ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Accelerating the Manufacturing of Energy-Generating Windows for Zero-Emission Buildings Leveraging Pilot-Scale Innovations

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency; renewable energy and advanced clean generation; energy-related environmental protection; transportation; and energy transmission and distribution.

In 2011, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned electric utilities — Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company — were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs to promote greater reliability, affordability, and safety for California electric ratepayers. EPIC investments advance these values by:

- Providing societal benefits.
- Reducing greenhouse gas emissions in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs, first with energy efficiency and demand response, next with renewable energy (distributed generation and utility-scale projects), and finally with a clean electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Accelerating the Manufacturing of Energy-Generating Windows for Zero Emission Buildings Leveraging Pilot Scale Innovations is the final report for the Accelerating the Manufacturing of Energy-Generating Windows for Zero-Emission Buildings Leveraging Pilot Scale Innovations project (EPC-22-011) conducted by NEXT Energy Technologies, Inc. The information from this project contributes to the CEC Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

The purpose of this project was to establish and demonstrate a low-rate initial production assembly line for NEXT Energy Technologies, Inc.’s energy-generating window system. In this project, the team developed and validated the manufacturing tools and processes required to assemble coated glass into photovoltaic window modules, using production-relevant methods. Specifically, steps included glass cleaning, bus bar application, edge seal, interlayer lamination, cover glass merging, curing, and inspection, and advanced from pilot-scale to low-rate initial production scale.

The project demonstrated that these low-rate initial production assembly processes achieved the performance, quality, and throughput necessary to scale toward full-rate manufacturing. In addition, the project team fabricated and installed a representative commercial facade, which showed the successful integration of large-format energy-generating windows into an architectural system.

The results of this project significantly reduced scale-up risks by validating production methods that are directly transferable to full-scale manufacturing. This outcome enabled the transition of NEXT Energy Technologies, Inc.’s window-photovoltaic technology from pilot demonstration to commercial deployment, which supports California’s statutory goals for zero-emission buildings and cost-effective onsite renewable energy generation.

Keywords: Energy, solar, organic photovoltaics, windows, glass, buildings, coating, energy-generating windows, building-integrated photovoltaic

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Background

NEXT Energy Technologies, Inc. (NEXT) transforms traditional windows into energy-generating assets by creating a window-photovoltaic system that looks like normal windows by selectively transmitting visible light with colors and transmission levels that meet window market requirements while at the same time selectively absorbing ultraviolet and infrared light to provide onsite energy generation. With buildings accounting for 41 percent of United States energy consumption (Kaur and Prasher, 2023), based on calculations by NEXT, the NEXT window-photovoltaic system addresses the largest and most controllable operating expense for commercial buildings — energy — by generating electricity directly from a building's facade. This radical breakthrough will have a significant impact on California's statutory energy goals: greater electricity reliability, lower costs, and increased safety. The NEXT window-photovoltaic system was developed and validated by both commercial partners and successful research and is now ready for initial production.

This California Energy Commission Realizing Accelerated Manufacturing and Production (RAMP) project, executed by NEXT, established a low-rate initial production assembly line for its processed organic photovoltaic window system. Specifically, the manufacturing line tools and processes (required to assemble the coated glass lites, which are single panes of standard window glass, into window-photovoltaic modules) were within the scope of the RAMP project. These assembly steps included cleaning the glass substrates, applying the busbars, edge seal, interlayer, and cover glass, curing the assembly, and inspecting the final product. The assembly tools demonstrated their capability to meet full-rate production objectives when further integrated into automated processes (including similarly advanced organic photovoltaic coating systems). The coated glass substrates that feed the RAMP manufacturing line were generated from the slot-die coating tool built during NEXT's corresponding Bringing Rapid Innovation Development to Green Energy project (EPC-20-014: Rapid Innovation Development of Energy-Generating Windows for Zero- and Negative-Carbon Emission Buildings).

Project Purpose and Approach

The overarching objective of this research project was to reduce manufacturing risks (de-risking) by specifying, procuring, qualifying, and operating low-rate initial production assembly tools that bridge pilot-scale achievements to full-rate production. The ultimate target audience for this technology is commercial office building owners and developers, architectural glazing contractors, and insulated-glass unit fabricators seeking to integrate onsite renewable energy generation into building facades without sacrificing either aesthetics or structural performance.

Specific tasks within the project were structured to cover different aspects of manufacturing de-risking including tool build-outs like ordering and installing, benchtop to large-area tool process transfer, and optimization of module fabrication. Additionally, the project scoped out and validated assembly techniques, demonstrated an in-building commercial-style facade facilitated by multiple partners, and performed market cost validation to determine the commercial viability of the product's entry into the commercial market.

Key Results and Conclusions

The goals achieved in this project were to:

- Specify, build, and install assembly tools for the fabrication and qualification of window-photovoltaic modules capable of handling commercially fabricated window glass for photovoltaic use.
- Use low-rate initial production tools to assemble previously coated lites into photovoltaic modules of high aesthetic quality and performance suitable for window and photovoltaic applications.
- Scale up and test a full module assembly with commercially relevant techniques at commercially relevant sizes, effectively moving from prototype pilot scale to low-rate initial production including the metrics of quality, yield, and cycle time.
- Build and test a window-photovoltaic module with commercially relevant assembly techniques at commercially relevant sizes in-house, with commercial partners on an installed window facade.
- Outline a plan for full-rate production with outcomes from low-rate initial production installations.

All of these goals were completed within the scope of the RAMP project, with supporting details described in Project Deliverables. Critical performance metrics included industry-required aesthetic standards for color uniformity and defect reduction, and low-rate initial production yields and cycle-time targets designed to validate scalable manufacturing. These requirements were essential to ensure commercial acceptance in the window and building industries. The NEXT team met or exceeded targets for the proposed low-rate initial production performance metrics, with yield and aesthetic targets either meeting or exceeding industry standards, and with cycle times scalable to full automation.

The project team also successfully fabricated and installed a six-unit demonstration facade at NEXT's Santa Barbara headquarters, demonstrating commercial feasibility and integration with established glazing systems. These results provide a strong foundation for scaling to full-rate manufacturing and support broader commercialization, with updated cost models and market validation further confirming ratepayer benefits. The findings and deliverables from this project will be carried forward into next steps for full-rate production and technology transfer.

Knowledge Transfer and Next Steps

The project leader NEXT continues multiple activities to accelerate commercial adoption of its building-integrated window-photovoltaic technology, including:

- Advancing low-rate initial production assembly processes through ongoing manufacturing analysis, process optimization, and lessons learned from tool implementation.
- Expanding technology verification testing, including performance validation of low-rate initial production modules and demonstrations on installed facades in California.

- Continuing market research, business development, and cost-performance modeling to support commercialization and investment in full-rate production.

These activities and related achievements coincided with the project goals of specifying, building, and qualifying low-rate initial production assembly tools that did not previously exist, and demonstrated the ability of those tools to produce modules with high aesthetic quality, yield, and cycle times suitable for commercial window applications. The successful fabrication and installation of a representative facade further validated the readiness of the technology for market adoption and provided critical data for scaling to full-rate production.

NEXT Energy Technologies, Inc.'s (NEXT) will leverage the results of the RAMP project in collaboration with its commercial partners to complete full-rate production planning, supply-chain integration, and knowledge transfers to both the window and solar photovoltaic industries. These steps position the technology for widespread adoption, which will additionally support California's mandates for zero-emission buildings.

Benefits to California Ratepayers

NEXT's window-photovoltaic technology delivers direct and measurable benefits to California ratepayers by enabling commercial buildings to generate onsite renewable energy using their existing facades, both reducing electricity demand from the grid and lowering operating costs for building owners.

Energy Generation and Cost Savings

Updated system-level cost modeling, incorporating electric rate schedules, time-of-use variations, demand charges, and incremental facade integration costs (validated through the Walters & Wolf demonstration project), together confirmed that NEXT windows can achieve a simple payback of two years or less for average commercial office buildings in California. This surpasses the project's high target metric of two years or less for California installations. The model also projects a levelized cost-of-energy below $0.03 per kilowatt-hour by 2030, which meets California Energy Commission program targets. The payback analysis was conducted across California cities including San Francisco, Sacramento, and Santa Barbara (as well as in national markets), confirming cost competitiveness under a wide range of conditions.

Greenhouse Gas Emissions Reductions

Widespread adoption of NEXT's window-photovoltaic technology could reduce up to 0.9 gigatons of carbon dioxide equivalent emissions by 2050, based on updated greenhouse gas reduction modeling that incorporated improved performance data from low-rate initial production assembly modules, facade testing, and broad market adoption scenarios. These scenarios were calibrated against the historical uptake of low-emission windows, energy savings from onsite generation, and reduced heating, ventilation, and air conditioning energy loads due to improved solar heat gain coefficients.

Grid Reliability and Distributed Generation

By enabling commercial building facades to contribute to onsite energy generation, NEXT's technology supports California's loading order, which prioritizes distributed generation before utility-scale resources. Distributed facade-integrated generation reduces peak grid loads in commercial districts, improving resilience for all ratepayers.

Benefits to Disadvantaged Communities

The demonstration installation at NEXT's Santa Barbara headquarters is located in a disadvantaged community as defined under California Senate Bill 535 and indicated by CalEnviroScreen 4.0 (California Environmental Protection Agency, 2022; De León, Chapter 830, Statutes of 2012). This installation demonstrates that NEXT's technology can be deployed in community-serving commercial buildings with direct energy cost and resilience benefits to residents in disadvantaged communities. Future deployment opportunities in disadvantaged communities have been identified through NEXT's stakeholder engagement program.

Economic Development and Job Creation

NEXT's manufacturing processes rely on California-based supply chain partners, advanced manufacturing techniques, and skilled fabrication and installation labor. Scaling to full-rate production will create new clean energy manufacturing jobs in California, which in turn support the state's broader economic development objectives. Letters of interest from major global window fabricators, representing potential revenue of 190 million dollars, reflect the substantial commercial market value under development by this California-funded innovation.

Recommendations for Further Adoption

To accelerate broader deployment, the project team recommends updating California building codes and Title 24 compliance pathways to better recognize building-integrated photovoltaic glazing as a credited onsite generation technology. This would develop streamlined interconnection standards for facade-integrated solar systems, which would both reduce permitting costs and timelines and expand California Energy Commission utility demonstration programs that support building integrated photovoltaic installations in both disadvantaged communities and affordable commercial buildings.

CHAPTER 1: Introduction

NEXT Energy Technologies, Inc. (NEXT) develops transparent solar photovoltaic (PV) window systems that convert sunlight into electricity while maintaining the appearance of conventional commercial glass. Buildings account for approximately 41 percent of energy use in the United States, and commercial building facades represent an underutilized opportunity for onsite renewable energy generation. Conventional solar panels require dedicated roof or ground area, leaving the largest surface area of most commercial buildings — the glazed facade — untapped. NEXT's organic photovoltaic (OPV) technology addresses this gap by enabling architectural glass to selectively absorb ultraviolet and infrared light for energy conversion while transmitting visible light at color and transmission levels that meet window market requirements.

Prior to this project, NEXT's manufacturing processes remained at laboratory and pilot scales. This California Energy Commission (CEC) Agreement EPC-22-011 — the Realizing Accelerated Manufacturing and Production (RAMP) project — was designed to bridge the gap between pilot-scale achievement and low-rate initial production (LRIP) capable of supporting pre-commercial volumes and real-world demonstration installations. Low-rate initial production refers to a manufacturing stage in which production tools and processes are validated at commercially relevant scales and throughputs, but *before* full-rate automated production is established. This stage is critical for identifying and resolving process challenges before committing to full capital investment in future automation.

This project supports California's statutory goals for zero-emission buildings and a carbon-neutral electricity grid by 2045. Commercial buildings are primary targets for decarbonization because they account for a substantial portion of California's electricity demand. Technologies that enable commercial building facades to generate onsite renewable energy can reduce grid loads, lower operating costs for building owners, and contribute to meeting California's loading order (which prioritizes energy efficiency and distributed generation resources before utility-scale clean energy generation resources). NEXT's window-PV product is uniquely well suited to urban commercial buildings where rooftop solar is constrained by structural, aesthetic, or zoning limitations.

This research project targeted the assembly steps that convert OPV-coated glass substrates into finished window-PV modules and insulated glass units (IGUs) suitable for commercial building facades. An IGU is a sealed multi-pane glass assembly used in commercial construction to provide thermal insulation. The coating process that produces the OPV-coated glass substrates was addressed separately in an earlier CEC project, the Bringing Rapid Innovation Development to Green Energy (BRIDGE) project (EPC-20-014). The RAMP project focused specifically on downstream assembly steps: glass washing, bus bar application, edge seal application, interlayer cutting and layup, cover glass merging, lamination, curing, and inspection. A bus bar is a conductive strip that collects electrical current generated by the OPV coating, an edge seal is a perimeter sealant that protects the module from moisture intrusion, and an interlayer is a transparent bonding film used to laminate the assembly into a durable glass-enclosed package.

