

WESTINGHOUSE TECHNICAL AND MARKET CAPABILITIES FOR HYDROGEN PRODUCTION



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EXECUTIVE SUMMARY

Global demand for hydrogen and its emerging applications is projected to increase by a factor of ten by 2050, surpassing the current infrastructure for producing and delivering hydrogen. This paired with increasing global pressure to decarbonize has created a unique opportunity for nuclear power plants to develop new revenue streams while supporting clean energy goals and combatting climate change.

In nonregulated markets, low natural gas prices and increased competitiveness of renewables are driving electricity prices below the point of competition for commercial nuclear power. This trend is forecasted to continue through 2050. Unless new revenue streams are identified, many commercial nuclear power plants will be forced to close.

As hydrogen usage expands from traditional industrial applications to the fuel of a clean future, the need to produce it in larger quantities and from green sources is clear. Nuclear plants, both existing and in design, large and small, are well-positioned to utilize electrolyzer technology to produce meaningful quantities of clean hydrogen with minimal disruption to operations. However, the nuclear industry also presents unique challenges that utilities, integrators, equipment suppliers, and hydrogen buyers will need to collaboratively solve.

As the premier provider of design, engineering, products, field and construction services to the nuclear industry, Westinghouse is ready to position our customers for a new source of revenue through hydrogen production. This paper outlines the market, opportunity, resources, and expertise available to our customers through Westinghouse. We are committed to bring our innovative leadership and our partnerships across the industry to support utilities, participating in all aspects of hydrogen production. This includes:

- **Consultation, design and engineering, construction, and site services to enable operating plants to generate revenue through hydrogen production**
- **Demonstration, use case, R&D, and academic efforts to advance hydrogen production technology in the nuclear industry**
- **Joint venture and partnership opportunities to seek funding from available sources (DOE and the inflation reduction act, etc.)**
- **Enable collaboration between utilities and hydrogen end users/off-takers**
- **Expand operating plant efforts to ensure advance plant designs enable hydrogen production**

As the original equipment manufacturer (OEM) for many pressurized water reactors, with extensive experience servicing and supporting nuclear power plants, no one is more equipped to evaluate the full spectrum of necessary hydrogen considerations than Westinghouse. Our position is enhanced by a full suite of secondary side evaluation and modifications, maintenance and construction experience plus engineering, procurement, and construction management capabilities to execute the entire plant modification package, site work, and electrolyzer island tie-in.

Westinghouse is the right partner for this market, with innovative technology, robust expertise, which enables a strong Return on investment (ROI) for our customers.

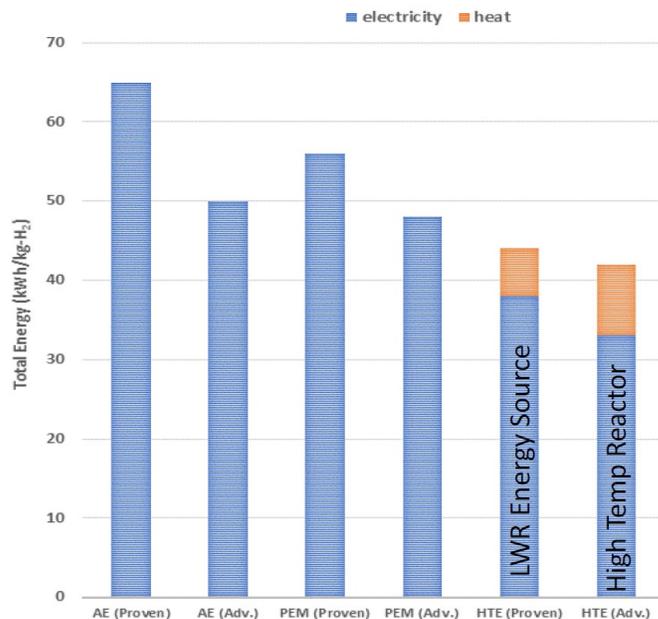
US HYDROGEN MARKET OVERVIEW

Only 1% of hydrogen produced today is manufactured via electrolysis; most of the 88 Million tons (Mt) currently generated in the world utilizes fossil fuels without carbon capture. As global net-zero goals near, and hydrogen needs increase to an anticipated 212 Mt annually by 2030, the need for more hydrogen with diversified generation methods is clear. These demands simply cannot be met without the support of nuclear plants, and with an aspirational price of \$1/Kg by 2030, clean electrolytic hydrogen presents a \$72B global opportunity to the nuclear industry.

