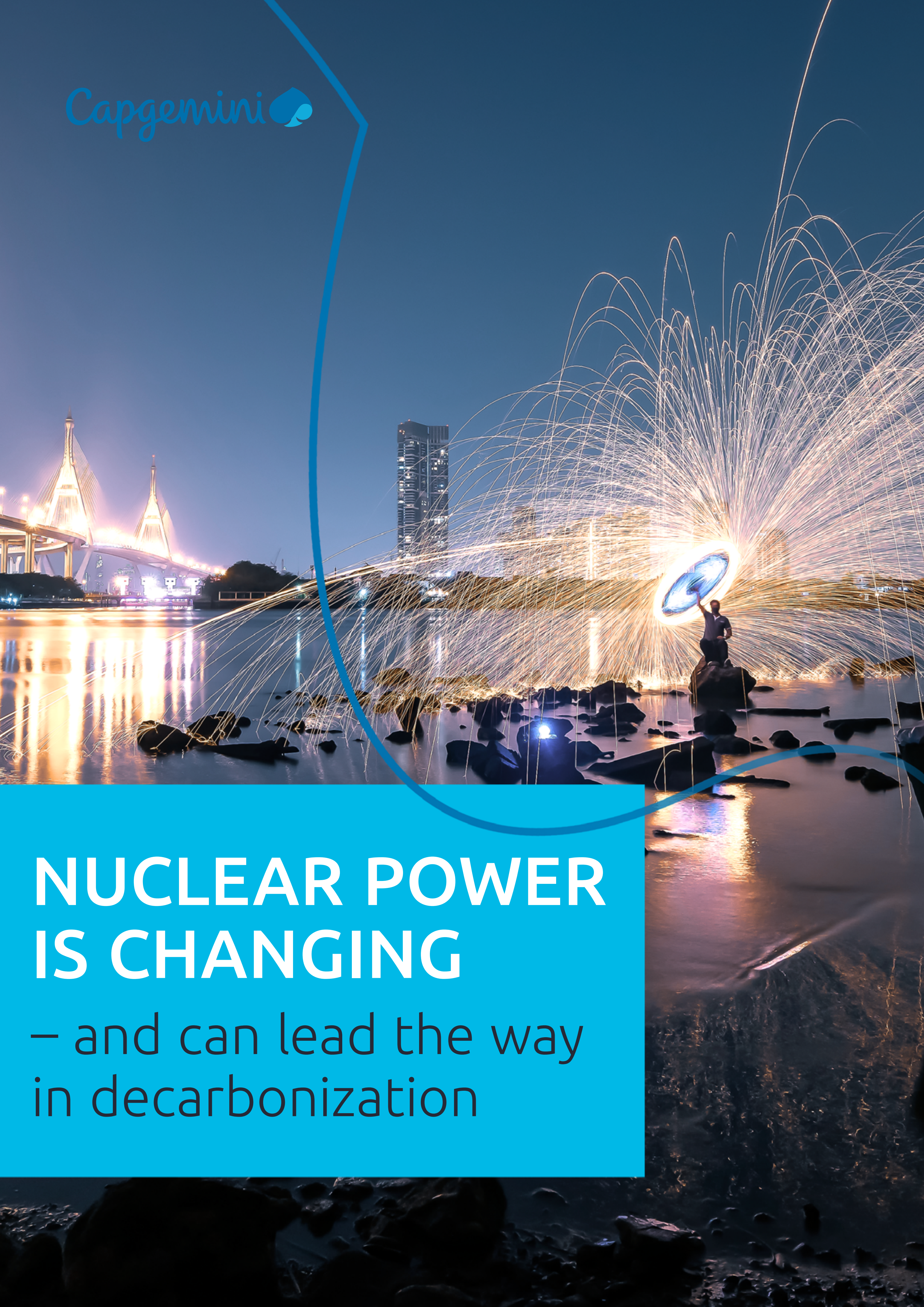

NUCLEAR POWER IS CHANGING

– and can lead the way in decarbonization

THE RACE IS ON

A new, disruptive generation of nuclear reactors is coming. Small reactors will be more compact and less complex than the larger light water reactors (LWR) in service today. They will also be assembled in a modular way, meaning they could be mostly built in a controlled factory setting and then installed module-by-module at the location where they will be deployed. Small modular reactors or SMRs, as they are known collectively, are well-suited to heavy industry and countries with less experience with nuclear power.

