways to conserve energy So we can act as an independent advisor to them. We help them to draw up region-wide strategies by offering them key messages and solutions, without necessarily encroaching on the political decision which is fundamental. Each local authority is different, each with its own area of responsibility, so we have to understand them to be able to effectively assist them on a range of subjects: technical, particularly in terms of energy and infrastructure refurbishment, financial, with an eye to the overall cost of projects, and communication (supporting consultation procedures, running workshops, etc.).



We also help local authorities to deliver urban design that is innovative in terms of energy design. We are working alongside the south-east Toulouse urban area authority (Sicoval) on the design of a positive-energy business area, the 'ZAC du Rivel' mixed development zone. As part of this project, we have studied the ideal energy mix to implement and the optimum conditions for its roll-out and operation.

Even though approaches and sensibilities vary, in many countries the prevailing aims are to create neighbourhoods and towns which are greener, more economical in terms of energy and resources, and nicer to live in and which emit less carbon. For example, in Denmark, we are conducting engineering design studies (buildings and infrastructure) and environmental impact studies for the new Kildedal district in Ballerup. The project is centred around a strong mixed-use development between an innovative life sciences business area and a series of housing, services and green spaces. In Luton, UK, Artelia is responsible for cost control on the Stage property scheme which includes the creation of housing, offices, leisure spaces, a public park and an urban design which encourages sustainable transport.

In France, as part of the ViaSilva urban development within the Rennes metropolitan area, we studied the renewable energy requirements and opportunities, considering transport services, mixed-use development, and increased urban density for the scheme, limiting encroachment on agricultural land. In particular, the project involves the construction of two metro stations, a park-and-ride facility, a bus station and a dense network of cyclepaths and pedestrian routes.



© L'Ylo et D&A



THOMAS BERNIER

Deputy director, development
Urban & Regional Development

Anaerobic digestion is fully in line with the energy self-sufficiency goals of Europe and France. It is in keeping with a move towards regional sovereignty and a reduction in dependence on fossil fuels. In the context of the current tensions relating to natural gas, the use of this process is likely to accelerate. We have extensive expertise in this area which has earned us the Qualiméthas certification, an ISO 9001 standard which certifies our experience with this type of project.

RENEWABLE ENERGY, ANAEROBIC DIGESTION AND WASTE-TO-ENERGY

The desire to increase local renewable energy generation and energy recovery is another strong trend for low-carbon towns and regions. We have seen this trend reflected in the installation in rural areas of differing sizes of wind and solar farms, generally connected to the grid. Thanks to its flexibility, solar power is increasingly frequently integrated into public urban areas with the underlying idea of offsetting energy usage for lighting, electric bicycles, WiFi routers and other energy-consuming services. As a result, Artelia regularly studies projects which involve making use of car park canopies or other building roofs to generate electricity. We have worked on a number of such projects with the developer GreenYellow, an expert in energy use in areas which have already been developed. In Paris, we are currently involved with an analysis of using solar power for electric bicycle and scooter charging stations. As part of the Grand Parc Garonne project in Toulouse, we are also studying the appropriateness of using areas liable to flooding which cannot be built on as locations for solar panels.

Local authorities also have the opportunity to introduce what is known as energy recovery technologies by making use of organic waste or household refuse to generate heat, biogas, or biofuels. One of these techniques is anaerobic digestion, a process where organic waste is fermented without oxygen. This produces a gas containing methane which, once purified, can

be fed into the gas network or be burned on site to generate heat and electricity, replacing fossil fuels. In France, the energy transition law for green growth sets a goal of growing the share of this renewable gas to 10% of national consumption by 2030. Another alternative is the distillation of plants containing sugar or starch and the esterification of oil plants or waste oil. These processes produce "biofuels" which can be used to partially replace other oil products, particularly for transport. The third way is the incineration of household waste and, under certain conditions, industrial waste.

We work for local authorities and private clients on energy recovery through anaerobic digestion. The advantage of anaerobic digesters is that they can operate with plant and animal waste, waste from the food industry or sludge from waste water treatment plants. The development of dedicated crops for the production of biogas and biofuels is also a possibility, but it is also widely criticised from an ecological point of view because it is liable, at a large scale, to lead to land-use conflicts with the food crop sector or cause further deforestation.

We have advised and supported a number of operators and agricultural unions on the implementation of these anaerobic digestion processes which offer them the opportunity to generate an additional revenue stream alongside their core business. Most recently, we worked



AFA - SANAE
architecture



We are actively engaged in optimising the anaerobic digestion units at the Valenton plant (Paris region) which processes waste water for around 3.6 million PE. The aim of the Owner, SIAAP, and its operator SEMOP SIVAL, is to increase the site's production of biogas to feed into the network, thereby creating one of the largest anaerobic digestion units to be built in France in a waste water treatment plant (production capacity 1,800 Nm³/h).

alongside the Methagri Meuse company on the implementation of an anaerobic digestion unit for generating biogas and feeding it into the gas network, whilst also making use of the digestate produced as a fertiliser. We are completing a similar facility for the Méthacollines company, created for a family farm in the Drôme region of France.

Historically, we have been very active in the waste water treatment plant sector where the anaerobic digestion of the sludge generated by the settling processes raises a two-fold challenge: generating biogas from the organic matter contained in the sludge, but also reducing the volume of sludge and stabilising the digestate created by the process, making it easier to use again, particularly for landspreading. We

are currently working on these issues for the Paris region waste water management agency (SIAAP), one of the largest agencies of its kind in Europe, which has decided to increase the generation of biogas at its Valenton plant. A large proportion of this gas is already used on site for operating the plant's heating systems, but SIAAP wants to go one step further by also recovering the biogas which is not yet used and feeding it into the network. We have therefore worked on drawing up a master plan based on this dual objective of improving the site's energy self-sufficiency and making use of this surplus biogas generation. Other operations (recovery of waste heat, use of sludge from another site) are also planned as part of this landmark project. The first phase of the works is currently in progress.



