New York State Greenhouse Technology Research, Outreach, and Education

NYSERDA
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New York State Greenhouse Technology Research, Outreach, and Education

Final Report

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Abstract

This report describes the impacts on horticultural research, engineering, technology adoption, education and workforce development, and industry trends that the New York State Greenhouse Technology Research, Outreach, and Education project achieved from 2017 - 2026. To guide the program's mission to advance energy efficient lighting and climate control in greenhouse production systems, Cornell University, Rensselaer Polytechnic Institute (RPI), and Rutgers University executed a project with 350 technical milestones spanning energy efficient LED systems, plant sensing, carbon dioxide enrichment, controls integration, energy modeling, and pilot implementation. The project was guided by feedback from a three-member Scientific Advisory Board of academics and scientific research consultants. The Greenhouse Lighting and Systems Engineering (GLASE) consortium housed at Cornell University facilitated an Industry Advisory Board and shared credible knowledge with the public on glase.org and via technical articles, webinars, short courses, conferences, and an online classroom. GLASE continues to expand understanding of greenhouse technology, develop the greenhouse industry workforce, and inspire young people to pursue careers in agriculture.

Keywords

Greenhouse, controlled environment agriculture, lighting, light emitting diodes, climate control, automation, energy efficiency

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Acronyms and Abbreviations

DLI	day light integral
ft	feet
kWh	kilowatt hours
m/s	meters per second
MW	megawatts
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
W	watts

Executive Summary

For ten years (2017—2026), the Greenhouse Lighting and Systems Engineering (GLASE) consortium has advanced the controlled environment agriculture industry through research, pilot demonstrations, engineering tool development, and broad-based outreach and training. With funding support from NYSERDA and additional support from the federal government, philanthropic foundations, and industry membership, GLASE has engaged academic partners, growers, and technology developers to improve energy efficiency, productivity, and sustainability in commercial greenhouse operations.

Key technical accomplishments include the validation of CO_2-responsive lighting control software (Lighting and Shade System Implementation, LASSI) called "CO_2 LASSI", which showed measurable gains in yield and energy use efficiency for crops like tomatoes and strawberries. Engineering and modeling efforts led to major enhancements in simulation tools such as Virtual Grower, enabling more dynamic and cost-optimized control strategies. Pilot studies in diverse commercial greenhouse facilities confirmed that advanced lighting controls like Daily Light Integral (DLI) controls can reduce energy consumption without compromising crop performance.

GLASE also became a recognized leader in industry outreach and extension, stakeholder engagement, and workforce development. GLASE outreach initiatives, including webinars, short courses, Summits, and a comprehensive website, reach thousands of controlled environment agriculture professionals each year and drive adoption of new technologies and best practices. Educational programming continues to expand with a new "CEA Works" set of courses which deliver credible training for growers and CEA business professionals.

Despite external challenges in the indoor farming and greenhouse sectors of the CEA industry, GLASE has maintained industry relevance. Updates to the GLASE financial sustainability strategy and consortium governance structure have positioned the consortium for long-term success despite a dynamic and sometimes volatile federal funding landscape. Looking forward, continued investment in workforce development, integrated control research with technology manufacturers and commercial growers, and market-driven modeling tools will be critical to sustaining progress and scaling impact across New York's rapidly evolving greenhouse sector.

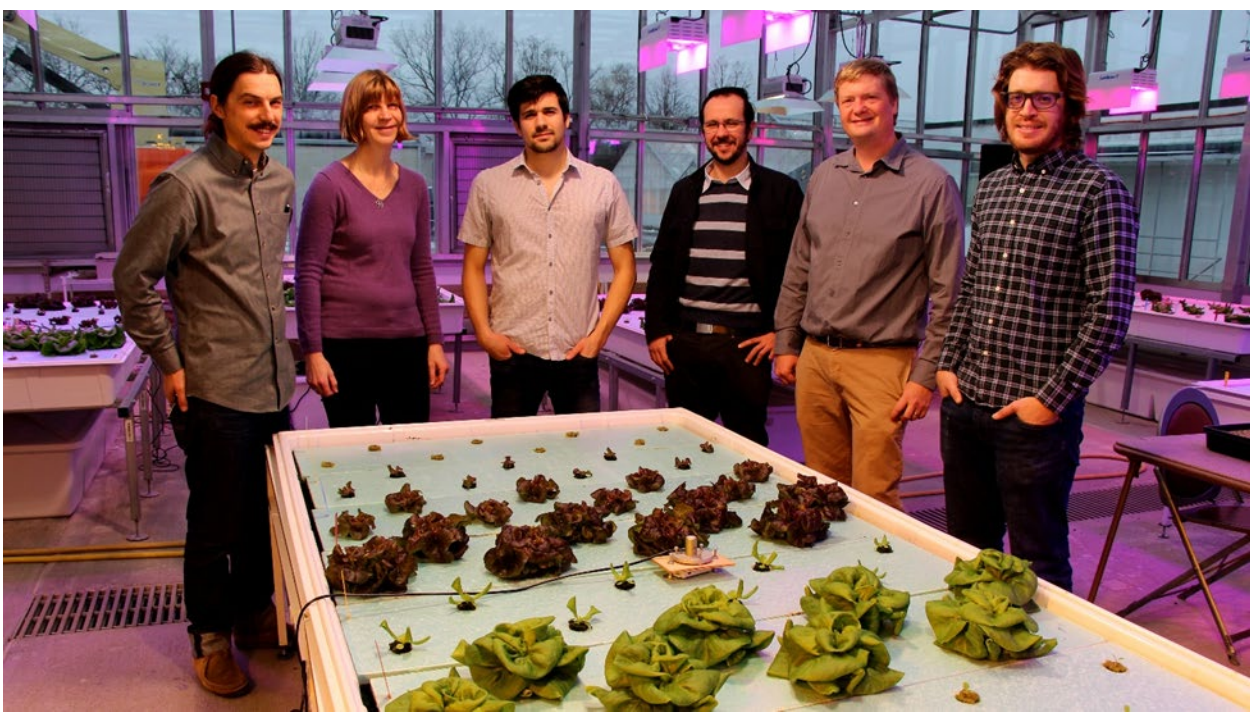
1. Introduction

GLASE began in 2017 with the establishment of a multi-institutional consortium and early-stage planning. By 2018, foundational work in energy modeling and LED lighting systems was underway. From 2019 to 2021, the team developed and tested LASSI lighting algorithms, initiated greenhouse trials, and began work on CO_2 enrichment strategies. In parallel, the project expanded outreach with webinars and launched pilot demonstrations at commercial sites. Between 2022 and 2024, GLASE matured operationally by receiving grant awards from the USDA and Mother Cabrini Foundation, launching new workforce development and research projects, refining its membership model, and expanding training with virtual short courses. In 2025, the consortium completed LASSI pilot installations and launched the CEA Works bundle of short courses on the Teachable online platform. In 2026, GLASE is focused on executing the Empowering Greenhouse Resiliency with an Optimized Workforce (E-GROW) project. The consortium remains focused on long-term sustainability, commercialization, and workforce training.

Figure 1. GLASE Staff in the Cornell University Greenhouses, 2019

Right to left: Nicholas Kazmar, Elsebeth Kolmos, Jonathan (Allred) Karall, Erico Mattos, Neil Mattson, and Jake Holley.