Project goals included qualifying LRIP assembly tools, validating that those tools produced modules that meet industry standards for both photovoltaic performance and architectural glass aesthetics, integrating the finished modules into commercial IGUs and a representative facade system, and developing a full-rate production strategy informed by LRIP outcomes. Success was measured against defined project performance metric targets including defect rates within the American Society for Testing and Materials (ASTM) C1172-09 for laminated architectural glass, color uniformity within ASTM C1376 (DeltaE2000 less than 2.0), module yield greater than 90 percent, and cycle times approaching seven units per hour.

The primary audiences for this project's results include commercial architects and building designers, glazing contractors, IGU fabricators, commercial building owners and developers, policymakers, and clean energy advocates. This work is directly relevant to any stakeholder involved in commercial building envelope specification, construction, or ownership, both in California and nationally.

CHAPTER 2: Project Approach

The purpose of this research project was to fund the scale-up of an LRIP line for the assembly of solution-processed organic photovoltaic (OPV) on architectural window glass into window-PV modules ready for integration into commercial IGU. This work contains the subsequent steps in the window-PV manufacturing process after the OPV coating process itself, which was the subject of the earlier CEC BRIDGE project (EPC-20-014). This window-PV system can make a significant contribution to the onsite energy generation of a commercial building, with minimal incremental cost over the baseline cost of installed window systems (treating the window as a sunk cost already required by the building), and this project additionally advances a manufacturing process substantially beyond the BRIDGE project.

This project built and validated the assembly steps that turn coated architectural glass into finished window-PV modules and IGUs suitable for commercial facades. The focus was on LRIP methods for bus bar application, edge seal application, interlayer cutting and layup, cover glass merging, lamination, inspection, and testing. The coating process was not within the scope of this project. The goal was to prove that these assembly methods meet window-industry aesthetic and safety expectations while holding photovoltaic performance in module sizes to commercially relevant formats, and further to show that the modules integrate cleanly into standard IGU fabrication and facade systems.

Proving LRIP assembly at larger sizes matters for two reasons. First, aesthetic quality and color uniformity must meet window standards so that the product will be accepted by architects and building owners. Second, modules must be packaged safely and integrate into IGU and curtain-wall systems using established supply chains so that commercial partners can fabricate, glaze, and install them without special handling.

The project achieved its objectives to:

- Transfer NEXT’s optimized, demonstrated pilot-scale processes to an LRIP process that is compatible with commercial deployment. Quantitative milestones for these processes included:
    - Building and ordering a semi-automated bus bar, edge seal, and interlayer packaging tool suitable for both solar module fabrication and commercial window fabrication.
    - Demonstrating fabrication of the module packaging on glass with increasing sizes to prove the ability to provide devices with comparable quality at commercially relevant sizes.
    - Evaluating the aesthetics, uniformity, and performance of window-PV lites assembled from new assembly equipment to ensure that devices comply with applicable industry standards.
- Integrate modules fabricated using the LRIP processing techniques into IGUs that meet identified performance metrics. Quantitative milestones for these modules included:

    - Consulting with building window system manufacturers to fabricate IGUs that pass applicable safety and durability tests.
    - Collaborating with a commercial integrator to fabricate and install a demonstration system using the IGUs from the previous step.
- Plan for upcoming full-rate production manufacturing.

Project Partners and Participants

The success of this project depended on close collaboration with established commercial partners and specialized vendors, each of which contributed expertise critical to validating LRIP methods for energy-generating windows. The selection of these partners ensured that at each stage of the project — from tool procurement to facade installation — was tested under real-world conditions using supply chains similar to those required for full commercial adoption.

Viracon, a leading single-source architectural glass fabricator, played a pivotal role as the project's primary glass fabricator. As one of North America's largest architectural glass manufacturers, Viracon fabricated the IGUs that incorporated NEXT's OPV-coated lites into commercial-grade glazing assemblies. Viracon's participation demonstrated that NEXT's technology could be seamlessly integrated into standard IGU fabrication lines without requiring special handling or retooling. This validation was essential because IGU fabrication is a core bottleneck in any commercial adoption pathway, and proving compatibility within Viracon's workflows instilled confidence that the technology could scale to volume production. Its work culminated in the fabrication of the six IGUs installed in the demonstration facade.

Walters & Wolf, a leading window installer and contractor for large commercial buildings, was responsible for facade system design, glazing, and installation. The company engineered a framing system that accommodated both the structural requirements of the facade and the electrical routing required for PV operation. Walters & Wolf's contribution was particularly valuable in bridging the gap between laboratory-scale fabrication and building integration. By ensuring that junction boxes, wiring, and other electrical components could be incorporated without compromising weatherproofing or aesthetics, Walters & Wolf validated that window-PV modules can be adopted using existing curtain wall practices. The successful installation of the demonstration facade at NEXT's headquarters additionally provided a permanent showcase for the technology and real-world validation of its architectural compatibility.

Benteler supplied the glass washer, a critical tool for scaling module sizes up to 40" x 60" lites. The washer was installed and commissioned during Task 3, and the qualification of the washer confirmed that uniform cleaning of architectural glass could be achieved within target LRIP cycle times. This tool eliminated prior bottlenecks associated with manual pre-washing and provided a pathway to throughput targets of more than seven units per hour.

Bent River Machine provided the laminator, used for packaging modules into glass enclosed assemblies. Qualification testing showed that the laminator consistently achieved defect-free lamination within ASTM standards. This tool allowed the project team to demonstrate repeatable encapsulation processes, a prerequisite for scaling LRIP modules into fully packaged IGUs.

Glaub Automation & Engineering (Glaub), while not a supplier during the LRIP phase, was evaluated as a future equipment vendor. The company's automation capabilities for bus bar and edge seal application were benchmarked against LRIP tools and provided confidence that cycle times and yields could be further improved as production scales. Although Glaub's equipment was not purchased during this project, vetting its solutions helped de-risk future full-rate production planning.

In addition to major equipment vendors, the project engaged multiple specialists in glass conveyance, interlayer cutting, and defect detection. These contributions, though smaller in size, were critical to refining process flow and ensuring that LRIP modules met defined project performance metrics.

Beyond commercial partners, guidance and oversight were provided by the CEC through its agreement managers and technical advisory committee (TAC). The TAC included subject matter experts in photovoltaics, glazing, and building integration, and reviewed plans and offered critical feedback at each stage of tool specification, facade design, and validation testing. The TAC's role ensured that the project remained aligned with both technical feasibility and market relevance. The committee's feedback was integrated into deliverables, including the Assembly Validation Report and the Full-Rate Production Strategy.

Finally, specialized consultants supported regulatory and certification planning. Engagements with safety testing organizations such as Underwriters Laboratories (UL) and Intertek were coordinated through external advisors, enabling the project to anticipate requirements under ASTM, the International Electrotechnical Commission (IEC), and UL standards while avoiding costly redesigns. These inputs were embedded into assembly validation and facade testing.

Taken together, the contributions of Viracon, Walters & Wolf, Benteler, Bent River, Glaub, the TAC, and specialized consultants ensured that the LRIP line was not only technically validated but commercially feasible. Each partner's involvement demonstrated that window-PV assemblies can be fabricated, packaged, and installed using standard commercial processes — an essential milestone for future scaling.

Approach Summary

The project's overall approach was structured as a sequence of tasks designed to move from tool procurement and installation through module assembly, validation, and ultimate integration into a representative facade system. Each step was defined in the scope of work and executed using methods that mirrored commercial glass fabrication practices while addressing the unique requirements of photovoltaic packaging. This approach can be summarized in four phases: tool installation and qualification, assembly validation, facade build and testing, and development of a full-rate production strategy.

This research project advanced through a series of milestones that demonstrated steady progress from planning to demonstration. First, the team completed the installation and qualification of critical LRIP assembly tools, establishing a reliable process foundation. Next, pilot-sized and larger modules were fabricated and validated to meet industry standards for aesthetics and performance. Building on this success, the modules were integrated into IGUs and installed into a demonstration facade with commercial partners, confirming compatibility with supply chain practices. The final milestone was the development of a full-rate production strategy, which translated lessons learned at LRIP scale into a clear roadmap for commercial manufacturing. Together, these milestones provided proof that LRIP methods can produce high-quality products while establishing a path to broader commercial deployment.

CHAPTER 3: Results

This chapter presents the technical results achieved across all project tasks. Overall, the project met or exceeded its key performance targets. LRIP assembly tools produced window-PV modules with yields at or exceeding the original laboratory benchtop processing across all assembly steps; color uniformity was within ASTM C1376 standards (DeltaE2000 less than 2.0), and glass-washing cycle times exceeded seven modules per hour. These results held for both pilot-sized (27″ x 35″) and large-area (40″ x 60″) modules, with the 40″ x 60″ modules more than 2.5 times the originally planned module area. This demonstrated the true scalability of the manufacturing approach. A representative six-unit commercial facade was successfully installed at NEXT's Santa Barbara headquarters, confirming compatibility with commercial glazing supply chain partners and architectural systems. The most significant technical challenge encountered was safe handling and conveyance of large-format glass through the process, which required specialized equipment and workflow adaptations. No major technical barriers prevented the achievement of project goals, and both market and supply chain partners confirmed the readiness of the technology for broader commercial deployment.

Task 2: LRIP Tool Specifications and Ordering

The goals of this task were to: (1) document all of the LRIP tool requirements and specifications for tool design partners, (2) specify and order the assembly tools for the fabrication and qualification of window-PV modules capable of handling commercially fabricated window glass for PV use, (3) ensure that proper consumables for assembly were identified, and (4) develop a plan for the proper installation and success of LRIP assembly equipment.

The Window-PV Test Plan established qualification criteria by combining architectural glass (ASTM C1048, ASTM C1172) and PV (IEC 61215-2) standards into a hybrid regime. Requirements included haze limits, adhesion, solder joint height, edge pinch, conductivity, and wet leakage resistance, thus ensuring LRIP tools met both PV and glass industry needs.

The Material Selection and Supply Chain Summary identified and secured critical consumables: transparent conductive oxide-coated glass, float glass, busbars, edge sealants, and interlayers. Specifications were finalized with primary and secondary suppliers to ensure compatibility, cost control, and redundancy.

The Tool Specification Summary translated test requirements into LRIP tool designs including a glass washer, a busbar application plan and tools for tape placement, an edge seal applicator, a lamination tool, inspection tools, and conveyance systems.

The Tool Order Summary Report documented procurement and costs. Major acquisitions included a Benteler glass washer and Bent River laminator, both long-lead, critical tools. Automated busbar and edge seal applicators were deemed unnecessary since optimized manual and semi-automated solutions achieved quality and throughput goals. Conveyance and defect detection tools were procured under budget. Overall, the team met performance targets while reducing costs, which validated selective automation.

The Manufacturing Line Layout and Integration Plan Summary Report combined tool and consumable specifications into an operational flow. The layout emphasized modularity, safe handling of large glass, and efficient transitions between process steps. Iterative design refined throughput and space utilization, creating both an LRIP line and a scalable blueprint for future expansion.

Lessons learned include the importance of early supplier engagement to manage lead times; selective automation paired with optimized manual processes offered better flexibility and cost-effectiveness than full automation. Careful layout and conveyance planning were essential for efficiency and scalability. Butyl extrusion equipment was not pursued since semi-automated or manual tape application proved effective and were validated in testing.

Task 2 delivered a full roadmap for LRIP tool specification, procurement, and integration. The test plan defined qualification standards, the Supply Chain Summary secured inputs, the Tool Specification Summary guided requirements, and the Tool Order Summary Report validated procurement, and the line layout report finalized process flow. Together, these de-risked LRIP assemblies ensured compliance with dual industry standards and positioned NEXT for scale-up.

Task 3: Build and Install LRIP Assembly Tools

The goal of this task was to build and install the fabrication tools specified in Task 2 to enable the fabrication and qualification of the window-PV units.

The Final Tool Installation & Qualification Plan Summary established the roadmap for tool buildout. The plan identified which equipment would be purchased from external vendors (for example, washer and laminator) and which would be assembled or adapted in-house (for example, bus bar and edge seal applicators). For each tool, the plan outlined installation requirements, qualification methods, risks, and mitigation measures. This structured approach ensured that long-lead tools were procured early, that custom-built equipment was pre-qualified before integration into clean-room environments, and that inspection and conveyance systems were validated against ASTM and project-specific performance standards. With this plan in place, the project team was positioned to execute both the successful LRIP tool installation and qualification.

The Final Tool Installation & Qualification Test Report Summary documented the actual installations, qualification testing, and results for each major tool.

The glass washer was installed with full manufacturer support and qualified through steam testing, film adhesion comparisons, and lamination trials. All tests passed, with no defects observed in pilot-sized laminated modules. The washer achieved ASTM C1172-09 standards and delivered high target performance, confirming it would not be a bottleneck for LRIP throughput (Figure 1).

Figure 1: Newly Installed Glass Washer

Photo Credit: NEXT Energy Technologies, Inc.

