ENERGY

Why Low-Carbon Capital Projects Demand a Different Playbook

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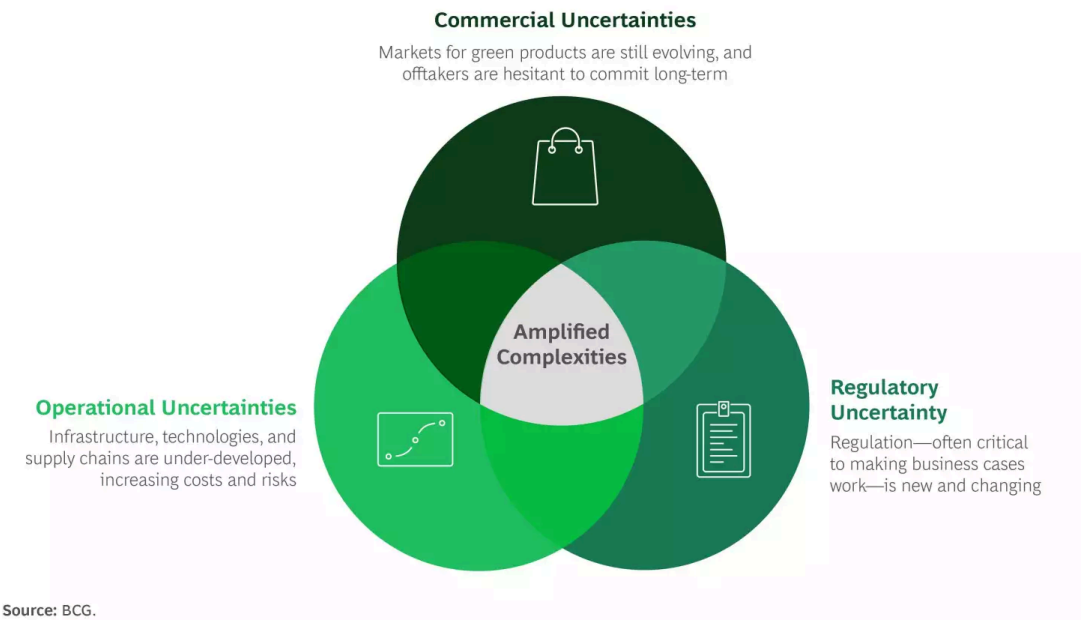
Some 3,000 cutting-edge low-carbon initiatives—spanning hydrogen; carbon capture, utilization, and storage (CCUS); bioenergy; and offshore wind—are currently under development, most in the early phases. Collectively, these projects, which require billions of dollars in global investment, could play a key role in accelerating a transformative shift in the energy system.

Certainly, energy infrastructure players have deep experience managing large capital projects—but proven playbooks can't be readily applied to these low-carbon projects. Many are pioneering by nature and face significant commercial, operational, and regulatory uncertainties that differ markedly from traditional large-scale energy or infrastructure projects. Among the most challenging are commercial issues such as undeveloped end-user markets; operational risks, including some related to innovation and technology; and a shifting regulatory landscape. (See exhibit.)

Low-Carbon Capital Projects Confront a Number of Complexities



Source: BCG.

Through extensive collaboration with clients, we've pinpointed the critical ways in which low-carbon projects differ from conventional capital projects and the steps required for success. Organizations that make these moves—embracing agility, robust partnerships, resilient supply chains, innovative financing, meticulous project delivery discipline, and AI and digital tools—can ensure the effective execution and scaling of ambitious low-carbon projects.

Step 1: Integrate flexibility into the low-carbon portfolio.

A portfolio of low-carbon projects demands an operating model suited to the higher risk levels of such projects, one built on flexibility and scenario-based thinking.

Key Challenges

Low-carbon projects often utilize emerging technologies, such as advanced carbon capture equipment or electrolyzers for the production of green hydrogen, that are at earlier technology readiness levels.

In addition, while mature industries operate within a relatively stable regulatory framework, low-carbon projects operate in an environment characterized by shifting incentives and emissions standards. Changes to carbon pricing, the launch of new competing projects, or regulatory evolutions can greatly impact financial viability—even after companies have moved beyond final investment decision (FID). Such shifts can force owners to re-evaluate timelines, cost assumptions,

and revenue forecasts and, in a worst-case scenario, derail execution—even when technical aspects are on track.