This need is being driven by refining applications, power production, and clean transportation. The refining industry has committed to becoming greener in the coming years, while power production will make up most of the demand for clean hydrogen in the next decade. Furthermore, the growing hydrogen, ammonia, and synfuel needs of the transportation industry can only be met if hydrogen production increases.

Westinghouse has determined that there is a strong business case for both high and low temperature electrolysis options paired with nuclear facilities for clean and efficient hydrogen production. Numerous industry pilots are already underway, utilizing low temperature technologies like Polymer Electrolyte Membrane (PEM). High Temperature Steam Electrolysis (HTSE), also referred to as Solid Oxide Electrolyzer Cell (SOEC) technology. SOEC is an exciting next step for hydrogen production and is expected to bring significant leaps in production efficiency over the next 1-5 years. Table 1 shows the current expected energy consumption of various electrolysis methods. The input requirements for SOEC (high temperature) technology are a natural fit with our nuclear industry.

Table 1: Steam Electrolysis with Nuclear Heat and Power



Source: Light Water Reactor Sustainability

The hydrogen economy and its associated production pathways are still forming today. It is imperative to understand the forces driving innovation and advancement in this area, including the important role of federal funding (e.g. DOE, H2@Scale, IRA, etc.), tax incentives and the constant evolution of technologies enabling hydrogen production.

Westinghouse is participating at both local and federal levels to explore funding opportunities for research and deployment, as well as closely engaging with suppliers, utilities and end-users. Additionally, Westinghouse has dedicated a cross-functional team of talented individuals to explore everything from designing the SOEC integration to understanding the various needs from engineering, uprating, thermal and electrical analysis, and successfully siting an electrolyzer at a nuclear plant. Westinghouse is prepared to deploy these resources and our knowledge base to support the effective and efficient delivery of hydrogen production technology to the nuclear market.

LARGE INDUSTRIAL FACILITY DESIGN AND CONSTRUCTION

Westinghouse has the capability to deliver projects that encompass the entire lifecycle of a major project: Engineer, Procure, and Construct (EPC). Our company has extensive and experienced nuclear construction resources and will self-perform, where appropriate, the majority of our projects. We have the resources to execute a broad range of project sizes up to the most complex EPC projects at operating nuclear facilities.

Westinghouse has the required depth of experience, expertise, vast resources, and installation capabilities to perform engineering services. Stone & Webster LLC, a Westinghouse Electric Company, is a product line offering Architect Engineer (A/E) and EPC services with a multitude of capabilities and deep technical knowledge in a broad range of disciplines. Westinghouse has extensive experience solving technical, licensing and operational issues and the proven project delivery skills to ensure certainty of delivery, excellence in execution, and value pricing for:

- Engineering and Design
- Engineering of Choice (EOC) Services
- Operations and Maintenance Support
- EPC Product Delivery
- Project and Construction Management/Oversight
- Specialty Engineering and Consulting Services
- Owners Engineer

Our capabilities encompass the entire project scope:

- Engineering
- Procurement
- Construction
- Implementation risk assessment and reduction
- Outage planning
- Field implementation, including oversight of subcontracted construction
- Commissioning startup and test
- Project closeout and turnover

Westinghouse Non-Proprietary Class 3

- Project and construction management

Westinghouse's talented staff has experience providing the A/E and maintenance, modification and construction (MMC) services to support the design and implementation of the plant infrastructure, geotechnical services, plant facilities, mechanical, electrical, I&C, civil, and structural considerations of the Hydrogen generation plant. This includes experience integrating the nuclear plant as a source of thermal and electric power to a hydrogen facility, as well as the site infrastructure. As an example, Stone & Webster prepared the detailed design for the National Enrichment Facility (NEF) buildings and site infrastructure. Additionally, Stone & Webster performed a similar scope of work for the Eagle Rock Enrichment Facility in Idaho. Stone & Webster engineering services developed the conceptual design and capital cost estimates of the facility and provided licensing inputs for the environmental report and other licensing-basis documents, such as the combined Construction and Operating License Application (COLA). The multi-discipline work effort included engineering and design of core process buildings, support buildings, and yard areas including:

- Separations building modules, with each composed of two separate cascade halls, a multi-level process service corridor, a handling annex for uranium hexafluoride (UF₆), and miscellaneous equipment rooms and corridors
- Buildings for blending, sampling, and preparation; cylinder receiving and shipping; centrifuge assembly, including hot test and post-mortem facilities; technical support; operations support; and mechanical and electrical services
- Architectural design services for administration buildings and support facilities, to LEEDS standards.
- Mechanical including piping, HVAC, equipment and electrical engineering and design to support the building infrastructure and centrifuge requirements.
- Developing the engineering and design requirements required for the close coordination and integration of three proprietary equipment suppliers plus the unique client requirements for operations and maintenance.

The yard areas include roads, parking facilities, cylinder storage pads, potable and fire water storage tanks/pumps, fire, medical and other support buildings for water and waste treatment, warehouses, and guard houses.

Westinghouse has the demonstrated technical and managerial experience in nuclear plant equipment and systems, engineering, design, and project management. Additionally, we have the complementary skills and experience of engineering and designing the most complicated infrastructures while integrating the design requirements of multiple vendors and design organizations. We want to bring these capabilities to our utilities for the development and integration of hydrogen technology and other compatible technologies in a contemporary nuclear power plant facility. As a member of your team, we can support and manage integration and coordination with hydrogen electrolyzer suppliers and other key equipment vendors, work with the utility's engineering and plant operations teams to integrate the necessary steam, electrical requirements, and other plant systems, and develop efficient conceptual and final designs while maintaining optimum plant operations.

We fully recognize that hydrogen equipment designs and scaleup are evolving and will require intensive integrated reviews, evaluations, and value engineering options with the utility's engineering and plant operations teams. An integrated partnership is essential in evaluating plant designs and parameters. The goal is to optimize operating conditions while minimizing any potential impacts to plant operations, cost effectively producing and delivering bulk hydrogen to the marketplace.

CHEMICAL INFRASTRUCTURE DESIGN

Hydrogen Generation

Westinghouse has the skills, collective experience, and integrated engineering resources to provide design services that span the full gamut of hydrogen production needs, such as thermal extraction design, licensing, electrical design, instrumentation and controls, plant modification packages, and optimization with high-temperature electrolyzer providers. These services and capabilities can be deployed across a range of work scope options, from piecemeal engineering to a turn-key build and everything in between.

Westinghouse is currently exploring the electrolyzer market and is actively engaged in bridging the gap between their expertise in hydrogen production with the necessary scale and expectations of a nuclear facility. This includes understanding where we can apply our architect engineering, manufacturing, and design capabilities to assist in the scale-up of existing concepts to create a large scale electrolyzer island design which is seamlessly integrated with the planned plant modifications and embedded control systems. In support of these efforts, Stone & Webster has built numerous, detailed models to evaluate the comprehensive, integrated performance of these systems in concert with various nuclear facilities across the United States. These include both pressurized water reactors and boiling water reactors and employ **unique and simplified integration methods** which have not been shown in other concepts.

It is our belief that these solutions have both efficiency and cost-of-integration advantages. Similarly, Westinghouse has completed detailed conceptual designs for the full suite of electrical modifications necessary to provide behind-the-meter electrical power to a representative electrolyzer island while maintaining the necessary safety considerations of a nuclear power plant. It should be noted that this electrical design work would also be applicable to a separate, low-temperature electrolysis island, should this be a preferred implementation.

At present, Westinghouse is furthering its confidence by taking the "on paper" design and evaluation input from the aforementioned activities and applying them at the hardware level within a candidate plant's 3D design model. Given the candidate plant's highly compacted layout, this is providing further assurances as to the efficacy of the proposed design modifications and their applicability and value to existing sites. Table 2 outlines Westinghouse's capabilities for the hydrogen production market.