The bus bar applicator was assembled in-house and qualified through thermal cycle testing, resistivity checks, positional accuracy testing, and visual inspections. Semi-automated or manual application proved sufficient for LRIP, while external vendor trials validated that fully automated methods could achieve production speeds. Current cycle times (less than 8 minutes/module) demonstrated compatibility with LRIP goals and future scalability (Figure 2 and Figure 3).

Figure 2: Bus Bar Applicator Trials

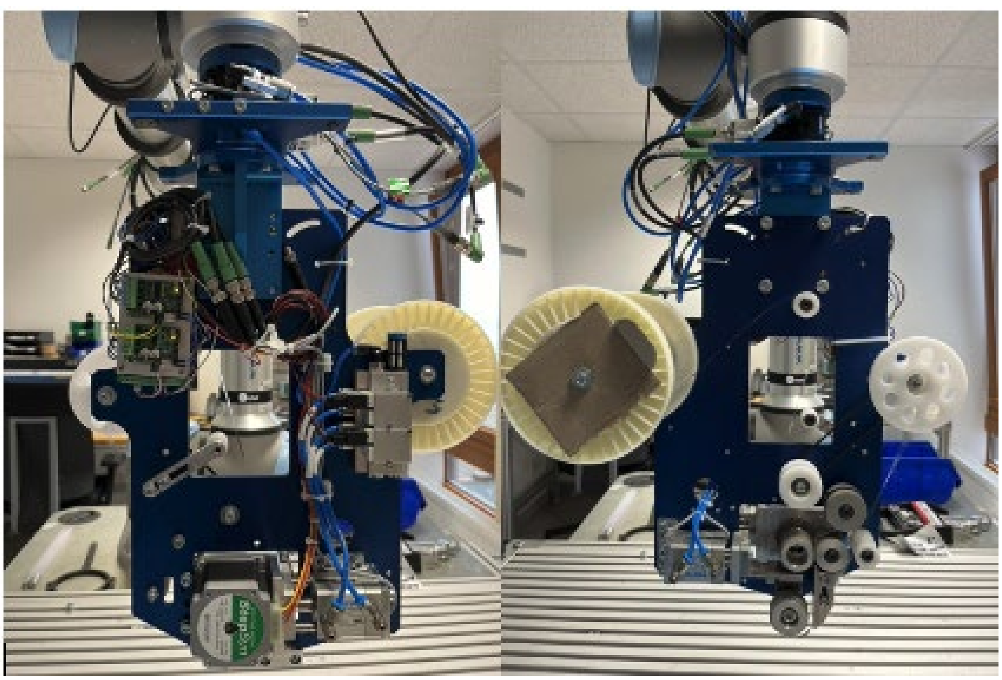


Photo Credit: NEXT Energy Technologies, Inc.

Figure 3: Bus Bar Cut Quality

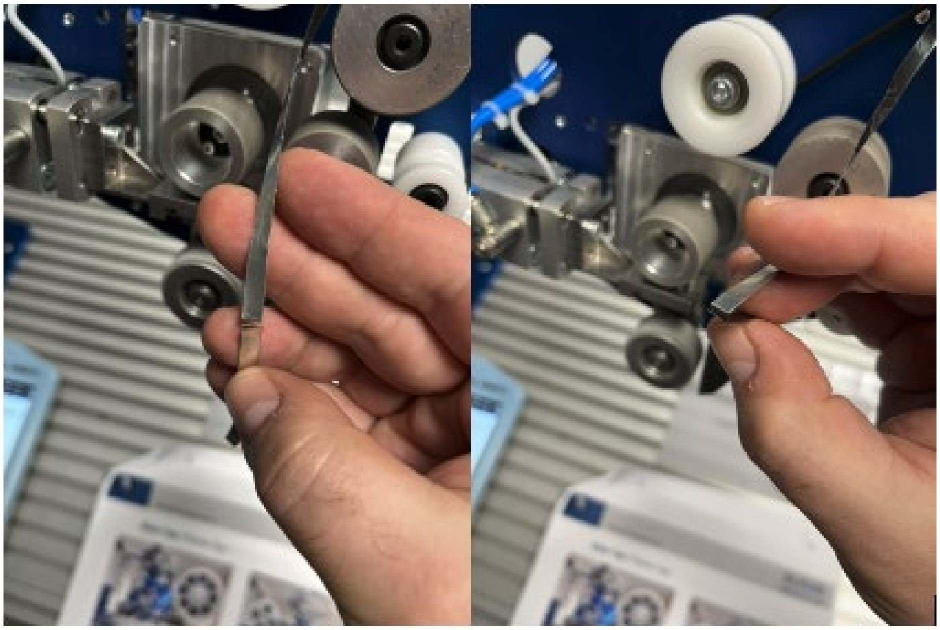


Photo Credit: NEXT Energy Technologies, Inc.

Like the bus bar process, semi-automated and manual edge seal applications were validated for LRIP use. External trials confirmed that robotic automation was feasible, but in-house methods provided the best balance of cost and flexibility at this stage. Application times were maintained at less than eight minutes per module, consistent with LRIP cycle targets (Figure 4 and Figure 5).

Figure 4: Edge Seal Applicator Trials

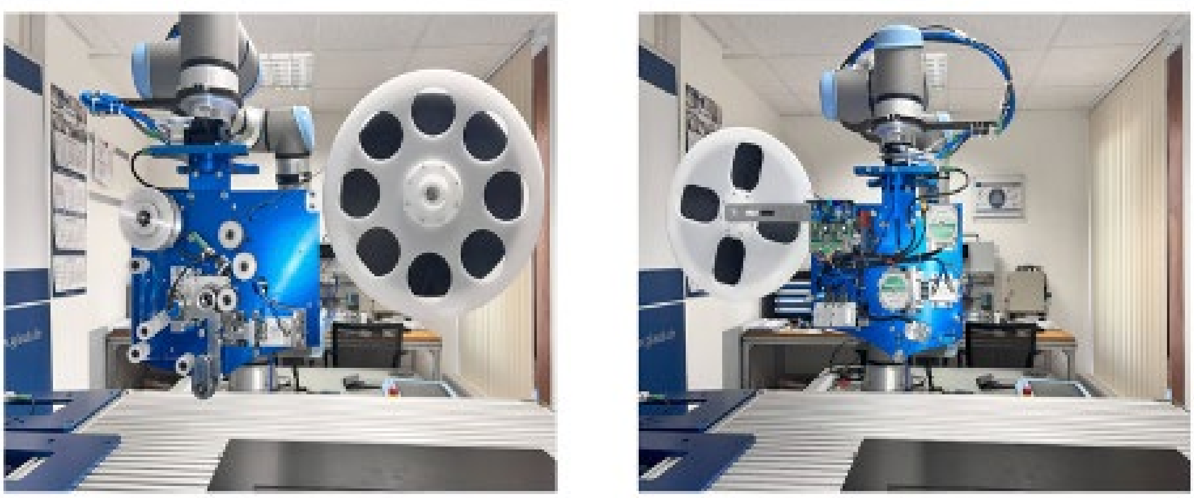


Photo Credit: NEXT Energy Technologies, Inc.

Figure 5: Edge Seal Cut Quality

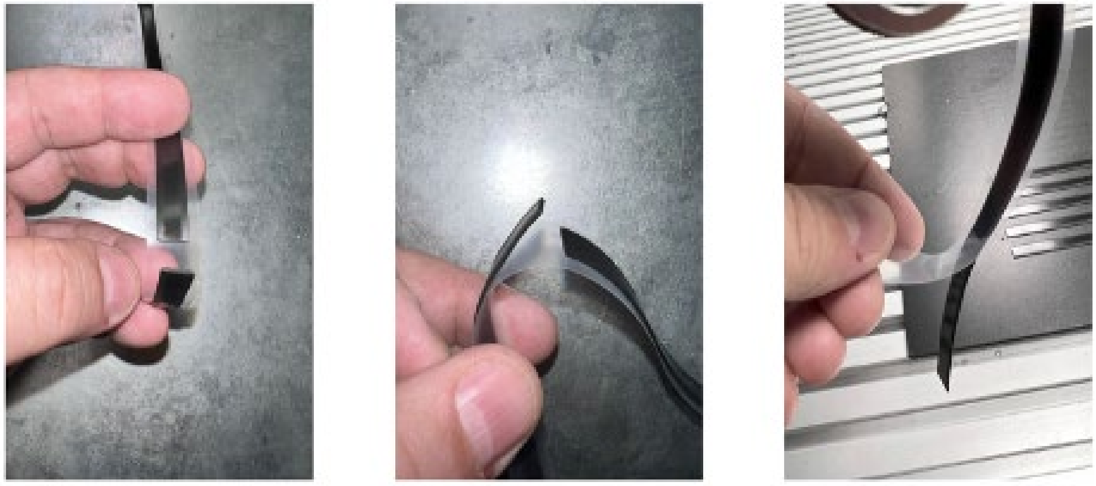


Photo Credit: NEXT Energy Technologies, Inc.

The laminator was purchased and installed with manufacturer oversight from Bent River. Qualification included environmental control testing (temperature, humidity, moisture) and defect inspections. Results confirmed defect-free assemblies, meeting ASTM C1172-09 and demonstrating bubble-free, uniform laminations. This tool was identified as one of the most critical to LRIP performance (Figure 6).

Figure 6: Top – Installed Laminator Before Use; Bottom Shows Laminator with Glass Placed and the Laminated Unit

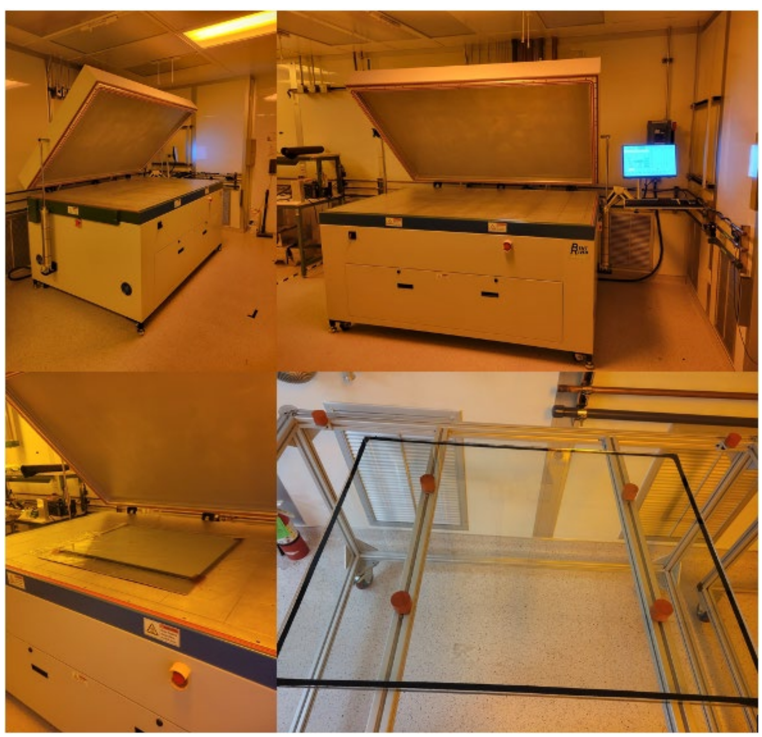
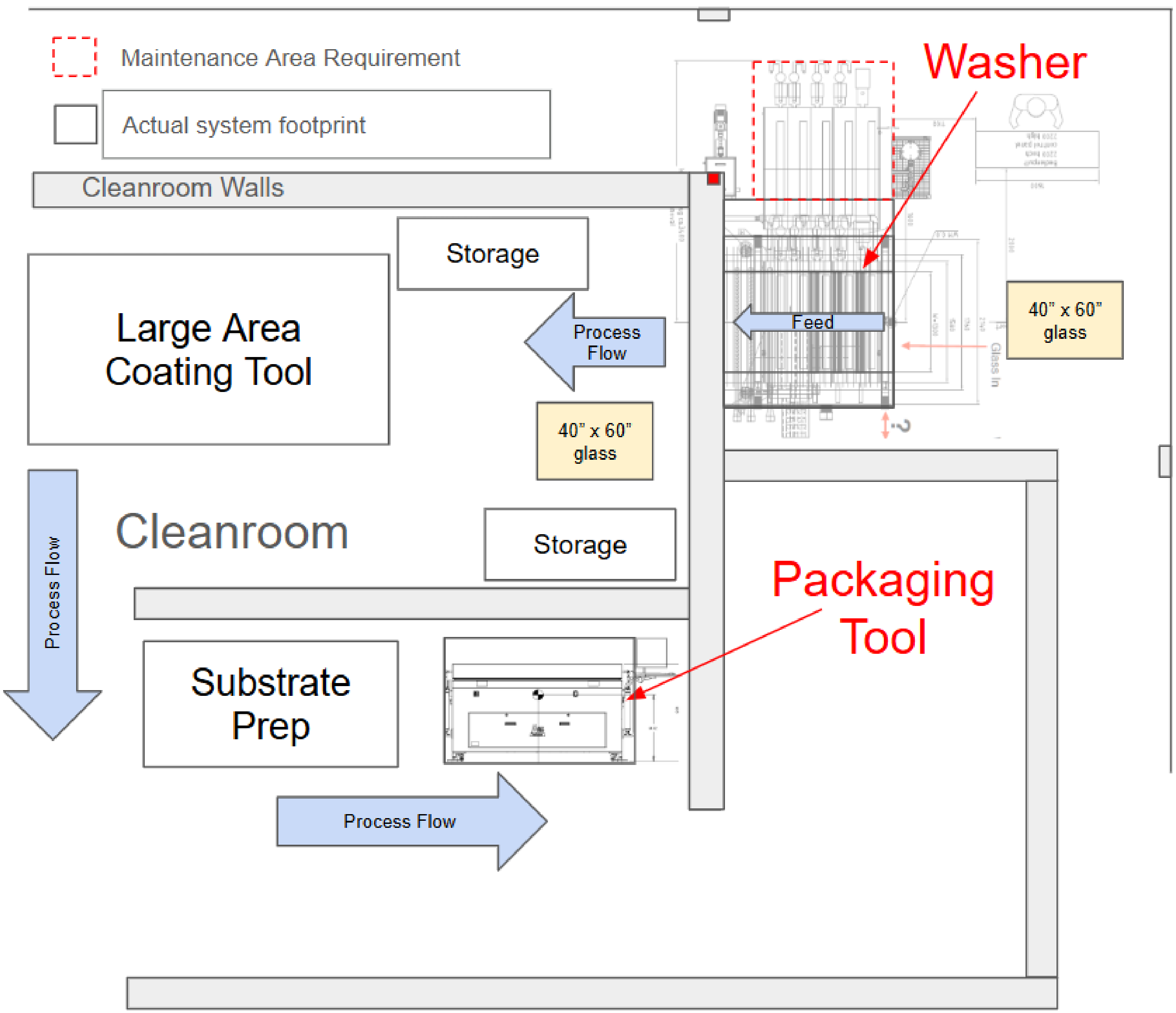


Photo Credit: NEXT Energy Technologies, Inc.