Targeted Actions

Companies need to manage these uncertainties and ensure they can adjust commercial strategies in real time.

At the portfolio level, scenario-thinking can be a powerful tool, enabling informed decisions on how to allocate capital across low-carbon technologies.

At the same time, companies can use stochastic models—which are designed to reflect uncertainty by generating a range of different outcomes—to make decisions about specific projects. These models provide a good view on the range of probable outcomes, including outliers at the positive and negative end of the spectrum. Taking this probabilistic approach can also allow companies to identify and focus on the factors that will have the biggest impact on the project outcome.

In addition, companies can leverage risk-based scenario modeling throughout the stage-gate process to ensure decisions strike the right balance among risk tolerance, cost, and option value. A smart stage-gate process can drive the optimal timing of investments in individual projects—allowing adjustments based on technology maturation, market and regulatory shifts, and pilot outcomes.

Companies should embrace a more intense iterative “test and learn” approach than they do with conventional projects. This can include a flexible development phase which accommodates multiple concepts being developed in parallel or highly frequent design iterations. Moving into execution, companies can leverage the pilot and demonstration phases to identify and address the risks that often emerge during scale-up. And companies must continuously monitor the regulatory environment to ensure they are able to adapt to changing policies.

Ultimately, rather than betting heavily on a single “moonshot” project, organizations can find it is valuable to take a portfolio approach by testing multiple pathways, such as different CCUS or electrolysis technologies. This approach can drive quick iterations and the reallocation of resources based on demonstrated performance and market signals.

Smaller companies, of course, are often investing in a limited number of related areas—making a true portfolio approach unfeasible. Still, scenario thinking can help guide decision making for these players as well, allowing them to anticipate the impact of regulatory changes in different markets or explore the potential of various partnerships.

Step 2: Build resilient supply chains.

Large-scale low-carbon initiatives face a more complex and fragmented set of supply chain issues, necessitating a differentiated and more adaptive procurement strategy.

Key Challenges

Supply chains for low-carbon projects and technologies are typically highly specialized. In addition, suppliers for some inputs may be less established than those for conventional projects.

For example, the number of suppliers for components such as specialized membranes (used in the production of low-carbon hydrogen), high-grade catalysts (used in the ammonia cracking process for low-carbon hydrogen production), and novel materials are often limited. As a result, supply constraints or lead times can be much longer and more unpredictable.

Targeted Actions

Companies need to recognize that procurement is about much more than securing equipment. It often requires co-investing in capabilities with manufacturers and forging long-term alliances that guarantee support throughout technology development. Companies also need to embrace additional uncertainties in their schedule and anticipate higher budget contingencies. This approach—which requires shifting to stochastic planning methods that consider multiple possible outcomes, instead of relying solely on traditional linear scheduling—can allow companies to better manage project risks, potential portfolio interdependencies, compounding impacts, and knock-on effects.

Step 3: Engage and partner early on.

Supply chains are not the only area where robust partnerships are vital. Given the high level of uncertainty that often surrounds low-carbon projects, they almost always involve a broad set of consortium partners (such as infrastructure owners, EPC firms, operators, and offtakers) and are influenced by a broader set of stakeholders (including local communities, green financing entities, and regulators) given the high uncertainty.

Key Challenges

The nascent nature of many low-carbon markets creates a host of issues. For example, companies developing biofuels projects must secure customer offtake arrangements to enable commercial certainty and a solid business case for the projects, while also striking deals with operators providing the necessary feedstock. Offtake agreements often include changes in terms and conditions based on external triggers—making project economics more sensitive to market fluctuations, particularly when the customer base is not diversified and the feedstock or product is not a mature commodity. Uncertain project economics can also complicate agreements with financiers and contractors delivering the project.

At the same time, low-carbon initiatives often require new or expanded infrastructure, such as renewable energy sources, dedicated CO_2 pipelines, or hydrogen storage. This, in turn, demands a different level of coordination with utilities, other project owners, and regulators. Additionally, EPC

firms are critical partners for low-carbon capital projects, but their scope must be carefully designed to ensure adequate process connections without inadvertently sharing or compromising core intellectual property.

