How US hydropower is redefining renewable energy

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Hydropower has changed considerably over the past six decades, from an industry focused primarily on generation to one balancing renewable energy, ecosystem restoration, climate resilience, and grid reliability. Based on the experience and viewpoint of the US consultant Kleinschmidt Associates, this paper discusses the evolution of hydropower through recent advancements in modernization, new development, fisheries engineering, digital technologies, and environmental innovation. Citing examples from current, ongoing, and recently completed projects in the USA and Canada, the authors offer perspectives on the lessons shaping today's decisions and the emerging trends likely to define the next generation of sustainable hydropower infrastructure.

Sixty years ago, hydropower projects were comparatively straightforward. Facilities were designed principally to generate electricity, deliver reliable performance, and operate safely for decades to come. Today's projects are quite different. Modern hydropower facilities are expected to generate renewable energy while strengthening grid reliability, restoring fisheries, protecting downstream communities, enhancing recreational opportunities, adapting to increasingly dynamic hydrological conditions, preserving cultural and historical resources, and navigating evolving regulatory and stakeholder expectations. Success is no longer measured solely in megawatts generated, but by how effectively projects balance competing priorities while delivering lasting value to the communities and ecosystems they serve.

Perhaps most notably, the industry's greatest innovations are not occurring within a single discipline. They emerge at the places where engineering meets ecology, where modernization meets resilience, and where collaboration creates opportunities that no single stakeholder could achieve independently.

Hydropower has quietly become one of renewable energy's most integrated technologies. That transformation did not happen overnight. It has evolved through thousands of decisions made across decades of projects, decisions that have fundamentally changed how we think about water infrastructure, environmental stewardship, and renewable energy development.

Looking back through 60 years of Kleinschmidt's experience throughout North America, one lesson stands above the rest: hydropower's greatest strength has never been its permanence, it has been its capacity to adapt. The projects redefining the industry are proving that hydropower's next chapter is not being discovered by accident; it is evolving by design.

Modernization covers more than just equipment

For decades, modernization meant replacing aging equipment and extending operational life. Today's projects demand something far more ambitious. They ask whether infrastructure that was built generations ago can continue meeting the needs of generations yet to come. Increasingly, modernization has become an exercise in integration, bringing together engineering innovation, environmental stewardship, collaborative project delivery, and long-term resilience.

A Canadian utility's multi-year turbine and generator overhaul programme exemplifies this transformation. The complex modernization effort represents far more than a traditional rehabilitation project. It was selected as the first hydropower life extension project to implement an innovative, collaborative, five-party contract, integrating the owner, engineers, equipment suppliers, contractors, and quality management teams throughout the project's life cycle, to navigate interdisciplinary and cross-functional challenges together with a 'best for project' mentality. This project demonstrates that modernization is becoming as much about integrating people, processes, and technology as it is replacing infrastructure.

At another Canadian generating station, modernization posed an even larger question. Supplying a significant percentage of the province's electricity, the large power-producing facility faced a defining moment: whether to remove, rehabilitate, or replace. The resulting decision reflects another important shift occurring across North America: modernization and environmental stewardship are no longer separate conversations. They are increasingly one and the same.

Hydropower facilities built decades ago are proving remarkably adaptable when paired with thoughtful engineering and long-term planning. Their continued value lies not simply in what they have produced, but in what they remain capable of becoming.

The future of hydropower may already be built

For decades, conversations surrounding renewable energy development have focused on a familiar question: What should we build next? Increasingly, the hydro profession is asking a different question: what has already been built that can be reimagined? Across North America, existing dams, abandoned lock chambers, and legacy water infrastructure are revealing new opportunities for renewable energy generation.

At the Tygart hydropower project in West Virginia, USA, innovation is not centred on building new infrastructure, but on unlocking renewable energy potential envisioned decades ago. The project proposes adding hydropower generation to an existing US Army Corps of Engineers' flood control dam by utilizing one of the power tunnels incorporated into the dam's original design for future hydropower development.