Inspection systems, including upgraded spectrophotometers and the Spire Spi-Sun 3500SLP flash solar simulator, were expanded to accommodate LRIP module sizes. Light measurement instruments were added to enclosures. All tools passed qualification and now provide reliable measurement of color uniformity and electrical output.

Conveyance systems were installed and validated for safety, ergonomics, and process flow. Operator handling of large-area glass was supported by roller tables and fixtures, and the LRIP floor layout was optimized to minimize risk and maximize throughput (Figure 7).

Figure 7: Schematic Diagram Detailing Locations of Installed RAMP Equipment



Source: NEXT Energy Technologies, Inc.

The installations were successful and demonstrated that long-lead tools such as the washer and laminator drive project timelines and must be prioritized early. Meanwhile**,** selective automation proved advantageous: semi-automated or manual methods for bus bar and edge seal applications achieved LRIP requirements while leaving a clear pathway to full automation in the future. Another lesson was the value of continuous improvement in glass handling, where relatively small investments in conveyors and optimized placement significantly boosted safety and process efficiency.

Task 3 confirmed that the LRIP toolset was fully installed and qualified, with all systems performing as expected. The washer and laminator were validated as critical-path equipment, while the bus bar and edge seal processes confirmed that cost-effective, flexible methods could meet LRIP goals without compromising future scalability. Inspection and conveyance systems further strengthened reliability and operator safety. With these installations completed, the LRIP line was now fully capable of supporting assembly, validation, and integration activities in subsequent project tasks.

Task 4: Assemble Window-PV Units

The goals of this task were to use the tools from Task 3 to assemble modules with high aesthetic quality and performance suitable for window-PV applications, develop a high-level plan to build modules of increasing size and throughput while maintaining performance metrics, and summarize the results for assembly validation.

In the Assembly Validation Plan, the project team developed a plan to show that the results will be judged based on the performance metrics of a completed window-PV module. All results will be shared based on a sample size of more than four units to provide sufficient reproducibility at this stage of the process. Most samples were originally planned to be sized at 27″ x 35″; however, due to the rapid progress achieved, some results were detailed using a more ambitious and commercially relevant sample size of 40″ x 60″.

The Assembly Validation Report presented the results of the assembly steps conducted under this plan. Across multiple runs, modules of pilot and LRIP scale were assembled and tested, demonstrating the following outcomes:

1. Demonstration of high-quality window-PV modules, using inspection tools to be compliant with accepted industry performance standards and metrics.
    a. This metric is critical because attaining a high-quality vision area is critical to the functioning of the window-PV module, both as a PV unit and, even more importantly in this instance, as a high-performance window. The LRIP process must not add any defects above current baselines to demonstrate the successful progression of the manufacturing readiness level (MRL) of the product.

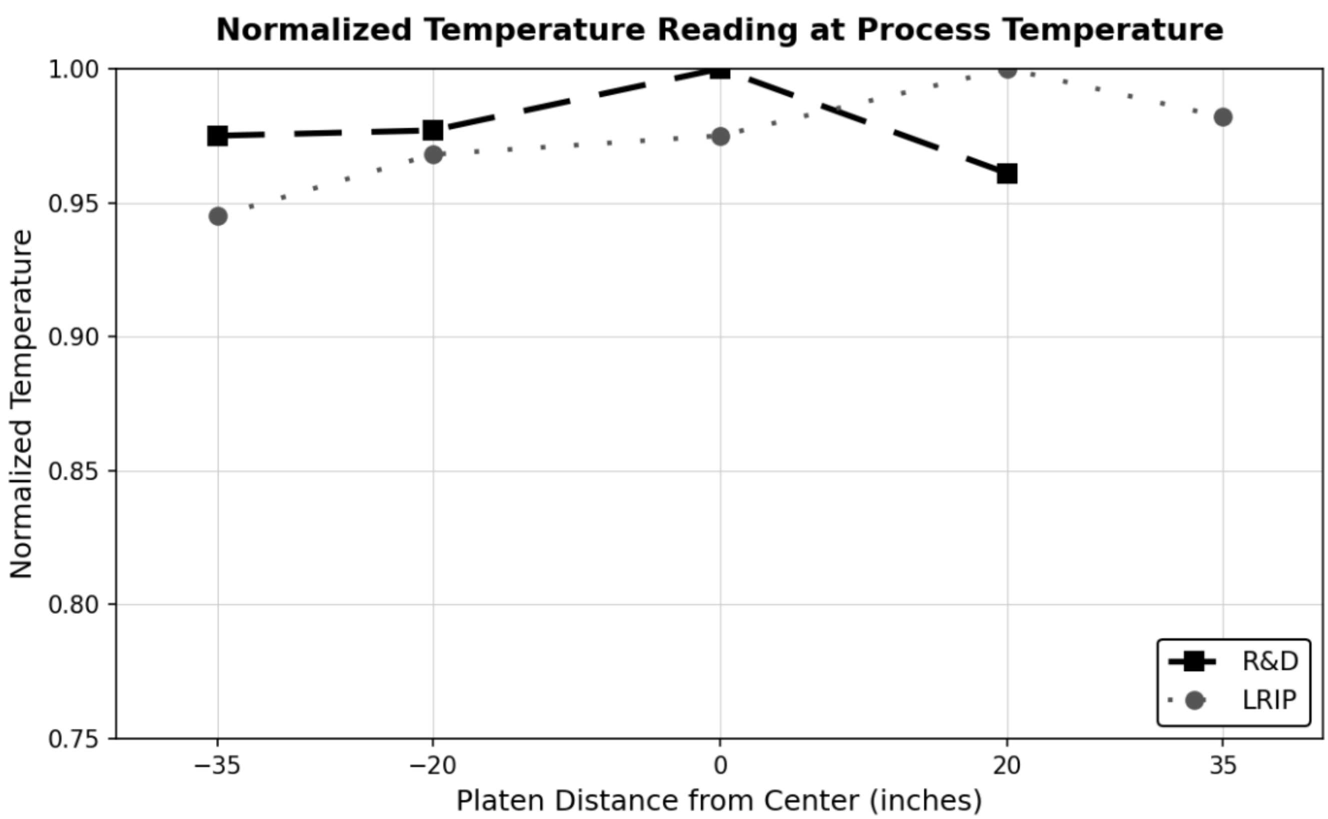
    Modules were inspected for uniformity and defects by digital photography. The module was mounted 8 feet from a white background and photographed from a distance of 16 feet at the module midpoint. The white background was sufficiently bright to essentially eliminate the front reflection.

    b. Project Performance Metric Addressed: Demonstrated that assembled pilot-sized (27″ x 35″) window-PV modules using LRIP methods were within ASTM C1172-09. ASTM C1172-09 sets the standards for the visual quality and aesthetic properties of laminated architectural glass, focusing on color uniformity and surface appearance while minimizing defects like distortion, blemishes, and interlayer haze. ASTM

C1172-09 also ensures that glass meets design and transparency expectations for building applications.

c. Performance Metric Achieved: High Metric: The window-PV modules assembled by LRIP methods were consistent with ASTM C1172-09, with greater yield than pilot-sized window-PV modules. Assembly fabrication methods including washing, edge seal, busbar installation, cover glass merging, and lamination did not cause defects unseen in other research and development (R&D) methods. The new tools were also all specified to perform to equal (or better) levels of consistency for manufacturability. As an example, the uniformity of the laminator is equal to or better than R&D methods (Figure 8).

Figure 8: Temperature Uniformity of Lamination Platen Comparing R&D Methods to LRIP Methods



Source: NEXT Energy Technologies, Inc.

Notably, this metric was also achieved with the 40” x 60” modules, which were more than 2.5 times the area of the modules originally planned for the pilot production. This achievement of a high-quality vision area, despite increased risk of defects and challenges that would otherwise be hypothesized to accompany the fabrication of relatively larger modules, highlights the true scalability of this technology.

2. Demonstration of high-quality window-PV modules measuring color uniformity within window industry standards using a spectrophotometer and accepted industry measurement techniques.

    a. High quality window-PV modules were fabricated based on previously reported methods. The coating and patterning methods that were developed in the CEC EPC-20-014 project continue to show low DeltaE values with the larger size modules, confirming high levels of uniformity.

    b. Project Performance Metric Addressed: Repeatability and uniformity of LRIP-sized (27″ x 35″) window-PV modules using LRIP methods.

    c. Performance Metric Achieved: High Metric: DeltaE2000 < 2.0. As anticipated after the successes reported in the EPC-20-014 deliverables, low DeltaE2000 were also readily achieved in the LRIP assembly. The LRIP assembly methods were designed with material, process, and equipment choices made to specifically not affect the color uniformity of the window-PV modules (for example, avoiding risks such as haze, yellowing, and nonuniformities in the interlayer material, which the team previously mitigated). A high-quality image of a 40″ x 60″ window-PV unit appears in Figure 9.

Figure 9: Single 40″ x 60″ Window-PV Unit with High Aesthetic Quality

Photo Credit: NEXT Energy Technologies, Inc.

3. Comparison of aesthetic quality of units of increasing substrate size assembled on LRIP equipment.

    a. The processes within the scope of this project (glass washing, edge seal, busbar, cover glass merging and lamination) were not shown to impact the aesthetics negatively in any way, as predicted in the Tool Installation & Qualification Test Report Summary. Risks included: particle generation from the glass washer that would be visible by coated layers; bubbles from lamination; and inaccuracies in edge seal, busbar, or cover glass placements.

None of these risks were revealed in the large area modules, so the project team did not see any defects or changes in uniformity associated with the foregoing processes during application to the larger area modules. As seen in Figure 10, the team used 40″ x 60″ modules as the test case rather than the 27″ x 35″ modules, showcasing more than 2.5 times greater surface area than previously planned.

Figure 10: Two 40″ x 60″ Window-PV Modules for Display

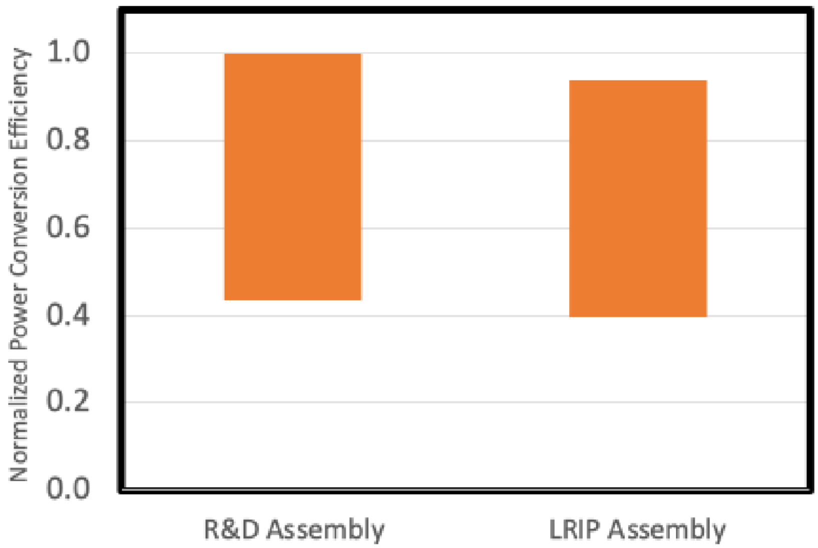
Photo Credit: NEXT Energy Technologies, Inc.