Table 2: Westinghouse Areas of Expertise in Hydrogen Production

Area	Description
Nuclear Steam Supply System (NSSS) Analysis	<p>Evaluations and/or analyses required against the following analysis of records (AORs) for added steam extraction or changes in power level:</p> <ul style="list-style-type: none"> • Setpoints and uncertainties • Licensing (including Requests for Additional Information (RAIs)) • Large-Break Loss of Coolant Accident and Small-Break Loss of Coolant Accident (LBLOCA & SBLOCA) • Design Transients • Transient Analysis • Main Steam Line Break (MSLB) – Mass & Energy (M&E) / Containment Analysis • Control System Analyses • Steam Generator Analyses • Probabilistic Risk Assessment (PRA) • NSSS/Balance of Plant (BOP) Interface Analyses
Hydrogen Explosion Analysis	<ul style="list-style-type: none"> • Using Modular Accident Analysis Program (MAAP) or MELCOR to determine how far to site the LTE/HTSE away from the nuclear plant. • This evaluation will be required to support siting the electrolyzer and would be separate from the PRA listed in the NSSS analyses.
Control System analyses	The location of the steam extraction point may have an impact on existing NSSS and BOP control systems, and this impact requires an evaluation to determine if existing control systems can operate as is or if they must be modified to accommodate hydrogen production.
Control System Design and Integration (leveraging existing or new digital I&C)	Modify existing control system designs to accommodate impacts due to steam extraction point.
Main Control Room Human Factors Engineering (HFE) and Human Machine Interface (HMI)	Provide the operator with the controls and necessary monitoring information to ensure the safe operation of the plant and the hydrogen electrolyzer.
Simulator Updates for new Control System	Update the simulator to reflect the controls and operation of the plant for operator training.
Data Integration of Hydrogen Island into Main Control Room	It's necessary to present the operator with the controls and necessary monitoring information to ensure the safe operation of the plant and the hydrogen electrolyzer. The necessary data will reside within the control system implemented for the steam extraction with a possible data link to the hydrogen electrolyzer controls if not implemented on the same platform.
Thermal Supply, Electrical Supply, and Water Supply	Steam supply to provide thermal input to HTSE, Electrical supply input to HTSE, and Water for cooling, processing and domestic use
Fuel Analysis and Core design requirements	Completion of any associated analyses related to fuel considerations
Civil/Structural Construction	Design of Hydrogen Plant Island foundation structure including geotechnical support and construction

Area	Description
Power Uprates and BOP	NSSS design and analyses may be impacts, hardware changes on the BOP side, and licensing impacts due to change in power level, including installation of components.

Hydrogen Transport & Storage

Westinghouse Global Logistics Programs maintains a cadre of qualified and proficient employees for domestic and international transport of Dangerous Goods/HAZMAT materials. Westinghouse HAZMAT shipments are scheduled, prepared, and tendered by logistics personnel at Westinghouse Cranberry, Waltz Mill, and Columbia locations. Documentation for each shipment is prepared by Westinghouse in accordance with 49 CFR and other applicable regulations.

Westinghouse maintains relationships with carriers that are active in hydrogen transport. Global Logistics sourcing personnel have extensive experience in securing short- and long-term contracts/partnerships with over-the-road (OTR) carriers with specialized HAZMAT capabilities. If necessary, our portfolio of HAZMAT carriers can be expanded. Our experience in nuclear materials transport gives Westinghouse a unique perspective on transportation safety, compliance, and carrier accountability.

Ammonia Production, Storage, and Transport

Westinghouse has extensive experience in purchasing and transporting ammonia at our zirconium nuclear fuel facilities. We also have a long history with a multitude of hazardous materials. We possess experience in handling, permitting, and outside entity relationships of hazardous substances (Department of Transportation (DOT), etc.), and are fully prepared to leverage this experience in this effort.

Westinghouse is also prepared to engage our Architecture Engineering and construction capabilities to leverage our robust knowledge and relationships with suppliers, working with an electrolyzer vendor and developing the subsystems required for storage, compression and transportation, including ammonia. Design work (foundations, electric, etc.) could also be developed for ammonia production.

PROCUREMENT AND MIDSTREAM RELATIONSHIP MANAGEMENT

Relationships with Hydrogen/Chemical Vendors and Electrolyzer Suppliers

Westinghouse has developed trusted relationships and regular communications with manufacturers at the forefront of electrolyzer technology. Input from leading electrolyzer suppliers has been sought to develop robust economic modelling for both HTSE and LTE technologies and modeling hydrogen production using a candidate plant. Maximizing electrolyzer design parameters, and even customizing units for nuclear inputs, is an ongoing topic of review between Westinghouse and several leading electrolyzer manufacturers.

