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Production Scale-Up of High Efficiency Adjustable Lighting Products

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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, energy transmission and distribution, and transportation.

In 2012, 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 CEC and the state's three largest investor-owned 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 that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission 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), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Production Scale-Up of High Efficiency Adjustable Lighting Products is the final report for the Production Scale-Up of High Efficiency Adjustable Lighting Products project (EPC-18-020) conducted by Glint Photonics, Inc. The information from this project contributes to the 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 CEC at ERDD@energy.ca.gov.

ABSTRACT

Glint Photonics developed and brought into commercial fabrication a new type of high-efficiency directional lighting fixture. The fixture, named Hero, produces beams of light whose direction can be adjusted by simple manipulation of a joystick, rather than pivoting the entire fixture. This functionality, enabled by a novel optical design, brings benefits in simpler and more flexible installation, reduced glare, and improved visual harmony. The optics produce tailored beam profiles that provide significant improvements over state-of-the-art in the efficiency with which light is directed toward its intended targets. Easier and more effective targeting of light not only improves the visual experience in lit environments, it also enables significant energy savings by reducing the amount of energy required in lighting. Potential savings of up to 10.2 terawatt-hours annually are possible within California investor-owned utility service areas, thereby supporting California's energy efficiency goals.

Through several rounds of prototyping and revision, the design of the Hero fixture was optimized for optical performance, energy efficiency, appearance, and ease of manufacturing and assembly. The final product design has been recognized in the industry for its novelty and innovation, winning a broad array of lighting and product design prizes for its technology and design. Glint developed Hero into a family of products for different mounting configurations and use applications, all of which have passed rigorous internal qualification testing as well as external certification testing. Glint developed and has begun scaling up an in-house production line to manufacture the Hero fixtures. Manufacturing capabilities include not only the production line itself, but also supporting functions in supply chain management, quality assurance, manufacturing execution, process control, document management, and more. Hero fixtures are now in commercial production with growing sales. Several installation examples that demonstrate the benefits of the fixture are described in this report.

Keywords: Solid-state lighting, adjustable lighting, directional lighting, LightShift, manufacturing

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Introduction

Light emitting diodes (LEDs) have rapidly displaced legacy technologies such as incandescent and halogen lamps in a wide range of lighting applications, dramatically reducing the energy required to generate light. Yet the design of most lighting fixtures, and the ways in which we deploy them in the built environment, remains largely unchanged. This is particularly true in the case of directional lighting fixtures, which often require complex and bulky installations, and continue to be sources of glare and misdirected (and therefore wasted) light.

This project was premised on the notion that LEDs offer many avenues for improving the performance of lighting products beyond their light emitting efficacy and that present fixture design leaves many of these advantages on the table. Compared to legacy sources, LEDs are not only more efficient, they are also much smaller in size and much longer lived, operate at cooler temperatures, and provide directional output, thus providing energy and monetary savings.

These features afford the opportunity to reconceptualize lighting fixtures, breaking from the traditional lighting fixture form factors. Most directional lighting products today maintain the same designs and form factors that have been in use for decades—they are typically cans mounted on gimbals, with the entire fixture pivoting in order to aim the beam. While deeply familiar, this design has a number of significant drawbacks: (1) complex installation requirements because the fixtures require a substantial volume within which to pivot, (2) substantial glare (light that shines directly into the eye of an observer) because the entire front of the fixture is tilted up and can point toward the face of an observer, and (3) unattractive installations because fixtures pointing in multiple different directions can make ceilings look messy and disorganized. These drawbacks limit the effectiveness of legacy directional lighting and result in wasted light (and therefore wasted energy) from glare and difficulty in adjusting beam direction to optimize lighting pattern. Further, wasted light results from the poorly defined beam patterns typical of most adjustable lighting products, with a significant fraction of light falling outside the beam target or even emerging at high angles that create glare in the observer's line of sight.

Glint's patented LightShift optical design, a unique illumination technology designed to address all these issues. The custom optics are designed to work with the latest high-brightness LED sources. Small in-plane adjustments to the position of the optics relative to the LEDs steer the output beam while maintaining beam shape, spectrum, and intensity. This novel design enables a completely new approach to beam adjustment. Instead of pivoting an entire fixture, the output beam itself can be steered simply by shifting the optics internally, while the fixture remains stationary. Beam shapes are optimized for visual comfort and application efficiency, with as much as 87 percent more light on target than competing fixtures.

Project Purpose

The purpose of this project was to bring into commercial production a new category of LED lighting fixture, enabled by LightShift optics, to offer unprecedented control over light placement combined with a new flexibility in simple, attractive, and low-glare installation. The project exemplifies a research and development program to spur innovation in energy efficiency, foster regional innovation, and bring ideas from the lab to the marketplace.

Project Approach

The project supported development of the complete Hero product design (implemented in a wide variety of product configurations), including an industrial design partnership, several rounds of design revisions to improve manufacturability, and qualification and certification activities.

Hero Product

Hero is an adjustable spotlight with a unique stationary linear form. A joystick at the end of the fixture allows easy adjustment of the beam pointing out to at least a 40-degree tilt in any pan direction without any movement of the fixture itself. The joystick operates by controlling the positioning of an internal optics array via a mechanical linkage system. Hero is now available in the commercial market in a wide range of configurations for different mounting types (track, ceiling junction box, architectural bracket, or recessed into the ceiling), housing colors, housing shapes, beam color temperatures, beam widths, dimming controls, and other options.

Hero fixtures can be installed in clean organized lines on the ceiling yet still have their beams aimed around the room as needed. They reduce glare by allowing aiming without tilting the face of the fixture toward the observer's eyes. The fixture's compact shape and stationary nature allow easy flexible installation in a wide variety of applications, including many that are difficult for conventional adjustable fixtures such as tilted ceilings, narrow plenums, and between wooden slats. Finally, the LightShift optics produce consistent optimized beam patterns, ensuring that the emitted light is directed toward the objects to be illuminated for high application efficiency and minimal energy use.

At the start of this program, Hero was realized in a demonstration prototype but was not a refined product ready for manufacturing. The product design was advanced during the program in multiple stages. An industrial design phase refined the cosmetic appearance, user affordances, and piece part assembly. The design was further improved for manufacturability through several rounds of prototype building and testing, using a design by a failure modes and effects analysis approach to systematically evaluate and address potential failure modes. Suppliers were identified, developed, and qualified for the many piece parts involved in the Hero product assembly. The product development effort culminated in internal qualification of Hero samples to all Glint performance specs as well as external certification to all applicable safety and performance standards.

Manufacturing Development

A range of activities were undertaken during the program to develop manufacturing capabilities at Glint. One focus of activity was development and implementation of a software-based manufacturing execution system to manage work orders, part inventories, and other details. Further software tools included a product documentation management system and in-process measurement tracking for statistical process control.

Standard operating procedures were developed to provide consistent execution on key activities including sales, manufacturing, shipping and receiving, engineering change management, and other activities.

Finally, Glint hired several new staff members to bring in additional expertise in supply chain management and manufacturing execution.

Pilot Production

Glint developed in-house production of Hero fixtures, in place of the contract manufacturing originally planned in this program. In-house production allows the engineering team to continuously learn from the manufacturing process and to execute improvements to the fixture design and assembly procedures. It also provides flexibility in supporting customer orders during the sales ramp following product introduction, which is characterized by spikey initial demand, requests for short lead-time manufacturing, and a broad mix of product configurations.

In-house assembly and testing were instituted at Glint by reorganizing the physical space with separate areas for incoming part quality assurance, production assembly, outgoing quality testing, boxing/shipping, and other activities. Staffing was expanded to include production engineering and assembly staff. The production line was certified through a rigorous initial factory assessment by a nationally recognized testing laboratory and undergoes unannounced quarterly inspections to retain this certification.

Project Outcomes

This project successfully achieved its targets. The Hero fixture matured from a demonstration prototype into a fully developed product in manufacturing, and available on the commercial market. The fixture met all performance targets and certification requirements and achieved the company's manufacturing cost targets ahead of the planned schedule.

Hero is a family of products, with four different mounting types and a plethora of different product configurations available. The design and unique capabilities of the Hero fixture led it to sweep nearly every available award within the lighting industry, as well as many prestigious awards for general product design. Initial installations demonstrated that the Hero fixtures provided the intended benefits over conventional fixtures in improved lighting quality and targeting, lower glare, better visual harmony with the architecture, and easier, more flexible, installation.

The work described in this report also transformed Glint as an organization. At the start of the Realizing Accelerated Manufacturing and Production program, Glint was a research and development organization, with a strong engineering team but without any manufacturing capability or commercial product sales. During this project, Glint built its experience in product design, brought in supply chain expertise, developed a network of trusted vendors, and developed the processes and tools with which to manage its supply chain. Rather than relying on outside contract manufacturers, Glint built up its in-house assembly operation. Finally, the development of this first commercial product line enabled Glint to develop a robust sales and marketing effort, including contract agreements with many sales agents to represent Glint products throughout the country and internationally. Glint's product sales are growing rapidly. The company continues to pursue research and development activities to continue advancing next-generation lighting products, but this work now occurs in parallel with a growing commercial manufacturing and sales activity.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

Project results were widely shared within the industry, primarily via Glint's product sales and marketing efforts. Glint established an extensive network of sales agents within the United States and has begun export sales in select markets. The Hero product is marketed by these sales agents and by Glint itself through a wide range of trade shows, industry conferences, award competitions, and press coverage. In addition, Glint staff participated in many technical conferences within the lighting industry.

Market adoption is demonstrated through completed installations by paying customers. Three example installations are highlighted in this report: Temple Israel in Alameda, California; Barnum Hall in Santa Monica, California; and 21 Moorfields in London, England.

Benefits to California

By developing a new lighting technology, this project has supported the EPIC goals of lower costs, increased safety, and greater reliability for California electricity ratepayers by advancing more precise and adaptable illumination in occupied spaces in California and working to increase the adoption rate for efficient, long-lasting, LED-based luminaires. Although commercial sales of this technology are still at a low initial level, the analysis presented in this report estimates the potential energy and cost savings assuming eventual widespread adoption of the Hero product and related products on Glint's product roadmap that draw from the same fundamental technology platform.

Glint's novel optical platforms and LED luminaires offer the possibility of a better match between lighting requirements and light output. This was achieved by the development of previously lacking functionality in LED luminaires including effortless control over beam aiming and spread, as well as through tailored beam distributions that make more efficient use of generated light. This affords a better match between the desired illumination in a lit space and the light generated, resulting in an increase in end-use energy efficiency, productivity, and safety in lit spaces. Furthermore, the increased value proposition will promote more rapid market adoption of energy-efficient LED-based lighting, offering additional energy savings when replacing older sources. A comparison of the beam distribution of the Hero fixture compared to example state-of-the-art competitor narrow-beam adjustable spotlights showed that Hero delivered 25 percent to 87 percent greater usable lumens per watt (lumens within two times the beam angle).

The optical beam steering functionality of certain Glint luminaires affords additional energy savings by providing lighting designers and end users more control over the illuminance distribution in a lit space. A total energy savings opportunity of 15 to 50 percent is estimated based on usable lumens and including the benefits of improved luminaire efficacy, reduced self-occlusion, and improved targeting of light. Assuming that approximately half of the residential and commercial lighting market is addressable by some form of luminaire using Glint's novel optical approaches, this corresponds to a potential energy savings of between 3.1 and 10.2 terawatt-hours in California investor-owned utility territories, with associated equivalent avoided emissions of 1 million to 3.4 million metric tons of carbon dioxide. This energy savings potential represents a monetary value between $375 million and $1.2 billion dollars per year.

Qualitative benefits of the Hero fixture include reduced glare, easier installation, and improved aesthetics. These benefits contribute to a better occupant experience and more effective lighting, with associated benefits to productivity and well-being. A final benefit to California is the growth of Glint as a local manufacturing company offering excellent jobs and supporting an ecosystem of local suppliers in an industry that is otherwise rapidly off-shoring most production.

CHAPTER 1: Introduction

Motivation for Project

Light emitting diodes have rapidly displaced legacy technologies in a wide range of lighting applications, dramatically reducing the energy required to generate light. But LEDs are not only more efficient than conventional light sources, they also offer additional avenues for energy savings due to their tiny size, directionality, cooler operating temperatures, and longevity. These features afford the opportunity to reconceptualize lighting fixtures, breaking from traditional lighting fixture form factors. Improved fixtures can offer better light distributions to fit the needs of diverse lighting applications, reduced material usage, easier installation, reduced glare, and improved visual appearance. These benefits all lead to more rapid adoption of advanced LED lighting, resulting in immediate energy savings. Well-designed beam profiles increase the portion of emitted light that is performing useful illumination in the room, reducing the amount of total light that must be generated, and thereby contributing additional energy savings. Finally, in addition to energy savings, improved lighting fixtures offer diverse benefits to building occupants, including better productivity, safety, and visual comfort.