4. Comparison of results to window-PVs assembled on benchtop equipment and demonstration of power conversion efficiency within 10 percent of larger LRIP-sized modules assembled on LRIP equipment, with all other conditions held as similarly as possible.
    a. Window-PV modules were fabricated on both R&D and LRIP assembly tools of different sizes. Within the ranges of module sizes from as small as 3.5″ x 3.5″ up to exceedingly large sizes of 40″ x 60″, similar assembly performances were achieved with normalized power conversion efficiency when determined to be overlapping (Figure 11). This modification of the project performance metric, which compared the usability of the different sets of tools as well as accounting for module size increases, is valuable and showcases that risks to initiating larger, more full-production style methods are relatively negligible.
    b. It is also important to note that the fabrications before assembly were kept as similar as possible, rather than described as "equal." This is because there may be

fabrication variations including, but not limited to, coating tool selection, environmental conditions, statistical variability, and different sample quantities.

Since modules cannot be tested prior to assembly, these slight variations (which were de-risked in EPC-20-014) prohibit statistically deconvoluting the results. This said, there were no signals that LRIP and R&D methods differed in any critical way.

Figure 11: Similar Power Conversion Efficiencies Ranges Achieved with Both Pilot-Scale and LRIP-Assembly Techniques



Source: NEXT Energy Technologies, Inc.

c. Project Performance Metric Addressed: Power output performance of LRIP-sized (27″ x 35″) window-PV modules assembled LRIP methods were compared with pilot sized window-PV modules assembled LRIP methods.

d. Performance Metric Achieved: Exceeded Low Target: The LRIP-sized (27″ x 35″) window-PV modules were within 10 percent of the power output performance of the (27″ x 35″) pilot-sized window-PV modules assembled by LRIP methods. Rather than using only 27″ x 35″ units, however, the team compared both smaller and larger units, from as small as 3.5″ x 3.5″ up to exceedingly large sizes of 40″ x 60″. Similar assembly performances were achieved with similar power conversion efficiency, within expected specifications. The project team determined that this more challenging achievement of the performance metric with the larger sized modules served as an even better predictor that the original performance metrics can be achieved regardless of substrate size or the use of the originally specified assembly tools, as rapid scale-up of the technology continues.

The fabrication processes just described focused on producing high-quality window-PV modules that met both photovoltaic and high-performance window standards. Inspection tools validated compliance with industry performance metrics, ensuring no defects were introduced during the LRIP processes tested. A key objective that accompanied this validation was aligning the assembled pilot-sized modules (27” x 35”) with ASTM C1172-09 standards, to emphasize both quality and reproducibility.

Project performance metrics were achieved when LRIP-assembled modules consistently met or exceeded ASTM C1172-09 standards, with an even higher yield than expected. Results were compared against anticipated benchmarks, which evaluated the uniformity, aesthetics, and performance of the modules across samples. These results were as expected. Lessons learned from the validation tests included ensuring proper equipment setup at the outset to allow for adequate testing of both aesthetics and tool functionality. Defects were generally so small that they were not visible at current test lengths as little as 6 feet away, so it was critical to set up much more stringent test methods using internal setups to properly analyze the limited defects in these LRIP processes.

Future work will explore strategies to maintain or enhance these attributes at small production scales, with implications for scaling up to larger production runs. This quality assurance standard will ensure that the modules produced in the future will meet high standards of reliability and appearance, both critical for further advancement of the product technology in the commercial market.

Task 5: Test Assembled Window-PV Units

The goal of this task was to test the assembly process against established performance metrics. This task focused on performance metrics such as aesthetic quality, yield, and cycle times. The project team took a baseline of these metrics (using LRIP tools) and improved the process to achieve the relevant goals validated by both window industry partners and customer specifications.

By comparing benchtop methods to LRIP tools, the project team identified process improvements, demonstrated scalability, and created a robust baseline to guide full production. The findings are documented in the Commercially Scalable Baseline Assembly Report.

The Commercially Scaled Baseline Assembly Report documents the significant advancements and process improvements achieved by NEXT in the assembly of commercially scaled window-PV modules. Building upon the foundational results outlined in the Commercially Scalable Baseline Assembly Report, this work specifically targeted enhancements in aesthetic quality, yield, and cycle times, which validated these improvements through rigorous testing and evaluation that aligned with established industry standards.

- Project performance metrics achieved at baseline testing of new tools and processes included the following.
  Project Performance Metric: Yield for each LRIP assembly step
    - Determined individual step yield based on ASTM C1172-09 and ASTM C1376.
    - Result: All LRIP steps were optimized to achieve 100-percent yield on NEXT internal facade project.
        - Metric Achieved: Overall high target performance

- Project Performance Metric: Yield for combined LRIP assembly steps
    - Determined compounded yield based on ASTM C1172-09 and ASTM C1376.
    - Result: All LRIP steps were optimized to achieve 100-percent yield on NEXT internal façade project.
        - Metric Achieved: Overall high target performance
- Project Performance Metric: Cycle time for each LRIP assembly step
    - Measured process time for each step to ensure a successful product.
    - Results: Glass Washer: High target (bus bar application), low target (edge seal application), high target (lamination), out of scope (per scope of work)
        - Metric Achieved: Overall low target performance due to bus bar application
- Project Performance Metric: Repeatability and uniformity of LRIP-sized (27” x 35”) window-PV modules, using LRIP methods
    - Color Uniformity (B, between units and W, within unit panel) Transmission DeltaE2000 < 4.5 as per ASTM C1376 for 10 units
    - Results: Samples measured within a sample were measured at four locations and compared with average color using CIE L*a*b* space as per guidelines from Viracon. Using all of the LRIP assembly tools it was seen that both within and between units all DeltaE2000 values were below 2.0, achieving the high target performance metric. CIE L*a*b* is a color space that quantifies color based on human vision, with **L*** representing lightness, **a*** the red-green axis, and **b*** the yellow-blue axis. In commercial windows, it provides a standardized way to measure and compare glass color and tint, ensuring visual consistency and aesthetic alignment across architectural elements.

Process Improvements and Current Performance

Glass Washing

The glass washing process was previously constrained by undersized equipment requiring manual pre-washing of larger substrates, which limited throughput. To address this, the team installed a new washer capable of processing substrates up to 40” x 60” without manual steps. The upgraded tool consistently achieved the industry cycle rate of more than seven modules per hour, with 100-percent yield and no defects, validating the washing step as fully scalable.

Bus Bar Application

Initially, bus bar application achieved about four units per hour using semi-automated manual methods, producing quality results but missing cycle targets. The team refined semi-automated fixtures with vendors and transitioned from a thermal-cured to a pressure-sensitive adhesive, improving positional accuracy and throughput. This achieved the target of seven modules per hour while maintaining 100-percent yield with one operator per bus bar.

Edge Seal Application

Edge seal application started at more than seven units per hour but was refined for consistency and scalability. Fixture and standard operating procedure adjustments maintained the high cycle rate and 100-percent yield, reaffirming readiness for scaling.

Interlayer Cutting and Lay-up

Manual processes limited initial throughput and module size (27” x 35”). Scalable tooling enabled handling of 40” x 60” units, reaching 7 modules per hour with consistent 100-percent yields.

Cover Glass Merging

Manual alignment of cover glass was a major bottleneck. Precision semi-automated fixtures streamlined the process, meeting the 7-per-hour cycle rate and ensuring repeatable, precise alignment with 100-percent yield.

Final Packaging (Lamination)

Packaging was previously constrained to 27” x 35” modules at about 0.5 units per hour. Advanced lamination equipment, designed for 40” x 60” units with environmental control, improved throughput to about 1 unit per hour. Parallelization will be required to reach 7-per-hour, though yields and aesthetics already met RAMP project goals.

Wet Leakage Test

Passing the International Electrotechnical Commission (IEC) 61730 wet leakage test was a critical milestone. Six LRIP-sized 40” x 60” modules exceeded the insulation resistance requirement ($\geq$ 40 MΩ/m² at 500V), confirming safety, robustness, and market readiness. Results are shown in Table 1.

Table 1: Passing Results of 6 Units Tested with Wet Leakage Setup

Unit	Wet Leakage Value	Result
Tested Unit 1	$\geq$ 40 MΩ/m² at 500V	PASS
Tested Unit 2	$\geq$ 40 MΩ/m² at 500V	PASS
Tested Unit 3	$\geq$ 40 MΩ/m² at 500V	PASS
Tested Unit 4	$\geq$ 40 MΩ/m² at 500V	PASS
Tested Unit 5	$\geq$ 40 MΩ/m² at 500V	PASS
Tested Unit 6	$\geq$ 40 MΩ/m² at 500V	PASS

Source: NEXT Energy Technologies, Inc.

Comparison of Cycle Times and Yield Results

Overall, cycle time and yield results surpassed initial expectations, reflecting that the successful integration of semi-automated processes with manual setups was possible.

Glass Washing consistently exceeded 7 modules per hour.

Bus Bar Application improved significantly, reaching the 7 modules per hour benchmark.

Edge Seal Application maintained exceptional cycle rates and consistency.

Interlayer Cutting and Lay-up, and cover glass merging both advanced notably, achieving industry-standard throughput and 100-percent yield.

Final Packaging markedly improved throughput, though continued future improvements are planned through tool parallelization.

Updated project performance metrics (updated mid-project to reflect the team's decision to test larger 40″ x 60″ modules in place of the originally specified 27″ x 35″ units), better captured commercially relevant cycle times and yield performance.

- **Project Performance Metric: Cycle Time for Each LRIP Assembly Step**
    - Measured process time for each step to ensure a successful product.
    - Results: Glass Washer: High target (bus bar application), high target (edge seal application), high target (lamination), out of scope (per scope of work)
        - **Metric Achieved: High Target Performance**
- **Project Performance Metric: Wet Leakage Current Test**
    - Keithley 237 high voltage source measurement unit applied more than 500 V to module submersed in electrolyte solution.
        - **Result:** Passed on six 27″ x 35″ IGUs

Aesthetic Quality and Yield

Aesthetic evaluation was performed rigorously using digital photography aligned with ASTM C1172-09 and ASTM C1376 standards. The inspection methods previously validated (Assembly Validation Report) showed exceptional aesthetic uniformity with DeltaE2000 values less than 2.0, signifying excellent color consistency. The yield improvements achieved were especially noteworthy since each assembly step consistently reached and maintained a 100-percent yield, demonstrating the repeatability and reliability of the enhanced LRIP assembly processes.

Discussion of Results and Lessons Learned

The iterative improvements described here demonstrate clear progress toward commercial-ready window-PV assembly processes. With larger modules enabled by new LRIP tools, notable gains in aesthetic quality, yield, and cycle times were achieved. As substrate sizes expanded to more than 2.5 times the original area, the team successfully adapted tooling and workflows, ensuring both manufacturability and scalability. A key lesson learned was that larger substrates introduced new handling challenges and longer processing times that required specialized conveyance and lifting equipment since manual handling was no longer either practical or safe.

Another insight was the value of collaborating with external tooling vendors. Their expertise was critical in designing scalable tools and fixtures that performed reliably without requiring immediate investment in fully automated equipment. This incremental approach provided flexibility, allowing parameters to be adapted easily with material or process changes. Internally built prototypes and fixtures further enabled customization, cost control, and rapid iteration. Success was driven by balancing external vendor knowledge with internal flexibility and control.

Conclusions and Next Steps

This Commercially Scaled Assembly Report shows that the implemented process enhancements met and, in some cases exceeded, project goals. Improvements in quality, yield, and cycle times were validated on both pilot and larger LRIP modules. The processes were proven to be scalable and robust, with clear pathways to automation and commercial readiness.

Next steps will address remaining bottlenecks, particularly by parallelizing lamination to reach the target rate of seven modules per hour. Further automation strategies will also be explored, leveraging insights from incremental scaling. These developments confirm the technology's readiness to transition from LRIP to full-rate production. The groundwork laid here validates the viability of enhanced manufacturing processes for large-scale adoption and underscores the importance of vendor collaboration and strategic internal development.

This task also included a critical project review meeting and generated the Critical Project Review Report, which summarized progress.

Task 6: Fabricate Representative Commercial Facade

The goal of this task was to demonstrate successful integration with supply chain partners and building systems by fabricating window-PV units into IGUs at one or more commercial partner sites and installing them into a representative commercial facade.

The Facade Build Plan Summary established the project framework. Working with Walters & Wolf, NEXT finalized a design for six large-area transparent PV IGUs, each measuring 40" x 60", installed within a 12' x 10' east-facing opening at NEXT's Santa Barbara headquarters. The east-facing orientation was chosen for minimal shading risk, and daily power output was projected at between 300 and 600 watt-hours.

Viracon was selected as the fabrication partner for the IGUs and provided a proven commercial manufacturing pathway. Each IGU incorporated NEXT's OPV-coated outboard lite (a low-emissivity inboard lite), and spacer systems were optimized for thermal and structural performance (Figure 12).