FRANÇOIS CLEIREC

Manager, Waste Treatment and Waste-to-energy

The incineration industry is very robust, efficient and economical in the face of soaring energy prices. Current assets are ageing and the issue of renewal is starting to be raised. A great deal of progress has been made in the design of plants, the energy efficiency of facilities, the treatment of fumes and the recovery of the waste heat contained in them.

Energy recovery from household waste is another very important lever for local authorities. To begin with, the aim was chiefly to destroy combustible waste by incinerating it to reduce the quantities sent to landfill. However, the heat generated by this process has gradually been recovered to supply district heating networks. In Europe, this waste-to-energy generation has become almost routine and accounts nowadays for around 6% of gross heat generation [Eurostat 2020]. Subsequent projects to update standards have helped to drive the sector forward. The latest European regulations, based on the BREF (Best Available Techniques Reference Document) relating to incineration, sets very high requirements in terms of energy efficiency and control of environmental impacts. In parallel, the system for taxing emissions adopted by some countries means that an incineration plant must today be coupled to a heating system or find another energy outlet if it is to be viable.

Obviously, incineration is not an end in itself. It is part of a waste management process which has also seen a number of significant changes. Today, the main objective is to avoid creating waste, and then to recycle as much of it is possible by sorting it, thus separating the organic part which can be anaerobically digested. The incineration of residual household waste (RHW) is therefore one of the final stages of the process, treating only that waste which could not be otherwise used. Alongside this RHW, there are also arisings of “industrial” waste (furnishings, ground tyres, etc.) which can be converted

into RDF (refuse-derived fuel). These can also be used for energy generation, provided that the fumes and residues are suitably treated, in direct accordance with the categories of waste incinerated. Recent European regulations now require the incineration industry to control and capture a number of compounds (acids, dioxins, heavy metals, dust, mercury). As in traditional thermal power plants, and the petrochemical and steel-making industries, CO₂ capture represents a significant issue.

Artelia operates across this whole sector (waste collection, materials recovery facilities, incineration plants). In energy terms, processes are now well established and it is more about optimising plants so that they meet the new regulations and the requirements of local authorities. This is the focus of our work with the Toulouse-Le Mirail urban waste recovery facility (France) for the Decoset agency. We first carried out a technical assessment of the plants and then drew up some suitable refurbishment proposals. Today, we are providing engineering designs for the works relating to the buildings and the plant’s incineration systems. In the same mould, we are contributing to the modernisation of the materials recovery and incineration facilities for the Grenoble metropolitan area. Through its teams in Denmark, Artelia has also been involved in the construction of a flagship plant, Amager Bakke in Copenhagen, which combines a waste-to-energy plant with a rooftop leisure complex.



Our Danish teams have contributed to the design of the Amager Bakke waste-to-energy plant which generates both heat and electricity for thousands of residents in the Copenhagen urban area. Its unique design also features a rooftop leisure centre which includes an artificial ski slope.



DAVID CHARBONNEAU

Head of Public Lighting and Sustainable Regions

The smart city is starting to take shape and offers a range of possibilities for improving the management of energy, water, transport, etc. At this stage, we are able to draw on some interesting learnings. To find the most convincing solution, we need to carefully analyse all use cases, ensuring we do not lapse into a collection of demonstrators, because the hardware of the smart city is pointless unless it is installed in accordance with a plan of action which is well thought-out and coordinated for the benefit of its users. In practice, feedback incorporating a cost-benefit component is vital for judging the meaningfulness of actions. This must be planned as soon as the project is set up.

OPTIMISING PUBLIC LIGHTING AND DEVELOPING CONNECTED CITIES AND REGIONS

Public lighting is currently one of the largest energy costs that cities face, and is therefore a key target for energy efficiency policies. In France, it accounts for nearly 40% of the energy usage of local authorities. Thanks to technology improvements in recent years in terms of the hardware and automation, reducing consumption by between 50 and 70% has become a very achievable target at a reasonable cost and with a similar level of quality, particularly if the original facility is old. As a result, numerous local authorities have launched projects to upgrade their public lighting systems.

The energy savings are achieved by a combination of reviewing the layout of the light sources, using LED bulbs (which require significantly less energy and have become relatively inexpensive) and installing motion sensors in places which are not busy to avoid permanently illuminating them at maximum intensity. The current energy crisis has also reopened the debate about the need to implement more restrained policies around lighting. Some have questioned the need to illuminate public spaces throughout the night when far fewer people use them after 10 pm. Others have expressed their preference for

turning off or changing the lighting to preserve biodiversity. Adjustments to the type of lighting (e.g. its temperature) and the creation of “dark corridors” are starting to be considered in order to protect wildlife. Ultimately, the issue of lighting is a real textbook case. It shows that while energy efficiency initiatives are largely widely accepted, because they involve little disruption for users, energy conservation on the other hand is a more sensitive issue because it affects the comfort and feeling of safety inherent in well-lit urban spaces.

Improving the energy efficiency of lighting and illuminated signage also involves introducing means of controlling and operating the lights, linking in with the much broader topic of smart cities and regions. Today, experts believe that the key to better control our consumption of resources, particularly energy, is to apply digital systems which can collect and process, in real time, information about changes in flows and the operation of public spaces and infrastructure. Modulation of lighting based on the requirements observed at any given moment is just a small part of the anticipated applications. The principle of “smart” cities and



The “Angers smart region” project aims to use digital technologies to optimise numerous urban services (lighting and illuminated signage, water and sewerage, parking, watering of green spaces). It is expected to deliver reductions in water and energy usage of between 20 and 66%. Artelia has been involved in engineering design services for the public lighting (50,000 light points).

regions involves optimising and coordinating the management of all urban services (energy, water, lighting, security, environment, transport, parking, waste management).

