

The US nuclear sector needs to shift to standardized products with replicable designs delivered by consistent, experienced suppliers.

Managing Drivers of Cost in the Construction of Nuclear Plants

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To make a meaningful contribution toward clean, reliable, and economical future energy systems, nuclear power plants (NPPs) must be cost and risk competitive with other low-carbon technologies within near-term time-frames. Recent new builds in the United States and western Europe have suffered from two phenomena. First, they are expensive in absolute and relative terms: the cost per MW installed, along with the size of the plant, makes them among the most expensive power plants of any type. Second, they have all been delivered overbudget and late, making NPP construction a risky investment, which in turn increases the cost of borrowing money for new projects.

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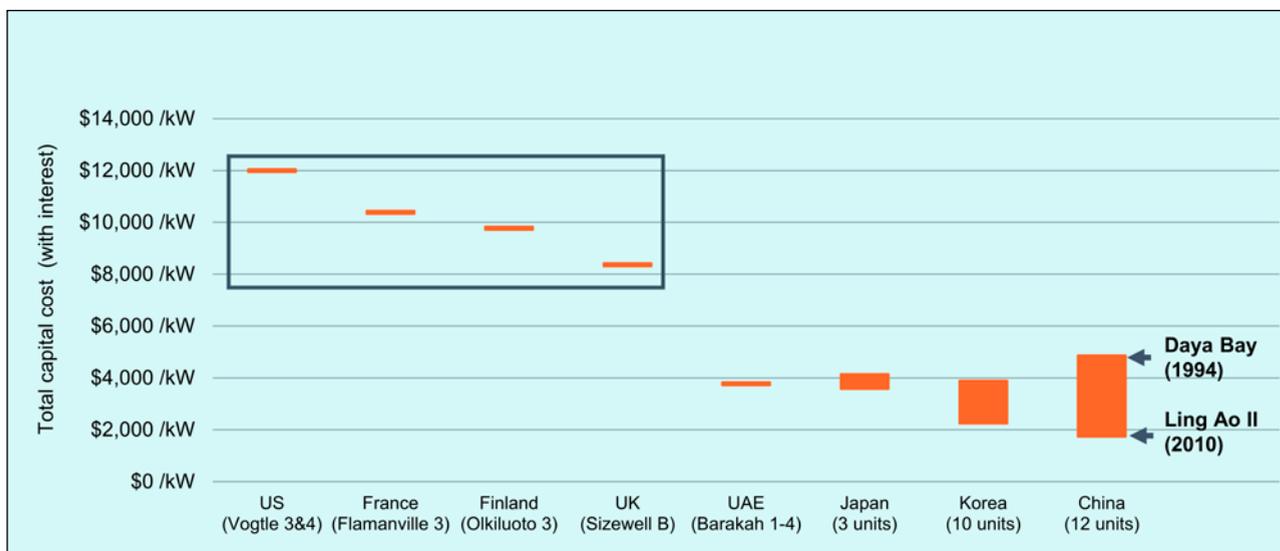


FIGURE 1 Total capital costs for historical and ongoing nuclear projects in eight countries. Costs comprise those for base construction plus contingency, interest during construction, owner’s cost (including utility startup), commissioning (nonutility startup), and initial fuel core. Reprinted from ETI (2018).

But the experience in Asia has been very different. Many new build projects there are highly cost competitive with both fossil fuels and renewables. Figure 1 highlights this contrast, plotting the costs for a sample of representative projects, four in the United States and European Union, and a number of projects in four Asian countries.

Understanding Differences in NPP Capital Costs

Research helps to explain the differences. The Nuclear Cost Drivers Project commissioned by the UK Energy Technologies Institute (ETI NCD study; ETI 2018) reviewed pathways for reducing capital costs, which comprise those for base construction plus contingency, interest during construction, owner’s cost (including utility startup), commissioning (nonutility startup), and initial fuel core (adapted from GIF 2007). Through an evidence-based study of historic, contemporary, and future NPPs, the project identified a small number of factors that drive NPP costs and risks and highlighted characteristics common among low-cost NPP projects and others common to high-cost projects.