Figure 12: IGU Fabrication Process at Viracon with OPV Lite Integration

Photo Credit: NEXT Energy Technologies, Inc.

The Facade Glazing Report confirmed the framing specifications. Walters & Wolf customized a curtain wall frame that could support both the glazing and electrical routing. Electrical connections were accommodated with integrated junction boxes and cable routing channels while preserving weatherproofing and architectural aesthetics.

According to the Final Facade Build Report, the IGUs were fabricated at Viracon using standard workflows, proving that NEXT's OPV technology is compatible with commercial-scale glass processing.

Walters & Wolf fabricated the framing at its facility and developed a system that incorporated standard curtain wall methods while allowing the integration of PV wiring. Installation took place at NEXT's headquarters (Figure 13), where an existing facade was replaced with the new building integrated photovoltaic (BIPV) assembly. The installation process mirrored conventional commercial glazing practices, with the added step of electrical connection and safety verification.

Figure 13: Installation of the BIPV Facade at NEXT Headquarters

Photo Credit: NEXT Energy Technologies, Inc.

The Facade Test Plan outlined the methodology for validating system performance. Modules were characterized both individually and as a complete system using pyranometers, source-measure units, and maximum power point tracking with calibrated photodiodes.

The Facade Test Report documented a number of important module features. All modules achieved power conversion efficiency within expected ranges. A 100-percent yield was achieved for LRIP-assembled modules, which surpassed the target of at least 80 percent. Color uniformity (DeltaE2000 less than 2.0) met ASTM C1376 standards, validating aesthetic performance. The integration of building electrical systems with structural systems was successful. Additionally, energy generation of the full facade aligned with design projections, demonstrating that LRIP-fabricated units could deliver commercial-quality results.

The facade showcased a neutral gray OPV coating that aligned with modern architectural preferences. Both exterior (Figure 14) and interior (Figure 15) views confirmed that transparency and daylighting were preserved. From the street, the facade looks like a conventional commercial glass wall, while inside it provides natural lighting with real-time energy monitoring.

Figure 14: External View of the Completed Facade

Photo Credit: NEXT Energy Technologies, Inc.

Figure 15: Interior View of the Complete Facade Showing Daylighting and Transparency

Photo Credit: NEXT Energy Technologies, Inc.

The project also validated commercial integration at every level through commercial partnerships. Viracon confirmed that IGUs with OPV-coated lites could be produced using standard processes. Walters & Wolf proved that curtain wall systems could integrate the required electrical components without deviation from conventional practices. NEXT's LRIP tools demonstrated scalability and yield consistency, ensuring future commercial deployment.

The permanent installation at NEXT headquarters now serves as a demonstration site for architects, investors, and policymakers, creating a platform for market education, which in turn accelerates adoption.

The facade build showed that NEXT's OPV technology integrates seamlessly into commercial glazing and curtain wall systems while preserving the aesthetics and performance required by architects and owners. Lessons learned include engaging supply chain partners early for smooth integration, incorporating electrical routing without compromising design or weatherproofing, and maintaining process controls alongside material quality to achieve high yields in large formats. By completing the world's first transparent OPV facade installation, NEXT validated the scalability of its LRIP manufacturing methods and created a permanent demonstration site to accelerate commercial adoption. The project bridged lab-scale innovation with real-world construction, confirming commercial viability and paving the way to broader deployment of energy-generating facades.

Task 7: Validate and Update Costs and Market Assumptions

The goal of this task was to use the data and experience gained in previous tasks to examine and update market assumptions and costs. Work completed during the project tasks with key customers and suppliers will be incorporated into appropriate models to ensure up-to-date information.

The work included updating the unit level cost model and extending it to a system level cost model, ultimately capturing engagement activities in the Stakeholder Engagement Summary and producing the comprehensive Ratepayer Benefits Report. Collectively, these reports validate the commercial viability and economic impact of NEXT's BIPV window technology.

Unit Level Cost Model

The updated Unit Level Cost Model assessed the per-square-foot manufacturing costs of NEXT IGUs when compared with baseline commercial IGUs. Building on the foundation established during the BRIDGE award, the RAMP model was refined with expanded data from LRIP tool specifications, supply chain quotations, and yield results from assembly validation work.

The model now reflects:

- An updated bill of materials for NEXT IGUs, incorporating proprietary OPV inks, adhesives, interlayers, busbars, and seals.
- Updated vendor quotations from key suppliers such as Benteler, Bent River, and Glaub for scalable tools and processes.
- Yield improvements validated in Task 4 and Task 5, including updated and improved yields for key LRIP steps (glass washing, lamination, and edge sealing).
- Verified cycle times approaching the commercial benchmark of 7 modules per hour, with scalability proven through semi-automated processes.

The resulting per-square-foot cost breakdown highlights the incremental costs associated with NEXT's OPV integration compared to standard IGUs, providing a reliable framework for pricing strategy and manufacturing scaling.

System Level Cost Model

Building on the unit-level analysis, the System Level Cost Model was updated to project total installed costs for BIPV window systems, including balance-of-system components such as inverters, wiring, labor, and permitting.

The Return to Building Owner Model developed under BRIDGE was expanded to include:

- Payback analysis across three California cities (San Francisco, Sacramento, Santa Barbara) and national markets.
- Sensitivity to electricity pricing, tax credits, and depreciation schedules.
- Incremental facade design integration validated by the Walters & Wolf demonstration project.

Results confirm that NEXT windows achieve a simple payback of 2 years or fewer in California, and fewer than 10 years in all modeled United States cities. This surpasses the project's high target of (at most) a 2-year payback for California installations. Additionally, the updated model projects a levelized cost of energy (LCOE) of less than $0.03/kWh by 2030, meeting program targets.

Stakeholder Engagement

Engagement with partners and customers was essential for validating assumptions. Supply chain collaborations with Viracon, Walters & Wolf, and Benteler demonstrated that NEXT's technology can be seamlessly integrated into established glass fabrication and curtain wall workflows.

NEXT also secured multiple letters of support and engagement commitments from suppliers, fabricators, and commercial developers, achieving the performance target of at least 10 letters of commitment of support. Stakeholder insights directly informed model cost updates, facade system designs, and commercial readiness planning.

Ratepayer Benefits

The Ratepayer Benefits Report expanded the greenhouse gas reduction modeling initiated under BRIDGE. Updated analyses incorporated:

- Improved performance data from LRIP assembly modules and facade testing.
- Broader market adoption scenarios calibrated against historical uptake of low-emissivity windows.
- Energy savings not only from onsite generation but also from reduced heating, ventilation, and air conditioning loads due to improved solar heat-gain coefficients.

The model projects that widespread adoption in the market (modeled on the historical low-emissivity window adoption rates and guidance from industry experts) of NEXT's building integrated photovoltaic windows could reduce up to 0.9 gigatons of CO_2 emissions by 2050, while lowering operating costs for building owners and providing direct benefits to disadvantaged communities, including the Santa Barbara headquarters installation, which is located in a disadvantaged community.

Task 7 validated that NEXT's technology provides a compelling economic case for building owners while delivering meaningful environmental and ratepayer benefits. The updated cost models confirmed manufacturing scalability and cost competitiveness, the system-level models demonstrated paybacks of two years or fewer in California, stakeholder engagement established clear supply chain readiness, and the ratepayer benefits analysis showed substantial greenhouse gas reduction potential. Together, these results indicate that NEXT's energy-generating windows are positioned for broad adoption in the commercial building market and will deliver significant long-term value to California ratepayers.

Task 8: Full-Rate Production Line Strategy

The goal of this task was to outline a high-level plan to advance the technology from LRIP to full-rate production and commercial readiness, with technical readiness and MRL levels higher than 8.

Using internal, commercial, and partner feedback from LRIP assembly tools and window-PV units, NEXT generated a full-rate production line strategy and submitted the Full-Rate Production Line Strategy Report, which, without limitation, included:

- Supply chain agreements.
- Purchase orders.
- Future line integration with commercial window partners to meet the scaling demands of market opportunities.
- Updated pricing including materials costs, labor costs, and processing costs.

This project advanced the manufacturing capability of NEXT's energy-generating window product from lab and pilot-scale tools and processes to a low-rate initial production manufacturing line. The project leveraged the organic photovoltaic coatings that were a focus of the BRIDGE project and assembled coated substrates into packaged photovoltaic modules, IGUs, and ultimately into building facade installations. The specifications and qualifications of the assembly and packaging tools that comprise the low-rate initial production line are key steps to advance manufacturing readiness from lab-built prototypes to LRIP units.

Based on the market readiness calculator supplied by the CEC (California Energy Commission, 2022), the project team assessed various aspects of the product development stages both before and after the project work. The results appear in Appendix B, Table 4.

Utilizing the market readiness calculator, the team more effectively communicated technology, manufacturing, and commercialization readiness levels in market-appropriate terminology. These results appear in Appendix B, Table 5.

Supply Chain Agreements

NEXT has engaged multiple tool manufacturers within the scope of this project that the project team expects to fully engage with for production line development. These manufacturers include but are not limited to Bent River, Benteler, and Glaub. Bent River and Benteler were the equipment manufacturers used in the equipment budget for the LRIP tools in this project. In doing due diligence, it was decided to use them partially due to their high likelihood to successfully scale equipment to full production in size, cycle time, automation, and yield. Glaub was also vetted, and even though the project team did not buy its equipment for LRIP, Glaub was also determined to be a strong contender for full production tools due to its size, cycle time, automation, and yield capabilities.

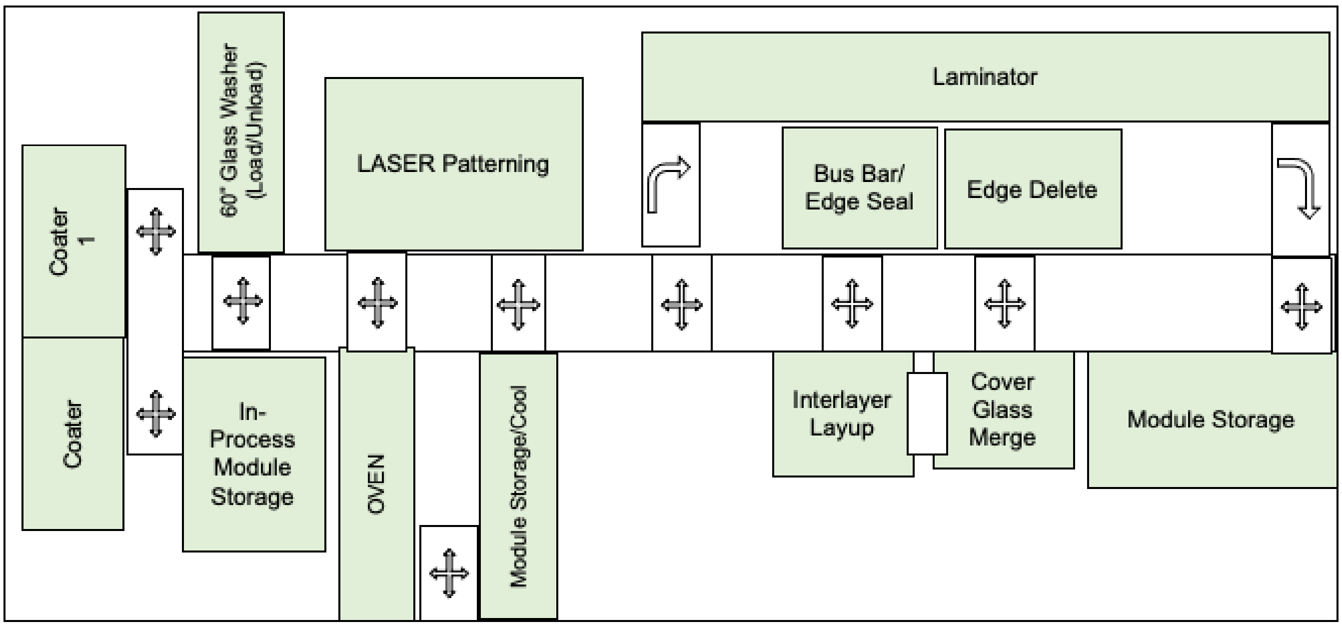
Purchase Orders

Within the duration of this project, NEXT has begun multiple bids for commercial facade projects as a result of the successful demonstration units fabricated by the project team.

Future Line Integration with Commercial Window Partners

In the current RAMP project, an LRIP line was built. This line used all scalable techniques while still being semi-automated with some low-risk assembly methods still performed by hand. Cycle times and yields were all still considered and can be found in the project performance metrics. Utilizing the lessons learned in this project, NEXT significantly reduced the complexity of the first iteration of a full production line. A full production line was defined as a stand-alone line that can be integrated at a partner or external facility, capable of producing 5′ x 10′ (or larger) units at similar throughputs and cycle times. This line diagram is illustrated in Figure 16. Its design was developed with both commercial window partners and supply chain partners to leverage as much experience as possible.

Figure 16: Production Line Schematic Based on Project Findings



Source: NEXT Energy Technologies, Inc.