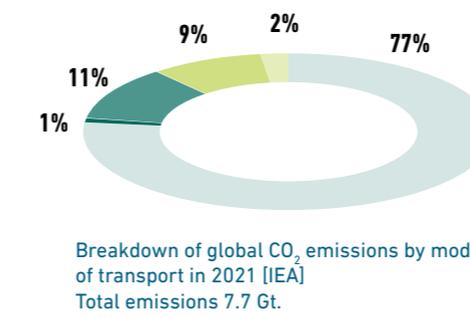
Artelia is working on these various issues with the majority of major French cities. Recently, we helped Paris city council renew its comprehensive performance-based contract for lighting and illuminated signage. We also provide complete design and works supervision services for urban lighting renewal operations, a current example being the city of Rennes (5260 light fittings). Our environmentalists are working on multiple studies relating to dark corridors, particularly for Siéml

(Maine-et-Loire inter-municipal energy agency) and Sydev (Vendée departmental energy agency). We are also contributing to smart cities projects, such as one for the Angers Loire Métropole authority which covers all urban services, and that of Pornichet town council focusing on the digital management of public lighting, transport, and video surveillance. In parallel, we are also actively involved in discussions of innovative approaches, particularly for the Paris-Seine-Ouest urban authority which is looking at the possibility of harnessing the widespread coverage of the lighting network to collect and transmit different types of information.

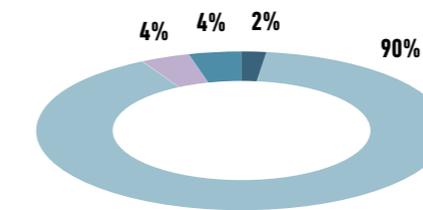


Contributing to other forms of mobility

Transport accounts for roughly 25% of global final energy consumption and generated nearly 40% of emissions in end-use sectors in 2021, proof of its substantial carbon footprint [IEA 2022]. These figures reflect the fact that fossil fuels predominate (91%) in all transport categories (land, sea, air). Two key changes have been initiated to improve this situation. The first involves encouraging a shift of some travel to modes of transport that generate lower CO₂ emissions. The second entails improving the energy and carbon performance of land, sea and air vehicles through adjustments to engine systems and fuels.



- Road
- Rail
- Maritime
- Air
- By pipeline



- Electricity
- Oil
- Natural gas
- Biofuels



KATIA TIBICHTE
Director, Strategy and Management of regions

The search for alternatives to private cars with ICEs is a key part of efforts to decarbonise travel. One solution lies in the development of public transport (train, metro, tram, bus) powered by electricity, biofuels or hydrogen. Efforts to promote walking and cycling also play a key role. This goal is prominent in current development projects.

REINFORCING LOW-CARBON PUBLIC TRANSPORT AND ACTIVE MODES

Radical changes to goods transport and private mobility were seen over the course of the twentieth century. Private cars with internal combustion engines (ICEs) became commonplace, symbolising liberty and completely restructuring our living spaces. Maritime transport saw unprecedented growth due to the globalisation of trade. This was followed by a boom in aviation enabling high-speed national and intercontinental travel, which stimulated business and prompted the rise of large-scale international tourism.

This extraordinary growth in transport that benefited one section of the global population through free trade has now resulted in a substantial carbon footprint, with 7.65 Gt of CO₂ emitted in 2021 [IEA 2022]. In order to improve this situation, certain developments need to be reviewed. This has led to a societal debate on travel for tourism, while other discussions have been held on relocating industrial activities. Significant focus has also been placed on methods of reducing the carbon footprint of everyday travel by encouraging people to switch to



Artelia has played an active role in the rollout of the tram network in Bordeaux from its inception. This is now a key piece of low-carbon public transport infrastructure covering the city's metropolitan area.

Artelia is currently working with the Société du Grand Paris to build the Grand Paris Express, a major extension of the Paris Metro for which 200 km of automated line and 75 stations are being built. This colossal, hugely complex project is now in its final stages.



less carbon-intensive modes of transport, in particular active and collective modes.

Artelia has gained extensive experience of these issues by contributing to the creation, modernisation, extension and restructuring of a variety of urban and regional transport infrastructure. As early as the 1970s, we began helping to draw up innovative transport plans seeking to keep motor vehicle traffic to the fringes of urban areas. We have also been involved in setting up metro systems. Over twenty years ago, we became actively involved in reviving electric urban tram networks, which have since flourished in many cities, covering progressively larger areas. These projects

have also triggered major redevelopment campaigns that have led to high-quality new pedestrian zones in city centres. On a larger scale, we have also helped build high-speed train lines and rehabilitate conventional railways, while playing an active role in policy on the renovation and development of river and port infrastructure.

Our overall approach to mobility now focuses more than ever before on low-carbon and multimodal solutions. In particular, we help local authorities to develop public transport infrastructure used to operate a wide variety of modes of transport tailored to specific requirements (metro, tram, cable transport,

bus rapid transit, regional trains). We are currently contributing to projects of this type in numerous urban areas (Paris, Bordeaux, Montpellier, Lyon, Toulouse, Reykjavik, Canberra, etc.) drawing on our twin areas of expertise in transport mode technology and urban integration. Plans to improve coordination between the various modes are now also regularly promoted to attract as many users as possible to these public transport networks. Another major development can be seen in steps to reduce the number of cars in city centres, with the focus switched to improving cycle lanes and recreating attractive pedestrian areas. These active modes are now systematically factored into urban planning projects whether to renovate a road network, regenerate a district or build a new bridge. We are also involved at regional level in developing cycle paths and

routes linking regions and providing a means for people to enjoy special sites of interest.

The decarbonisation of transport remains a very open-ended issue. Solutions are still needed for suburban and rural areas where housing is often highly dispersed and thus difficult to cover. The COVID-19 pandemic has also prompted reflection on public transport resilience and health issues. In addition, the many developments currently occurring in relation to changing fuels and engine systems require new balances to be struck between private vehicles, public transport systems and active modes.



SYLVAIN CABANEL

Operations director
Shell-Artelia partnership

Investment in electric vehicle charging infrastructure (EVCI) is very high and will probably remain so for a few years, before hydrogen takes over. With Shell, we have built an innovative strategy for EVCI provision. There is a business development component that consists in going to see all those businesses that have parking spaces (car park operators, supermarkets, restaurants, shopping centres, gyms, banks, and more). Then we fulfil the Design & Construct and Operation & Maintenance aspects.