The opportunity for improved lighting fixture design, and increased energy efficiency, is particularly strong in directional lighting, where new optical designs are enabled by the small size of LEDs, the directionality of their output, and the ability to place them in close proximity to polymer optics. Yet most directional lighting products today maintain the same designs and form factors that have been in use for decades, with only the light source changed to LEDs. They are typically cans mounted on gimbals, with the entire fixture pivoting to aim the beam. While deeply familiar, this design has a number of substantial drawbacks.

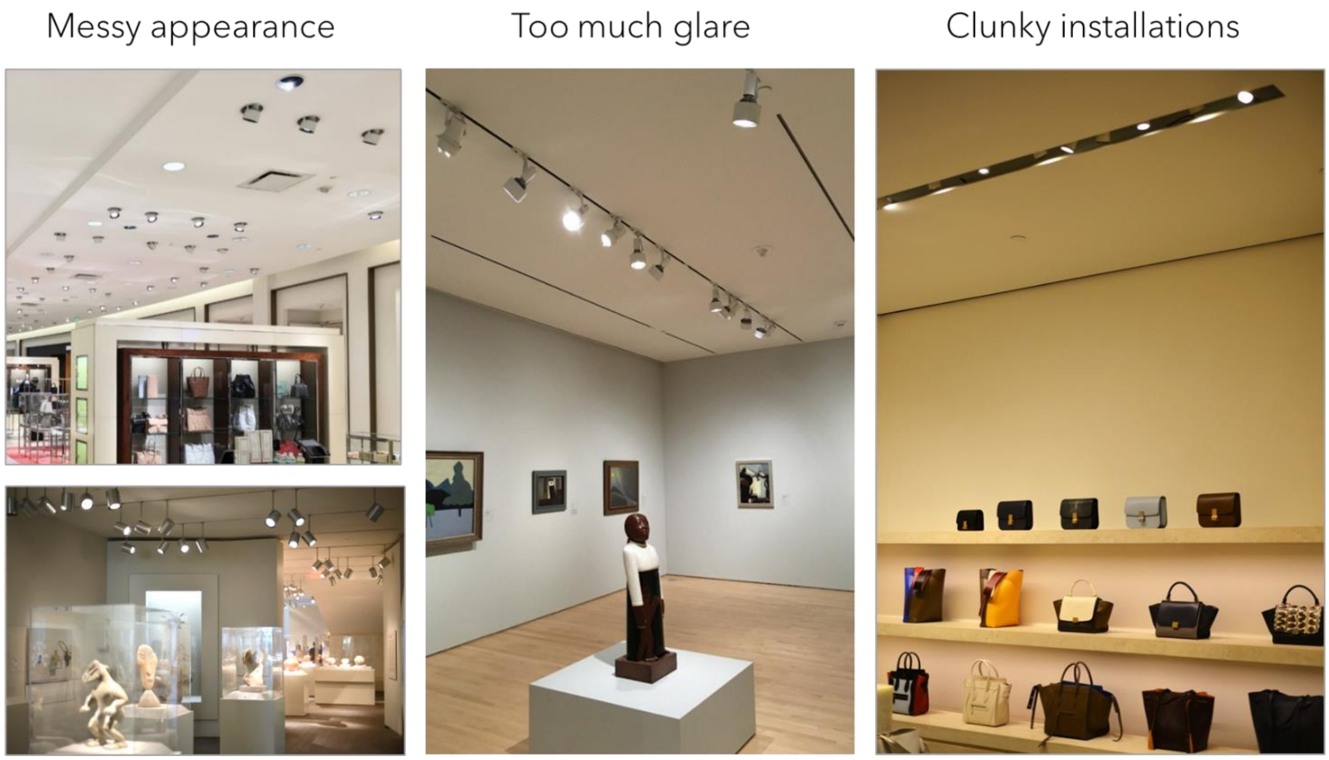
First, gimbaled fixtures can result in complex installation requirements because they need a substantial volume within which to pivot. On a ceiling, this means that either the face of the fixture must protrude down below the ceiling plane to aim or a large cutout is required in the ceiling. Such large cutouts create additional installation cost, limit how closely the fixtures can be packed, limit installation in narrow plenum ceilings, and create substantial complexity on sloped ceilings. And even when such large cutouts are constructed, they typically still clip a portion of aimed beams, creating light loss (poor energy efficiency) and distracting bright spots.

Second, gimbaled fixtures can create substantial glare. Glare is light that shines directly into the eye of an observer. Glare light is uncomfortable and can even cause a debilitating safety issue in extreme cases, and of course, also represents lost efficiency as it is light not shining on the objects and surfaces needing illumination. Gimbaled fixtures create glare because in aiming the beam the entire front of the fixture is tilted up, so that it can point toward the face of an observer. Gimbaled fixtures also create glare when placed close together, as light from one fixture may strike its neighbor.

Third, gimbaled fixtures can result in unattractive installations. With fixtures pointing in multiple different directions, ceilings can look messy and disorganized. The visual distraction created in this way is present at all times in the peripheral vision of room occupants and undermines the architectural design intent of the space.

These problems are illustrated in Figure 1, which presents a mosaic of photos of directional lighting installations in galleries and retail locations in San Francisco.

Figure 1: Problems with Gimbaled Fixtures



Source: Photos taken by Glint staff at various stores and museums.

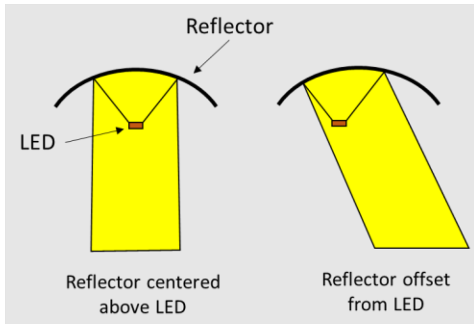
LightShift Technology

Glint's patented LightShift optical design is a unique illumination optic designed to work with the latest high-brightness LED sources. These reflective lenses are used in an array and placed in close proximity to a matching array of LEDs. The LEDs face into the fixture body and fire back into the reflectors. This design provides a highly compact collimating optic and low glare because the emitters are facing away from viewers. Adjusting the position of the LEDs relative to the optics adjusts the angle of the light beam leaving the luminaire, as shown in Figure 2. Only small (millimeter-scale) in-plane motions of the optics are required to steer the beam.[1] The design of the optics has been optimized to maintain beam shape, spectrum, and intensity as the beam is steered and to allow beam steering up to 45 degrees in any direction. Specific optics were developed to create different beam widths as needed for different lighting applications.

[1] Lloyd, J., P. Kozodoy, C. Gladden, and A. Kim. "Stationary Adjustable Luminaires Via Optical Beam Steering," in *Optical Devices and Materials for Solar Energy and Solid-state Lighting 2019*. Burlingame, California, 2019.

This novel optical design enables a completely new approach to beam adjustment. Instead of pivoting an entire fixture (and thereby aiming its fixed beam distribution), the output beam itself can be steered simply by shifting the optics internally, while the entire fixture remains in a fixed configuration. Put more simply, LightShift allows users to aim just the light, not the light fixture.

Figure 2: Beam Steering with LightShift Optics



The ability to aim the light independent of fixture position and orientation creates a sea-change in how directional lighting can be installed and used. The messy appearance of gimbaled fixtures can be immediately eliminated, with fixtures installed in neat and orderly arrangements still able to aim their beams as needed. Installations become much easier because the fixtures do not need a large volume within which to pivot. They can be easily installed into narrow plenums or small slots and provide a fixed output face flush with the ceiling plane. Finally, unwanted glare can be greatly reduced since the fixed output face means the fixture does not need to tilt up toward viewers. Glare cutoffs implemented in the fixture remain stationary and do not pivot with beam aiming.

The LightShift beam-aiming capability is particularly striking when implemented with a linear array of optics. Linear fixtures are visually appealing and in widespread use, but previously there had been no adjustable spotlights available in a linear shape. This is because, without LightShift, there is no way to aim the beam from a linear fixture without tilting the whole form. LightShift optics solve this problem, and this unique capability was the inspiration for Glint's Hero light fixture.

Figure 3 shows the potential design and installation benefits of Hero versus conventional fixtures in a gallery setting. Figure 4 shows how Hero can fit snugly into a wood-slat ceiling yet still provide adjustable beam aiming, an easy and visually pleasing installation not matched by any other adjustable fixture.

Figure 3: Gallery Lit by Conventional vs. Hero Fixtures

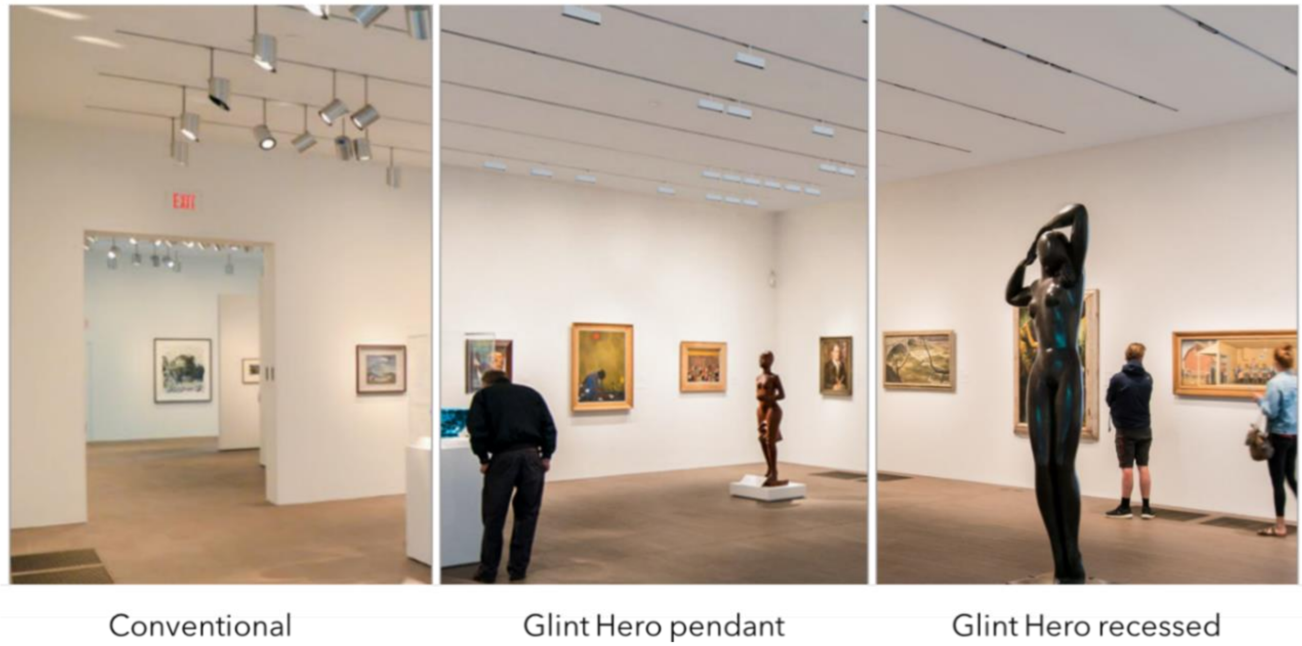
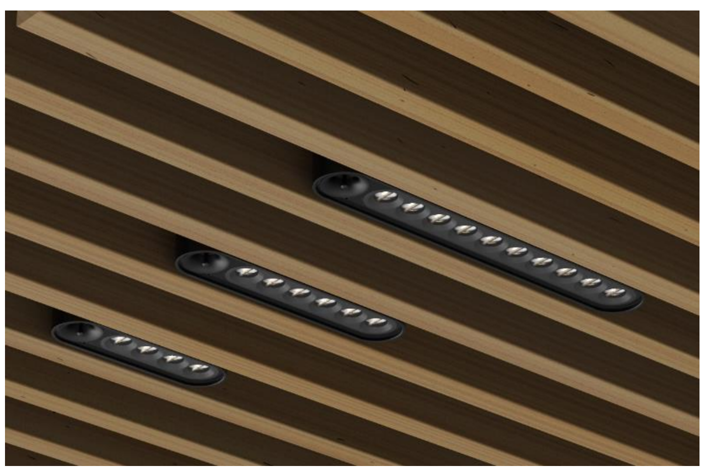


Figure 4: Hero Fixtures Installed in Wood Slat Ceiling

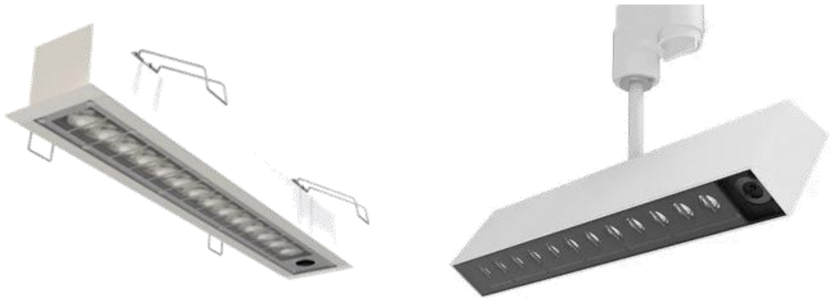


Early Hero Prototypes

At the start of the Realizing Accelerated Manufacturing and Production (RAMP) program, Glint had already developed the product concept for the Hero spotlight using LightShift optics. Early prototypes had been designed and built, and the basic construction approach and optical performance were validated. As seen in Figure 5, these prototypes used a linear array of LightShift optics with a joystick at one end of the fixture that moved the optical array relative to the LED array, an architecture that remained in place throughout the product development.