Updated Pricing of Materials, Labor, and Processing

Pricing, materials costs, labor costs, and processing costs have all been updated and re-forecasted and are described in detail in the Task 7 reports.

In summary, this project's technical accomplishments demonstrated increased technology, manufacturing, and commercialization readiness levels to fulfill project goals. Supply chain agreements, purchase orders, future line integration with commercial window partners (to meet scaling demands of the market opportunity), and updated pricing show that all materials costs, labor costs, and processing costs were successfully completed as expected. This allowed the team to create an efficient production line schematic, with most tools from commercial partners. A key lesson learned is the importance of listening to commercial partner feedback in manufacturability when designing and purchasing new tools.

CHAPTER 4:
Knowledge Transfer

NEXT Energy Technologies, Inc. (NEXT) carried out a multi-faceted knowledge transfer and stakeholder engagement program over the course of the project. This program was designed to broadly disseminate findings, demonstrate commercial viability, and educate industry professionals on the integration of transparent OPV technology into commercial building facades.

Demonstration Installation

The centerpiece of the knowledge transfer effort was the design, fabrication, and installation of the world's first commercial-scale transparent OPV building integrated photovoltaic (BIPV) facade. Completed in August 2025 at NEXT's Santa Barbara headquarters, the installation comprises six windows, each measuring approximately 40” x 60”, which collectively cover close to 100 square feet of energy-generating architectural glass. The facade was fabricated in partnership with Viracon (IGU fabrication) and Walters & Wolf (curtain wall framing system and installation), and serves as a permanent, real-world demonstration site for architects, developers, glazing contractors, utilities, and investors. The installation includes real-time energy generation monitoring displays and educational signage, providing ongoing educational value for all visitors.

Technical Advisory Committee

NEXT organized and engaged a technical advisory committee (TAC) throughout the project to provide expert oversight, industry perspectives, and feedback. The TAC reviewed the Draft Project Case Study Plan in September 2023, and its comments were incorporated into the Final Project Case Study Plan, submitted to the CEC in October 2023. Technical advisory committee participants included professionals from architecture, sustainability, glazing, and solar integration industries. Key TAC feedback was then incorporated into project activities including guidance on electrical infrastructure requirements for BIPV installations, the application of actual electric rate schedules in economic analyses, and expanded dissemination through the National Glass Association. A full list of TAC participants appears in Appendix A of the Final Project Case Study Report.

Industry Conferences and Events

NEXT was selected as a featured speaker at the National Glass Association GlassBuild Conference in Dallas, Texas, in September 2024. This is the largest glass industry trade show where a breakout session focused on next-generation glazing technologies. NEXT also participated in the RE+ Conference, attended by approximately 36,000 participants, and the Advanced Building Skins Conference and Expo in 2025. Presentations at these events showcased the transparent OPV technology, this project’s demonstration installation, and the commercial pathway for facade-integrated solar generation.

Media and Podcast Outreach

A NEXT executive appeared as a guest on the National Glass Association GlassCast podcast (which reached a national audience of glass industry professionals) to discuss NEXT's OPV technology, project achievements, and broader opportunities for the glass industry in the energy transition. NEXT also authored a series of blog posts and social media content documenting project milestones, which resulted in significant growth in both NEXT's following and dozens of media exposures through articles and videos.

Innovate, Manufacture, Partner, Engage, and Launch Accelerator Program

NEXT was selected to participate in Lawrence Berkeley National Laboratory's Innovate, Manufacture, Partner, Engage, and Launch accelerator program, expanding NEXT's reach into national clean energy research, policy, and investment communities and providing additional technical validation and credibility.

Stakeholder Engagement

Over the course of the project, NEXT engaged with 17 customers and commercialization partners, 13 supply chain partners, 4 joint product development partners, 23 end users and influencers, and 7 industry organizations and government agencies. NEXT executives visited Gensler's Los Angeles office to present a freestanding demonstration unit featuring four 27”x 35” transparent OPV windows, introducing NEXT's technology to one of the largest and most influential commercial architecture firms in the world. Letters of interest from top global window fabricators represent combined potential revenue of 190-million dollars, with 10 additional letters of support received for further research and development funding.

Product Integration Demonstrations

NEXT conducted live product integration demonstrations, including six windows integrated into an operable commercial overhead door — demonstrating a self-powered door system — and a NEXT-coated window assembled with commercial integrated blinds powered by the OPV coating. These demonstrations were presented to key stakeholders at industry events and meetings.

Project Write-Up

Project findings and deliverables are accessible through both the CEC's research publications and through NEXT's digital media channels. Project deliverables are available upon request by emailing pubs@energy.ca.gov. More information about this project can also be found at the [Energize Innovation fund website](https://www.energizeinnovation.fund/projects) (at https://www.energizeinnovation.fund/projects).

CHAPTER 5: Conclusion

Within the scope of this *realizing accelerated manufacturing and production* (RAMP) project, the NEXT team achieved a series of critical milestones that advanced transparent window-PV technology — from pilot-scale demonstrations to LRIP. Specifically, the project team was successful in:

- Specifying, building, and installing LRIP assembly tools.
- Validating LRIP assembly processes for yield, cycle time, and aesthetics.
- Fabricating large-area modules with commercially relevant techniques and sizes.
- Completing installation of a representative demonstration facade.
- Developing a full-rate production strategy, informed by LRIP outcomes.

These accomplishments significantly reduced scale-up risks and created a strong foundation for future commercialization. Multiple fabrication module runs were completed on the LRIP line, with successful outcomes. Large-area modules fabricated during the project achieved excellent aesthetics, surpassing stringent industry requirements for color uniformity and defect reduction. The LRIP yield- and cycle-time metrics confirmed that the technology could be scaled to meet full-rate production demands with cycle times reaching values consistent with a target throughput of seven modules per hour in future automation. These outcomes were anticipated and achieved due to the precision of the assembly tools and the suitability of previously developed coating and materials processes.

Lessons Learned

This research project generated valuable lessons regarding process control, tool design, and system integration. The LRIP assembly environment highlighted the importance of precision alignment, robust equipment setup, and consistent material handling to achieve high-quality results. For example, even minor inaccuracies in tape application or interlayer placement could lead to non-uniformities. Addressing these challenges required careful calibration of fixtures, optimization of tool interfaces, and close coordination with equipment suppliers. These insights will directly inform the future design and automation of full-rate production lines, ensuring higher reliability, repeatability, and throughput.

The RAMP project also validated that existing supply chain partners can support LRIP and eventually full-scale production. Commercial engagement with suppliers and integrators such as Walters & Wolf and Viracon confirmed that the assembly methods developed in this project align well with standard glazing practices. This compatibility reduces the need for new infrastructure and eases adoption by fabricators, installers, and building owners.

Demonstration and Validation

A central accomplishment of the project was the successful fabrication and installation of a six-unit demonstration facade at NEXT's Santa Barbara headquarters. This installation provides a real-world testbed for validating performance, aesthetics, and integration with existing building systems. The facade confirms that the modules can be installed with methods similar to conventional IGUs, and that the modules deliver both energy generation and improved thermal performance when compared with standard low-emissivity glass. By demonstrating the technology at commercial scale in a visible, public-facing project, NEXT significantly advanced stakeholder confidence in the readiness of the product for broader commercial deployment.

Market Potential and Industry Engagement

Alongside the technical progress, the project strengthened market validation for NEXT's window-PV technology. Engagement with leading commercial glass and facade companies reinforced that a transparent, energy-generating window product represents an unmet need in the commercial office building segment (NEXT's primary beachhead market), particularly for mid- to high-rise buildings in California cities where facade areas are abundant, rooftop solar is constrained, and energy costs are high. Future market targets include multifamily residential, hospitality, and public institutional buildings. Partners confirmed that NEXT's modules met or exceeded expectations for aesthetics, performance, and cost competitiveness relative to other emerging BIPV products. These endorsements provide powerful external validation of NEXT's technology and underscore its differentiation from competing approaches.

In addition to partner validation, the project updated cost models and greenhouse gas reduction analyses. The updated system-level cost model incorporated materials, labor, and a balance of system costs (including incremental framing and glazing labor), while accounting for the unique ability of NEXT's product to replace conventional windows at marginal cost. The greenhouse gas reduction analysis confirmed that widespread adoption of NEXT's window-PV technology could deliver significant emission reductions, helping California meet its statutory energy goals for zero-emission buildings and a carbon-neutral electricity grid by 2045.

Commercialization Pathway and Next Steps

The RAMP project established a clear pathway from LRIP to full-rate production. The lessons learned from tool installation, process validation, and facade demonstration will provide the roadmap to the design of a fully automated manufacturing line. This next phase will involve further scaling of equipment, increased automation, and continued cost reductions through process optimization.

NEXT will continue to collaborate with its commercial partners to integrate the technology into large-scale projects including office buildings, multifamily housing, and public infrastructure. Ongoing efforts include refining the supply chain, completing additional facade demonstrations, and pursuing independent testing and certification. These activities will ensure that the technology is fully validated for widespread market adoption.

Conclusion

In summary, the RAMP project was a critical milestone in advancing NEXT's window-PV technology, from pilot-scale demonstrations to LRIP-scale production. All project objectives were met or exceeded, including the installation of LRIP assembly tools; achievement of aesthetic, yield, and cycle-time metrics; demonstration of commercial facade integration; and development of a full-rate production strategy. The outcomes of this project de-risked the manufacturing scale-up, validated the market opportunity, and confirmed substantial ratepayer and societal benefits.

By bridging the gap between pilot innovation and commercial deployment, the RAMP project established the foundation for full-rate production and widespread adoption of NEXT's transparent, energy-generating windows. This work positions NEXT and its partners to accelerate commercialization, deliver cost-effective renewable energy solutions, and support California's transition to a clean, resilient, and zero-emission building sector.

Benefits to California Ratepayers

Ratepayer Benefits and Policy Alignment

The results of this project demonstrated both clear benefits to California ratepayers and alignment with the state's energy policy legislation. NEXT's window-PV technology addresses a critical barrier in achieving zero-net-energy commercial buildings: the lack of sufficient rooftop space to deploy conventional solar panels. By enabling the building envelope itself to generate energy, NEXT provides a pathway for building owners to meet onsite generation requirements in an aesthetically seamless and cost-effective manner.

Ratepayer benefits include lower energy costs for building owners, reduced greenhouse gas emissions, and increased grid resilience through distributed generation. The technology also supports economic development in California by fostering advanced manufacturing, leveraging existing supply chains, and creating new clean-energy jobs. Furthermore, by reducing incremental costs relative to traditional PV installations, NEXT's product contributes to achieving the state's target levelized cost of energy of $0.03/kWh by 2030.

List of Terms/Glossary

Term	Definition
ASTM	American Society for Testing and Materials (standards organization)
BIPV	building integrated photovoltaic
BRIDGE	Bringing Rapid Innovation Development to Green Energy
CEC	California Energy Commission
IEC	International Electrotechnical Commission
IGU	insulated glass unit
LCOE	levelized cost of energy
LRIP	low-rate initial production
MRL	manufacturing readiness level
NEXT	Shortened company name for “NEXT Energy Technologies, Inc.”
OPV	organic photovoltaic
PV	photovoltaic
RAMP	realizing accelerated manufacturing and production
R&D	research and development
TAC	technical advisory committee
TRL	technology readiness level
UL	Underwriters Laboratories

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De León, Kevin. 2012. California Senate Bill 535 (De León). Chapter 830, Statutes of 2012. Sacramento, CA: California Legislature. Requires that a portion of proceeds from the state's cap-and-trade program be invested in projects that benefit disadvantaged communities as defined by CalEnviroScreen.