EXTENDING ELECTRIC CHARGING AND THE DISTRIBUTION OF ALTERNATIVES TO FOSSIL FUELS

Given our globalised economy and continuing infatuation for travel, it is difficult to imagine a significant reduction in transport volumes over the coming years. This makes it even more necessary to improve the fuel efficiency of vehicles and replace the dominant fossil fuels with low CO₂-emission fuels.

Under the pressure of new regulations, such as the European Union's ban on the sale of new petrol or diesel engine vehicles as of 2035, transformations have been started in the field of road transport, which accounts for more than three-quarters of emissions in the sector and represents a key challenge. Uncertainties still remain, but for the moment the "electric motor and on-board battery" system seems to dominate in the light vehicle field, while the 'electric motor, fuel cell and pressurised hydrogen tank' system is favoured for heavy haulage (trucks, trains). Compressed natural gas (CNG) and liquefied petroleum gas (LPG) are interim alternatives to petrol and diesel, particularly for heavy goods transport. They would make it possible to extend the lifetime of combustion engine vehicles and could ultimately be replaced by biofuels obtained from biomass transformation.

Artelia has been involved in this transition for several years alongside

the leading global fuel distributors (Shell, TotalEnergies, Exxon-Mobil, etc.) and numerous national companies, by managing the modernisation of entire service station networks in dozens of countries. In this way, we are contributing to improving access to CNG, LPG, biofuels, electricity, and - more recently - hydrogen, particularly in Europe. We are also supporting public transport in the transition towards these alternative fuels. We participated in creating one of the first hydrogen-powered bus networks in France, in the city of Pau. We are also a stakeholder in two innovative projects for trains running on hydrogen, one in Germany for Deutsche Bahn, and the other in Italy on the Brescia-Iseo-Edolo long-distance line (the "H2Iseo Hydrogen Valley" operation).

Currently, however, electrifying road transport is the main thrust of these engine and fuel changes. Battery electric vehicles appear to be the most accessible decarbonisation solution, provided that supplies of rare earth elements can be secured amid the current market pressures, and that enough low-carbon electricity can be generated to cover future demand. However, distributing such vehicles on a large scale requires the roll-out of suitable charging infrastructure in public spaces. So we are involved in



On the Fulham Road, in Greater London, we managed the entire conversion of a conventional Shell service station to all electric by installing ultra-fast charging points (20 minutes), alongside an economically-priced slow charging option.

In France, we contributed to creating the Fébus bus rapid transit (BRT) in Pau, an original network that operates articulated buses running on hydrogen to serve 14 stations on a 6 km route within the city.

drawing up EV charging point roll-out strategies alongside local authorities and private stakeholders.

In France, where legislation now requires a proportion of parking spaces to be set aside for charging points, we are helping local authorities pinpoint needs and anticipate their development. Working jointly with all the 'EPCIs' (public establishments for inter-municipal cooperation), we are drawing up regional master plans incorporating existing capacities, future needs and regulatory obligations. Given that about 90% of vehicle charging is currently done outside public spaces, it is important to set the investments at the right level. We are also working in France and other countries

with the major energy suppliers on rolling out electric vehicle charging networks. In particular, we have developed an innovative concept with Shell, which plans to roll out several thousand charging terminals across the world. We are also working in Italy and other European countries for a number of players (Acea, Allegro, Audi, Becharge, Bolloré, EnBW, Eni, Enel X, Engie, Ionity, Mercedes-Benz, TotalEnergies, and more). In Germany for EnBW, for instance, we have just finished designing a standard fast-charging hub, a modular solution that is easy to build and combines technical efficiency and architectural quality.



ROBERTO BONINI

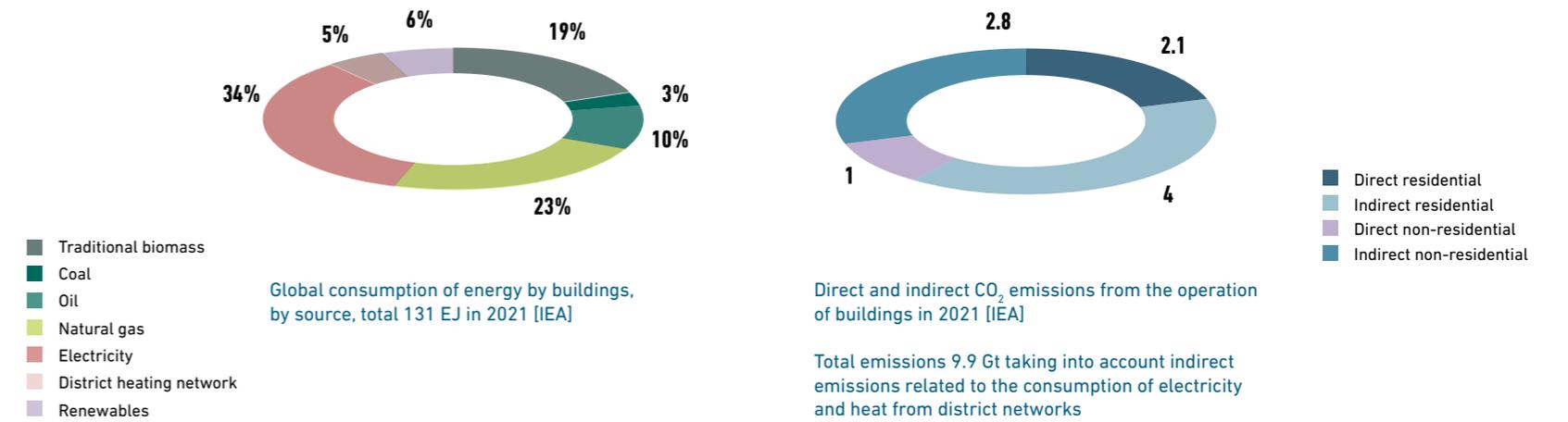
Manager, Renewable Energy
Artelia Italia

In Italy, we have completed the engineering designs and overseen the construction of multiple charging stations and terminals for electric vehicles. For Enel X, we took part in installing more than 1,000 fast and ultra-fast charging points on the motorway and main road networks. We have also installed 570 terminals in parking areas for Bluetorino (Bolloré group), acting as turnkey contractor, and equipped the Porsche dealerships in Italy with fast charging stations. We are currently working on rolling out more than 350 terminals for Becharge and more than 200 for Acea.