Figure 2 contrasts the elements of capital cost across four groups of NPP projects: (i) a high-cost (first-of-a-kind) group based on current experience in Europe and the United States, (ii) a benchmark plant (“previous US median”), (iii) best-performing US plants, and

(iv) low-cost plants based on current experience in the rest of the world (ROW).¹

The first thing to notice is that despite wide variation in EU/US and Asian labor costs, this category is not the largest contributor to differences in cost outcomes. Second, the green bars show considerable differences in interest during construction, primarily reflecting the duration of construction and capital costs (interest during construction was leveled at 7 percent for all cases here)—projects that experience severe delays cost more. Third, indirect services costs (dark blue) also show substantial variation; they are driven by (in)efficiencies in design completion and the need to resolve quality and regulatory issues, which often entail extensive engagements with regulators and suppliers, additional design engineering work, onsite rework, and delays.²

The small sample of highest-cost NPPs shown here are first-of-a-kind (FOAK) projects being built in Europe and the United States after decades of inactivity in construction. In contrast, the majority of those at the low-cost end of the scale are nth-of-a-kind units.

¹ The ETI NCD study analyzed a range of current and recent projects against a “benchmark plant” representing the median experience from the US fleet build recorded in DOE (1986).

² Indirect services costs comprise field indirect costs, construction supervision, commissioning and startup costs, demonstration test run, design services off- and onsite, project/construction management services off- and onsite, and contingency on indirect services cost (ETI 2018).

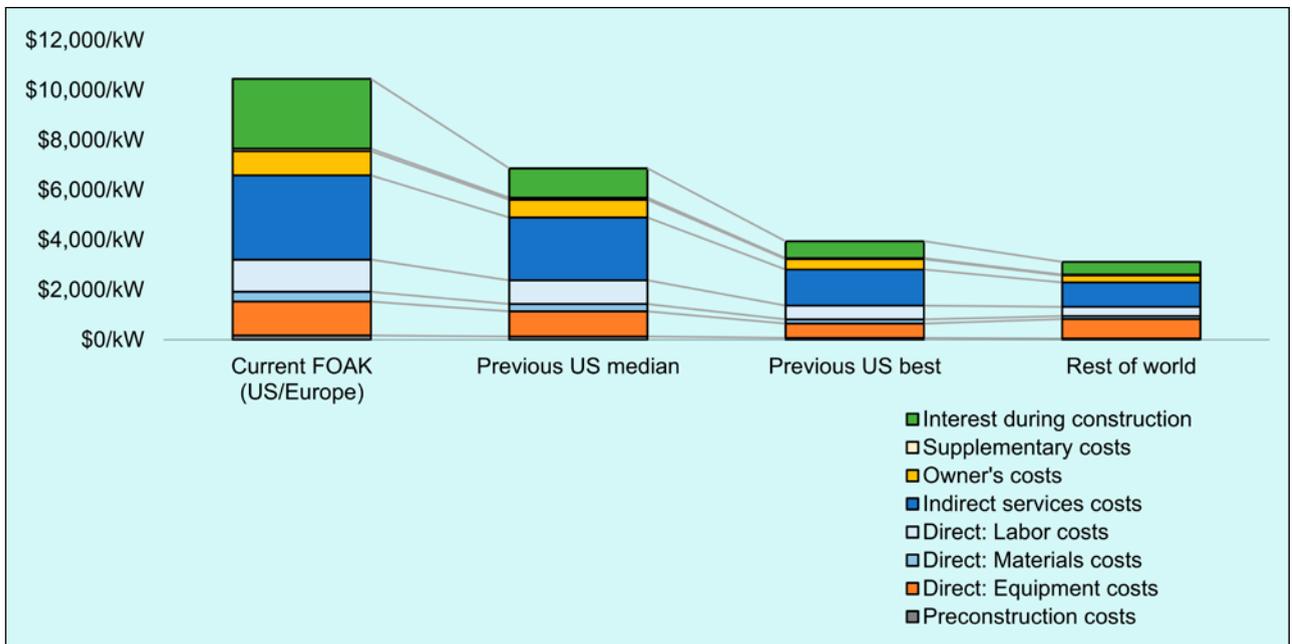


FIGURE 2 Differences between high- and low-cost nuclear plant projects (in 2017 USD). FOAK = first of a kind. Adapted from ETI (2018).