Cornell University photo



2. Technology Transfer

GLASE research, education, and workforce development has transformed the greenhouse industry since 2017 via the New York Greenhouse Technology Research, Outreach, and Education project. Market transformation efforts by GLASE have accelerated the commercialization and adoption of innovative LED horticultural lighting and lighting controls products for greenhouses and indoor farms CEA industry. GLASE contributions produced for this project and through other grant-funded research and workforce development projects demonstrate the value of energy efficiency, energy management, and high-performance technologies to save growers money, reduce utility bills, and lower greenhouse gas emissions from CEA farms.

GLASE, as an industry organization, has transformed the CEA market by teaching key stakeholders about innovative greenhouse technology and incentivizing grower adoption of efficient systems.

- GLASE is a recognized brand providing the public with credible training based in real research at academic and commercial greenhouses.
- Implementers of energy efficiency programs leverage GLASE resources for their program design and implementation.
- Students and professionals learn and network with GLASE online and at in-person industry events.

In 2026, two technologies (LED horticultural lighting and automated lighting controls) are more widely adopted than they were in 2017. Neither are industry standard practice in New York State, but both have seen accelerated adoption since GLASE began researching greenhouse technology and educating the CEA industry.

The DesignLights Consortium's Qualified Products Library for horticultural lighting now has nearly 1,500 certified products by over 150 manufacturers; it is estimated to represent around 90% of the non-residential horticultural lighting market. The need for third-party validation of manufacturer performance data has been satisfied by the technical requirements which are now in Version 4.0. Since the implementation of DLC's first technical requirements for horticultural lighting, the average efficacy of listed products has increased by 25%.

Figure 2. LED Supplemental Horticultural Lighting in a Cucumber Greenhouse, 2023

Light fixtures at the Horteca Greenhouse in Leamington, Ontario use integrated and automated lighting controls to maintain a target setpoint for Daily Light Integral.

GLASE photo

Awareness and trust of automated greenhouse lighting systems have increased substantially across North America and in New York. Larger growers commonly use integrated control systems to manage greenhouse heating, ventilation, and lighting systems. However, many smaller growers and some larger growers do not implement spectral tuning or daily light integral controls. Greenhouse automation hardware and software vendors offer some intelligent algorithms for lighting (including dimming and spectral tuning), adoption of LASSI in its various forms is low. Field demonstrations researching Basic, CO_2, and Real-Time LASSI in six commercial greenhouses in New York found diverse benefits for floriculture and food greenhouses including better control of light, increased crop quality, and reductions in energy for lighting when not needed.

3. Statewide Annual Benefits

Over the past decade, New York State has experienced significant growth in controlled environment agriculture, including greenhouse and indoor farm operations. In New York, early investments such as the NYSERDA-supported launch of the GLASE consortium have contributed to steady progress in areas like horticultural lighting, climate control, and data-driven management systems aimed at improving sustainability and resource efficiency. Over the past five years in New York State, greenhouse vegetables, herbs, and tomatoes experienced a 26% increase in acreage and a 74% increase in wholesale farmgate value. During the same period, greenhouse floriculture saw an 18% increase in acreage and a 34% increase in wholesale farmgate value.

Two major trends continue to shape the industry. The first is the rapid development and adoption of advanced lighting and environmental control technologies. The second is the increasing use of automation and sensor-based systems to optimize growing conditions and reduce labor demands. These innovations help operations produce crops more efficiently, strengthen local food systems, and maintain consistent yields throughout the year. In New York, these improvements are especially valuable given the state’s variable climate and high energy costs.

Despite this progress, the industry is facing several headwinds. Indoor vertical farming models remain challenged by high energy intensity and limited profit margins. Many startups in this space have struggled financially, particularly in a tight investment climate. However, recent indicators suggest a more stable outlook. As interest rates level off and federal support for sustainable agriculture continues to grow, the conditions may improve for renewed investment and long-term viability.

New York’s CEA sector is positioned for continued advancement through collaboration among researchers, growers, manufacturers, and public agencies. By focusing on applied research, education, and technology transfer, the state can help ensure that CEA becomes an increasingly resilient and economically sustainable component of the regional food system.

4. Results

The New York Greenhouse Technology Research, Outreach, and Education project explored the following topics:

1. GLASE consortium project management
2. Development of high-efficiency dynamic light-emitting diode (LED) systems
3. Spectrum/irradiance optimization and plant sensing
4. Energy efficiency and radiometry
5. Carbon dioxide enrichment studies
6. Greenhouse experiments with energy efficient lighting and control systems
7. Engineering and modeling
8. Pilot demonstrations
9. Training, outreach, and technology transfer
10. GLASE consortium development and operation
11. Machine learning and data analytics in controlled environment agriculture (CEA)
12. Response of hemp to light and carbon dioxide
13. Development of Chlorophyll Fluorescence Point and Shoot (CFPS) monitor

See Appendix A for detailed scope descriptions for each topic.

4.1 GLASE consortium project management

The GLASE consortium was established in 2017 to manage the New York Greenhouse Technology Research, Outreach, and Education project.

4.1.1 Key Outcomes

GLASE's project management structure has improved through clearer leadership roles, stronger coordination between Cornell and RPI, and more focused strategic planning. Changes in staffing, including the hiring of a full-time Extension Support Specialist, have enhanced internal communication, improved daily operations, and strengthened engagement with external partners. The GLASE team managed a kickoff meeting and annual progress meetings to wrap up each year of research and extension milestones.

The consortium developed new digital platforms including the Greenhouse Course Catalog and the GLASE online classroom for CEA Works and E-GROW. These tools have expanded opportunities for member engagement, educational outreach, and revenue generation. They also provide a solid foundation for long-term collaboration and organizational growth. Future grant-funded workforce development projects will benefit from this existing infrastructure for education and outreach.

Project coordination has supported efforts to secure diverse funding sources, broaden research priorities, and identify opportunities for commercialization. Together, these outcomes reflect the growth of GLASE into a more mature organization with the capacity to serve both academic goals and industry needs.

4.1.2 Impact Assessment on the Industry

GLASE has played an important role in connecting academic research with real-world applications in the greenhouse and indoor farming – collectively referred to as controlled environment agriculture (CEA) – sector. Through applied technologies such as the Light and Shade System Implementation (LASSI) greenhouse lighting control system and research partnerships with industry stakeholders, the consortium has demonstrated how innovative tools can be adapted for commercial greenhouse operations. An example of this work is the USDA-funded Specialty Crop Block Grant project demonstrating LASSI in four New York State greenhouses.

Education and workforce development have also been major points of impact. GLASE webinars offered free to the public, annual online short courses, and public in-person summits held in the United States and Canada have increased industry awareness of GLASE and serve as widely accessible platforms for sharing research findings and best practices. The GLASE Library serves as a repository of all GLASE technical publications going forward. New digital infrastructure like Teachable for CEA Works makes it easier for both members and the broader public to access these resources and stay informed about emerging trends.

Figure 3. GLASE Summit Attendees Visit a Tomato Greenhouse, 2023

Growers, manufacturers, researchers, educators, and GLASE staff visited Horteca in Leamington, Ontario. *GLASE photo*

Although industry instability has posed challenges for membership recruitment and retention, the consortium's evolving management strategy and stronger digital presence have helped maintain engagement and set the foundation for future growth. The combination of research, education, and public-private partnerships has helped GLASE influence the broader direction of innovation and workforce planning in the greenhouse and indoor farming sectors.

4.1.3 Future Research Needs

Workforce development remains a key need. Expanded training programs and more accessible educational resources can help address the labor gap in controlled environment agriculture. Training products for professionals, students at higher education institutions, and youth can also be a reliable supplemental source of revenue for GLASE amidst industry volatility.

Commercialization strategies should be studied further to identify the points in product development where partnerships with manufacturers can accelerate adoption.