Moving towards sustainable buildings

In 2021, the building construction sector accounted for 30% of the world's final consumption of energy and 15% of the total indirect emissions of CO₂ from the end-use sectors [IEA 2022]. Year by year, despite the efforts made to improve energy efficiency, this consumption is rising inexorably as built floor areas increase to keep pace with population growth. If the targets of Net Zero by 2050 are to be met, it is therefore vital to transition towards energy-neutral buildings, for both new-build projects and the refurbishment of existing assets. We are becoming better and better at designing and building sustainable buildings.



TAKING ENERGY AND CARBON INTO ACCOUNT OVER THE ENTIRE LIFE CYCLE

Thermal regulations have changed substantially in recent years to incorporate CO₂ emission reduction targets as well. This approach is prompting players to consider the complete life cycle of buildings (design, construction, operation, maintenance, refurbishment) in order to gain a better understanding of the energy they consume and the emissions they generate. Today's carbon assessments therefore focus primarily on direct emissions (inherent to energy consumption during operation), but also examine indirect emissions (related to the collective production of electricity, heating and cooling and, more broadly, the materials used for construction, maintenance, etc.).

The International Energy Agency has identified 80 countries worldwide that have implemented energy standards or codes for the building construction sector. The European Union, which accounts for 40% of final energy consumption and 36% of greenhouse gas emissions, has issued several directives concerning energy performance in recent decades. The most recent ones clearly aim to accelerate the pace of transformation, especially as regards refurbishment. In either response to or anticipation of this trend, most European countries have enacted their own laws on this matter. After initially relying heavily on incentives such as subsidies and tax credits, governments are now stepping up the regulatory



The central idea behind the Living places concept, developed by Artelia Denmark, Velux, Effekt Architects and contractor Enemærke & Petersen, is to substantially reduce the CO₂ emissions generated by single-family houses by designing each space more efficiently, placing the priority on managing energy sparingly and using bio-based materials. An initial prototype is to be built in the Jernbanebyen district of Copenhagen.

constraints to force all players in the sector to take tangible steps to improve energy efficiency and reduce carbon footprints. Environmental certification systems dedicated to buildings have closely followed these changes in legislation, and are also continuing to be developed. Whether they are national or international in scope (BREEAM, LEED, HQE, etc.), they set standards encompassing energy performance along with many other sustainability-related criteria, such as the quality of the materials used, project management, systems dedicated to resource efficiency, and health and comfort for the end users.

As a long-standing player in this sector, Artelia has fully embraced this approach of working on the entire life cycle of buildings to improve their energy efficiency and reduce emissions. We contribute to each phase of this cycle by proposing targeted actions. Right from the design stage, with a view to reducing the building's future consumption, we optimise its operating principles by performing thermal calculations, dynamic simulations, and analyses of the materials and equipment. Then, throughout the

implementation phase, we ensure that the works are carried out in accordance with best practice in construction and energy performance. During the first few years of operation, we then stay involved to adjust the equipment and ensure that the handover is completed correctly. Lastly, after the building has been operating for long periods, we perform energy audits (technical assessments of the condition and performance of the facilities) and draw up plans of action to upgrade it in line with current standards.

We also work as an independent technical advisor with ministries and accreditation agencies, helping them to update regulations and certification procedures. In France, we contributed to the development of the 'BBCA' (low-carbon building) ecolabels, and are still involved in their ongoing adaptation. We are also helping the Vietnamese ministry of construction with implementation of the EECB project aiming to improve energy efficiency in commercial and high-rise residential buildings. In Denmark we have just participated in an interesting initiative called "Living places", aiming to create a new standard for healthier,



AURÉLIE BLOTTIÈRE

Head of the Environmental Design, Energy and Carbon Strategy Unit

Building construction is a sector with very high impacts in terms of energy consumption and carbon emissions, but is also one in which there is tremendous potential for action and improvements. The main recent changes in legislation, such as the RE2020 thermal regulations in France, involve taking carbon emissions into account and considering the complete life cycle of the building.



© W02



Artelia is assisting W02 with environmental design services for the Arboretum campus, which is breaking new ground in workplace design by featuring 125,000 m² of offices and services built mainly of solid wood. Energy consumption is both reined in, at 61 kW final energy/m²/year - 2.5 times less than the average for French commercial premises according to the sustainable buildings watchdog 'Observatoire de l'Immobilier Durable' - and decarbonised, through the large-scale use of geothermal sources. With BBBCA (low-carbon building) certification at the Excellent level (design phase), Arboretum is ahead of its time. It complies with "carbon" limit values for construction and energy that do not come into force under French environmental regulations (RE2020) until 2030.

more sustainable single-family houses with energy consumption and CO₂ emissions slashed to particularly low levels.

We have been applying our sustainable buildings expertise to new-build projects of all types in the countries where we operate for many years. In Paris, we have just completed construction of the Duo towers on behalf of Ivanhoé Cambridge. This mixed-use office and hotel complex holds the French HQE (green building) certification and is in the process of obtaining LEED and WELL certification at the highest possible levels. Also in the Paris area, we are acting as energy, environment, carbon and certification expert for the creation of the Arboretum campus. This project is now

nearing completion to particularly ambitious standards in terms of energy efficiency, low-carbon construction, and integration with the natural environment. In Copenhagen, we are working with developer Kilden & Hindby to design the TRAE building, a 20-storey timber office block composed partly of recycled materials in order to minimise the carbon footprint of its construction. In Denmark, we are also contributing to a project to build the first school holding the Nordic Swan ecolabel, which sets very high standards in terms of thermal comfort and the use of sustainable, environmentally-friendly solutions.