The current development of SMRs can be compared to the space race of the 1950s and 60s, when significant advancements in technology and engineering fueled global competition between pioneers who had ambitions to lead the development of first-of-a-kind (FOAK) technology in uncharted territory. Currently, around 1,800 SMR projects worldwide are in the discussion phase for potential construction, and this figure is growing.

Companies such as Rolls Royce, General Electric, Westinghouse, and EDF are building on their extensive reactor design experience to develop compact light water reactors based on mature reactor technology. Meanwhile, emerging advanced reactor (AR) companies are approaching reactor design and the associated nuclear fuel with fresh perspectives that include inherent safety features and extended use cases. Both the established players in the nuclear sector and companies that are new to the market share a common emphasis on research and innovation.

Yet despite interesting ideas and approaches being put forward multilaterally, tangible developments at scale are yet to materialize, leaving observers eagerly anticipating which vendor and technology will rise to prominence in this SMR race.

HOW SMALL NUCLEAR REACTORS WILL BE UTILIZED

Electric utilities are under pressure to transition from gas and coal to decarbonize their power generation portfolio while expanding their generation capacity to meet commercial and industrial demand for clean power. SMRs can help utilities decarbonize and can easily be integrated into existing nuclear sites or re-power coal and gas facilities with existing infrastructure and strong grid connections. A key benefit for utilities is that SMRs allow for the upgrading of existing coal-fired power generation facilities by replacing the steam source while preserving the existing power conversion system. Utility companies already have considerable operating experience for the large power generation assets, which may include nuclear power. This operating experience reduces the barrier to market entry and puts them in a good position to offer assistance and collaboration to new entrants in the nuclear power sector. Additionally, the cost and construction of SMRs is less risky compared to large nuclear reactors while their high and firm power density makes them a valuable addition to a utility portfolio.

While electric utilities are the obvious choice for the deployment of new nuclear, SMRs have some new and unique advantages that are disrupting this paradigm and expanding the use of nuclear beyond utilities. The disruptions caused by SMRs need to be accepted by the boardroom and the broader public. SMRs are scalable and use advanced technologies that provide both process heat and electricity. SMRs not only have smaller power density compared to large nuclear reactors, they also have smaller footprints.

Their smaller size means that SMRs can be sited close to demand, whether it's industrial sites or cities that require electricity. Siting closer to demand and the reducing power outputs also greatly simplifies the connections to the grid, which can add considerable time and cost for large nuclear. In short, SMRs are a disruptive technology that has broadened both the use cases and customer base for nuclear power.

Heavy industries, such as mining, are also considering SMRs as a way to transition away from carbon-intensive power sources, such as diesel generators at large remote mines. Other power-hungry industries such as petrochemical facilities and steel production, can also be decarbonized using SMRs. Advanced high-temperature reactors can provide both process steam, critical for many industrial processes, as well as electricity, which makes them ideal as a platform to decarbonize.

SMRs have also drawn considerable interest from the technology and commercial sectors, as they strive to achieve net zero and reduce secondary emissions because of their large electrical energy demands, for example to power data centers.

SMRs also offer an alternative and reliable way to generate power. This includes the electrification of emerging economies that largely rely on fossil fuels, mostly older oil-fired stations or distributed diesel or gas generator sets. Inherently safe advanced reactors could allow for the broad-scale deployment of nuclear energy in emerging economies and remote communities while maintaining nuclear safety and assurance.

Micro-modular reactors – small SMRs up to 15 MWe – can power remote communities, light industry, and markets that are underserved with reliable and consistent electric power. Their simplified designs drive both installation and operating costs making them attractive to emerging economies.

What are advanced reactors (ARs)?