Decision-support tools such as greenhouse climate simulators offer promising opportunities to enhance grower training and real-time management of lighting and environmental controls.

4.2 Development of high-efficiency dynamic LED systems

4.2.1 Key Outcomes

In 2017, light-emitting diode (LED) systems for general purpose human lighting were becoming industry standard practice due to quickly advancing form factors with improving operating efficiency and decreasing system costs. LED lighting technology was being produced for plant production, but the products were not optimized for plant growth. Manufacturers of lighting for humans were introducing horticultural lighting products to the market but many offerings were not tested with commercial growers of CEA crops.

Figure 4. Spectrally Tunable Greenhouse Light Fixture Developed by GLASE Researchers

GLASE researchers conducted experiments with custom equipment developed by Rensselaer Polytechnic Institute (RPI) in greenhouses at Cornell University.

RPI photo

In greenhouses, if supplemental lighting was used at all, it was typically high-pressure sodium lighting, due to the durable nature of the fixture designs. Double-ended high-pressure sodium (HPS) fixtures also offered better electrical operating efficiency than other legacy fluorescent lighting.

There was emergent interest in applying the spectral tunability of LED lighting sources to better match the spectral requirements of various greenhouse crops to improve greenhouse crop growth efficiency, nutritional value and overall economic performance of greenhouse operations.

GLASE Operating Hypothesis for LED Development: Dynamic control of LED light fixture spectral power distributions could be used to grow plants with lower electrical energy inputs and with higher yields than possible with existing greenhouse lighting systems. The automated control of the LED lighting spectrum used for plant growth could be used to:

- Customize spectrum for different crops and/or for different stages of crop development.
- Compensate spectral variations in sunlight throughout the day to maintain ideal spectral power distributions for crop growth independent natural variations in solar irradiance.
- Continue to benefit from improvements in monochromatic LED efficacy to provide additional energy saving benefits for the greenhouse grower.

This vision required the development of color-tunable greenhouse lighting fixtures and a means by which the solar spectrum in the greenhouse could be measured so the LED lighting could "correct" naturally occurring solar lighting (intensity and spectral power distribution) for optimized crop growth.

Spectrally tunable LED lighting fixtures are more challenging to manufacture for fundamental reasons:

- To create a uniform spectrum at the crop canopy using discrete monochromatic LEDs requires color mixing strategies that reduce the operating efficiency of the fixture.
- Green LEDs have a much lower efficacy than blue or red LEDs. To create full spectrum light, green LEDs are required, dropping the efficacy of the overall fixture. (Note that most white LEDs have a green component provided by phosphor conversion of blue LED output, not produced by a green LED).
- Controlling multiple LED channels to maintain a stable spectral power distribution for plant growth is challenging as compared to a single white LED for indoor human lighting applications.

A tunable, six wavelength LED fixture (Phase I) was designed, and deployed at Cornell. The wavelengths and tunability requirements were first developed in experimental lighting modules (TIGER lights) developed at RPI's Center for Lighting Enabled Systems and Applications before the start of the GLASE program. The light engine (LED boards and optics) was designed in a collaboration between RPI and Lumileds LLC, selected because of their extensive experience in manufacturing very high-efficiency, high-power LEDs across a full range of colors of value for crop growth.

A second tunable (Phase II) GLASE fixture was also designed based, in part, on lessons learned from the first fixture, and these units were deployed to Cornell near the end of the program but have not undergone extensive testing or use in the greenhouse. The flux, spectral control and light uniformity were extensively tested at RPI before delivery to Cornell. This fixture was a simpler optical and thermal design and used high performance LEDs manufactured by Luminus Devices, the US arm of the Chinese LED manufacturing company, Sanan Inc.

Another instrument developed for lighting management was a solar spectrum measurement tool that could be installed in the greenhouse, measuring solar spectrum variations in real time (every 3 minutes). The system collected solar spectral data for a full year, and an analysis of the data showed that, generally, while solar intensity (e.g., due to cloud cover) would change, the spectral characteristics of the sunlight varied slowly from sunrise to sunset, without any short-term changes in spectrum that would require adjustment of the color tunable lighting.

4.2.2 Impact Assessment on the Industry

The LED lighting system research funded by NYSERDA did not have a significant direct impact on either the lighting industry or on CEA during the NYSERDA funded lifetime of GLASE, though as the CEA industry continues to develop, the GLASE concepts (color tuning for optimize crop growth) are gradually emerging.

When GLASE started, the global interest in the use of LEDs for horticulture was nascent and coincided with the saturation of energy efficiency improvements in white LED technology for the general lighting industry. In the United States, the Department of Energy (DOE) was transitioning from funding research on higher efficiency LED manufacturing to applications research focused on driving the adoption of energy efficient LEDs into the general lighting business.

In horticulture, there was a misplaced expectation that the significant improvement in LED light production efficiency between 2003 and 2015 would continue unabated, driving, in part, the enthusiasm for LED adoption in vertical farming where energy use was a huge challenge to the financial viability of indoor farming. This application space drew the attention of both the DOE and lighting companies to explore market opportunities in horticulture. GLASE researchers played a significant role in educating both the U.S. Department of Energy and domestic lighting manufacturers and distributors on the opportunities for LEDs in horticulture. LED manufacturers could quickly optimize the spectral output of general lighting LEDs for plant growth and build high power fixtures for replacing conventional greenhouse lighting. These LED horticulture lights were extremely efficient but not color tunable.

By the end of the NYSERDA funding of GLASE, several lighting companies and growers were starting to deploy LED horticulture lighting that included some modest tuning capability, where the advantages were not in the area of reduced energy consumption, but in optimizing specific crop characteristics (nutrition, color, yield, and fruit shape as discussed in industry media.) This trend continues today, but the cost of color tunable LED systems for horticulture remains a barrier to adoption.

4.2.3 Future Research Needs

Currently, it is quite likely that all of the future CEA lighting energy reduction progress will be made through gradual incremental improvements, primarily in manufacturing cost reduction (drives adoption), DC power distribution using advanced power systems, and improved fixture optical efficiency.

Perhaps most importantly, the holistic design of LED lighting fixtures integrated with other growth facility hardware and integrated IT control systems would be the best direction for the development of future CEA lighting systems. This would require a more integrated approach to greenhouse (and vertical farm) systems design with a focus on modularity, portability, and integrated sensing capability.

4.3 Spectrum/irradiance optimization and plant sensing

4.3.1 Key Outcomes

At RPI, research on the impact of spectral selection on crop growth was established in controlled environments. Spectral tuning was found to primarily impact nutrient values in crop products. These data were passed on to Cornell University to evaluate in-greenhouse settings.

Figure 5.. Strawberries Produced in Controlled Environment Growth Chambers

RPI researchers conducted experiments with light fixtures that delivered a range of spectral outputs to explore the impact on crops like strawberries.

RPI photo

Cornell University built off the spectral findings from RPI to develop and test updated versions of the LASSI lighting control algorithm.

Real time (RT) LASSI was developed to dim LED fixtures every 10 minutes in response to sunlight so that sunlight plus supplemental light hit an instantaneous PFD target. The algorithm was tested in on-campus trials with lettuce, tomatoes, and strawberries. As compared to control greenhouse with standard LASSI and HPS fixtures, RT LASSI with LEDs led to a 33% reduction in electricity usage with similar crop performance in lettuce and about 30% greater crop yield for tomatoes and strawberries. It was hypothesized that the strategy of dimming LEDs (i.e. spreading the same total light level across a longer period of the day) enhances plant photosynthetic efficiency and thus yield.