However, there was much work still to do to turn these early proof-of-concept prototypes into actual products. The product appearance had to be developed and refined, especially for the design-conscious customers that would be the early adopters for the product. The mechanical design had to be vetted and reworked with design-for-manufacturing and design-for-assembly considerations in mind. Suppliers for several key components had to be identified and quality assessments completed. Product safety and performance certifications had to be completed. An assembly process had to be developed, optimized, and qualified.

Figure 5: Early Hero Prototypes for Recessed Installation (left) and Track (right)



Project Goals and Objectives

The goals of the work performed under this project were to:

- Scale-up Glint's lighting technology from prototype to pilot production.
- Speed adoption of Glint's lighting technology with agile, efficient, scalable manufacturing processes.
- Reduce the cost and complexity of configurable lighting systems.
- Improve user experience and safety in lit spaces.
- Help enable greater market penetration of solid-state lighting.
- Help meet California's lighting energy use goals.

The specific objectives of the project to address these goals were identified as follows:

- Prepare Glint's luminaires for production scale-up through design for manufacturing/assembly.
- Establish the processes, tools, and team required for effective pilot line production.
- Develop strategic supplier relationships to reduce cost, increase quality, and reduce lead times.
- Develop and establish a robust supply chain model to meet delivery reliability targets.
- Build an agile and capable pilot line quickly and efficiently by working with a manufacturing partner; thus, also ensuring smooth future scaling of volume.

These objectives represent the key steps to advance the Hero product from the initial demonstration-level prototype to a fully designed product with a robust manufacturing process that can grow from supporting pilot level commercial sales to mass production.

CHAPTER 2:
Project Approach

This chapter discusses five major areas of Glint's approach to the project: product design, supply chain expertise, certification, manufacturing development, and pilot production.

Product Design

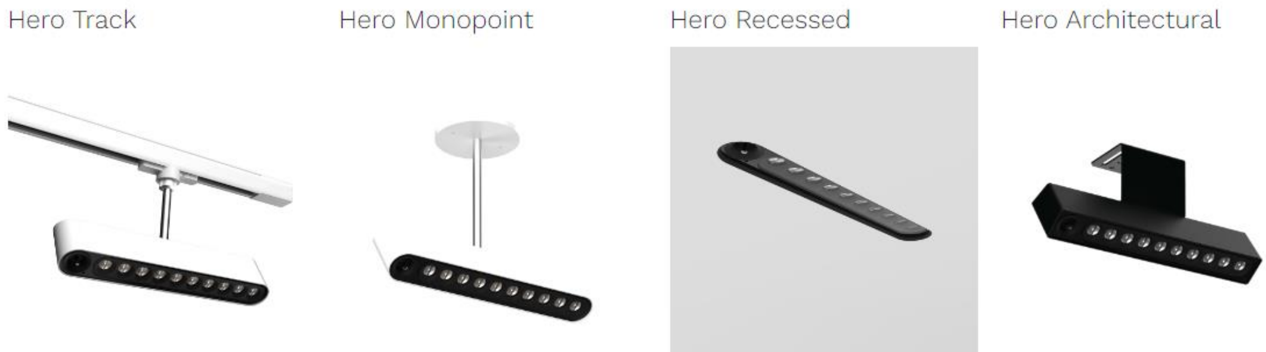
This section describes the product design for the Hero fixture. The design developed in several stages over the course of the program. Key developments included:

- Industrial design development, working with Whipsaw to finalize the overall form and external design.
- Adoption of a modular construction to enable straightforward proliferation into a variety of mounting configurations.
- Design refinement using design for manufacturing (DFM) and design for assembly (DFA) methodologies to evolve the piece part designs.
- Testing and qualification work, which resulted in further design tweaks to fine tune performance.

Hero was initially introduced to the market in the track-mounted configuration seen in Figure 6. Over the course of the program, additional mounting configurations were developed and ultimately released as commercially available products. These included monopoint (stem-mounted to a junction box), architectural (attached to a bracket and wired via conduit or cable) and recessed (mounted within the ceiling). These various configurations are shown in Figure 7.

Figure 6: Track-mounted Hero Fixture with Rounded Endcaps (left) and Rectangular Endcaps (right)

Figure 7: Hero Fixture Mounting Configurations

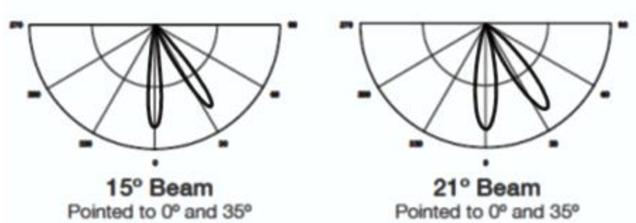


Key Specifications

The Hero fixture uses Glint's patented LightShift optics to produce a spotlight beam that can be steered via a joystick mounted in the fixture, without swiveling the fixture itself. The beam can be steered at tilt angles up to at least 40 degrees (°) in any pan direction. Customers can choose fixtures configured with a variety of beam angles (11°, 15°, 21°, or 34°) and correlated color temperature values (2700 kelvin [K], 3000K, 3500K, 4000K). In all cases, the color rendering index exceeds 92. Output power is at least 1260 lumens at 3000K.

Table 1: Key Specifications of Hero Light Fixtures

Photometrics	
Light Output	1260 lumens @ 3000K
Efficacy	55 lm/W @ 3000K
Color Temperature	2700K, 3000K, 3500K, or 4000K
Color Rendering	Ra > 92, R9 > 65
Beam Width	11°, 15°, 21°, or 34°
Adjustment	
Adjustment Range	±40° rated tilt (45° max), infinite pan
Orientation	straight or inclined 35°, field-servicable



Source: Glint Hero datasheet

External Form and Design

The Hero external form was designed in close coordination with Whipsaw as their industrial design partner. The fixture has a linear form factor featuring an array of 10 light sources with a joystick at one end. The joystick permits steering and aiming of the beam while the fixture itself remains stationary. A small hole near the joystick allows tool access to a screw that locks the joystick in place and prevents beam aiming from being accidentally changed. The joystick tip can also be unscrewed and removed to prevent subsequent adjustment, if desired (Figure 8).

Figure 8: Close-up of Joystick Area of Fixture

The linear form factor is advantageous in several ways: (1) it is slim and compact, and visually coherent with the track itself, so that the end result is visually harmonious; (2) it blends in well to a wide variety of architectural features; and (3) linear form factors are a growing trend in lighting, but prior to Hero there was no linear fixture that provided fully adjustable beam aiming.

The fixtures are available in black and white housing colors and in two external form factors: rounded ends and rectangular ends. In both cases, the overall dimensions of the fixture body are 311 millimeters (mm) x 45mm x 74mm. The lid of the track, monopoint, and architectural fixtures are tilted at an angle and attached to the fixture body by a series of screws. By removing the screws and rotating the lid 180°, the fixture may be switched between two mounting configurations: pointing straight down (appropriate for center of room applications) and tilted up at a 35° angle (appropriate for edge of room applications), as shown in Figure 9. In the latter configuration, the beam may be steered from the top of the wall all the way past a straight-down pointing angle, as well as right and left, with the light-emitting face always tilted up toward the wall to eliminate any glare. The track and monopoint fixtures feature a stem with a knurled nut at the top that enables the rotation of the stem in the track adapter or canopy to be locked.

Figure 9: Hero Track Fixture Oriented Straight Down and Tilted Up at 35 Degrees

The cosmetic design of the fixture was carefully coordinated to ensure harmonious alignment of the curved elements of the housing, cover mask, glare baffle on the optics, joystick surround, and joystick shape. This attention to design was recognized through a wide array of design awards for the product.

Thermal Design

Heat produced by the LEDs must be conducted to the external surfaces of the luminaire (or its mounting hardware) for convective cooling into the environment. Hero's thermal design includes optimization of the circuit board design, housing design, and the thermal interface between the two.

The housing is made of extruded aluminum, which provides an excellent thermal path. Optimization of its design for convective heat shedding has been carried out experimentally by varying the shape and surface area of the housing and testing its thermal performance under a range of ambient and drive conditions.

Manufacturing Methods

A modular design was developed to facilitate proliferation into a wide variety of installation types. A core module contains the LED circuit board, optics, and aiming mechanics within an internal extruded aluminum housing. The mechanics are comprised of polymer and metal pieces that fit together with tight tolerances to ensure proper alignment and motion of the optics. The motion of the optics is driven by movement of the joystick through mechanical linkages. The mechanical components are assembled using a combination of fasteners and snap-together features and were carefully engineered through many rounds of DFM/DFA advancement to optimize for precise positioning and simple assembly.

This core can then fit into a wide variety of cosmetic shells. For the track product, the shell is made of an extruded aluminum housing, injection-molded plastic endcaps, and an aluminum lid with the attached stem. The aluminum housing and injection-molded endcaps are painted to provide a consistent appearance and the desired housing colors. The driver (the power supply for the fixture) is installed in the upper portion of the shell for track, monopoint, and architectural units. The core can also be inserted into different housings for use as a recessed ceiling-mounted product.

The core/shell architecture (Figure 10) not only provides easier product proliferation, it also aids manufacture and inventory management by providing a universal module that can be stocked as a sub-assembly and integrated into different final product stock-keeping units (SKUs) with a short lead-time.

Figure 10: Fully Assembled Core (bottom) Ready for Insertion into Shell (top)

Evaluation of Sample Builds

Several rounds of sample builds were completed. All met the key product specifications listed in Table 1, but some failed other internal metrics for characteristics such as feel of the joystick motion, beam shape and uniformity, and cosmetic finish of the housing materials (for example, due to sink marks and paint blemishes). Some of these issues were resolved through design revisions to specific piece parts, and others through working with the suppliers involved to tighten process controls.

Failure Mode and Effects Analysis Risks

At the kickoff of the program Glint staff undertook a detailed failure mode and effects analysis (FMEA) study. For each key piece part in the assembly, a list was produced of all failure modes and their effects, assigning a 0 to 10 ranking for each in terms of Severity of Effect, Likelihood of Effect, and Difficulty of Detecting. The product of these three rankings is the Risk Priority Number. Those risks with Risk Priority Number values higher than 100 are considered significant. Seventy-nine such significant risks were catalogued at the start of the program. Through the engineering and testing efforts at Glint, and with input from suppliers and from Whipsaw, Glint retired 54 of those risks (68 percent). In some cases, the risks were retired because the design was improved to eliminate or greatly reduce the risk. In other cases, it was because further testing revealed the risk severity or likelihood to be lower than originally estimated.

The significant risks that remain primarily reflect the possibility of receiving out-of-spec parts from suppliers, which could compromise performance significantly and therefore score high on Severity. True Likelihood is uncertain at this early stage in pilot production, because there is not yet a robust statistical basis for evaluation. However, these risks are generally easy to detect with careful inspection of incoming parts, so incoming quality assurance was made a key part of the production process.

Supply Chain

Supply chain was another important area of work. Glint hired supply chain expertise into the company and took a systematic approach to identifying and evaluating vendors for the many custom parts within the Hero product. This work was particularly challenging because it took place just as the COVID pandemic shutdown global travel and snarled supply chains and shipping globally.

Bill of Materials Overview

The bill of materials (BOM) for Hero spotlight products comprises more than 40 separate items. Many of these are custom-manufactured parts, and a variety of processes are involved including circuit board fabrication, aluminum extrusion, computer numerical control machining, sheet metal stamping, and plastic injection molding, as well as a wide range of finishing processes. Hero's unique beam-steering design imposes tight mechanical tolerances across the entire finished assembly to maintain optical performance, which translates to tight specifications on individual parts and sub-assemblies. In addition, the product requires a high cosmetic finish, meaning that parts must be free from visible defects and that external parts must be highly consistent in color and finish.