ARs, or Generation IV reactors, are new reactor designs that are either gas-cooled or liquid metal/molten salts-cooled and use new, inherently safe fuel designs with higher enrichment. As a result, they are very compact and can provide both heat for process steam or district heating and electricity, while boasting long refueling cycles. They can be relatively small, with power capacities ranging from 15 and up to 100 megawatts. They are easily combined in a single site based on the power requirements. This means that they meet a lot of different use cases, giving them more operational flexibility than conventional nuclear power.

However, it’s important to note that despite their potential advantages, ARs use different technologies than SMRs – and are currently in development for at-scale commercial deployment. ARs need to progress through research and development cycles and prototyping before they can be deployed at scale. In addition, their fuel supply chain is in development for both the high-assay, low-enriched uranium requirements (HALEU) and associated fuel packaging, whereas the mature conventional fuel supply chain is robust and established. ARs are sure to have a strong place in the energy market, but their larger SMR counterparts will lead the first wave of new nuclear.

FORTUNE WILL FAVOR THE BOLD

To reach net zero targets, approximately 130 SMRs will need to be deployed annually by 2040. This will be a huge challenge, even in established industries such as automotive, as a new car design at scale can take five years or more.

Currently, there are several lead projects in North America to demonstrate the technical and commercial viability of SMRs, with first power expected near the end of this decade.

Velocity is key here. Vendors need to transition as soon as possible from obtaining licensing approval and completing detailed design to constructing FOAK products and demonstrating the commercial viability of the technology based on build schedules, cost, long-term reliability, and availability.

The sooner the FOAK products have been built and deployed, the sooner they can be built on the scale necessary to meet net zero targets.

Vendors, such as GE-Hitachi, Westinghouse, Rolls-Royce, and EDF are scaling-down proven conventional designs; so instead of a 1,000-megawatt reactor, it becomes a scaled-down and simplified 300-megawatt reactor.

The challenging timeline to get to first power and the potential for significant cost and schedule overruns means that digital levers will be very important. They offer ways to accelerate the various stages of the design, construction, and commissioning process. Reactor vendors can take advantage of the considerable advancement in digital technologies and the successful track records of large capital projects in other industries, such as oil and gas and aerospace.

They can utilize these levers to accelerate time-to-market, control costs, and demonstrate their commercial viability.

Innovation will be key for vendors. But it's not only vendors that need to be bold. The adoption at scale of SMRs will be disruptive across the energy sector and requires assertive and forward-thinking steps to be taken by all stakeholders – including end users. Just as SMRs represent advanced technologies, reduce complexity, and increase reliability, end users will need to re-evaluate their operating models and build new solutions from the digital foundation of their SMR vendors. Collaboration will allow governments, research institutions, and private companies to share knowledge, resources, and funding. Such public-private partnerships can accelerate research, development, and deployment efforts by leveraging the collective expertise of stakeholders.

DIGITAL CONTINUITY IS THE ROCKET FUEL

There are two key pillars that will propel the adoption of SMRs, making them more economically viable and quickly deployable:

- Time-to-market acceleration, and
- Streamlining the cost per unit.

Mastery of these two key pillars will enhance SMR commercial viability and investment while strengthening the favorable public acceptance for nuclear power as whole, and SMRs specifically.

Time to market can be reduced by employing advanced design and project management practices, including digital twin technology and AI-driven simulations, to optimize assembly schedules, improve resource allocation, and identify potential bottlenecks in the deployment process. Data analytics can be leveraged to identify bottlenecks and digital twins, including a construction twin, which can be used for rapid iterations to streamline problem-solving and quickly converge on the ideal solution. AI and business process automation can be deployed to reduce the overall workload and improve efficiency by eliminating time-consuming and routine tasks, such as specification and contract development of the supply chain, or construction package development.

Additionally, schedule delays greatly impact the overall project costs as run costs continue throughout the delay, and the overall return-on-investment recovery is delayed as the project is extended.