A version of RT LASSI that adjusts red and blue light output from LEDs to achieve a stable spectral ratio every 10 minutes was also developed. RT spectral LASSI was not tested beyond the simulation level but presents a framework that could be commercially adopted to produce uniform quality plants (ex. height, pigmentation) regardless of fluctuating light quantity and spectrum during growing seasons.

4.3.2 Impact Assessment on the Industry

Work at RPI enabled a better understanding of how growers can customize LED spectral distributions for impact crop growth performance.

Growers and producers are much more aware now than at the start of the project of LED dimming and spectral tuning capabilities (vs. HID fixtures which are typically all on or all off). These benefits include being able to adjust light output when some supplemental light is needed but not 100% of capacity. In addition, there is greater awareness of crop specific effects of light spectrum (e.g. higher blue light can increase chlorophyll or anthocyanin pigment resulting in plants with greater consumer appeal and potentially nutritional content).

While there was limited success with commercial adoption of the RT LASSI algorithm into commercially available lighting control systems, there have been many cases where commercial systems for greenhouse climate control (e.g. Argus) or lighting control (e.g. Sollum's Sun as a Service) now incorporate these principles.

The DesignLights Consortium (DLC) has established a Horticultural Lighting Controls Working Group to define the performance requirements for dynamic lighting control systems. This is an important step toward recognition of dynamic lighting control as an energy efficiency technology that could qualify for energy rebates.

Figure 6. LED Supplemental Lighting in a Pepper Greenhouse, 2023

GLASE staff visited the Allegro Acres greenhouse where dynamic lighting systems can deliver customized spectral outputs using combinations of LED diodes.

GLASE photo

4.3.3 Future Research Needs

Greater work is needed with technology suppliers to integrate sophisticated versions of LASSI growth algorithms into software products.

More work is needed to test if there are substantial crop quality benefits from adoption of stable spectral ratio as well as case studies where greenhouse spectrum adjustment can be used to steer/enhance crop growth.

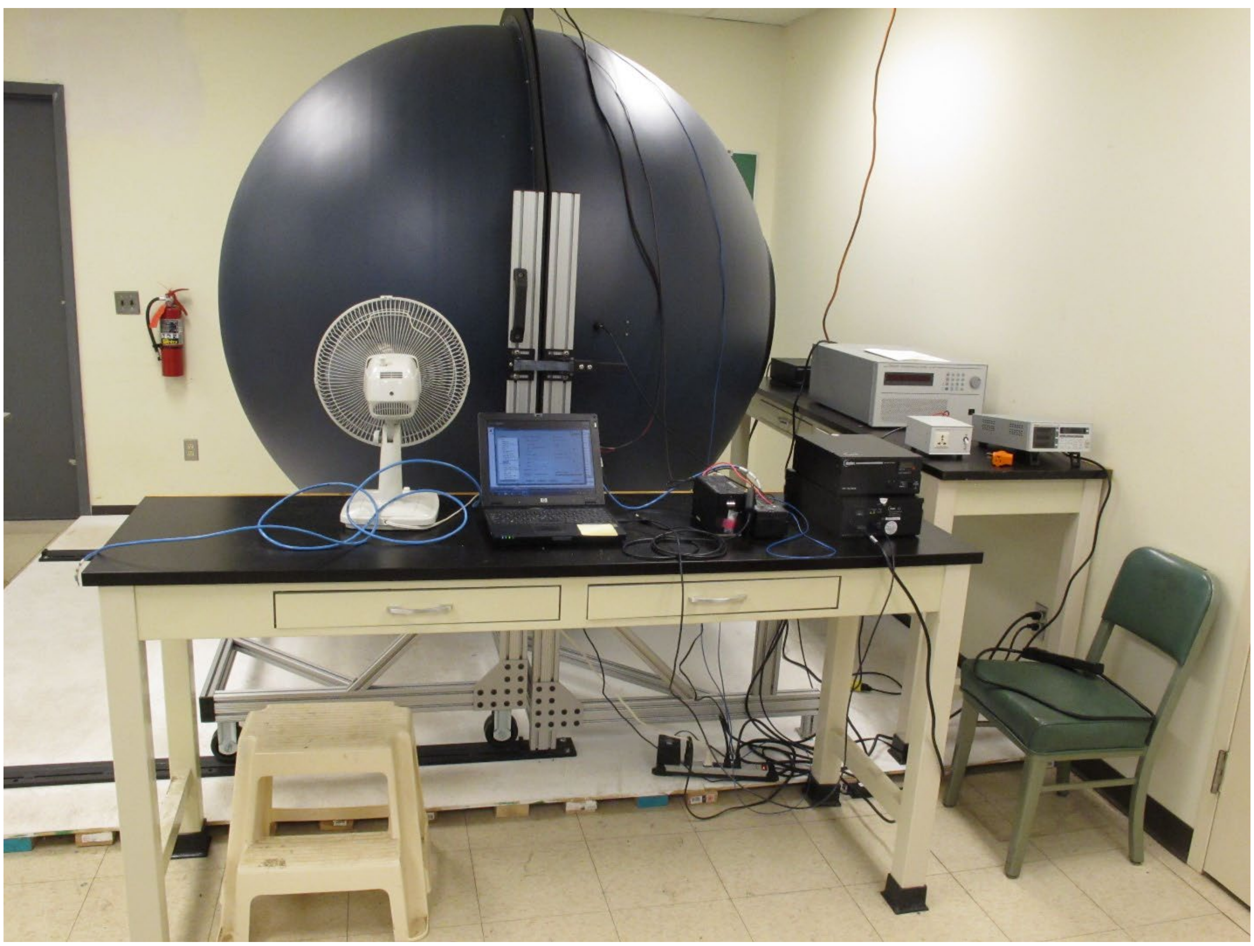
4.4 Energy efficiency and radiometry

4.4.1 Key Outcomes

Using a 2-meter diameter integrating sphere and a darkroom, a number of horticultural lighting fixtures were tested at Rutgers University using protocols developed by the lighting industry. Test reports included specific performance metrics such as spectral output, power consumption, efficacy, light distribution, and included a product performance summary that can be used for easy comparison among different lighting technologies and product models. The fixture performance summary was first proposed in: Both, A.J., B. Bugbee, C. Kubota, R.G. Lopez, C. Mitchell, E.S. Runkle, and C. Wallace. 2017. Proposed product label for electric lamps used in the plant sciences. HortTechnology 27(4):(544-549). Testing results were shared with manufacturers, researchers, and growers.

Figure 7. Integrating Sphere for Testing Light Fixtures

Rutgers University researchers conducted tests to evaluate horticultural light fixture performance.
Rutgers University photo



Technical contributions were made to the ASABE engineering standard titled: Recommended Methods for Measurement and Testing of Electromagnetic Radiation Sources for Plant Growth and Development (ANSI/ASABE S642.1).

Light distribution in tall canopy crops was evaluated from 2021 - 2025. Preliminary data was collected during a 2021 tomato experiment at Cornell University. Additional data was collected in 2025 using a simulated tall crop at Rutgers.