Supplier Overview

A large fraction of the effort expended in this RAMP program went into assembling Glint's supply chain for manufacturing the parts in the Hero product. Parts are sourced from a variety of suppliers located around the world. In all cases, Glint worked closely with suppliers to ensure that parts are consistently made to specifications. While part price was an important consideration in choosing and working with suppliers, it was not the main driver in supplier selection. Instead, Glint prioritized suppliers with high quality standards and quality maintenance systems in place and suppliers that can accommodate low-volume initial orders yet still scale well to larger volumes in the future.

As a start-up manufacturer still establishing an industry reputation and sales channels, Glint expected that product sales would begin at lower annual volumes and ramp up over time. Assuring high quality parts for all initial sales is critical in building a strong reputation. Further, engineering changes to piece part designs were anticipated to be frequent in early production as a result of learning as assembly volumes began to scale. Consequently, Glint sought to identify suppliers with excellent internal quality systems, with the flexibility to accommodate small part orders and design changes over time, with the ability to scale over time to higher volumes, and with reasonable initial prices and the ability to drive prices down with increasing volume.

The relative importance of these different considerations varied for different BOM components and processes. Low-cost items like fasteners could be purchased in bulk with greater emphasis on cost than flexibility. Precision mechanical and optical components or cosmetically critical parts required greater attention to quality over cost.

Scorecard Approach for Comparing Suppliers

Glint adopted a scorecard approach for comparing multiple suppliers for a given part. This scorecard was divided into five categories: Technology, Quality, Cost, Flexibility, and Service/Support. Within each category Glint staff defined several metrics and assigned a weight to each so that they totaled 100 percent. For example, within Service/Support the metrics might be tool lead time, part lead time, responsiveness, and customer service, each worth 25 percent of the total Service/Support score (or some different weighting). Within the Technology category, the metrics might reflect specific capabilities or tolerances relative to the part under consideration.

Each supplier was given a score from 0 to 5 on each metric, based on quantitative and qualitative information that they provided and on subjective impressions from discussions. For some quantitative metrics this was straightforward (for example, tolerances, costs, lead-times). Qualitative metrics attempted to capture intangibles like the degree of difficulty in communicating changes.

A weighted average of the metrics represented the category value, and the weighted average of the category values then represented the total supplier score. Typically, the category weightings resembled Technology 20 percent, Quality 30 percent, Cost 20 percent, Flexibility 20 percent, and Service/Support 10 percent.

This system provided a consistent rubric for evaluating and scoring suppliers and also forced a careful evaluation of the characteristics most critical in selecting suppliers.

Supplier Audits

Glint performed different types of supplier audits to check procedures for fabrication, quality assurance, maintenance of documentation, and other factors. Some of these audits were performed via in-person visits by Glint personnel to supplier factories, although these were impossible for a portion of the program period due to pandemic travel restrictions. Others were carried out by remote meetings and via questionnaires provided to suppliers.

The supplier quality audit checklist consisted of about 100 questions, divided into the following sections:

- Quality management system
- Technical capabilities and infrastructure
- Metrology
- Process control
- Control of documents and records
- Supplier & resource management
- Change control
- Incoming quality assurance
- Continuous improvement activities
- Product identification and traceability
- Control of non-conforming material
- Outgoing quality assurance
- New product introduction
- Commercial details
- Ordering, planning, and communication

For each question, the supplier provided a response that Glint audited during the visit (if possible). The audit checklist was used to identify issues and also to provide an overall grading for each supplier.

Bill of Materials Cost Impact

The bill of material costs were about 15 percent lower than had been estimated at the start of the RAMP program. However, this number was not a fair representation of the total impact of the supplier development work undertaken during this program because the estimated BOM costs at the start of the RAMP program were highly inaccurate. At that point, Glint's supply chain was not fully developed. The company lacked suppliers for some parts altogether and had only placeholder cost values. For other parts, costs were estimated based on initial quotes from potential suppliers, but these quotes were unrealistically low because they did not yet reflect full alignment on tolerances and quality requirements. In reality, the impact of the RAMP program was much larger than 15 percent and was probably closer to a 50 percent reduction in costs, in part due to supplier development work and in part due to design improvements undertaken through the program to reduce manufacturing and assembly costs.

Product Certification

The Hero products underwent rigorous safety evaluation to receive product certification. Following is a summary of the certifications achieved.

Certifying Body

Intertek Testing Services NA, Inc. in Los Angeles is a nationally recognized test laboratory that is widely used in the lighting industry and tests to the same standards as Underwriters Laboratories (UL). The testing standard included:

- Track-mounted products tested and certified under standard UL-1574 (standard for track light systems) and Canadian Standards Association (CSA) Standard C22.2#250.570
- Monopoint and architectural products tested and certified under standard UL-1598 (standard for luminaires) and CSA Standard 22.2#250.0
- Recessed products separately tested and certified under standard UL-1598 (standard for luminaires) and CSA Standard 22.2#250.0

Testing Activities

Each certification test included a number of steps:

- Construction evaluation to ensure all elements of the design meet the standard
- Thermal testing under operation in varying configurations, with installed thermocouples to monitor operating temperatures throughout the device
- Mechanical load testing on luminaire to ensure adequate mechanical strength
- Electrical testing to ensure proper grounding and high-potential performance

Configurations Certified

A large number of product configurations were included in each certification. For example, within the track filing the following configurations were included:

- Nine different specific drivers and two generic driver types
- Six different track adapters
- Two different endcap types
- Five different length configurations
- Two different product tilt configurations
- Two different LED product lines
- Any stem length within a defined range

Manufacturing Development

Quality Management

This section describes the quality management system implemented at Glint through the RAMP program and its ongoing development. Progress on quality management system development was matching pace with production, which was scaled for low-volume manufacturing but ramping up as order volume grew.

Team

The RAMP program enabled Glint to expand the manufacturing operations team and bring in key personnel with relevant manufacturing experience to augment the executive team already in place at Glint. Appendix A includes salient background details for each new team member.

New Systems Support Quality Management

Glint established several software systems to support quality management of production operations.

Product data management was implemented with Solidworks PDM, a robust system tightly integrated with the primary mechanical design software for product revision control.

Document control management was implemented with Microsoft Sharepoint. Recent improvements in revision and access controls made it a practical solution for a business of Glint's scope and scale.

Manufacturing execution system (MES) was implemented with Lillyworks, a novel planning-focused shop floor system that was well-suited to Glint's theory of constraints approach to managing the wide product mix characteristic of the lighting industry.

Statistical process control (SPC) data was recorded as flat tables in Microsoft Excel, with plans to transition to an SQL database as the manufacturing operations matured. Data analysis and charting for SPC and measurement systems analysis was performed in Excel or MATLAB, with plans to develop more automated approaches for routine SPC programmed in a system such as R or SPSS with a move to an SPC database.

FMEA and design review by failure mode were standardized with templates and training from experienced consultants.

Standard Operating Procedures

Glint established 10 production-relevant standard operating procedures, including:

- Non-disclosure agreement management
- Supplier audit
- Purchase order management
- Materials receiving
- Production process
- Production in-line test
- Out-going quality assurance
- Shipping
- Labeling
- Corrective action process

The Glint staff documented the specific assembly and test processes related to the various Hero products and developed corresponding build travelers. The engineering staff at Glint was trained in all of the standard operating procedures, and the team conducted production training with all of the non-administrative staff.

Pilot Production

This section describes Glint's work identifying a contract manufacturing partner for initial fabrication of the Hero spotlight fixture, as called for in Glint's original plan, and the evolution of Glint's decision in the end not to work with a contract manufacturer for initial production but instead to pursue in-house assembly. Glint anticipates engaging a contract manufacturer in the future as sales volumes ramp up and the fabrication process matures.

Contract Manufacturers Considered

Glint identified seven contract manufacturers located in the San Francisco Bay Area and an additional six candidates outside the Bay Area that were considered to be good candidates for initial manufacturing of the Hero fixture. Almost all of these manufacturers had experience in small-batch fabrication of demanding luminaires or lighting elements, including custom fixtures for high-end retail customers.

Candidates were chosen with an emphasis on assuring high-quality outcomes rather than rock-bottom pricing. Glint focused on local manufacturing operations, despite the higher prevailing labor costs, because of the Bay Area's well-developed infrastructure for modest volume batch assembly and the proximity to company offices to enable the close supervision typically required for initial fabrication.

Contract Manufacturer Evaluation

Local Bay Area contract manufacturers were evaluated through on-site visits by Glint personnel; those outside the Bay Area were evaluated through video calls and discussions. In all cases Glint personnel were able to view operations and see examples of prior work. The evaluation focused on a number of key parameters: labor cost, manufacturing overhead, technical capabilities, and volume.

Labor Cost

Each contract manufacturer evaluated the fixture design and assembly process based on details provided by Glint and provided an estimate of the total assembly cost, with final numbers varying significantly.

Manufacturing Overhead

Manufacturing overhead included the turnkey pieces of component ordering, incoming quality assurance, part kitting, inventory management, and managing shipping and returned materials. Contract manufacturers quoted manufacturing overhead rates in the range of 10 percent to 30 percent.

Technical Capabilities

Glint queried contract manufacturers on their traceability systems. All had appropriate systems in place, ranging from travelers to barcodes to QR code labels. There was no added cost for traceability of manufactured assemblies, but requiring component traceability generally added to the manufacturing cost.

Glint also asked contract manufacturers about the availability of cleanroom spaces to ensure dust-free assembly of the optical systems in the luminaires. Only one contract manufacturer offered this capability, but all others were willing to consider installing necessary equipment with investment from Glint.

Volumes

Glint made inquiries of contract manufacturers about minimum order quantities and about how assembly costs and lead-times would scale with order quantity.

In general, the contract manufacturers operated by allocating an assembly area and dedicating staff to the project. This could have been configured to support a constant build rate over time, or a build campaign to deliver a certain volume of product in a certain window of time. Given the overhead in setting up the build campaign, the minimum practical order quantity would have been around 1,000 parts.

Final Decision for Pilot Production

In the end, Glint decided not to engage a contract manufacturer for initial production but to instead pursue this in-house. There were two main reasons for this decision.

The first reason was the anticipation that customer orders for the Hero product would be sporadic at first and grow over time at a rate that would be hard to predict. The first year of production was expected to be driven primarily by sporadic bursts of demand as the Hero product received individual project orders. This type of production would have been a poor fit to a contract manufacturer solution, as it would require small build campaigns executed on short notice. A build-to-inventory strategy was not a viable approach to address this, as the large number of product configurations available meant products would have to be built to order. As the sales pipeline grows over time, product demand will eventually reach a sufficiently consistent flow to enable successful transfer to a contract manufacturer.

The second reason to pursue initial in-house fabrication was to maximize learning by Glint's engineering and operations teams regarding the production fabrication process, sources of variability, and yield loss in fabrication, as well as approaches to improve the product design for assembly.

The team will likely look to engage a contract manufacturer in the future for volume manufacturing. This two-step plan allows Glint to transfer the process to a contract manufacturer after pursuing improvements that result from in-house production experience, and once the sales volumes provide a good fit for contract manufacturer operations. It would also allow Glint to transfer a more mature fabrication process to the contract manufacturer, greatly improving the likelihood of a successful transfer.

Pilot Line Certification

To label the Hero products as having passed safety certification testing, two types of certifications were required. The first was certification of the product itself, as described in a previous section in this chapter. The second was certification of the factory operations. This second certification is provided via a rigorous Initial Factory Assessment (IFA) inspection by a nationally recognized testing laboratory, followed by quarterly re-inspections.

The IFA of the assembly line for the Hero product fabrication was performed on February 26, 2021, by Eric Schultz of Intertek over the course of several hours at Glint's Burlingame, California facility. Various Glint personnel were present, both in-person and remotely via video call.

The following activities were part of the IFA assessment:

- Review of systems for quality control, including MES software, document control approach, assembly travelers, and standard operating procedures.
- Inspection of materials and components documentation, including the BOM and review of purchasing documentation for each component to ensure consistency with the construction that was approved at product certification.
- Physical inspection of materials and components, including verification of electrical ratings on components and performance of physical measurements of mechanical components.
- Review of incoming quality assessment procedures for parts, inventory control systems, and systems for segregating accepted versus unaccepted parts.
- Review of work instructions for product assembly, systems for record keeping, and production line testing procedures, including a live demonstration.
- Review and approval of product labeling.

The production line passed inspection with no issues identified. Approval was granted on the spot, including Authorization to Mark, which enabled placement of certification labels on fabricated luminaires for the first time (see Figure 11).