MAKING PROGRESS ON THE CRUCIAL ISSUE OF REFURBISHMENT AND SETTING PERFORMANCE TARGETS

Existing buildings vary extremely widely in terms of their quality and state of repair, and refurbishment and retrofitting is a complex, strategic challenge in meeting the targets of Net Zero by 2050. Most of the buildings that will be in use in twenty or thirty years' time already exist, and most of them were constructed to energy standards that fall far short of today's requirements. Transforming them is hence a necessity, one that is being increasingly targeted by regulations. In France, it has been compulsory since 2020 to refurbish commercial buildings more than 1000 m² in surface area, and pressure is also being stepped up in the housing sector. These measures aim to achieve energy savings of 40% by 2030, 50% by 2040, and 60% by 2050. Several other European countries have set similar objectives.

We hence adapt our services to the specific requirements of national regulations, but apply the same proven methodology in all cases. To obtain an efficient, carbon-neutral or positive-energy building, we start by assessing it in its current state and identifying the types of energy it consumes. We then work on reducing its

needs (by optimising its outer envelope), making its systems (heating, ventilation, air conditioning, etc.) more efficient, and introducing renewable energy sources (e.g. solar or geothermal).

In Europe we are currently working on a number of projects to improve energy efficiency and reduce carbon emissions. In France, we are contributing to the reconfiguration of several high-rise buildings in the Paris La Défense business district dating from the 1970s and 80s, with a view to obtaining high levels of environmental certification. In Spain, we have upgraded the head office of the Generali group to current standards of efficiency and user comfort, thereby cutting its energy consumption by 30%. In Norway, we are involved in improving the energy performance of Stortovet 7, one of the largest property complexes in central Oslo. In London, we are contributing to the project to refurbish a building owned by Birkbeck, University of London, which is aiming to achieve BREEAM Excellent certification. We are implementing similar projects in Rome, with the refurbishment of Enel's headquarters, which aims to obtain high-level LEED and WELL



FANNY GELIN
Manager of the Commissioning and Operation Unit

An energy assessment forms the basis of any action to combat global warming. This includes the behavioural component, the way in which the premises are used, and then the performance of the envelope and the facilities. Our method is always the same: identify the need, manage it, and see how it will change over time. And on that basis we can look at alternative solutions to be rolled out.

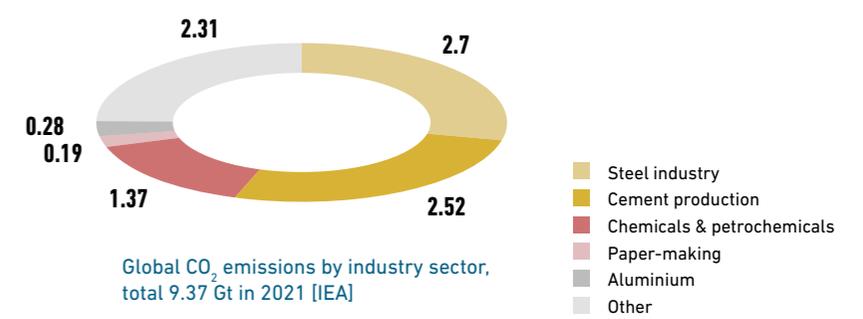
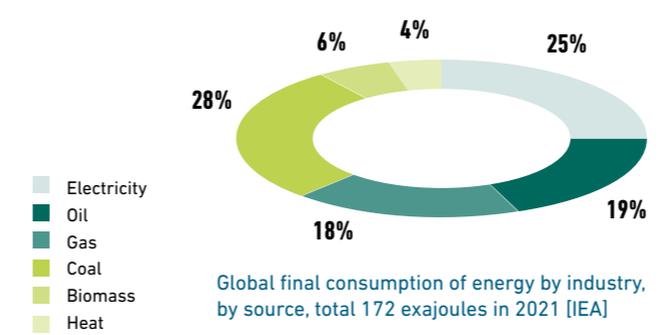


In the context of a comprehensive performance-based contract signed with Paris city council, we have undertaken to achieve a 30% reduction in the energy consumed by 140 schools, by managing the complete process of refurbishing them from design through to operation.

certification, and in Milan, where we are upgrading the Vetra Building by rolling out a complete environmental strategy comprising energy efficiency, water savings, indoor air quality, use of eco-materials, and more.

In France, we have also done substantial work to develop our approach centred on a binding "energy commitment". In the context of comprehensive performance-based contracts, we undertake to meet specific consumption reduction targets, which entails managing complete projects from the design stage to supervision of the works and monitoring of operation over several years. We have used this type of approach with a number of municipal and regional authorities. In doing so we act as general contractor and perform the works by calling on subcontractors. We are the only engineering firm that offers such a comprehensive and integrated service package for energy projects of this kind. In Italy, we are also helping joint owners of properties to improve the energy efficiency of their buildings by taking advantage of the government-funded 'Superbonus' scheme, which reimburses the complete costs of studies and works for insulation projects, the installation of green heating systems, solar panels, etc. We are currently supporting about fifteen operations of this type.

Over the past few years we have also made a great deal of progress in the field of smart buildings. We have had opportunities to address a variety of issues relating to sensor configuration, and data processing and analysis. This experience, acquired in the framework of binding energy performance contracts, has strengthened our ability to design these digital systems for monitoring and controlling consumption by focusing on the indicators that play a key role in boosting performance. In this regard we advocate a degree of rationality, to ensure in particular that introducing these monitoring systems does not lead to unreasonable additional costs in the operational phase. We are also continuing to make progress on aspects relating to user behaviour and ways to take their practices and habits more fully into account, an aspect that is emphasised by environmental certification processes. On behalf of Saint-Gobain, before and after the firm moved into new premises, we conducted surveys to assess levels of employee satisfaction in a number of areas, such as acoustic, thermal and visual comfort. This is a highly valuable process for pinpointing areas that need to be improved.



Supporting the decarbonisation of industry

Industry accounts for more than one third of global final energy consumption and 45% of total indirect emissions of CO₂ from end-use sectors [IEA 2022]. These data for 2021 clearly show that a transformation of the industrial sector is critical if net zero is to be achieved by 2050. Replacing fossil fuels with low-carbon sources, especially through electrification, improving the energy efficiency of facilities and rolling out carbon capture, storage and recovery technologies are some of the main levers under consideration to reach these goals.