Equally significant is how the project is being developed. Marine and general contractors were engaged early in the design process to provide construction-informed perspectives well before final design decisions were made. By evaluating ease of construction, construction sequencing, project risks, and cost considerations alongside engineering requirements and environmental sensitivities, the project team has been able to assess practical alternatives and improve project feasibility. The approach reflects an important lesson emerging throughout the industry, that collaboration during project development often produces better engineering outcomes.



The Lock No. 14 hydropower project, in Heidelberg, Kentucky.

Along Kentucky's historic river navigation system, another project demonstrates that some of hydropower's greatest opportunities may be hiding in plain sight. The Lock No. 14 Heidelberg hydroelectric project is transforming an abandoned navigation lock chamber into renewable energy infrastructure designed to withstand extreme flood events, while minimizing environmental impacts and long-term maintenance requirements. Rather than imposing new development upon the landscape, the design embraces and reimagines the infrastructure already present. By housing the entire powerhouse within the existing lock chamber and utilizing fully submerged, oil-free turbine-generators, the project reduces both operational complexity and environmental risk while improving flood resilience. The innovative horizontal turbine configuration also reduced concrete requirements significantly compared with earlier designs while increasing generation capacity by approximately 30 per cent.

Yet perhaps the project's most compelling contribution extends beyond engineering. Together with its companion hydropower facility at Lock No. 12, the project will enable Berea College to offset more than 100 per cent of its electricity consumption with renewable hydropower, while supporting economic development in Appalachian Kentucky. Revenues generated by the project support Berea College's mission of providing educational opportunities to students of limited financial means, while local communities benefit from construction employment, increased tax revenues, and expanded recreational opportunities. What was once abandoned infrastructure supporting 19th century commerce is now helping advance 21st century sustainability objectives; a powerful reminder that thoughtfully designed hydropower projects can simultaneously create environmental, economic, and community benefits.

Upstream cofferdam construction at the York Haven Nature-Like Fishway on the Susquehanna river, Pennsylvania.



Projects like Heidelberg and Tygart suggest that one of hydropower's greatest opportunities may not lie in discovering entirely new places to build, but in discovering new ways to utilize the infrastructure which has already been built. Across North America, thousands of existing dams and water infrastructure assets represent similar opportunities to advance renewable energy goals while minimizing environmental impacts and maximizing previous investments. Hydropower's future may not simply be something we build; it may be something we strategically uncover.

The environment is no longer a constraint, but rather a design driver

Historically, environmental considerations were often viewed principally as challenges requiring mitigation. Today's projects are based on a different perspective. The environment is no longer simply something to accommodate, it is increasingly shaping how projects are conceived, designed, and delivered.

Perhaps nowhere has hydropower's evolution been more apparent than in fisheries engineering. As the industry's understanding of aquatic ecosystems has advanced, so too have the expectations placed on hydropower infrastructure. Today's projects are no longer designed solely to generate renewable energy, they are expected to support environmental stewardship, species restoration, resilient infrastructure, and long-term operational objectives simultaneously. Fish passage facilities have become powerful examples of this integration, bringing together biology, engineering, hydraulics, dam safety, ease of construction, and environmental stewardship in increasingly innovative ways.

The York Haven Nature-Like Fishway project on the Susquehanna river (Pennsylvania's largest river) illustrates how dramatically that thinking has evolved. Originally conceived as a 300 ft (approximately 91 m)-wide in-river fishway, the project faced significant challenges related to dam safety, ease of construction, extreme hydraulic conditions, and complex stakeholder interests. Through advanced hydraulic modelling, value engineering, and collaborative regulatory engagement, the project was transformed into a more efficient and constructable solution anticipated to reduce costs by approximately half while continuing to achieve its biological and hydro powerhouse operating objectives.

Innovation continued during construction when unusually low river conditions created an opportunity to replace a large cofferdam with a turbidity curtain, an adaptation that eliminated approximately 5000 yd^3 (approximately 382 m^3) of temporary fill material and avoided nearly 16 000 ft^2 of in-river impacts. The York Haven Nature-Like Fishway project demonstrates that power generation, environmental stewardship, and affordability need not exist in opposition. Increasingly, they are being advanced together.