Re-inspections have been performed, as required, on a quarterly basis, generally as a surprise visit by the certifying official. All such re-inspections have been passed successfully with no issues identified.

Figure 11: First Luminaire Assembled after Passing IFA Certification

CHAPTER 3:
Project Results

This chapter presents the results of various processes of the Hero project and their energy-saving potential.

Quality Management Results

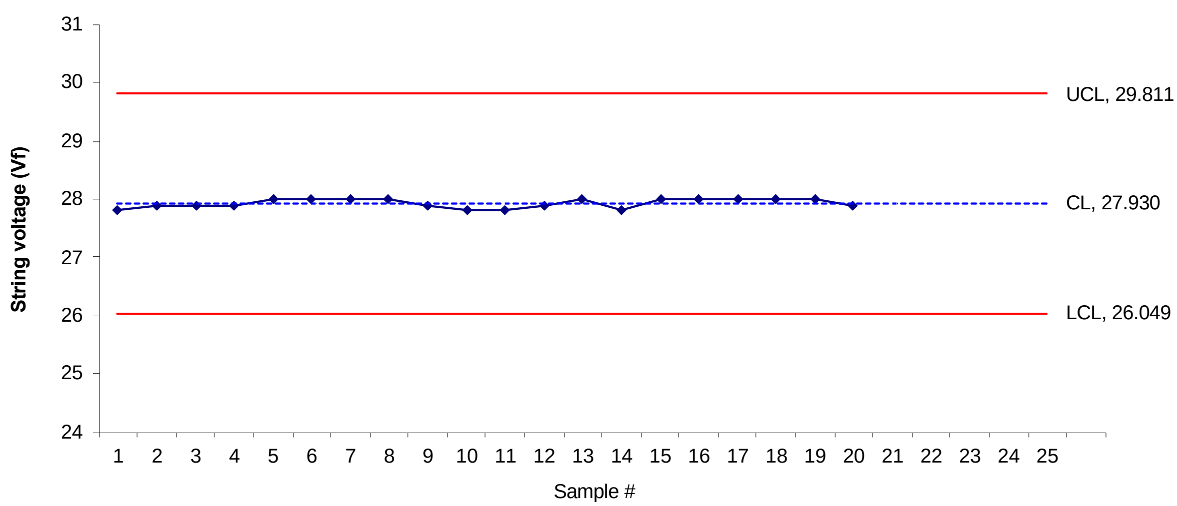
The Glint quality management system was effective for ensuring quality during initial low-volume manufacturing operations.

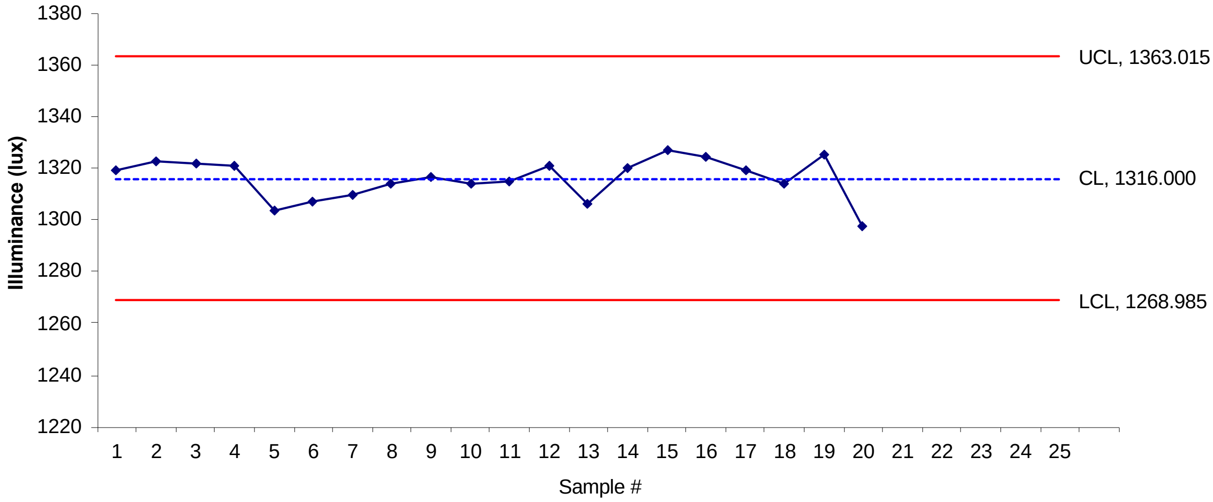
Glint successfully passed the initial factory assessment and quarterly inspection from Intertek, which audits quality assurance, materials handling, production process, testing, and labeling related to conformance to UL requirements.

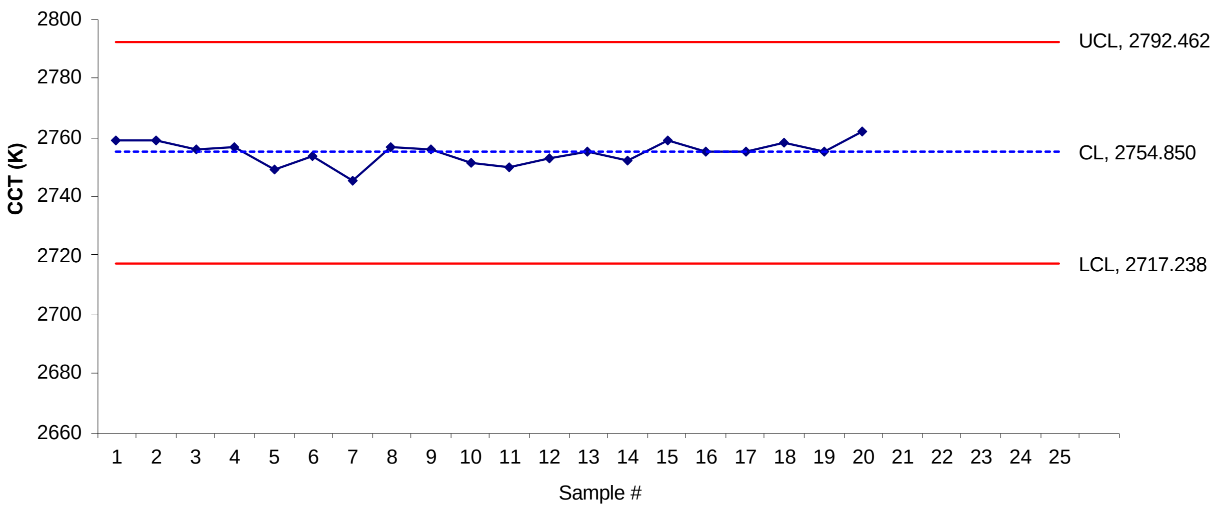
Glint saw highly capable SPC results from strategic parts suppliers for key performance indicators identified in the product FMEA, with a sampling of SPC results and charts for the very critical light engine assembly (LED circuit board) shown in Figure 12.

Figure 12: SPC Data for Hero Light Engines

Characteristic	String Voltage (V)	Illuminance (lux)	CCT (K)
Target	27.200	1320.000	2725.000
+ Tol	4.500	260.000	145.000
- Tol	3.000	260.000	145.000
USL-LSL	7.500	520.000	290.000
s	0.080	7.726	4.017
sest	0.051	6.206	3.593
Cp	24.355	13.966	13.453
Cpk	24.225	13.751	10.684
Pp	15.599	11.218	12.033
Ppk	15.516	11.046	9.556







Qualification Results

Glint executed two rounds of qualification for Hero in 2020: (1) an engineering qualification of Hero track fixtures assembled from production first article components tested according to a comprehensive qualification plan; and (2) a build of sales representative samples for the newly formed United States sales network. Qualification results successfully met all primary performance targets that were specified in product datasheets provided to customers, as summarized in Table 2.

Table 2: Key Performance Metrics versus Results Achieved in Qualification

Customer datasheet performance specifications		
	Target	**Qualification**
Light output (@3000K)	>1200 lumens	1260 lumens
Efficacy (@3000K)	≥50 lm/W	55 lm/W
Color rendering (@3000K)	≥90	96

Customer datasheet performance specifications		
	Target	**Qualification**
Beam width:		
very narrow beam	11° ± 3°	11°
narrow spot beam	15° ± 4°	14°
spot beam	22° ± 6°	21°
wide spot beam	35° ± 6°	34°
Adjustment range	≥40°	45°

lm/W = lumens per watt

Process Revisions

Some units failed in qualification for beam roundness, an internal performance specification not reported in product datasheets; subsequent serial production of samples for sales representatives confirmed the issue. The beam roundness issue was addressable via rework and manual tuning to enable shipment of samples, during which the root cause of the problem was diagnosed to two components out of specification and an unfavorable stack up of mechanical tolerances. A robust manufacturing solution was developed. The two components out of specification were corrected with the suppliers, and a moderate redesign was completed to greatly simplify the tolerance stack up; the solution was reviewed and rapidly prototyped and validated to bring beam roundness into specification. It is now in production with the associated supplier.

Two opportunities for yield and cycle-time improvement were identified in optics assembly and wire harness fabrication, prompting a revision to the standard work for Hero.

Painting the Hero enclosure was also finally resolved to satisfaction. Experiments with the high-volume painting facility resulted in a high-quality, cost-effective result for both standard black and white fixtures. Four local paint shops were also evaluated to service low-volume custom paint orders, which have been down-selected to two shops after an initial test round.

New Product Introduction Effectiveness

The new product introduction process was effective. The start of the Hero production met all key performance targets, reduced the cost entitlement for pilot production, and resulted in a shippable product.

The FMEA process was generally effective. Serious failure modes associated with basic lighting function were retired during development and resulted in meeting all key performance targets. The mechanical system that controls beam roundness (as well as other parameters) was identified early on as high risk, resulting in significant redesign activity before qualification and relatively modest revisions after qualification to meet all external and internal performance specifications.

The team identified opportunities to further improve analysis of the stack up of mechanical tolerances in complex systems and discussed changes to the design process to capture cost reduction opportunities earlier.

Pilot Line Performance

The pilot line at Glint included stations for inspection and quality assurance of incoming parts, storage of strategic materials and part inventories, dedicated areas for front- and back-end assembly, a clean bench for assembly of critical optical parts, and areas for in-line testing and for packaging. Manufacturing activities were managed through the Lillyworks MES software package. Engineering work was segregated from production builds to ensure the integrity of the production assembly process. At the time, Glint operated one assembly pod. Approximately 3,000 square feet were dedicated to production assembly and inventory space in the facility, capable of supporting a scaling to four pods as needed.

Figure 13: Various Glint Pilot Line Stations

Incoming quality assurance

Strategic materials

General inventory

Clean assembly

Front-end assembly

Back-end assembly

In-line test (hi-pot)

Lighting products are notorious for having enormous numbers of product variations or SKUs. Even the simple Hero product line encompasses tens of thousands of possible SKUs when considering the available options for correlated color temperature, beam width, enclosure design, enclosure color, driver type, and mounting options. Building each product to order from scratch would result in very long lead times. Instead, Glint adopted a modular architecture that provided significant SKU postponement. This included three levels of subassembly. The first was a mechanical core that contains all the mechanical elements for beam steering adjustment and is universal to all Hero products. The second was the complete core, which is a mechanical core with optics and an LED circuit board added. There were 16 possible complete core SKUs, of which about four make up the majority of order demand.

The final level of assembly was the finished product, in which the complete core was mounted into a shell of the desired color and configuration and equipped with the desired driver and mounting hardware.

Through the operation of the pilot line, Glint staff analyzed the cost and labor component at each level of subassembly. Approximately 60 percent of the BOM cost and a similar fraction of the labor component were embodied in the complete core. Therefore, these complete cores could be built and stocked in the high-demand configurations, ready for integration into shells as orders came in. This approach allowed rapid completion of finished goods to customer specifications as needed, with short lead times.