Evidence from NPP new build programs around the world indicates that FOAK plants represent a major investment in skills and capability. Significant productivity improvements and cost effectiveness can be gained in subsequent projects with respect to the project governance, workforce, supply chain, and regulators, in general illustrating the role of experienced leadership, design standardization, and mature capability in reducing costs, delays, and risks (Mignacca and Locatelli 2020).

Ways to Reduce New Build Costs

Of course, cost improvements are not automatic. A review of learning rates with different technologies showed that they vary according to the technology, time of the study, location, and other factors (Rubin et al. 2015). The nuclear industry has had among the lowest learning rates. The lack of standardization in design and the project delivery chain is a key reason for this poor performance.

Once again, however, there is contrasting experience. South Korea has demonstrated a fleet build approach combined with good project management, efficient construction execution, and technology innovation to deliver new NPPs domestically and even in newcomer

countries (e.g., the United Arab Emirates) at significantly lower costs than those recently experienced in Europe and the United States (Choi et al. 2009).

It is reasonable to ask whether low-cost outcomes in China, Japan, and Korea, for example, are transferable to the US or European contexts, given cultural and economic differences and country-specific working practices. Evidence gathered in the ETI NCD study suggests that best practices leading to these low-cost outcomes are not country- or even technology-specific. In fact, as highlighted above, analysis reveals that previous US best practice experience (expressed in 2017 USD, and with a standard interest rate during construction of 7 percent applied across all units) corresponds reasonably with current ROW experience, as shown in figure 2 (DOE 1986, table 5-4).

Several studies have identified factors that are key to determining the cost and risk of NPP new build projects (e.g., Buongiorno et al. 2018; ETI 2018). Table 1 reports the main cost drivers and corresponding stakeholders for a new NPP construction project, along with actions that can reduce the impact of each cost driver.

A highly focused, deliberate program can drive down costs and improve efficiency of the construction process over time through consistent, rational implemen-

TABLE 1 Summary of cost drivers, stakeholders, and actions to reduce costs for a new nuclear power plant (NPP)

Cost driver	Action owner	Cost driver description	Actions for cost reduction
Plant design	Developer	All preconstruction efforts related to plant design, including design decisions, design completion, and ability to leverage past project designs; plant-specific details such as capacity, thermal efficiency, and seismic design, as well as broader aspects related to constructability and project planning processes	<ul style="list-style-type: none"> • Complete design before starting construction • Design for constructability (see Jergeas and Van der Put 2001) • Prioritize increased modularity in the design to shorten and derisk the critical path • Ensure that plant design team is multidisciplinary and has current construction expertise • Design for plant design reuse • Replicate design to minimize redesign • Consider specific design improvements against full costs and potential benefits of implementation
Equipment and materials	Developer	Quantities of equipment, concrete, and steel (both nuclear and nonnuclear grade) used in the plant as well as strategies used to address materials cost	<ul style="list-style-type: none"> • Reduce quantity of nuclear-grade components as much as possible • Substitute concrete with structural steel where possible • Develop opportunities to use emerging technologies used in other sectors (e.g., high-energy-density welding of thick sections, laser cladding) • Reduce overordering/waste of materials via (digital) production management
Construction execution	Developer	All decisions, practices, and support tools used in engineering, procurement, construction (EPC) during project delivery, from site planning, preparation, and design rework through all onsite decisions (e.g., project execution strategies, interaction with subcontractors and suppliers) to commercial operation date. Includes independent inspection processes, quality assurance and control, and other major cost and risk centers during project construction. This driver is a measure of efficiency and productivity across the entire delivery consortium. For multiunit construction on the same site, this should get better with each subsequent unit.	<ul style="list-style-type: none"> • Hire effective and experienced managers • Engage an integrated project delivery team operating as a long-term enterprise with aligned incentives • Leverage more offsite fabrication and onsite prefabrication • Ensure that systems/processes are in place for the transfer of people and expertise between projects • Establish a digitally enabled production management system (workflow and coordination) linked to a digital twin and managed by an integrator
Workforce	Developer	All direct and indirect construction labor performed on the project site as well as labor related to offsite manufacturing or assembly; covers productivity, wages, training and prep costs, percentage of skilled workers with direct applicable experience, etc. This driver measures efficiency and productivity at the individual level.	<ul style="list-style-type: none"> • Innovate methods for developing alignment with labor around NPP projects • Improve labor productivity by increasing training and using the same people across multiple projects • Invest in the labor force with training that emphasizes quality