Targeted Actions

These challenges demand smart approaches throughout the full project lifecycle. Companies can develop collaborative contracting models with both customers and contractors that share risks and align incentives. Alliance or partnership agreements with contractors, for example, can equitably distribute risk and leverage collective expertise—a departure from more adversarial, fixed-price approaches common in traditional sectors. Companies can also strike strategic partnerships with startups that have specific technology capabilities critical to the project. (In some cases, the larger player may even take a stake in the startup to align incentives.) At the same time, companies have an opportunity to coordinate closely with other stakeholders, such as utilities, governments, and other project owners, to manage infrastructure interdependencies.

Aligning project goals from the start with regulators, local communities, contractors, and potential offtakers can mitigate surprises and expedite execution. This also opens the door to public-private partnerships. And companies that ensure they engage with stakeholders openly and proactively can build goodwill—an asset that can significantly mitigate reputational and political risk should the project run into challenges.

Step 4: Leverage a full suite of financing tools.

Low-carbon initiatives have different capital requirements than traditional infrastructure projects. Developers must adopt new financial approaches, including phased investment strategies.

Key Challenges

Low-carbon capital projects have unique characteristics that demand flexible financing. But low-carbon infrastructure can demand even higher early investment owing to factors such as:

- A capital structure with a higher weighting of equity than traditional capital projects given greater levels of uncertainty
- The need for earlier, phased investment to lower the risk and accelerate the maturity of certain technologies
- Development trajectories characterized by additional iterations and redesign
- The need to invest in components across an entire value chain, each with different risk profiles and maturity levels

- The requirement to invest before offtake certainty materializes or the regulatory framework is fully defined

As a result, companies developing these projects must craft a more flexible financial structure—one that accounts for policy shifts, carbon pricing volatility, and/or uncertain offtake markets.

Targeted Actions

Companies can adopt creative financing that blends traditional loans, equity, government grants, green bonds, carbon credits, or public-private partnerships. They also can leverage phased investment strategies, with funding provided at a series of intervals governed by a disciplined stage-gate process.

Companies also should embrace transparency. Robust financial reporting and forecasting can help manage capital risk. And transparency in performance metrics—like carbon intensity reductions—can also attract more patient, impact-oriented capital. To enable a robust financial structure and focus on the right metrics, companies should double down on financial modeling to factor in unpredictable revenue streams, carbon pricing volatility, and lengthy payback periods.

Step 5: Ensure rigorous project execution and discipline.

The actual physical buildout of low-carbon projects comes with unique hurdles—and requires tailored strategies and skills. And the speed of execution matters. A focus on moving swiftly can allow companies to adapt to an ever-changing regulatory landscape and lean into modular, simplified designs instead of overly complex, “gold-plated” plans.

Key Challenges

Companies developing and constructing low-carbon projects confront a host of potential obstacles, including:

- **Performance complexity.** Low-carbon projects require measuring and optimizing a broader set of metrics—beyond the usual cost, schedule, and quality indicators. KPIs may include carbon capture rates, hydrogen production efficiency, energy consumption intensity, and overall environmental impact.
- **Development timelines.** The combination of emerging technology, complex permitting, and stakeholder engagement can extend project schedules significantly beyond those for conventional infrastructure.
- **Cost estimation.** There is a lack of well-established benchmarks and reference data for cost estimation for many low-carbon projects. For example, traditional references from oil and gas

or civil engineering projects do not align with green or blue hydrogen production or carbon capture projects.

- **Need for specialized knowledge.** Low-carbon projects demand expertise in a range of emerging technologies, such as carbon capture, ammonia cracking, and electrolysis, which are not typically encountered in traditional capital projects. Teams must be equipped to evaluate, select, and integrate these technologies in a seamless way, requiring new skill sets and strong cross-functional collaboration. This heightened focus on technology integration extends beyond standard engineering disciplines.
- **Construction, integration, and commissioning.** First-of-a-kind low-carbon technologies often don't scale as predictably as established solutions, leading to unexpected downtime, cost overruns, extended commissioning, and rework during ramp-up. Integrating new processes into existing or co-located facilities adds further complexity, especially when standard construction methods, quality checks, and commissioning protocols have not yet been adapted to these emerging technologies.