Cost of Goods

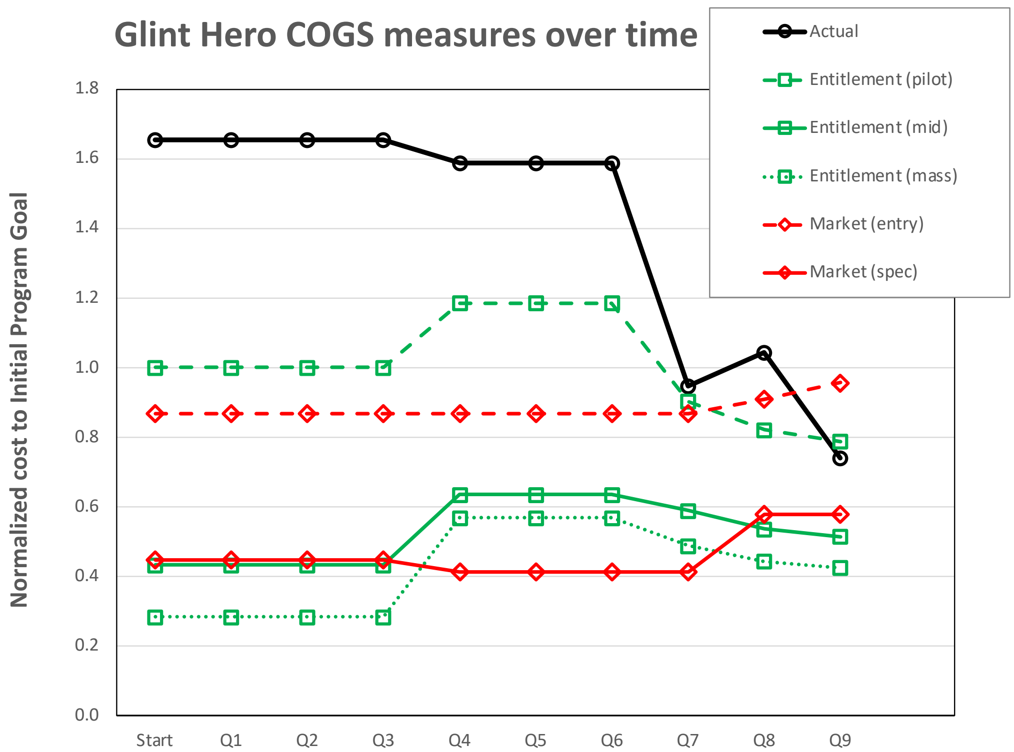
Glint made excellent progress on achieving cost of goods goals set at the beginning of the program, despite significant changes to the product design and cost headwinds from trade wars and supply chain disruptions.

Glint tracked its actual cost to manufacture, entitlement costs at low-volume pilot production, medium volume, and mass production based on a comprehensive cost model and cost targets based on market analysis. Figure 14 charts actual, entitlement, and market target costs by RAMP program quarter.

The market cost targets remained flat for most of the period, with the usual two percent to five percent price erosion of light fixtures offset by price increases due to trade wars and COVID-19. Market cost targets increased in Quarter 8 and Quarter 9 in part due to the rising cost of components, which drove price increases across the industry, and also in part due to an improved understanding of the market value of the Hero product on the basis of initial sales prices through Glint's network of sales agents.

The cost entitlements calculated from the cost model increased in Quarter 4 of the RAMP program, primarily due to realization of increased assembly time, design changes to improve performance and modularity for all Hero products, and COVID-19-related cost increases. The cost entitlement for mass production was overly optimistic at the start of the program and the gap between mid-volume and mass production cost entitlements narrowed over time, primarily because the first year of sales inquiries revealed that lighting designers specifying a high-end lighting product will truly demand a wide range of options; that is to say, production will entail a high mix of options and there was no clear high-volume runner to manufacture at mass scale.

Figure 14: Costs for Glint Hero Light Fixture



Cost entitlements were significantly improved in Quarter 7 through Quarter 9 as a result of investing in high-capacity tooling for key components where payback time was less than two years, increasing the number of batch processes, design for assembly improvements, and aggressive business negotiations with strategic suppliers.

The actual cost of goods fell substantially starting in Quarter 7, as Glint started building with production parts in serial production. Actual cost came to parity with the cost model entitlement for low-volume production as batch sizes increased in serial production and the operations team gained more experience.

Overall, the cost of goods results achieved through the RAMP program were excellent, with low-volume pilot production entitlement and actual costs dropping down to the market entry cost targets at the start of production, and long-term mass production entitlement costs meeting the required levels for broad success in the specification-grade lighting market.

Potential Energy-saving Benefits

Energy savings originate from several different characteristics of Glint luminaires:

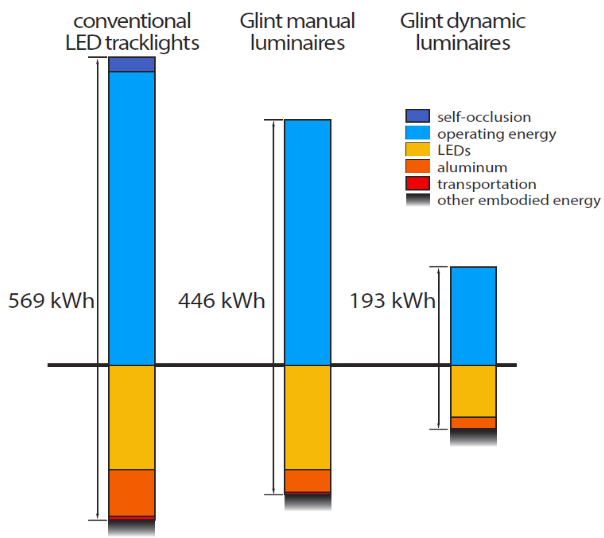
Reduced Self-occlusion

Gimbaled spotlights deployed in proximity (for example in a track system) can occlude each other, wasting light and creating glare. Pivoting lights that are recessed into an enclosure in the ceiling often spill light inside the enclosure when steered. Glint luminaire designs built on LightShift optics eliminated these loss mechanisms. The estimated energy savings are five percent on average.

Reduced Embodied Energy

Glint's analysis indicated that the embodied energy of a typical LED spotlight luminaire is equal to its energy draw over about 2.5 years of operation. This embodied energy is primarily from fabrication of the LEDs and the aluminum heatsink/enclosure. LightShift luminaires use less aluminum than conventional spotlights because the luminaire orientation is fixed so the heat-sink design can be optimized. Further, the ability to dynamically steer light where it is needed can reduce the number of luminaires installed since each is more flexible and capable. This results in substantial savings in embodied energy. (Figure 15).

Figure 15: Energy Benefit of Glint Hero Luminaires

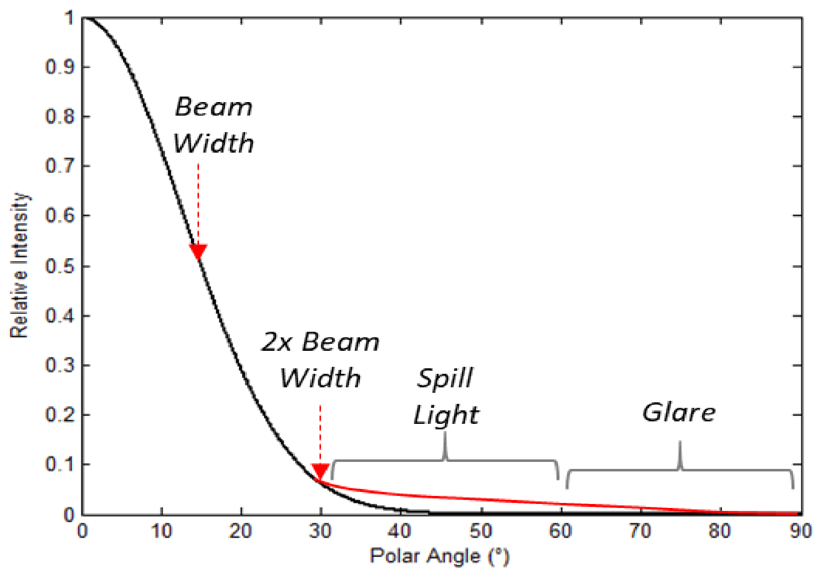


Improved Targeting

The potential for improved targeting arose from two related aspects of the novel optical platform of Glint luminaires. The first was the carefully tailored light distributions that are possible in a compact form from Glint's LightShift optics. Light is directed into a beam profile that provides aesthetically pleasing intensity roll-off while avoiding higher angle light that either does not contribute to the desired illuminance or is undesirable glare. The second was the new functionality of optical beam steering and spread, which allows effortless adjustment of the intensity distribution from installed luminaires without tools, additional optics, or disassembly of the luminaire.

The tailored static light distributions from Glint luminaires exploit the compact and novel LightShift optical platform. The intensity distribution from Glint luminaires was designed to provide aesthetically desirable beam profiles where the maximum possible amount of light is directed in useful directions, avoiding light spilled into higher angles and glare. Figure 16 depicts a gaussian beam, which is generally a desirable distribution for lighting designers and architects. The beam depicted has a 15-degree full-width half-max, known as the beam angle, a common narrow-spot beam angle. The intensity of the beam fell to below 10 percent of the center beam intensity by two times the beam angle, at which point the beam is not significantly contributing to desired illuminance on surfaces. Beam edges that are too abrupt are unappealing, but a gaussian spread where only approximately five percent of the light is emitted at angles greater than twice the beam width is gradual enough to be pleasing and blend well. The red line indicates a beam profile with excessive spill light and glare. Although the area beneath the red line appears small, because of the large solid angles that correspond to high polar angles, there is significant energy represented in the spill light and glare. Glint luminaires carefully diffuse an imaging optical system to provide a near gaussian edge of beam, minimizing both light spilled into higher angles that is not useful and undesirable glare.

Figure 16: Polar Beam Intensity Plot Comparing Gaussian Beam (black line) to Typical Luminaire Beam (red line)



The energy significance of this high angle spill light and glare is evident in Table 3, which depicts measured photometric data from a Hero adjustable luminaire compared with two competitor adjustable downlights. These competitor downlights boast "best in class efficacy," but efficacy is a metric that considers all light emitted from the luminaire, regardless of angle. As is clear in the table, significant light is emitted from both fixtures at the higher angles that would be considered spill light or glare. Despite these two adjustable narrow spots being top of class in their luminous efficacy, the actual lumens used per watt of the Hero fixture is 25 percent greater than LED downlight #1 and 87 percent greater than LED downlight #2. This advantage is even more impressive when considering that Hero delivered a narrower beam than the two competitors, as narrow beams are typically more challenging to deliver efficiently in a compact optical system.

Table 3: Utilized Luminous Efficacy Comparison of Hero versus Conventional Fixtures

	Beam Angle	Field Angle	% Lumens within 2x Beam Angle	Luminous Efficacy (Lm/W)	Utilized Luminous Efficacy (Lm/W)
LED Downlight #1	17	35	73%	82	60
LED Downlight #2	15	28	60%	67	40
Glint Hero	13	23	94%	80	75

The optical beam steering functionality of certain Glint luminaires affords additional energy savings by providing lighting designers and end users more control over the illuminance distribution in a lit space. This is true for manually re-aimed luminaires (like the Hero fixtures that reached commercial production in this RAMP program) as well as remotely adjustable motorized luminaires. The DOE Solid-State Lighting (SSL) roadmap estimates that up to three times the improvement in lighting use efficiency is theoretically possible through increased control over light distributions.[2,3]

A 20 percent reduction in illuminance of excessively lighted areas, a lumen contrast ratio that would be nearly imperceptible to most people, results in a 10 percent to 15 percent reduction in total lumens and concordant energy consumption. Thus, reasonable estimates for energy savings spans from 10 percent in a very conservative and simple installation, to 70 percent for advanced controllable networks of luminaires.

The extent and value of this potential energy savings can be calculated. Approximately half of the residential and commercial lighting market is addressable by some form of luminaire using Glint's novel optical approaches. Total energy savings of between 15 percent and 50 percent were estimated based on lumens used and including the benefits of improved luminaire efficacy, reduced self-occlusion, and improved targeting of light. This corresponded to a potential energy savings of 3.1 terrawatt-hours (TWh) to 10.2 TWh in California investor-owned utility territories, with associated equivalent avoided emissions of between 1 million and 3.4 million metric tons of carbon dioxide.[4] This energy savings potential represents a monetary value between $375 million and $1.2 billion dollars per year.

[2] U.S. Department of Energy. 2016. Solid-State Lighting Research and Development Plan.

[3] Tsao, J. Y. T., et al. "Toward Smart and Ultra-efficient Solid-State Lighting," *Advanced Optical Materials*, vol. 2, 2014.

[4] U.S. Department of Energy, Energy Efficiency and Renewable Energy. "LED Market Adoption: Status and Trends." November 2015.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

The lighting industry can be conservative in adopting new technologies, so technology and knowledge transfer activities were critical for promoting a new approach such as the one developed in this work. Furthermore, there are many influencers throughout the lighting sales chain that had to be considered. Specification-grade lighting products such as those manufactured by Glint are generally not sold through retail channels. Instead, the manufacturers were represented by local sales agents who promoted the company's products to lighting designers and architects within their territory. The lighting designers and architects typically specify the product for use in projects, and the product is ultimately purchased by a construction contractor and supplied through an electrical distributor.