REPLACING FOSSIL FUELS WITH LOW-CARBON SOURCES

The majority of CO₂ emissions attributable to the industrial sector (excluding electricity generation) come from three specific sub-sectors: steel making, cement production, and the chemicals industry. The first two of these still use a lot of coal, either as a source of energy or as a key component in the manufacture of certain products (for example, steel making uses coking coal to both reduce iron and provide heat). Similarly, the chemicals industry uses a lot of oil and natural gas as key raw materials (the majority of plastics are still made from oil). Reducing the CO₂ emissions of these industries will come down to making changes to both the manufacturing processes and to the overall energy consumption of these plants.

This transformation also has to take place against a background of increasing demand for industrial products and strong international competition. This permanent tension is driving the sector as a whole to

search worldwide for the lowest manufacturing costs, a situation which is obviously not conducive to the spontaneous adoption (without regulatory obligations) of more environmentally friendly processes. Alongside technological progress, economic and political factors hence play a crucial role in the roll-out of alternative solutions. To support the growth of a less carbon-intensive industry, the European Union has, for example, decided to introduce a carbon tax at its borders. Advances are also starting to be seen in some sectors. For example, the Swedish steel company SSAB has recently patented and conducted manufacturing trials on a steel making process using an electric arc furnace powered by fossil-free energy.

Artelia is supporting its industrial clients in their transition. In France, where the national low-carbon strategy targets an 80% reduction in emissions for the



FABRIZIO TEREZI

Manager, Energy Efficiency
Artelia Italia

Artelia Italia is regularly involved in tackling industrial energy efficiency issues. We are installing trigeneration systems (electrical, thermal, mechanical) which are more efficient and which use absorption cooling processes that consume less water. We have recently built a facility of this kind for Meccanotecnica Umbra at Campello sul Clitunno, a global leader in the production of mechanical seals. We also design solar power systems for supplying companies and factories. This reduces their primary energy demand and their draw on the grid, helping to reduce CO₂ emissions.

Artelia has been appointed by TotalEnergies to draw up preliminary designs for the redevelopment of the Grandpuits refinery into a zero-crude site focussing on other activities: recovering plastic waste (pyrolysis), manufacturing biofuels and bioplastics, recycling plastics, and generating solar power.

industrial sector by 2050, we have hence been involved in the redevelopment of much of the TotalEnergies refinery in La Mède (near Marseille) into a site for producing biofuels. Today, we are contributing to a similar project to convert the Grandpuits refinery (near Paris) into a zero-crude platform. We have been particularly involved in the incorporation of a plastic waste-to-energy unit and are remodelling all the site facilities to include solar power generation and the manufacture of biofuels and bioplastics.

Another significant part of our work involves helping industrial firms to roll out renewable production, use low-carbon electricity, or connect to heating and cooling networks. We are currently conducting a study for the Arlit (Orano) mining site, a project which will see the traditional generation units replaced with solar power plants, requiring a very thorough analysis of the constraints of this type of operation in order to identify solutions that can deliver this conversion. In parallel with sustainable electricity, we also contribute to the installation of biomass boilers on industrial sites to replace systems powered by coal or gas. We are working on a project of this type for the Nestlé site in Boue (France). In Italy, we are also contributing to improving the efficiency of a number of industrial facilities by rolling out high-performance trigeneration systems and large-scale renewable generation systems.



© TotalEnergies



FABIEN BESSIÈRES

Site Director,
Artelia Industrial Facilities,
Paris

Replacing highly resource-intensive processes with new more efficient ones has been at the core of our work for a long time. We have always sought to optimise the economical aspects of projects, reusing existing equipment where possible. Previously, we would replace a machine above all to increase and improve production, whereas now we are adding energy efficiency and the reduction of carbon emissions to our approach as key objectives. It is a period of transition, and we are adapting our approach, our assessments and our tools accordingly.

IMPROVING THE ENERGY EFFICIENCY OF FACILITIES AND DEVELOPING PROCESSES FOR CAPTURING AND STORING CO₂

In the Net Zero by 2050 scenario put forward by the International Energy Agency, nearly 50% of the expected savings in the industrial sector must come from improving the energy efficiency of existing facilities. At the same time, carbon capture, usage and storage (CCUS) technologies, which are still at the development stage, must also be scaled up in the coming decades. When associated with some very high-emission manufacturing processes, they could, by 2050, prevent the emission into the atmosphere of several million tonnes of CO₂.

Having been involved in the modernisation of industrial facilities for more than 50 years, Artelia has a range of proven methodologies for tackling the current efficiency and decarbonisation challenges of the sector. Our systemic approach allows us to consider the issue rationally by conducting audits and carbon assessments for an industrial firm, and then rolling out in a coordinated manner the solutions best suited to the challenges to be addressed: making processes more

energy efficient, refurbishing buildings, recovering waste heat and gas, turning to CCUS, transforming logistics operations to electricity or hydrogen, etc.

We are currently conducting numerous energy audits in Italy for companies in a wide variety of business sectors such as mechanical engineering, food, plastics, chemicals, pharmaceuticals, foundries, aeronautics, cement, and the automotive industry. For some of these, we apply our energy consumption monitoring tools. In France, we have conducted the carbon assessment for the Cigéo nuclear waste repository project, creating a dedicated tool for managing the various sub-systems of the facility and assisting with the analysis of the data set.

The recovery of waste heat and gas is another subject to which we are devoting a great deal of effort. Many industrial manufacturing processes give off heat which is currently mostly removed and lost.

Artelia contributed to the design and construction of a pilot plant on the ArcelorMittal site in Dunkirk, using the DMX™ process to decarbonise blast furnace gases. This pilot, which is considerably less energy-intensive than existing solutions, marks a key step in the development of this process at an industrial scale.

In Denmark, Artelia is designing a technical solution to recover waste heat for the Danpo chicken nuggets plant. By making use of this heat, the Give Fjernvarme district heating cooperative will be able to reduce its consumption of wood chips by 50%, do away with natural gas, and connect its network to the neighbouring town of Farre, which will reduce accordingly its own consumption of oil and gas.