- A variety of commonly used lighting fixtures for horticultural applications were evaluated and results were published in a peer-reviewed publication (Shelford, T.J. and A.J. Both. 2021. On the technical performance characteristics of horticultural lamps. AgriEngineering 3:716–727).
- Three peer-reviewed conference proceedings articles were published (Llewellyn, D., T.J. Shelford, Y. Zheng, and A.J. Both. 2022. Measuring and reporting lighting characteristics important for controlled environment plant production. Acta Horticulturae 1337:255-264; Shelford, T., A.J. Both, and N. Mattson. 2022. A greenhouse daily light integral control algorithm that takes advantage of day ahead market electricity pricing. Acta Horticulturae 1337:277-282; Shelford, T., C. Wallace and A.J. Both. 2020. Calculating and reporting key light ratios for plant research. Acta Horticulturae 1296:559-566.).
- Two trade-journal articles were published (Shelford, T.J. and A.J. Both. 2023. Lighting: The design phase. Produce Grower. April Issue; Both, A.J. 2022. A quick look into LEDs. GrowerTalks. April Issue. pp. 50-51).
- Two GLASE technical publications were written (Shelford, T.J. and A.J. Both. 2020. Plant lighting fact sheet; Both, A.J. 2019. Revisiting the measurement of light. GLASE Technical Article Series).
- Three Cultivate tradeshow presentations were delivered (Both, A.J. 2024: Measuring and Controlling Light, Both, A.J. 2023: Supplemental Lighting Technology for Crop Production; Mattson, N. and A.J. Both 2022: What to Expect When You're Selecting? Light Systems and Economics).
- One GLASE Short Course presentation was delivered on horticultural lighting (Both, A.J. 2019. Light Uniformity Assessment).
- Two different prototype light fixtures developed by RPI were subjected to performance testing.

4.4.2 Impact Assessment on the Industry

Due to the often rapid developments in the horticultural lighting industry, it is challenging to keep up with the independent testing and evaluating the latest changes and improvements.

Some manufacturers have gone out-of-business (e.g., Illumitex, LumiGrow), making their technology obsolete. In addition, testing a single unit of a particular model may not provide sufficient information about overall fixture performance in a commercial application. When manufacturers provided fixtures for testing it wasn't always clear whether or not they provided a unit that was specifically selected for its performance. Lighting manufacturers were less excited as expected about standardizing a product label that can be used for easy comparison with other models or manufacturers.

Figure 8. LED Horticultural Light Fixture

Red LED diodes are more energy-efficient than white or blue diodes at converting electrical power into Photosynthetically Active Radiation (PAR).

Rutgers University photo

While several growers expressed their appreciation for making fixture testing results available, it was observed that most growers relied on manufacturers' data and guidance when making lighting decisions for their operations.

The CEA industry transition from high-pressure sodium (HPS) to light-emitting diode (LED) is taking longer than expected at the onset of this project. Reason for this include:

1. LED fixtures designed for horticultural applications are still more expensive than HPS fixtures that produce a similar PAR intensity,
2. The price of electricity has been increasing relatively slowly,
3. The spectrum produced by LED fixtures is often quite different from the spectrum produced by HPS fixtures, resulting in different plant responses that can impact the growing strategy,
4. LED fixtures that are dimmable and able to produce different light spectra require additional research before researchers can develop recommended light recipes,
5. Due to the perceived risks and costs involved, many growers have been reluctant to switch from HPS to LED lighting systems, and
6. While some electric power companies offered financial incentives for the transition to LED lighting, a regional patchwork of rules and regulations exists that makes it more difficult for growers to understand and take advantage of the financial opportunities.

4.4.3 Future Research Needs

The horticultural lighting industry is continuously developing with lighting manufacturers releasing new fixture models and researchers developing novel lighting strategies for a variety of crops. Installation costs (including purchase price) and energy costs have a major impact on lighting decisions made by growers. In addition, new control strategies are being developed based on novel tools (e.g., artificial intelligence, machine learning, model predictive control) that can better balance the need for product quality with the cost of production. This highly dynamic horticultural lighting ecosystem will continue to require research, testing, and outreach in order to assist growers with their lighting needs.

4.5 Carbon dioxide enrichment studies

4.5.1 Key Outcomes

Tomato and strawberry specific equations modeling interactive effects of daily light integral (DLI) and carbon dioxide (CO2) concentration were developed based on growth chamber trials and scientific literature. The equations were implemented into CO2 LASSI whereby for each time step the algorithm determines the cheapest way (through a combination of supplemental lighting and CO2 enrichment) to gain the same effective growth rate. The algorithm was subsequently tested in the greenhouse experiments described in the following section.

4.5.2 Impact Assessment on the Industry

Relatively few of New York's commercial greenhouse producers add carbon dioxide to increase crop yield, but this is a relatively common practice in large high-tech commercial greenhouses.

CO2 LASSI was originally developed for lettuce in which there is a growth penalty for pushing the crop too quickly through increased DLI and CO2 which CO2 LASSI accounts for. However, for growers of fruit crops, instead of trying to maximize energy efficiency with CO2 it may be more realistic for them to add CO2 on top of their supplemental lighting increasing yield.

4.5.3 Future Research Needs

Our research found that specific crop types (perhaps even specific cultivars) respond differently to DLI and CO2. Thus, industry adoption requires additional onsite testing or development of crop specific light and CO2 equations.

4.6 Greenhouse experiments with energy efficient lighting and control systems

4.6.1 Key Outcomes

CO2 LASSI was tested in greenhouse experiments with fruiting crops of tomatoes and strawberries.

For strawberries, the CO2 LASSI approach led to similar berry yield in cultivar 'Cabrillo' using about 15% less electricity from lighting as compared to LASSI at ambient CO2. Cultivar 'Albion' was more responsive to CO2 exhibiting a nearly 50% yield increase (again with the same reduction in electricity).

Figure 9. Strawberries Produced in a Greenhouse

Cornell University researchers conducted experiments on strawberries with various approaches to CO_2 enrichment and supplemental lighting to observe impact on plant growth and development.

Cornell University photo

For tomatoes, the CO_2/DLI equation that was tested appeared to overestimate the benefits of CO2 enrichment.

Figure 10. Tomatoes Produced in a Greenhouse

Cornell University researchers conducted experiments on tomatoes to verify modeled results.
Cornell University photo

An additional series of greenhouse experiments was conducted to test a CO_2 RT LASSI (i.e. LASSI algorithm integrating CO_2 responses as well as 10 minute, i.e. real time LED dimming intervals) for lettuce, strawberry, and tomato. Responses were compared to counterparts grown under HPS fixtures with standard LASSI.

- Lettuce plants had some subtle differences in morphology and yield comparing CO_2 RT LASSI to LASSI. CO_2 RT LASSI with LEDs was estimated to reduce energy use by 40% compared to LASSI with HPS.
- Tomatoes and strawberries using the CO_2 RT LASSI were estimated to have a 41% lower energy use vs LASSI with HPS counterparts.

- In addition, both tomatoes and strawberries exhibited about 20% larger fruit size and overall yield with CO_2 RT LASSI which demonstrates yield benefits of dimming LEDs to complement the sun and with CO_2 enrichment.

4.6.2 Impact Assessment on the Industry

The New York State greenhouse industry has been slow to adopt CO_2 enrichment. However, in NYS and nationally, the biggest/highest technology commercial vegetable greenhouses have largely adopted CO_2 enrichment (mainly through use of CO_2 capture from boilers in heating season and injection of CO_2 from liquid tanks in summer).

For producers of fruiting crops, the feedback received is they are less likely to reduce their supplemental lighting when they have CO_2 enrichment but rather take advantage of the additional yield benefits. While this doesn't offer a whole facility energy use reduction, it does lead to greater energy efficacy of crops, i.e. increase biomass per unit energy used (kg/kWh).

Suppliers (such as Biotherm, Skytree, Direct Carbon) are responding to the need for more flexible CO_2 delivery and sensing systems by developing director air capture systems which take CO_2 from ambient air to enrich greenhouse CO_2.