To inform the broad commercial market and other potentially interested parties about Hero and its innovative technologies, the project results were shared with the lighting community through presentations at conferences, meetings, and tradeshows whose audiences included: (1) the lighting designers and architects who specify lighting fixtures; (2) other companies active in the lighting industry; (3) academic researchers in lighting and lighting technologies; and (4) government labs and funders of lighting research.

During the course of this program, Glint staff worked to develop a network of sales agents to promote the Hero product and secure product specifications in construction projects. This network consisted of premier lighting manufacturer representatives in most of the major territorial markets in the United States, and initial discussions with representatives in various overseas markets were also underway. Glint's marketing efforts to promote this technology included: (1) trade show presentations; (2) detailed training sessions with the sales agents; (3) product presentations to specifiers conducted through the sales agents; (4) participation in industry award competitions; and (5) some limited public advertisement.

Public Presentations

- Andrew Kim, "Lighting Product Design: A Modern Renaissance," LightSpec West, Los Angeles, September 21–22, 2022.
- Glint Lighting, Light! design expo, San Francisco, July 21, 2022
- Glint Lighting, Lightfair trade show, Las Vegas, June 21–23, 2022
- Glint Lighting, LEDucation trade show, New York City, March 15–16, 2022
- Andrew Kim, "Light Extraction," DOE SSL R&D Workshop 2020, San Diego, January 29, 2020
- Peter Kozodoy, panel presentation, "Building Design with Innovation in Mind: Efficiency as a Secondary Benefit," California Energy Commission Electric Program Investment Charge, Reimagining Buildings for a Carbon-Neutral Future, virtual forum, September 3, 2020

- Peter Kozodoy, "Transforming Directional Lighting," Energy Commission Technology Showcase, Sacramento, October 25, 2019
- Glint Lighting, Light! design expo, San Francisco, July 11, 2019
- Glint Lighting, Lightfair trade show, Philadelphia, May 21–23, 2019

Government Presentations

- Peter Kozodoy, "Rethinking Optical Tradeoffs in Directional Lighting," DOE SSL R&D Workshop, virtual forum, September 7, 2021
- Peter Kozodoy, "Transforming Directional Lighting," Energy Commission Review, Sacramento, December 9, 2019

Press Coverage (selected)

- "LEDucation's Very Successful Day 1," EdisonReport, March 16, 2020. Accessible at: https://edisonreport.com/2022/03/16/lightpitch-at-leducation-2/
- "Here Are the 2020 LightFair Innovation Award Winners," Inside Lighting, May 15, 2020. Accessible at: https://inside.lighting/news/20v/here-are-the-2020-lfi-innovation-award-winners
- "Department of Energy Grants $200K to Six SSL Tech Companies," Inside Lighting, May 22, 2020. Accessible at: https://inside.lighting/news/20v/doe-grants-200k-6-ssl-tech-companies
- Maury Wright, "Luminaires Evolve Beyond Legacy Form, Leverage LED Advancements," LEDs Magazine, June 10, 2020. Accessible at: https://www.ledsmagazine.com/architectural-lighting/article/14177269/luminaires-evolve-beyond-legacy-form-leverage-led-advancements-magazine
- "Glint Lighting Launches Hero, Builds Agent Network," Electrical News, n.d. Accessible at: https://electricalnews.com/glint-lighting-launches-hero-builds-agent-network/
- "Best Lighting Products of 2020," Architectural Record, December 1, 2020. Accessible at: https://www.architecturalrecord.com/articles/14889-best-lighting-products-of-2020
- "Glint Adds New Monopoint and Architectural Luminaires to the Award-Winning Hero Family," Electrical News, n.d. Accessible at: https://electricalnews.com/glint-adds-new-monopoint-and-architectural-luminaires-to-the-award-winning-hero-family/
- Wanda Lau, "Profiles in Lighting: Glint Lighting," LEDs Magazine, September 2, 2022. Accessible at: https://www.ledsmagazine.com/architectural-lighting/article/14280526/profiles-in-lighting-glint-lighting

Awards

Hero has won many product awards, both within the lighting industry and for general product design. These are listed below:

- 2018 IES Progress Report Selection
- 2020 German Innovation Award (Gold)
- 2020 LIT Lighting Design Award

- 2020 LEDs Magazine Sapphire Award
- 2020 Design Excellence Award from Lightfair
- 2020 Design Plus Award from Light + Building
- 2020 Best Product Award from Architectural Record
- 2020 IDA Silver Award Winner
- 2020 International Design Excellence Award
- 2020 Good Design Lighting Award
- 2020 SPARK Platinum Award
- 2021 Red Dot Award
- 2021 iF Product Design Award

Sales Agencies

At the time of writing, Glint had contracted with more than 30 different sales agencies with sales territories that include almost all areas of the United States and some areas of Canada. A current list of sales agencies representing Glint products and actively promoting the Hero fixture may be accessed at the company website: http://www.glintlighting.com.

Installations

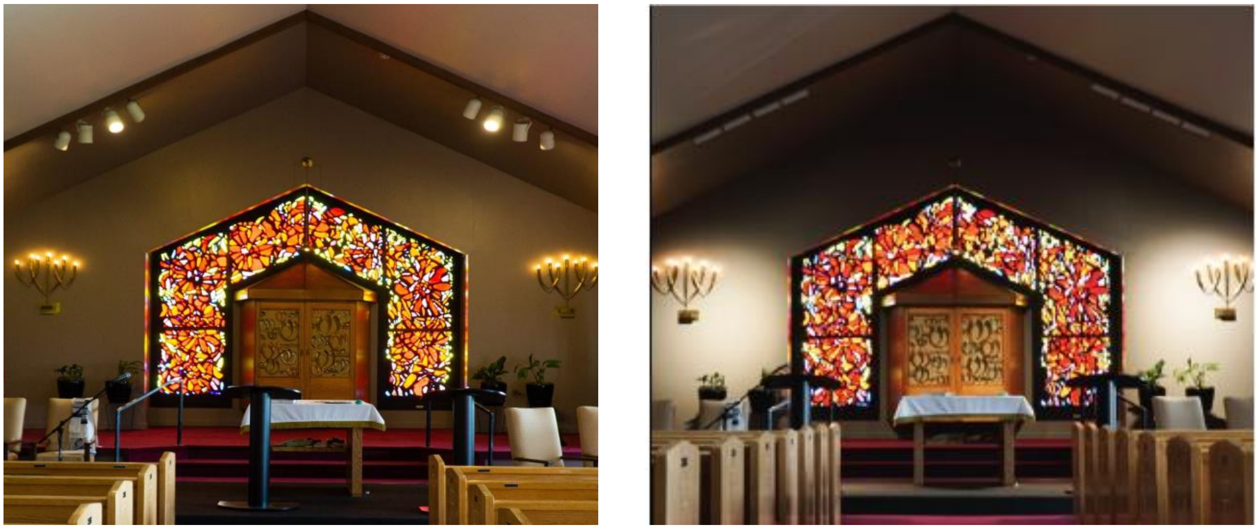
Since their initial market introduction, Hero fixtures have been installed by customers in numerous installations around the United States and beyond. Three early installations that demonstrate the versatility, performance benefits, and design advantages provided by the fixture are highlighted here.

Temple Israel, Alameda, California

This installation provides a great example of Hero's benefits on sloped ceilings, as found in many houses of worship. Hero fixtures replaced conventional track lights mounted on the ceiling. The original lights were large and unsightly, created significant glare for the conger-gation members, and provided poorly focused light resulting in a washed-out appearance.

The Hero fixtures sit snugly against the sloped ceiling, providing a greatly reduced visual impact that helps restore the architectural intent of the space. The glare light shining into the congregation was eliminated, and the clean focused beams provide dramatic lighting of the stage area (Figure 17).

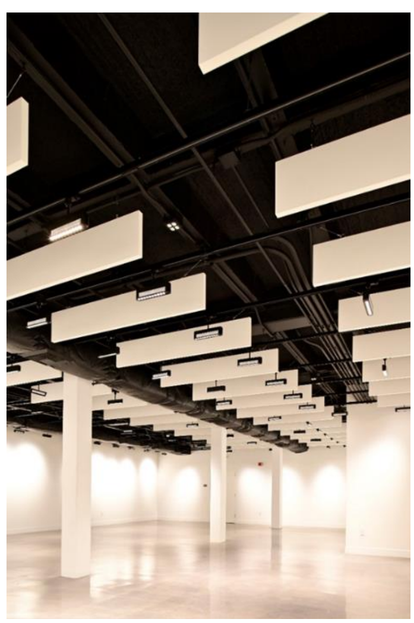
Figure 17: Temple Israel in Alameda, California before (left) and after (right) Retrofit with Hero Fixtures



Barnum Hall Gallery, Santa Monica, California

This newly constructed gallery and cultural center houses changing art displays. Movable partitions allow the room to be configured in multiple ways, so the light fixtures must be flexible and easy to adjust. The architectural design features hanging white acoustical panels, and the lighting fixtures could not protrude below the bottom of the panels. With conventional gimbaled fixtures, this arrangement would have resulted in bright spots whenever fixtures were aimed up as beam edges would strike the acoustical panels. Hero fixtures provided a unique solution, with a fixed front face and unchanging glare cutoffs that prevent stray light from striking the panels, even as the beams are aimed around the room as needed. Ninety-seven Hero fixtures were installed in this gallery (Figure 18).

Figure 18: Barnum Hall Gallery in Santa Monica, California



21 Moorfields, London, United Kingdom

21 Moorfields is a large office building located in the center of London. The ground floor houses retail stores and there is an underground station located below the building. The building features a bold lattice of steel girders backed by a glass façade. The design calls for narrow beams of light along the glass façade behind each girder, backlighting the girders at night. This was a challenging lighting design, requiring tailored narrow beams and precision control of fixture placement and aiming in an inaccessible location. The original design developed by the construction team included custom fixture development and complex articulated brackets to hold the fixtures. This design was determined to be infeasible, both because of the difficulty in developing the custom fixtures and because the cantilevered articulated brackets could not be relied upon to keep the beam aiming steady and withstand vibration and slippage on the building façade.

The unique properties of Hero fixtures made them the perfect solution for this lighting challenge. Hero's beam aiming capability eliminated the need for adjustable brackets, allowing the use of well-braced stationary brackets with beam aiming controlled from the fixture. The integrated steering lock on the Hero fixture prevents the beam from wandering once aiming is set. Glint's LightShift optics provide the tailored narrow-beam profile required in the project.

Glint shipped 86 Hero fixtures to light the façade and mezzanine of 21 Moorfields. At the time of writing, the building construction was nearing completion (Figure 19).

Figure 19: 21 Moorfields in London (architect's rendering)

CHAPTER 5: Benefits to Ratepayers

This project supported the EPIC goals of lower costs, increased safety, and greater reliability by advancing more precise and adaptable illumination in occupied spaces in California and working to increase the adoption rate for efficient, long-lasting, LED-based luminaires. The project developed a valuable new lighting technology. As commercial sales of this technology are still at low initial levels, the analysis presented here estimates the potential long-term energy and cost savings opportunity, assuming eventual widespread adoption of the Hero product and related products on Glint's product roadmap that draw from the same fundamental technology platform. These include remotely adjustable fixtures, such as the motorized Hero fixture that Glint developed in parallel with the activities described in this report through a complementary grant from the Energy Commission BRIDGE program. Such fixtures offer the potential for automated lighting systems that dynamically re-aim in response to changing room use, placing light wherever it is needed at any given moment. Other related fixture products on the Glint product roadmap include adjustable spotlights of various form factors and scales, as well as static fixtures with highly precise and/or bespoke tailored illumination patterns.

Every lit space has an illumination objective function that lighting designers, facilities managers, and occupants strive to achieve. The illumination objective function is specific to every lit space, and it is naturally a function of both time and space, as the occupation and use of spaces change on multiple timescales. Any mismatch between actual illumination and the illumination objective function has undesirable costs to occupants and ratepayers. Insufficient illumination reduces the productivity and effectiveness of lit spaces and potentially poses a safety hazard to occupants. Excessive illumination is wasted electrical generation with all the associated economic and environmental costs of generation and distribution.

Glint's novel optical platforms and LED luminaires offer the possibility of a better match between lighting requirements and light output. This is achieved by the development of previously lacking functionality in LED luminaires including effortless control over beam aiming and spread, as well as through tailored beam distributions that make more efficient use of generated light. This functionality affords a better match between the desired illumination in a lit space and the light generated, resulting in an increase in end-use energy efficiency, productivity, and safety in lit spaces. Furthermore, the increased value proposition will promote more rapid market adoption of energy-efficient LED-based lighting, offering additional energy savings when replacing older sources.