Recovering this heat, for use on site or to supply public networks, is a practice which is now encouraged by the authorities in several countries. In the Danish town of Farre, we are working on a project for the Danpo factory, which specialises in the production of chicken nuggets. The heat emitted by the powerful freezing equipment on the site will soon be used in the Give Fjernvarme district heating system. We are also supporting a number of companies in France such as Cabot and Oril with modernisation projects that incorporate the reuse of waste heat. We have also contributed to a number of feasibility studies, particularly for the Provence-Alpes-Côte d'Azur regional authority (France) which clearly show the importance of these sources of industrial heat.

Carbon capture is another growth area in which we are involved. Current technological developments are pursuing

a number of avenues. The most interesting one at present involves capturing CO₂ at very high-emission facilities (thermal power plants, petrochemical and steel making sites) and then reusing it in an industrial process or transporting it and re-injecting it into the subsoil, such as into old cavities (e.g. former oil fields). This is the solution used for the DMX™ pilot plant being developed in Dunkirk by Axens in partnership with TotalEnergies, ArcelorMittal and IFP Energies Nouvelles. The process involves capturing the CO₂ contained in the blast furnace fumes, processing it and transporting it out into the North Sea to be injected into an oil well. Using the process developed by Axens, Artelia prepared and then produced detailed design studies for this pilot facility (pipework, structure, electricity, instrumentation) which was inaugurated in March 2022.



PHILIPPE LAPLANCHE

Manager, Data Centre
Development

Waste heat from industrial sites, data centres, etc. is heat which already exists, which has not been created, and which is therefore very attractive for recovery purposes. Today there is a desire to harness it and technical solutions exist. Two major challenges present themselves: getting producers and potential users of waste heat to communicate, and identifying opportunities for storing heat and returning it when it is needed. There is enormous untapped potential.



Benoît Clocheret - Chief Executive Officer



Energetically
committed to the
green transition!

As this round-up of the current changes taking place in the energy system shows, the transition towards a low-carbon world is underway. And yet a huge amount remains to be done to set humanity truly on a course in line with the Net Zero by 2050 scenarios. A vital roadmap ensuring us a sustainable future has been charted, but following it - collectively, globally and peacefully - is one of the biggest challenges of our time. It is clear that we are still only in the early days of this sweeping transformation and true revolution, which we hope will be smooth.

Energy sovereignty and, above all, the climate emergency, which is gradually shifting the lines of regulations, now pervade all of the sectors in which we operate. Moving away from coal to generate electricity, refurbishing inefficient housing stocks to prevent heat loss, reducing the energy consumed by cities or limiting the CO₂ emitted by transport

and industrial facilities, are among the key objectives of a growing number of players whom we will continue to guide, help and accompany in achieving them. Our societies are clearly becoming increasingly aware of these issues and accelerating their efforts to address them, but many hurdles must still be overcome for these transformations to reach the necessary scale.

This is what has driven Artelia, in recent years, to build its capabilities in the field of energy and the transition to a low-carbon world in the broader sense. Our positive action is reflected in both the support we provide for our clients and our own in-house practices, which are underpinned by a set of increasingly ambitious CSR commitments.

What does it mean today to support clients in the transition to a low-carbon world? First of all, giving them the means to embed

greenhouse gas emission reductions in the core criteria for their project right from its inception. To do this we propose our eco-design and work site eco-monitoring methods, which cover the entire project life cycle. Supporting clients in the transition also obviously means proposing operational solutions tailored to the challenges they are facing. So we tirelessly enhance our technical expertise to ensure that we always have the best options to implement, in terms of carbon-neutral production, energy efficiency, sustainable construction, low-carbon transport, resilience to climate change, and more. Within the Group, nearly 400 environmental specialists work on a daily basis to provide support in these areas to our thousands of experts across our different business lines.

True to its corporate purpose, “Designing solutions for a positive life”, our Group wants to be a partner on projects that make sense. We don’t want to adopt a dogmatic stance

consisting in refusing on principle to allow some activity sectors to benefit from our services because they have been singled out. We do want to contribute to development projects in keeping with our values and our commitments. So we exercise extreme caution in selecting the construction projects in which we participate, by evaluating their social and environmental impacts beforehand using an ESG assessment grid in a spirit of transparency, independence and responsibility.

The challenges inherent to the transition to a low-carbon world - of which energy is a core component - are immense, delicate, and compelling. They offer Artelia and all its employees a host of opportunities, starting with playing a leading role in building the kind of future we want to live in.

This book was created by...

SUPERVISION, DESIGN AND GENERAL COORDINATION

Marc Giroussens - Sébastien Kafi - Eymeric Lefort - Pascal Lucas
Anne-Laure Paté - Michel Rochon - Pascal Thévenet

EXPERTISE

Paolo Alberti - Béatrice Arbelot - Christian Avert - Thomas Bernier - Fabien Bessieres - Jean-Michel Bilon - Aurélie Blottiere - Roberto Bonini - Sylvain Cabanel
Sébastien Cappy - David Charbonneau - David Chotard - François Cleirec - Alain Deforche - Claire Demairé - Xavier Ducos - Michel Galas - Virginie Gaillat - Fanny Gelin - Kenneth Graa
Cyril Hauer - Yan Hiltcher - Nicolas Jallade - Philippe Laplanche - Sébastien Ledoux - Jérôme Mercier - Adrien Namur - Knud Erik Nielsen - Adrien Poret - Yann Renoul
Guillaume Ruffin - Julien Saint - Jacob Sten Petersen - Christelle Tarchalski - Fabrizio Terenzi - Katia Tibichte - Thibault Trancart - Mathieu Vrinat - Olav Weider

SUPERVISION AND OPERATIONAL COORDINATION, GRAPHIC DESIGN

Artelia - Marketing, Communication & CSR Department
Marilyne Fons - Véronique Lavastre

BOOK CREATION, RESEARCH, TEXTS

Éric Robert - Dire l'Entreprise sarl

PRINTING

PressVercors

TRANSLATION

SETS

PHOTO CREDITS

Artelia photo library unless otherwise stated, Adobestock

Published in June 2023




ARTELIA