4.6.3 Future Research Needs

Response of crops to CO_2 enrichment is species and cultivar dependent. Thus, growers will need to adjust CO_2 growth equations to their specific crops/cultivars.

Building on this project's pilot tests described later in this report, more work is required to validate the crop yield benefits and energy savings of CO_2 RT LASSI in larger commercial greenhouses.

4.7 Engineering and modeling

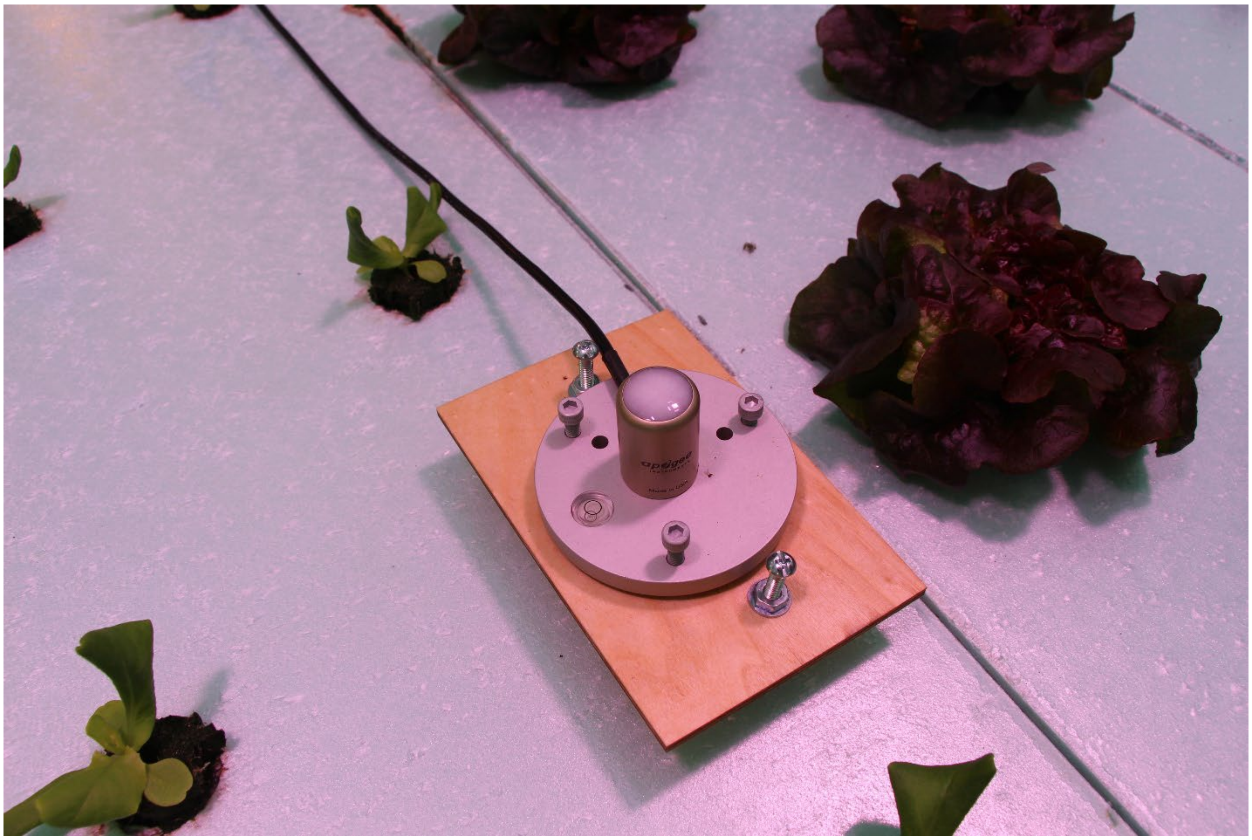
4.7.1 Key Outcomes

Several enhanced light and energy modeling features were developed and incorporated into Cornell's Greenhouse Energy Model (GEM) platform including: model tuning based on real-world data from a small and large size greenhouse pilot, extending LASSI lighting control settings to add tomatoes and strawberries and in response to dimmable LEDs (i.e. real-time LASSI), and ability to adjust red and blue light spectrum. Collectively, these efforts demonstrate that GLASE's original goal of showing a pathway to decrease energy use in lighting of up to 70% (vs. 2014 HPS status quo) is possible through adoption of energy efficient LEDs (50% energy reduction possible), better controls (20-30% reduction possible), carbon dioxide enrichment (20-30% reduction), and light spectrum (5-10% gains).

Figure 11. Quantum Sensor Measuring PAR Light Received by Lettuce in a Greenhouse

GLASE researchers use sensor outputs to calibrate models that calculate energy use from greenhouse supplemental lighting systems.

Cornell University photo



A version of LASSI that incorporates day ahead market (DAM) pricing for electricity (DAM LASSI) was developed. DAM LASSI avoids lighting during periods of peak grid demand (when electricity is more expensive) was developed. Based on three years of electricity pricing data and for 3 locations in NYS it was found this could save 50-60% in electricity costs (not energy use per se) over original LASSI by taking advantage of this more advantageous electricity. This finding also demonstrates the potential utility of including greenhouses as part of the solution to balance grid supply and demand by taking advantage of crop flexibility to lighting.

4.7.2 Impact Assessment on the Industry

The newest version of USDA ARS's Virtual Grower which incorporates more sophisticated energy modeling (control strategies, HVAC, shading) is in Beta testing prior to becoming publicly available. This resource allows individuals to run energy simulations for their own greenhouse configurations with upgraded features.

Commercial greenhouse climate control systems (ex. Argus/Priva) have incorporated features that allow users to turn off lights when electricity is expensive or under peak demand.

4.7.3 Future Research Needs

Regarding DAM LASSI, more research is needed to determine how flexible crops are to when they receive their light during a day so that growers can capitalize on flexible electrical rate structures.

More comprehensive research should be conducted on how CEA facilities can enhance electrical grid resiliency, for example through onsite and renewable energy generation and scheduling electricity use to complement grid supply and demand.

4.8 Pilot demonstrations

4.8.1 Key Outcomes

LASSI lighting control systems were installed and tested in a total of 6 commercial greenhouses in New York State. Initially the goal was to work with the same two operations to iteratively test more advanced versions of LASSI over time.

Figure 12. LASSI Pilot Demonstration in a Basil Greenhouse

GLASE researchers conducted experiments with LASSI lighting control algorithms in New York greenhouses like Goodness Gardens in Orange County.

Cornell University photo

However, operations had their own objectives and timelines for lighting systems upgrades and so an ad hoc approach of testing one version of LASSI in each of six operations was developed. For example, some operations had HPS while others had LED fixtures. Many operations did not have retractable shade curtains and the operations did not have CO2 enrichment. Additionally, some operations had constraints on the hours of the day they could operate their lights due to wanting to avoid light pollution to their neighbors during certain times of the night. In all cases, a version of LASSI was selected with input parameters that met the operation's needs.

A major takeaway is that most operations gained a much greater knowledge of the light their crops are receiving. Prior to installations many operations either had uncalibrated light sensors or did not have light sensors at their crop canopy. Many operations had undersized lighting systems relative to crop specific lighting needs and thus were not able to achieve Daily Light Integral targets during the winter months.

4.8.2 Impact Assessment on the Industry

The majority of pilot operations wish to continue using LASSI and have also led to planned lighting system improvements including: adding additional lighting capacity, switching from HPS to LED fixtures, and moving toward dimmable LEDs for greater control.