Reducing costs is not only important from a business standpoint it's also necessary if nuclear power wants to compete with other high-capacity energy sources. Large nuclear reactors have had significant cost overruns and capital challenges in the recent past, whereas SMRs can solve the CapEx challenge. Where a large twin-unit nuclear plant has cost up to USD30 billion, an SMR may be built for around USD1-2 billion per unit at scale.

Achieving both the reduction in installed cost and a quicker time to market requires harnessing advanced digital continuity and data-centric technologies to maximize efficiency, ensure collaboration across stakeholders, and manage a complex build process involving multiple projects, sites, and end users. The same digital foundation will support highly efficient operations and high availability over the lifetime of the asset, making them a valuable addition for the end user's portfolio. This means that digital assets must be managed from their inception and throughout their lifecycle to ensure a seamless development process and to support the asset's growth in other words - Intelligent Industry.

Digital continuity is maintained by duplicating the asset digitally. Digital twins allow organizations to oversee assets, monitor ongoing operations, and undertake predictive maintenance. Insights taken from the digital twin can also be integrated into iterative design cycles to drive continuous enhancements. Additionally, a data-centric approach will result in a "single source of the (design) truth," eliminating the inefficiencies of a document-centric approach and reducing the inherent risk of interfaces or "hand offs" that is the legacy of a document-based approach.

Applying digital continuity and using digital levers at the early stages of the development process increases investor confidence and is viewed as a competitive advantage by end users. Furthermore, a strong digital foundation will allow SMR vendors to enhance their offering to include an operating model and the associated digital solutions for the many new entrants to nuclear operations.

INTELLIGENT INDUSTRY FOR EFFICIENCY

The production of SMRs requires a focus on design maturity, the build schedule, and enterprise readiness to achieve on-time delivery and to rapidly scale up to the anticipated demand. Intelligent Industry, proven in related industries, is the foundation to achieve these objectives.

Design maturity

To make a design mature and resilient, organizations can use cutting-edge digital tools such as advanced design software and simulations. These tools help ensure that the project is cost-effective while meeting safety and regulatory standards.

A strong and collaborative data platform is the foundation of Intelligent Industry. Such a platform is needed to ensure data continuity and the data-centric approach required for design resilience. The data platform is the foundation for the completion of the detailed design within an advanced project lifecycle management (PLM) solution closely integrated with a digital design twin. This foundation becomes the single source of design truth, and sets the requirements for the build schedule, supply chain and procurement, and operations.

Build schedule

It is possible to revolutionize project planning, execution, and supply chain engagement through the integration of advanced digital technologies and integration of key partners (e.g., civil) to optimize the build schedule. Real-time analytics, data-driven decision making, and automated processes improve velocity and collaboration while minimizing work holds or re-work to overcome the paradigm of change, moving from a document-centric to a data-centric organization.

Building on the data platform and a resilient design, a construction twin allows for the rapid response and integration of the many field-change requests from the FOAK construction to be efficiently evaluated, the design changes updated in the design, and approved field change packages incorporated into a revised build schedule and procurement as appropriate.

The advanced PLM and data platform allow for the integration of suppliers and process automation that improves supplier responsiveness, transparency, and quality. Finally, the data platform, design, and construction twins can be leveraged for advanced analytics to identify bottlenecks and rapidly iterate solutions that will maintain or accelerate progress to schedule.

Enterprise readiness

An organization can optimize its readiness through the strategic implementation of enterprise resource planning (ERP). Adopting solutions for managing supplies and procurement, as well as HR systems, can help improve communication, make resource allocation more efficient, and promote a culture of innovation that empowers the organization to thrive.

Extending Intelligent Industry and the digital platform to ERP will improve readiness to deploy at scale as and when the market dictates. Furthermore, the digital twin can be extended to include a maintenance twin, to support pre-deployment maintenance, condition monitoring, training, and knowledge transfer to speed up transition through commissioning while the digital platform and advanced PLM allow for the integration of an advanced EAM and attendant systems, which speeds up commissioning while capturing “as-built” design via the data platform to ensure configuration management for the life of the asset.