Our strategy in this arena is developing quickly. Westinghouse is prepared to leverage our existing relationships, as well as our robust internal resources, as we actively evaluate opportunities to best serve our customers in a seamless, integrated approach. This includes possible partnerships, joint ventures, and Merger & Acquisition (M&A) opportunities.

Supplier Networks and Relationships

Westinghouse maintains an extensive global network of over 6,000 high quality suppliers through its Global Supply Chain Solutions (GSCS) organization. The Westinghouse supplier base includes, but is not limited to, raw material, construction, services, fabrication, permitting, and transportation suppliers. Westinghouse maintains multiple internal fabrication facilities within the United States, Canada, Sweden, and Italy.

GSCS contains the Westinghouse Supplier Oversight organization which ensures Westinghouse suppliers perform to the highest industry quality standards. Supplier Oversight rigorously reviews, audits, rates, and implements corrective actions to ensure Westinghouse and Customer requirements are achieved. In addition, Westinghouse is continuously evaluating new suppliers to support customer localization goals and streamline delivery requirements.

Westinghouse has established relationships and partnerships with its core supply base to ensure the certainty of supply for our AP1000® plant construction and to the long-term material supply for our Nuclear Fuels division. Westinghouse GSCS is the catalyst that drives Westinghouse's extensive network of suppliers to safely deliver high quality, cost effective, low risk products and services that fully satisfy customer and regulatory requirements.

Waterway/Railway Access and Transport Experience

Westinghouse Services projects and AP1000® construction projects give Westinghouse a long history of planning and executing projects that used over the road (OTR), waterways (near-shore ocean and rivers), and railways. Many projects have required a combination of modes.

AP1000® Reactor Vessel Internals had a single route that required the use of OTR, near-shore ocean, and railway. This required an orchestration of effort among heavy truck carriers, derrick barge carriers, railroads, authorities, and material handlers at multiple ports.

Watt Bar 2 Steam Generator replacement required ocean, inland waterways, and OTR. This required extensive coordination with the port official, material handlers, specialized haulers, and the US Army Corps of Engineers (USACE). USACE coordination included arranging for timed release of water on the Tenn-Tom waterway and Tennessee River.

For AP1000® Steam Generators and Reactor Vessels, Westinghouse planned and executed transport that required rail track bridge undercuts, rail bridge replacement, and port pier reinforcements. This three-year effort resulted in successful delivery of three Reactor Vessels (each weighing 400 tons) and six Steam Generators (each weighing 800 tons).

STARTUP AND OPERATIONAL EXPERTISE

As part of Nuclear Plant integration, Westinghouse can provide commissioning and startup support services following the nuclear plant upgrades needed to implement the integration of the nuclear plant with the hydrogen generation plant. Stone & Webster has provided commissioning and startup support services following large nuclear plant modification and component replacement.

Westinghouse developed the start-up and commissioning procedures following Extended Power Uprates (EPU). EPUs typically involve large secondary plant component replacements to support an increased plant output of up to 20% and are critical to ensure the plant can efficiently deliver the increased plant output. This requires development of the acceptance criteria and commissioning procedures that verify the plant performance. In addition, the commissioning has to be integrated with normal plant power ascension. Stone & Webster has developed an EPU commissioning program and procedures to safely implement the EPUs. Precautions and contingency actions are developed as part of the commissioning plan to ensure an event-free plant power ascension following the EPU implementation.

CONCLUSION

Hydrogen demand is expected to outpace production in the coming years unless new infrastructure is created. A clean hydrogen economy, our collective long-term goal, is steadily becoming reality thanks to the advancement of hydrogen technologies, local and federal support, and valuable industry partnerships.

Westinghouse is committed to bringing efficient, large-scale hydrogen production to nuclear facilities through operating plant integration, new build design incorporation, and participation in near-term demonstrations and pilot projects. Hydrogen has the potential to add significant yet flexible revenue streams to the nuclear industry, and Westinghouse is well positioned to partner with our customers to implement and operationalize hydrogen production at their facilities.