While there has been limited success with commercial adoption of the LASSI family of lighting control algorithms into commercial systems, the GLASE Team carefully followed and guided the development of similar advanced lighting control algorithms into commercial systems for: greenhouse climate control (e.g. Argus) lighting controls incorporated into commercial LED fixtures: (e.g. Heliospectra, Signify, Sollum), and lighting control service providers (e.g. CEA Microclimates, GrowFlux).

Further, the DesignLights Consortium (DLC) has established a Horticultural Lighting Controls Working Group to define the performance requirements for dynamic lighting control systems. The is an important step toward recognition of dynamic lighting control as an energy efficiency technology that could qualify for energy rebates.

4.8.3 Future Research Needs

More research is needed to address the ability of flexible greenhouse lighting algorithms to address grid supply and demand. The version of LASSI that also takes day-ahead market pricing of electricity into account to make the most cost-effective lighting systems needs to be tested for crop responses to dynamically changing light output during the day in response to electricity demand/costs.

Figure 13. LASSI Pilot Demonstration in a Lettuce Greenhouse

Case studies of the LASSI experiments summarize the benefits researchers observed at the different pilot demonstrations, like the tests conducted at Wheatfield Gardens in Niagara County, New York.

Cornell University photo

In addition, future research should look at dynamically changing light output or light spectrum during the crop cycle to fine tune lighting to crop's changing needs over time.

4.9 Training, outreach, and technology transfer

4.9.1 Key Outcomes

GLASE developed and sustained a wide-ranging training, outreach, and technology transfer program that engaged academic, industry, and public stakeholders. Activities included ten years of annual short courses, webinars, and member satisfaction surveys; the release of reports and peer-reviewed publications; trade journal articles; academic presentations; the development and maintenance of the GLASE website; the knowledge transfer at the GLASE Summit held in Ithaca, New York (2022), Leamington, Ontario (2023), and Montreal, Quebec (2024). GLASE also had booths at Cultivate in 2022 and 2023, CEAg World Conference and Expo in 2024 and 2025, and Indoor Ag-Con in 2025 and 2026.

Figure 14. GLASE Summit Attendees Tour a Canadian Pepper Greenhouse, 2023

GLASE organized one-day conferences to share the latest academic research and findings from grower case studies, learn from the evolving CEA industry in the U.S. and Canada, and network with members.

GLASE photo

A consistent highlight has been the delivery of highly-attended educational webinars, short courses, and industry events that created a forum for knowledge exchange and community building. Additional efforts included the publication of a national lighting label concept and a multi-year marketing plan to increase program visibility and value to industry. The consortium also organized annual meetings and member outreach, including surveys to assess satisfaction and better tailor programming. A wide body of materials was created and distributed through various channels, including digital platforms, press releases, and partner networks.

4.9.2 Impact Assessment on the Industry

GLASE's outreach and education initiatives significantly contributed to the broader adoption of energy-efficient lighting practices in controlled environment agriculture. By translating research findings into accessible materials and fostering connections across academia and industry, GLASE positioned itself as a knowledge hub. Stakeholder feedback collected over multiple years through satisfaction surveys and membership meetings affirmed the program's value and relevance.

Participation in short courses and webinars increased industry awareness of horticultural lighting technologies and best practices. Peer-reviewed publications and trade articles helped validate and disseminate technical findings, while the website and marketing efforts extended GLASE's reach to a broader audience. The program played an important role in connecting commercial growers, technology developers, and researchers, ultimately supporting NYSERDA's goals of market transformation.

4.9.3 Future Research Needs

The CEA industry needs an industry-recognized certification program that standardizes core competencies in energy-efficient lighting and systems management for CEA professionals. This would provide a clear credentialing pathway for the workforce and help employers identify skilled candidates.

More work is needed to scale up access to training for underrepresented/ underserved growers and workforce segments and update course content and outreach strategies to reflect rapid advancements in automation, artificial intelligence (AI), and data-driven controls in controlled environments.

4.10 Consortium development and operation

4.10.1 4.10.1 Key Outcomes

GLASE successfully established and maintained a multi-institutional consortium with a clear governance structure that includes leadership and advisory boards, institutional oversight, and defined task management.

GLASE adapted its operations to reflect changes in industry needs and funding priorities.

GLASE developed digital platforms such as a website and learning management system to improve engagement with GLASE educational products and deliver content in a more accessible and sustainable way.

The membership program was refined using annual feedback and resulted in several active research partnerships with technology demonstrations ongoing at Cornell University.

New services like the CEA Works online training platform were launched to expand stakeholder value and advance workforce development for four types of CEA careers.

Despite external pressures in the CEA sector, GLASE demonstrated resilience by maintaining operations, fostering collaboration, and supporting applied research and outreach.

4.10.2 Impact Assessment on the Industry

GLASE has positively influenced the CEA industry by building connections between researchers, growers, and technology providers, and by creating a trusted platform for sharing knowledge and accelerating innovation.

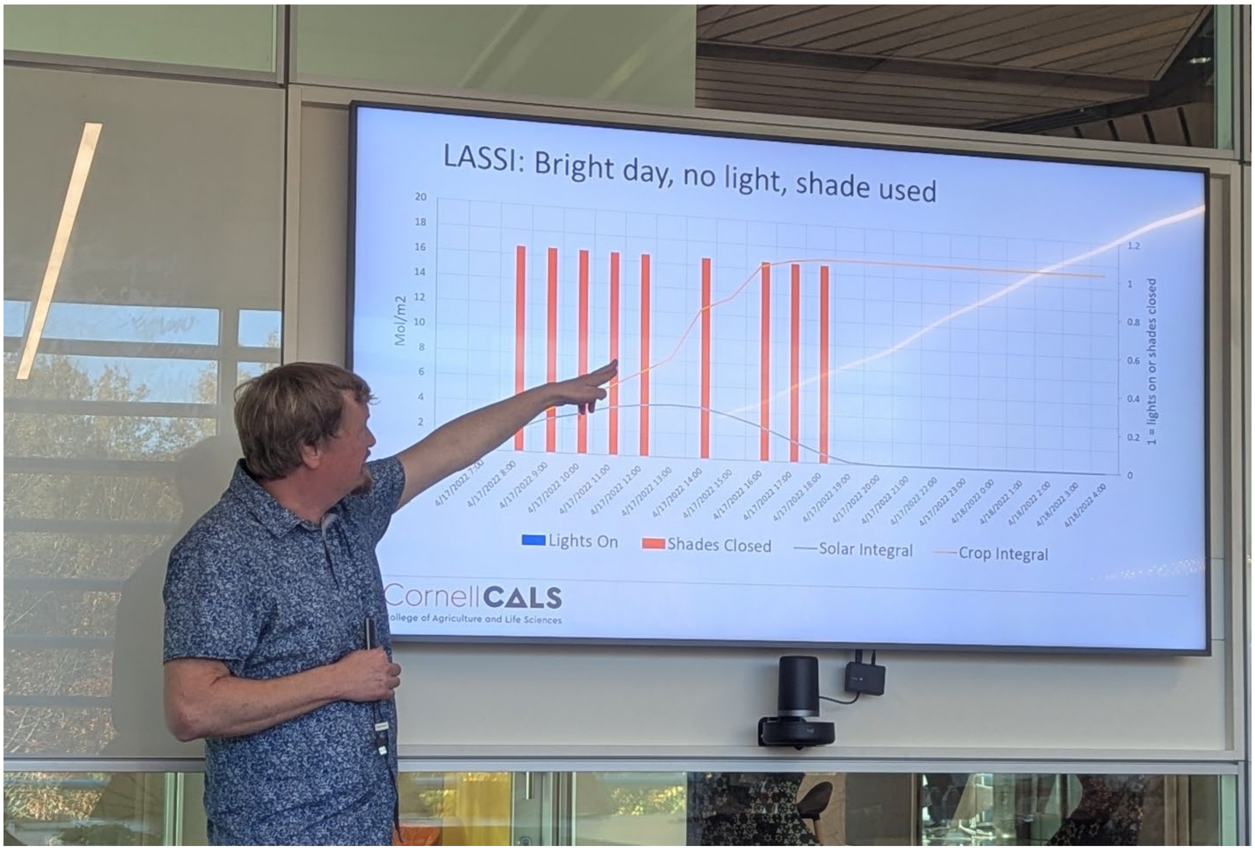
GLASE governance and membership model supported a space for pre-commercial research and stakeholder-driven solutions. Although industry fluctuations posed challenges to member retention, GLASE responded with targeted improvements such as updated member benefits and a new membership management system. These efforts helped maintain engagement and positioned the consortium as a reliable source of information, tools, and training.