Quantitative Estimates of Potential Benefits to California Investor-Owned Utility Ratepayers

Energy savings originate from several different characteristics of Glint luminaires:

Reduced Self-occlusion

Gimbaled spotlights deployed in proximity (for example in a track system) can occlude each other, wasting light and creating glare. Pivoting lights that are recessed into an enclosure in the ceiling will often spill light inside the enclosure when steered. Glint luminaire designs built on LightShift optics eliminate these loss mechanisms. The estimated energy savings are five percent on average.

Reduced Embodied Energy

Glint's analysis indicates that the embodied energy of a typical LED spotlight luminaire is equal to its energy draw over about 2.5 years of operation. This embodied energy is primarily from fabrication of the LEDs and the aluminum heatsink/enclosure. LightShift luminaires use less aluminum than conventional spotlights because the luminaire orientation is fixed so the heat-sink design can be optimized. Further, the ability to dynamically steer light where it is needed can reduce the number of luminaires installed since each is more flexible and capable. This results in substantial savings in embodied energy.

Improved Targeting

The actual lumens used per watt of the Hero fixture was 25 percent and 87 percent greater, respectively, than two of its primary LED competitors.

The DOE SSL roadmap estimates that up to three times an improvement in lighting utilization efficiency is theoretically possible through increased control over light distributions.[5,6]

A 20 percent reduction in illuminance of excessively lighted areas, a lumen contrast ratio that would be nearly imperceptible to most people, results in a 10 percent to 15 percent reduction in total lumens and concordant energy consumption. Thus, reasonable estimates for energy savings span from 10 percent in a very conservative and simple installation to 70 percent for advanced controllable networks of luminaires.

The extent and value of this potential energy savings can be calculated. Approximately half of the residential and commercial lighting market is addressable by some form of luminaire utilizing Glint's novel optical approaches. Total energy savings of 15 percent to 50 percent are estimated based on lumens used and including the benefits of improved luminaire efficacy, reduced self-occlusion, and improved targeting of light. This corresponds to a potential energy savings of between 3.1 and 10.2 terrawatt-hours in California investor-owned territories, with associated equivalent avoided emissions of between 1 million and 3.4 million metric tons of

[5] U.S. Department of Energy. 2016. Solid-State Lighting Research and Development Plan.

[6] Tsao, J. Y. T., et al. "Toward Smart and Ultra-efficient Solid-State Lighting." *Advanced Optical Materials*, vol. 2, 2014.

carbon dioxide.[7] This energy savings potential represents a monetary value between $375 million and $1.2 billion dollars per year.

Qualitative Benefits to California Investor-Owned Utility Ratepayers

The primary initial markets that benefit from the enhanced capabilities and aesthetics of the Hero fixture and other Glint luminaires are directional lighting for retail, hospitality, architectural, gallery, and high-end residential spaces. With continued development of the Hero product line and proliferation of related products, costs can be driven down, and the value of the realizable energy and cost savings will eventually bring value to mass-market office and residential applications as well.

Hero fixtures offer a number of significant qualitative benefits.

Reduced Glare

Conventional adjustable lights create unpleasant glare when pivoted upward to aim the beams. In contrast, the LightShift optics in Hero mean that the beam can be aimed independent of the fixture face, and glare cutoffs remain stationary rather than pivoting upward.

Further, Hero is designed to be uniquely low-glare through the use of backward-firing LEDs, integrated glare baffles, and the latest low-reflectance optical materials technology.

Easier Installation

Conventional adjustable lights must pivot to aim the beam. For recessed fixtures, this requirement typically results in the need for large enclosures to accommodate the moving fixture. Complex recessed coves are often constructed to house an array of adjustable fixtures. Installing adjustable fixtures on sloped ceilings is particularly difficult and can require large cutouts in the ceiling.

In contrast, Hero can be installed simply on any ceiling surface, either pendant on stems, flush mounted, or recessed into the ceiling. Because the fixture itself never tilts to aim the beam, all the complexity of conventional recessed fixture installations is avoided. The compact housing and simple installation gracefully accommodate even narrow plenums, and the stationary nature of the fixture prevents light loss from beam clipping.

Improved Aesthetics

Pivoting fixtures facing in multiple different directions create a distracting and disorderly appearance that detracts from the architectural design of interior spaces. Gimbaled round fixtures disrupt the clean lines of modern room design. Chaotic visuals and accompanying glare that are present in the peripheral vision of room occupants can activate basic threat response pathways in the nervous system. In contrast, Hero helps realize the architectural intent of interior design. Hero fixtures install in orderly lines and disappear into narrow slots or between ceiling slats yet can still aim their beams wherever light is needed.

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[7] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. "LED Market Adoption: Status and Trends." November 2015.

Potential for Job Growth

Finally, this RAMP program has been pivotal in establishing Glint as a commercial manufacturing company. With rapid sales growth for an innovative product, Glint expects to undergo substantial company expansion in the coming years. Glint's California-based design and manufacturing will contribute to job growth and the retention of local manufacturing and fabrication capabilities in an industry that is otherwise rapidly off-shoring most production.

CHAPTER 7: Conclusions

Project Outcomes

This project successfully achieved its targets in support of California's goals to promote energy- and cost-saving opportunities. The Hero fixture was matured from a demonstration prototype into a fully developed product available on the commercial market. Hero is a family of products, with four different mounting types and a plethora of different product configurations available. The products met all the performance specifications that were targeted during their development. They passed all relevant safety and performance certifications. The striking design and unique capabilities of the Hero fixture led it to sweep nearly every available award within the lighting industry and for general product design. Initial installations completed by paying customers demonstrate that the Hero fixtures provide the intended benefits compared to conventional fixtures in improved lighting quality and targeting, lower glare, better visual harmony with the architecture, and easier, more flexible, installation.

The work described in this report has also transformed Glint as an organization. At the start of the RAMP program, Glint was a research and development organization, with a strong engineering team but without any manufacturing capability or commercial product sales. In the course of this project, Glint built its experience in product design through design failure mode and effect analysis (DFMEA), DFM, and DFA methodologies. The team brought in supply chain expertise and developed a network of trusted vendors and the processes and tools with which to manage its supply chain. Rather than relying on outside contract manufacturers, Glint built up its in-house assembly operation, including the associated staffing, controls, inventory management, MES software, and other processes. Finally, the development of this first commercial product line enabled Glint to develop a robust sales and marketing effort, including contract agreements with many sales agents to represent Glint products throughout the country and internationally. Glint's product sales are growing rapidly. The company continues to pursue research and development activities to continue advancing next-generation lighting products, but this work now occurs in parallel with a growing commercial manufacturing and sales activity.

These outcomes, for the Hero product and for Glint, would have been much more difficult to achieve without the RAMP funding. The program has positioned Glint as a successful and growing manufacturer in California, and a recognized technology leader in advancing the design and performance of solid-state lighting.

Product Impact

Because product sales have only recently begun and are still at a relatively low volume, it is too early to make any assessment of the overall impact of the Hero product or LightShift optics in terms of energy usage or lighting quality. However, there are a number of impacts that can be identified although commercial activity is at an early stage.

First, it is clear that Hero has solved real problems for its early customers, delivering improved lighting outcomes and installation flexibility in applications as diverse as galleries, corporate lobbies, building facades, and houses of worship. Growing sales, along with the many product awards, speak to the traction that the product has achieved within the lighting community.

Second, Glint's work on LightShift optics and products helped to catalyze a growing focus on beam manipulation and lighting application efficiency, both within lighting research and among other manufacturers. These topics were rarely featured in industry or DOE conferences in the past, but now receive consistent attention. Lighting application efficiency remains the largest opportunity for energy savings in solid-state lighting, and at the same time can deliver an improved experience to building occupants. This win-win makes it a natural focus for the lighting community, and Glint is proud to have played some role in bringing attention to the topic.

Third, Glint's work on developing and commercializing Hero has led to the identification within the company of multiple new product opportunities that build on LightShift optics and related approaches. These are the outcome of detailed discussions with customers, sales agents, and other lighting industry players and come from the development of Glint into an active manufacturer and supplier of lighting products. These opportunities will inform Glint's product development roadmap going forward. They provide a mechanism to broaden the overall impact of Glint's work by solving more customer problems and bringing the company's energy-saving and lighting-quality approach into more application areas so that it can have the greatest impact.

Follow-on Activities

The development of the Hero product and associated manufacturing capability documented in this report will directly enable several planned follow-on activities.

The first is further proliferation of the Hero product line to fill out the many different configurations called for in lighting projects. Planned proliferations include products at different lengths and total power levels, products for outdoor use, products for specific mounting configurations, and more.

The second is further development of remotely adjustable automated Hero products. These were prototyped through an Energy Commission BRIDGE program that was carried out in parallel with this RAMP program. The LightShift optical design naturally enables high-reliability, low-cost automation since the beam can be aimed simply through small in-plane motion of a lightweight optic, rather than requiring pivoting of the entire heavy fixture. Automated Hero designs replace the joystick with a pair of motors that drive the motion of the optics and a Bluetooth wireless control system to control them. Remotely adjustable fixtures are a natural fit for high-ceiling spaces and multi-purpose rooms where multiple lighting configurations are desired. They provide the opportunity for greatly enhanced energy savings through routine adjustment of the lighting pattern to suit changing needs within a space. In the long-term, such fixtures could be paired with sensors that automatically detect changing room use and independently determine and implement optimized lighting patterns, turning lighting into a dynamic, user-focused, energy- and cost-saving experience rather than a static element of the built environment.

A third area of follow-on product work at Glint is the use of LightShift optics to generate complex beam patterns in static configurations. This is achieved by aiming different elements of a LightShift optical array in different directions, effectively building up a complex illumination pattern from an array of individually aimed mini spotlights. Such configurations can provide precisely tailored lighting distributions, such as lighting a winding pedestrian pathway by aiming light to precisely follow the curving path, thus preventing the wasted light produced by conventional lamps that would fall, for example, onto the surrounding bushes. Glint is currently pursuing the development of prototype configurable outdoor fixtures using this approach.

These examples represent both research areas and future products on Glint's product roadmap. They will be part of the large portfolio of products planned at Glint, all embodying the company's focus on precision light management with innovative optics to deliver improvements not only in lighting quality and installation flexibility, but also in reduced energy usage and consequent cost savings that support California's energy goals.

LIST OF ACRONYMS

Term	Definition
ARPA-E	Advanced Research Projects Agency for Energy
BOM	bill of materials
BRIDGE	Bringing Rapid Innovation Development to Green Energy
CSA	Canadian Standards Association
DFA	design for assembly
DFM	design for manufacturing
DFMEA	design failure mode and effect analysis
DOE	United States Department of Energy
EPIC	Electric Program Investment Charge
FMEA	failure mode and effect analysis
IFA	initial factory assessment
K	kelvin
LED	light emitting diode
mm	millimeter
MES	manufacturing execution system
RAMP	Realizing Accelerated Manufacturing and Production
SKU	stock keeping unit
SPC	statistical process control
SSL	Solid-state lighting
TWh	terawatt-hours
UL	Underwriters Laboratories

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CALIFORNIA
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NATURAL
RESOURCES
AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A:
Manufacturing Operations Team

Month Year | CEC-500-2024-002

APPENDIX A:
Manufacturing Operations Team

Bob Gardner contributed to the development of a product manufacturing plan as a consultant at Glint. Bob is an expert in new product introduction, with more than 25 years of organizational leadership in strategic planning, research, product development, and manufacturing transfer of volume products at companies including Hewlett Packard, Semrock, and Lunera Lighting. Bob holds a BS in Mechanical Engineering from Rice University and a SM degree from the Massachusetts Institute of Technology.

Patrick Freeburger served for several years as Glint's Director of Supply Chain and helped to establish many key supplier relationships. Patrick brought deep experience in procurement and sourcing from a long career at Emcore, Lumileds, Spansion, and other companies. Patrick has a BA degree from the University of Minnesota and a MS from Arizona State. He also has military experience as a Lieutenant Colonel in the US Army.

Ken Morrison joined the team to replace Patrick Freeburger and take over as Director of Supply Chain and Manufacturing. Ken has deep experience in supply chain planning, and yield and throughput improvement, practiced at National Semiconductor, Micrel, Intersil, Lumileds, Global Foundries, and Emcore. Ken has a BS degree in Physics from the University of Strathclyde and an MBA degree from Glasgow University.

Dennis Henderson joined the team as Production Engineer. Dennis has extensive experience in product engineering, manufacturing, and supplier management including roles at Sun Microsystems, Cisco Systems, Symantec, and Dell.

Telina Page joined the team as Purchasing Manager. Telina has a wide range of procurement and supply chain experience practiced at numerous Silicon Valley companies including Western Digital, Lumileds, glo-USA, and Adept Technology (acquired by Omron).