Targeted Actions

To ensure excellence in project delivery, companies should systematically address these issues. Key actions include:

- **Focusing on performance management.** Robust data collection, real-time monitoring, and analytics capabilities can help track progress and drive integrated continuous improvement. Single accountability in the project team—along with a clear decision mandate—are of paramount importance.
- **Setting a realistic timeline early on.** Use insights from comparable past projects or scopes to build a realistic schedule. Map out dependencies (such as regulatory changes) clearly, identifying opportunities to accelerate timelines—such as running certain activities in parallel—to enhance efficiency and reduce delays.
- **Deploying new budgeting approaches.** Project teams must rely more heavily on front-end engineering studies, pilot results, and scenario-based cost modeling to capture and manage uncertainties in capital outlays, operating expenses, and scaling costs.
- **Building the right expertise.** Low-carbon projects are by default multidisciplinary and require a broad set of often-novel competencies. Project developers should invest in these capabilities well ahead of FID.
- **Ensuring disciplined execution.** Through robust risk management, real-time monitoring, and integration and collaboration across engineering, procurement, and construction, teams can identify potential issues early, minimize rework, and keep the project on time and on budget—even under rapidly changing market and policy conditions.

Step 6: Leverage AI and digital tools.

Companies that tap into new AI and digital solutions can improve planning accuracy and risk management for low-carbon capital projects while accelerating timelines. To realize such benefits, they must first overcome obstacles such as limited model training data and varied stakeholder readiness.

Key Challenges

The lack of standardized historical data is a key challenge in fully harnessing the power of AI and digital for low-carbon capital projects. Because low-carbon technologies—such as advanced carbon capture systems or e-fuel production—are often still emerging, there are limited reference points for AI systems to analyze. This makes predictive analytics and AI-driven scheduling less precise.

In addition, the digital capabilities of partners in large low-carbon projects are likely to differ significantly. Introducing complex AI solutions, like supply chain platforms or AI-driven feasibility studies, requires extensive training, clear communication, and coordinated effort. Without alignment and careful management of these factors, the potential impact from AI and digital tools can be severely diminished.

Targeted Actions

Companies can overcome these obstacles first by establishing standardized data libraries and structured knowledge-sharing. Capturing data from pilots—such as performance data from electrolyzers for hydrogen production or advanced battery systems —helps AI improve predictions on timelines and costs.

Second, proactive investment in training and stakeholder alignment is crucial. Regular communication and common digital standards help partners—from suppliers to regulators—adopt new tools more effectively. This approach encourages trust and open data sharing, driving continuous improvement.

Finally, adopting a phased approach to digital transformation allows companies to build confidence gradually. Piloting targeted applications—like AI-based supply chain or risk monitoring solutions—demonstrates early value. Scaling these proven solutions with clear metrics ensures smoother adoption.

The six best practices outlined here can help guide the successful development, execution, and, if necessary, strategic course corrections of low-carbon capital projects. (See “Resetting the Course for a Pioneering Project.”)

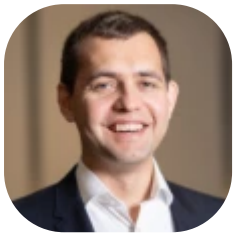
— Resetting the Course for a Pioneering Project

A leading energy infrastructure company embarked on an ambitious, first-of-its-kind offshore energy project designed to accelerate the low-carbon transition. Early into execution, however, the project encountered significant budget overruns and heightened complexity due to unforeseen cost escalations and supply chain bottlenecks. Uncertainty surrounding permitting, the execution timeline for novel construction methods, and logistical constraints exacerbated these challenges. Diverging stakeholder priorities among the board of directors, customers, and policymakers further complicated decision making and risk management.

To resolve these issues, the company conducted a strategic reassessment, leveraging detailed scenario-based business cases and adopting a data-driven probabilistic analysis. Transparent scenario evaluations helped stakeholders align around a shared understanding, facilitating the necessary rescoping and rebaselining of the project's planning and budget. By explicitly addressing the unique complexities inherent in pioneering low-carbon initiatives, including significant uncertainty and the need for adaptable planning, the organization successfully stabilized the project, enabling it to advance with renewed clarity and stakeholder alignment.

By recognizing the unique challenges facing these projects, companies can adapt their approach and position themselves as industry leaders in the low-carbon economy.

Authors



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