Kaur and Prasher. 2023. "Robust Super Insulation at a Competitive Price" Report. Publication number: CEC-500-2023-028. Available at: https://www.energy.ca.gov/publications/2023/robust-super-insulation-competitive-price

Project Deliverables

Technical Tasks

Task 2: LRIP Tool Specifications and Ordering

- Window-PV Test Plan
- Material Selection and Supply Chain Summary
- Tool Specification Summary
- Tool Order Summary Report
- Manufacturing Line Layout and Integration Plan Summary Report (draft and final)

Task 3: Build and Install LRIP Assembly Tools

- Tool Installation & Qualification Plan Summary (draft and final)
- Tool Installation & Qualification Test Report Summary (draft and final)

Task 4: Assemble Window-PV Units

- Assembly Validation Plan
- Assembly Validation Report

Task 5: Test Assembled Window-PV Units

- Commercially Scalable Baseline Assembly Report
- Commercially Scaled Assembly Report
- Critical Project Review Report

Task 6: Fabricate Representative Commercial Facade

- Facade Build Plan Summary (draft and final)
- Facade Glazing Report Summary
- Facade Test Plan
- Facade Test Report
- Facade Build Report (draft and final)

Task 7: Validate and Update Costs and Market Assumptions

- Unit Level Cost Model Report
- System Level Cost Model Report
- Stakeholder Engagement Summary
- Ratepayer Benefits Report (draft and final)

Task 8: Full-Rate Production Line Strategy

- Full-Rate Production Line Strategy Report

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Project Performance Metrics

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Appendix A: Final Project Performance Metrics

Table A-1: Final Project Performance Metrics

Performance Metric	Benchmark Performance	Current Performance	Low Target Performance	High Target Performance	Evaluation Method	Significance of Metric	Relevant Report	Goal Target Performance
Demonstration that assembled pilot-sized (From 27” x 35” up to 40" x 60"-sized units) window-PV modules using LRIP methods are within ASTM C1172-09	High-quality window-PV modules fabricated on pilot-sized glass with defects consistent with ASTM C1172-09 for ten units	N/A	Window-PV modules assembled by LRIP methods are consistent with ASTM C1172-09 with equal yield as pilot-sized window-PV modules.	Window-PV modules assembled by LRIP methods are consistent with ASTM C1172-09 with greater yield as pilot-sized window-PV modules.	As per ASTM C1172-09, all visual inspection shall be made with 20/20 vision. The viewer shall look at the sam-ple at an angle of 900 (perpendicu-lar) to the surface using the follow-ing lighting unless specified other-wise: daylight or other uniform diffused back-ground lighting.	High quality vision area of the window-PV module is critical to functioning both as a PV unit but here, more importantly, as a high-performance window. LRIP production pro-cess should not add any defects above current baseline to demonstrate successful pro-gression of MRL.	**Complete High Target Performance** Tool Installation & Qualification Test Report Summary AND Assembly Validation Report	**Actual Performance Value:** The window-PV modules assembled by LRIP methods were consistent with ASTM C1172-09, with greater yield than pilot-sized window-PV modules
Repeatability and uniformity of LRIP-sized (from 27” x 35” 27” x 35” up to 40" x 60"-sized units) window-PV modules using LRIP methods	Color Uniformity (B, between units and W, within unit panel) Transmission DeltaE2000 < 4.5 as per ASTM C1376 for [10] units.	N/A	DeltaE2000 < 4.5	DeltaE2000 < 2.0	Samples measured within a sample will be measured at 4 locations and compared to the average color using CIE L*a*b* space as per guidelines from Viracon.	Aesthetic uniformity is criti-cal to achieving a successful win-dow integrated product as well as an excellent indicator of good module perform-ance and reproducibility. ASTM C1376 is the uniformity standard for window products.	**Complete High Target Performance** Commercially Scalable Baseline Assembly Report	**Actual Performance Value:** Color Uniformity (B, between units and W, within unit panel) Transmission DeltaE2000 < 4.5 as per ASTM C1376 for 10 units using CIE L*a*b* space as per guidelines from Viracon, using 27x35” equivalent sizing on 40x60” Façade modules

Performance Metric	Benchmark Performance	Current Performance	Low Target Performance	High Target Performance	Evaluation Method	Significance of Metric	Relevant Report	Goal Target Performance
Power output performance of LRIP-sized (from 27" x 35" up to 40" x 60"-sized units) window-PV modules assembled LRIP methods compared to pilot-sized window-PV modules assembled LRIP methods	N/A	Modules of 3.5" x 3.5" and 14" x 20" within 10% power output performance when fabricated by hand	LRIP-sized (27" x 35") window-PV modules within 10% power output performance of pilot-sized window-PV modules assembled by LRIP methods	LRIP-sized (27" x 35") window-PV modules within 5% power output performance of pilot-sized window-PV modules assembled by LRIP methods	Measurement using in-house calibrated Spire Spi-Sun Simulator 3500SLP Flash Solar Simulator with Class ABB performance; Samples to be measured at Standard Test Conditions and/or Nominal Operating Test Conditions	Important to predict that performance metrics can be achieved independent of substrate size or specific tool as rapid scale-up of technology continues	**Complete Low Target Performance** Assembly Validation Report	**Actual Performance Value:** The LRIP-sized (27" x 35") window-PV modules were within 10% of the power output performance of the (27" x 35") pilot-sized window-PV modules assembled by LRIP methods. However, rather than using only 27" x 35" units, the team chose to compare both smaller and larger units, from as small as 3.5" x 3.5" up to oversize modules of 40" x 60". Similar assembly performances were achieved with similar power conversion efficiency within expected specifications.
Wet Leakage Current Test (IEC 61215)	Any device more than 0.1m^2 should have an insulative resistance, multiplied by the area of the module, should not be less than 40 MΩ/m^2 less than applied voltage > 500V.	PASS on 14" x 20" IGUs	PASS on six units with a minimum size of 27" x 35" up to a size of 40" x 60" post assembly into an IGU	PASS on six units with a minimum size of 27" x 35" up to a size of 40" x 60" post assembly into an IGU	Keithley 237 High Voltage Source Measurement Unit to apply > 500V to module submersed in electrolyte solution	Passing requirement for IEC 61215-1 and UL 61730 (Safety); Critical for sale of energy-generating window or any solar module	**Complete High Target Performance** Commercially Scaled Assembly Report	**Actual Performance Value:** Testing verified that all LRIP-sized modules exceeding the targeted 27x35" size, at 40" x 60" LRIP size, comfortably met the insulation resistance requirement (≥ 40 MΩ/m² at 500V).
Yield for each LRIP assembly step	N/A	> 50% when assembled manually	> 80%	> 90%	Determine individual step yield based on ASTM C1172-09 and ASTM C1376.	High yield is critical for low-cost window-PV module fabrication and demonstrates an improved MRL relative to current baseline performance level.	**Complete High Target Performance** Commercially Scalable Baseline Assembly Report	**Actual Performance Value:** 100% yield was achieved for assembly steps during LRIP and within LRIP tools during test duration.

Performance Metric	Benchmark Performance	Current Performance	Low Target Performance	High Target Performance	Evaluation Method	Significance of Metric	Relevant Report	Goal Target Performance
Yield for combined LRIP assembly steps	N/A	~50% when assembled manually	> 50%	> 90%	Determine compounded yield based on ASTM C1172-09 and ASTM C1376.	High yield is critical for low-cost window-PV module fabrication and demonstrates an improved MRL relative to current baseline performance level.	**Complete High Target Performance** Commercially Scalable Baseline Assembly Report	**Actual Performance Value:** 100% yield was achieved during for LRIP assembly steps and within LRIP tools during test duration.
Cycle time for each LRIP assembly step	7 modules/hr as specified by Commercial Partner Viracon	N/A	1 module/hr	7 modules/hr	Measure process time for each step to ensure a successful product.	A goal for full-rate production based on projected sales in the first 6 years is a total cycle time of 7 window-PV modules per hour resulting in ~1.5M square feet of window-PV units per year.	**Complete Low Target Performance** Commercially Scalable Baseline Assembly Report	**Actual Performance Value:** Glass Washer – High Target, Bus Bar Application – Low Target; Edge Seal Application – High Target; Lamination – Out of scope as per Scope of Work Metric Achieved: Overall Low Target Performance due to Bus Bar Application
Verify that a simple payback of 10 years or less is achievable for an average California commercial building based on updated results from this project	Simple payback of 10 years or less	NA	Simple payback of 10 years or less is achievable for an average California commercial building.	Simple payback of two years or less is achievable for an average California commercial building.	Net Present Value analysis of the main benefit streams of NEXT technology: • Energy Savings • Accelerated depreciation • Investment tax credit	Simple payback is an investment criterion that building owners, developer and end users of the technology use to make purchase decisions.	**Complete High Target Performance** TASK 7 – System Level Cost Model Report	**Actual Performance Value:** Under current taxation policies, the cumulative benefit of installing NEXT windows is greater than the incremental fully installed cost of NEXT windows, indicating a strong return and one-year payback on the building owner's investment.
Validate a potential projected LCOE of $0.03/kWh by 2030 based on updated results from this project.	LCOE of ~$0.06/kWh-$0.40/kWh	NA	Projected LCOE of $0.03/kWh by 2030.	Projected LCOE of $0.02/kWh by 2030.	Lifetime cost of solar relating to the energy production of the system	Industry standard for the competitiveness of energy-generating technologies	**Complete Low Target Performance** TASK 7 - Ratepayer Benefits Report	**Actual Performance Value:** Updated models continue to project an LCOE less than $0.03 kWh in 2030 when including currently available tax incentives and post-tax incentives (based on current administration priorities) for 2030. Our calculations also show an LCOE of $0.04 KwH in 2030 could be possible without including the Investment Tax Credit.

Performance Metric	Benchmark Performance	Current Performance	Low Target Performance	High Target Performance	Evaluation Method	Significance of Metric	Relevant Report	Goal Target Performance
Obtain 10 or more letters of commitment or support from supply chain partners indicating interest in development, adoption, purchase or use of our technology based on updated results from this project.	NA	Six letters of commitment from commercial partners, strategic developers or investors	Ten letters of commitment or support from supply chain partners indicating interest in development, adoption, purchase or use of our technology	Fifteen letters of commitment or support from supply chain partners indicating interest in development, adoption, purchase or use of our technology	Submit letters of commitment to Commission Agreement Manager	Validates technology and market value for introduction in BIPV environment for performance and aesthetics	**Complete Low Target Performance** TASK 7 - Stakeholder Engagement Summary	**Actual Performance Value:** Ten letters obtained

Source: NEXT Energy Technologies, Inc.

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B: Technology and Manufacturing Readiness Levels

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Appendix B: Technology and Manufacturing Readiness levels

Table B-1: Before and After Assessment of Product Status using CEC Market Readiness Calculator Levels (Technology Readiness Level and Manufacturing Readiness Level scale of 1–9)

Aspect	Pre-Award	Post-Award
Technology	Level 5 Laboratory-scale integrated product/ system demonstrates performance in the intended application(s)	Level 5 Laboratory-scale integrated product/ system demonstrates performance in the intended application(s)
Product Development	Level 2 Pilot-scale product/system has been tested in the intended application(s)	Level 3 Demonstration of a full-scale product/ system prototype has been completed in the intended application(s)
Product Definition/Design	Level 5 Comprehensive customer value proposition model has been developed, including a detailed understanding of product/system design specifications, required certifications, and trade-offs	Level 6 Product/system final design optimization has been completed, required certifications have been obtained, and product/system has incorporated detailed customer and product requirements
Competitive Landscape	Level 5 Full and complete understanding of the competitive landscape, target application(s), competitive products/systems, and market has been achieved	Level 5 Full and complete understanding of the competitive landscape, target application(s), competitive products/systems, and market has been achieved
Team	Level 4 Balanced team with technical and business development/commercialization experience running the company with assistance from outside advisors/mentors	Level 4 Balanced team with technical and business development/commercialization experience running the company with assistance from outside advisors/mentors
Manufacturing Research	Level 5 Prototype components have been produced in a production relevant environment, and planning to address scale-up issues has begun	Level 5 Prototype components have been produced in a production relevant environment, and planning to address scale-up issues has begun
Manufacturing Scale Up	Level 2 A preliminary manufacturing system design has been developed, and further design changes are required for a successful demonstration of the system	Level 5 The system has successfully achieved low-rate production and is ready to enter full-rate production with minimal design changes

Aspect	Pre-Award	Post-Award
Go-To-Market	Level 5 Partnerships have been formed with key stakeholders across the value chain (for example, suppliers, partners, service providers, and customers)	Level 6 Supply agreements with suppliers and partners are in place
Supply Chain	Level 3 Relationships have been established with potential suppliers, partners, service providers, and customers and they have provided input on product and manufacturability requirements	Level 5 Products/systems have been pilot manufactured and sold to initial customers
Finance	Level 5 Private investment has been raised	Level 6 Purchase orders from customers have been received

Source: NEXT Energy Technologies, Inc.

Table B-2: Before and After Assessment of Technology, Manufacturing, and Commercialization Readiness Levels using CEC Market Readiness Calculator Composite Levels (scale of 1–9)

Readiness Level Category	Pre-Award	Post-Award
Technology Readiness Level	Level 6 Representative engineering-scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up on the demonstrated readiness of a technology.	Level 7 Prototype full-scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field.
Manufacturing Readiness Level	Level 6 Capability to produce a prototype system in a production relevant environment has been achieved. The majority of the manufacturing process has been defined and characterized, but there are still significant engineering and/or design changes needed in the system itself. Cost, yield, and rate analyses have been performed to assess how prototype data compare to target objectives.	Level 8 Materials and equipment have been proven on the pilot line and are available to begin low-rate production. Manufacturing quality processes have been proven on the pilot line. Known issues pose no significant challenges for low-rate production. Cost model and yield and rate analyses have been updated with pilot line results.
Commercialization Readiness Level	Level 5 Product is defined. A comprehensive cost-performance model is created, and a comprehensive competitive analysis is carried out. Active relationships are established with potential suppliers, partners, and customers. A basic financial model is built with projections for near- and long-term costs, revenue, and so on.	Level 7 Product design is complete. Supply and customer agreements are in place, and all stakeholders are engaged in product/process qualifications. All necessary certifications and/or regulatory compliance for product and production operations are accommodated. Comprehensive financial models and projections have been built and validated for early stage and late-stage production.

Source: NEXT Energy Technologies, Inc.