continued

TABLE 1 Continued

Cost driver	Action owner	Cost driver description	Actions for cost reduction
Project governance/development	Developer	All factors related to developing, contracting, financing, and operating the project by the project owner; covers topics from the interdisciplinary expertise of the owner's team to number of units ordered (at the same site), discretionary design changes, weighted average cost of capital, and contracting structures with the EPC	<ul style="list-style-type: none"> • Ensure that the owner's organization has an experienced, multidisciplinary team • Ensure that the project owner develops multiple units (minimum of 2, but fleet benefits increase with additional units) at a single site with the same project delivery chain • Implement programmatic approach to planning multiple projects, including systems/processes to transfer people/expertise among them • Follow contracting best practices (per ETI 2018) • Procure for a cyberphysical asset (i.e., the plant's digital twin) • Establish long-term cooperative partnership between owner and vendor • Plan at the program level rather than project level • Sequence multiple projects to maintain labor mobilization and consistency in delivery teams and the construction supply chain
Political and regulatory context	Government	Country-specific factors related to regulatory interactions and political support (both legislatively and financially): regulatory experience, pace of interactions, details on the site licensing process, and topics related to the government's role in financing and how well it plays certain roles otherwise reserved for the project customer	<ul style="list-style-type: none"> • Make government support contingent on systematic application of best practices and cost reduction measures • Help put in place a framework to enable project financing • Design a program to maximize and incentivize learning, including clarity on potential future projects • Work closely with the regulator to deliver on cost-effective safety • Engage the regulator early and agree on a process for resolving licensing issues
Supply chain	Suppliers/vendors	Factors that characterize supply chain experience, readiness, and cost of nuclear qualification as well as nuclear- and non-nuclear-grade equipment and materials	<ul style="list-style-type: none"> • Embrace a highly proactive approach to supply chain management and qualification • Develop incentive program for suppliers against a schedule of milestones • Develop long-term agreements to involve suppliers across several projects • Develop reasonable risk management strategies, allocating risks to the most appropriate stakeholders (e.g., owner, developer, supplier)
Operation	Owner	All costs related to NPP operations (e.g., fuel price, staff head count, wages, capacity factor, unplanned outages, etc.)	<ul style="list-style-type: none"> • Involve commissioning staff and operators in project planning and related construction activities • Develop excellence in plant operations and maintenance through training and benchmarking (e.g., World Association of Nuclear Operators peer review program)

tation of best practices, regardless of location, if there is a strong commitment from the major stakeholders. Literature on the cost of megaprojects, across a variety of sectors besides nuclear, validates these points (e.g., Locatelli 2018; Merrow 2011).

Further Cost-Reducing Options

In addition to the adoption of best practices for project management and execution, new technologies may further reduce cost and risk even for GW-scale conventional light water reactors. Examples include the use

of seismic isolation to reduce the need for site-specific design changes, and advanced construction materials such as high-strength reinforcing steel and ultra-high-performance concrete to reduce the installation cost of concrete structures (Buongiorno et al. 2018).

Even more radical cost reductions could come from new delivery models in industries that already deliver large, low-cost, high-quality, and complex machines at the scale of NPPs. Shipyards, aircraft factories, and auto manufacturing plants are good examples.

Learning from these other industries demonstrates that steep, near-term cost reduction is achievable by shifting from traditional “stick-built” construction projects to high-productivity manufacturing environments such as a shipyard or factory. Moving from traditional construction to a highly integrated manufacturing, assembly, and installation process on one site could enable high-quality, repeatable processes, with quality assurance designed into every step. For example, thanks to the standardization of design and suppliers, the aerospace industry achieved over the decades extraordinary cost reduction and safety improvement, making flying safe and convenient.

Conclusion

The nuclear sector in the United States and Europe needs to shift from artisan-crafted projects to standardized repeatable products, with NPP planning based on a few replicable designs delivered by a consistent network of experienced suppliers. It is up to the nuclear sector to shift its mindset and lead this transition.

The nuclear sector must also engage with its many stakeholders to explain why nuclear *products* instead of *projects* can deliver lower costs and other wider societal benefits. This is important to create the societal “pull”

in the same way that has made flying safe, convenient, and affordable today.

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