Similarly, the Lake Conestee dam replacement project in South Carolina involved replacing a non-powered dam while balancing public safety, environmental protection, historical preservation, and community priorities simultaneously. The resulting design protects downstream ecosystems while preserving the site's historical significance, demonstrating how environmental outcomes are increasingly serving as design objectives rather than project constraints.

Environmental stewardship is no longer occurring at a project's margins, it is influencing decisions from conceptual planning through construction and long-term operations.

Collaboration has become critical infrastructure

The greatest challenge facing hydropower today may not be technical, it may be collaborative.

Today's projects exist at the intersection of communities, regulators, resource agencies, Indigenous communities, environmental organizations, recreational interests, and renewable energy needs. Successfully navigating these relationships has become every bit as important as solving engineering challenges.

One southern US utility's relicensing efforts offer an important example of how collaboration has become critical infrastructure. Through an intentionally collaborative process involving 19 organizations, stakeholders developed consensus around protection, mitigation, and enhancement measures that will influence project resources for decades to come.

The industry's most complex challenges rarely exist within a single discipline. Decisions affecting operations influence fisheries outcomes. Environmental considerations affect engineering solutions. Regulatory requirements shape construction approaches. Community priorities influence long-term project objectives.

Collaboration has therefore become its own form of infrastructure, and one requiring thoughtful investment, transparency, and sustained engagement throughout a project's life cycle.

The most effective hydropower solutions do not come from applying the same solution everywhere. Every watershed, community, regulatory environment, and project history brings its own unique opportunities and challenges. Strong local relationships and a deep understanding of regional needs must be combined with the collective expertise of specialists across North America. That combination makes it possible to develop practical, resilient solutions that reflect local realities while benefiting from decades of experience across disciplines that fit the needs of each client.

Resilience will define the next 60 years for hydro

If the past 60 years have been defined by adaptation, the next 60 will likely be defined by resilience.

Hydropower occupies a unique position within North America's renewable energy future. It must continue delivering reliable generation while responding to increasingly dynamic hydrological conditions, evolving regulatory expectations, aging infrastructure, and growing demands for environmental performance.

Perhaps nowhere is this shift more evident than in the industry's growing focus on dam safety and climate resilience.

A project for a public utility in the Pacific Northwest illustrates this transformation. Faced with the need to safely accommodate extreme flood events, the project required far more than routine infrastructure upgrades. Through a comprehensive options assessment evaluation process, improvements were developed that enhance spillway performance, strengthen inspection and maintenance capabilities, and support long-term stewardship of a critical water supply asset. The project reflects an important evolution occurring throughout the industry, resilience has become a project objective in its own right.



The Lake Conestee dam replacement, project in Greenville, South Carolina.

Resilience is also increasingly being informed by data. Developed for the Ontario Waterpower Association, the Fisheries Entrainment and Impingement Risk Assessment tool represents an innovative application of fisheries science, predictive analytics, and desktop modelling. Built based on four decades of fish passage and entrainment science, the expert system uses programmed decision trees and advanced analytical tools to provide consistent environmental risk classifications without requiring costly site-specific field studies. Projects like this offer an important glimpse into hydropower's future, one where data science and predictive analytics increasingly complement engineering expertise to support smarter infrastructure decisions.

The future will demand more from hydropower than in the past. Infrastructure will need to be smarter, and projects will need to be more collaborative. Environmental stewardship will continue shaping engineering decisions. Existing assets will require new ways of thinking about modernization and resilience.

After six decades of innovation, it is clear that hydropower has never stopped evolving. Its greatest strength has never been its permanence; it has been its remarkable capacity to adapt. The future of hydropower will not be built at the intersection of competing priorities. It will be built through their integration.

Renewable energy and environmental stewardship, innovation and resilience, engineering excellence and collaboration are no longer separate ambitions; they are shared objectives flowing in the same direction.

The next chapter of hydropower will not be defined by a single technological breakthrough or regulatory change. It will emerge from thousands of thoughtful decisions that recognize the industry's greatest opportunities lie not in choosing among competing priorities, but in advancing them together.

The next chapter not waiting to be written. Across North America, it is already underway. ◊



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