Thinking big with virtualization technology

When building an SMR, approvals and inspections play a key role in ensuring that components meet the required standards. The integration of virtualization technology could revolutionize this area.

By virtualizing the entire manufacturing process, including factories, supply chains, and material flows, a comprehensive view of the production process would emerge.

Within an augmented and virtual reality, vendors would be able to observe the progress of components through various stages and see their assembly transform into modules. Additionally, control sensors could enable real-time monitoring and analysis of operations.

Clients would have the ability to access this virtual environment and track the status of their order, right from the manufacturing phase to assembly and eventual shipment. The immersive experience – using virtual goggles – could provide unparalleled transparency, eliminating any possibility of concealment or delays.

Applying the concept of augmented and virtual reality to the manufacturing of an SMR would change our understanding of the entire production landscape. Whether it pertains to a single manufacturing line, operations center, or design facility, the metaverse accommodates a seamless integration of various domains, effectively blurring the lines between them.

The integration of virtualization technology within manufacturing offers transformative possibilities that usher in unprecedented levels of transparency, efficiency, and accountability.

LEVERAGING INNOVATION FROM ACROSS INDUSTRIES

The nuclear industry itself hasn't been very digitally enabled over the years and, in some areas, it is decades behind other sectors. To ensure that the rapidly emerging SMR market progresses at the speed it needs to, vendors must look to other industries for technologies that they can reapply or learn from.

Reactor vendors can see how new technology has been deployed elsewhere in the energy sector or they could look to the highly regulated aerospace industry to understand best practices when bringing high-tech products to market effectively in the virtual world. Airplane vendors are building very complex planes in modules that are factory assembled and deployed, coordinating a global supply chain for multiple manufacture sites while maintaining uncompromising quality and safety standards.

In the aerospace industry, Intelligent Industry is utilized during the initial design phases to streamline various processes, such as obtaining design regulatory approvals and conducting virtual simulations. These steps preemptively address potential challenges before any physical manufacturing begins. When designing a new plane, aircraft manufacturers subject the aircraft to rigorous digital testing across a range of scenarios. These simulations serve the purpose of stress-testing the design until it reaches a point of optimal performance.

There are significant similarities for SMR vendors, with their modular, assembly line construction of the nuclear island, coordinating dozens of suppliers, and building at scale with uncompromising quality. Aerospace utilizes intelligent operations and supply chain optimization to be successful, with digital platforms, data interoperability, and accelerators. The building of a large airliner or an SMR involves the design, procurement, and assembly of tens of thousands of parts from a global supply chain to build a product at scale and at a high level of quality.

FINISHING FIRST

Intelligent Industry is an accelerator for SMR vendors to meet the aggressive and unproven build schedules and prepare to build and deploy at scale. The required efficiency, collaboration, and coordination across multiple global stakeholders and the multi-site, multi-project delivery, necessitates a strong digital foundation and solution. SMR vendors understand that a strong engineering, procurement, and construction (EPC) partner is important for their long-term success. But they should also be confident that their digital partner can help deliver on the promises of design maturity, build schedule, and enterprise readiness for SMRs.

At Capgemini, we have experience working with the nuclear industry but, crucially, we work across multiple industries; helping businesses transform their operations with a digital and data-centric approach that focuses on innovation. We help simplify the complex coordination of design, manufacturing, and assembly with expertise in digital solutions engineering. By drawing on our proven knowledge, experience, and results, we will help reactor vendors lead the way on the SMR market.

About Capgemini

Capgemini is a global leader in partnering with companies to transform and manage their business by harnessing the power of technology. The Group is guided every day by its purpose of unleashing human energy through technology for an inclusive and sustainable future. It is a responsible and diverse organization of nearly 350,000 team members in more than 50 countries. With its strong 55-year heritage and deep industry expertise, Capgemini is trusted by its clients to address the entire breadth of their business needs, from strategy and design to operations, fueled by the fast evolving and innovative world of cloud, data, AI, connectivity, software, digital engineering, and platforms. The Group reported in 2022 global revenues of €22 billion

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