As a result, GLASE has contributed to the advancement of energy-efficient technologies, informed workforce development efforts, and shaped the broader direction of innovation in greenhouse production.

Figure 15. GLASE Research Presentation at the CEAg World Conference and Expo

GLASE researcher Dr. Neil Mattson shares findings from LASSI pilot demonstrations at industry conferences to translate experiments into applications for commercial greenhouse food production.

GLASE photo



4.10.3 Future Research Needs

After operating a public-private partnership model throughout the COVID-19 pandemic and volatile changes in competitive federal grant programs, the GLASE consortium continues to evaluate the mechanisms for long-term financial sustainability. The Industry Membership model has evolved to focus on research partnerships. The organization currently focuses on USDA and NYSERDA grant-funded technology transfer projects like LASSI demonstrations and greenhouse benchmarking in New York and workforce development projects like CEA Works and E-GROW.

In 2026, GLASE is kicking off a new grant-funded research project: CROP-SIM, a greenhouse climate and energy simulation tool for training new leafy greens growers. GLASE will continue to provide a key project and data management role to support Cornell University and the technology partner Hoogendoorn.

Future research is needed for strengthening outreach strategies to enhance the value and impact of GLASE tools and training products.

4.11 Machine learning and data analytics in CEA

4.11.1 Key Outcomes

Extensive greenhouse environmental data sets (10-minute timescale over 6 months for 4 greenhouse sections) were processed and uploaded to the Controlled Environment Agriculture Open Data (CEAOD) online platform.

Figure 16. Sensor Measuring Spectral Outputs Received by Greenhouse-Grown Crops

GLASE researchers conducted experiments in greenhouse environments to optimize LASSI algorithms.
RPI photo

The data were used to train a machine learning model to better predict greenhouse ventilation requirements, an important factor when deciding whether to enrich a greenhouse with CO_2 at any given time. The machine learning model gave much more accurate predictions than previous CO_2 LASSI logic which relied on simply outdoor and indoor greenhouse temperature.

A simple user guide to using the CEAOD platform was developed and shared with more than 50 greenhouse researchers across the U.S.

4.11.2 Impact Assessment on the Industry

GLASE has positively influenced the CEA industry by building connections between researchers, growers, and technology providers, and by creating a trusted platform for sharing knowledge and accelerating innovation. A few public researchers and a couple of private industry members have now also publicly shared data on CEAOD and it is also being used as a platform to test machine learning models for greenhouse climate and energy management.

Specialized companies that develop AI based solutions for CEA (ex. Koidra, IUNU) are now working with commercial greenhouses to optimize climate control models for energy efficiency as well as remote crop health sensing to improve productivity.

Mattson (Cornell) and Both (Rutgers) participated on a team with Koidra in the third autonomous greenhouse challenge (held by Wageningen University in 2022). The team won the challenge - effectively growing lettuce more cost effectively than 4 other competing teams as well as a team of expert growers through the use of AI tools.

4.11.3 Future Research Needs

More work is needed in modeling crop responses to climate control strategies to further guide training of new growers and help producers make energy-saving climate control decisions. The Cornell team has collaborated with GLASE member Hoogendoorn to successfully propose a project to USDA NIFA: Greenhouse Crop Response Onboarding Platform with Simulated and Interactive Models (CROP-SIM). CROP-SIM will develop models for greenhouse lettuce growth integrated with the greenhouse energy model (GEM) and Hoogendoorn's computerized climate control system to train the next generation of growers in energy efficient greenhouse climate control.

4.12 Response of Hemp to Light and CO2

4.12.1 Key Outcomes

Three autoflowering (day neutral) hemp cultivars were grown in a greenhouse under four DLI treatments (15, 20, 25, 30 mol·m-2·d-1) to determine response (flower yield and CBD content) to light. Greatest flower yield and CBD concentration for two cultivars was found at 20 mol·m-2·d-1 DLI with no further benefits of increasing light, one cultivar showed yield and CBD increases up to 30 mol·m-2·d-1. Overall autoflowering cultivars appear to have lower lighting requirements than photoperiodic cultivars (which prefer 30-40+ mol·m-2·d-1).

Figure 17. Hemp Produced in a Greenhouse

GLASE researchers conducted experiments to explore the impact of LASSI algorithms on hemp crops.
Cornell University photo

Implementation of CO_2 RT LASSI effectively produced similar or greater net yield than production under HPS fixtures with original LASSI. One cultivar had similar yield and one had 22 percent great yield. CO_2 RT LASSI used 42 percent less electricity than HPS fixtures with LASSI. The energy savings was attributed to 33% from LED electricity savings over HPS and 9% based on reduced need for supplemental lighting from CO_2 enrichment. Further benefits of CO_2 are expected for mid-winter crop runs when there is less greenhouse ventilation. Overall, the results suggest that hemp can be effectively grown with CO_2 RT LASSI, however, commercial operations should evaluate on a trial basis testing each individual cultivar before adopting on a larger scale.

An experiment was conducted to determine the impact of light quality on yield and CBD/THC concentration of two hemp cultivars. Flower yield and cannabinoid concentration of one cultivar, 'T2', had little impact from light source. The other cultivar 'TJs CBD' was more responsive to light quality treatment with white LED and HPS treatments generally leading to the greatest flower yield cannabinoid concentration (over red:blue LEDs). Overall, the white LED results are very promising for replacing less energy efficient HPS fixtures with white LEDs and being able to achieve the same flower yield and CBD concentration.

4.12.2 Impact Assessment on the Industry

Research with hemp has been important due to lack of scientifically validated data for this emerging crop. Importantly, the research found that energy efficient LEDs could be used to produce yields and chemical composition greater than or equal to HPS fixtures with substantial energy savings. Many states (including New York) have incorporated energy efficiency standards into their hemp/cannabis licensing programs.

The finding that hemp is relatively insensitive to light spectrum (in greenhouses with a background of sunlight) further underscores the importance of lighting selection based on energy efficacy, cost, and operational needs rather than specific spectra.

4.12.3 Future Research Needs

Future research with a greater range of DLI treatments for photoperiod cultivars would help guide decisions related to the upper limits of lighting requirements.

In the trials, powdery mildew was observed as the most common hemp disease in CEA production, emerging research is showing benefits of UV radiation for disease control (and in some cases insects). Thus, future opportunities for UV in pest and disease control should be explored.

4.12.4 Development of Chlorophyll Fluorescence Point and Shoot (CFPS) Monitor

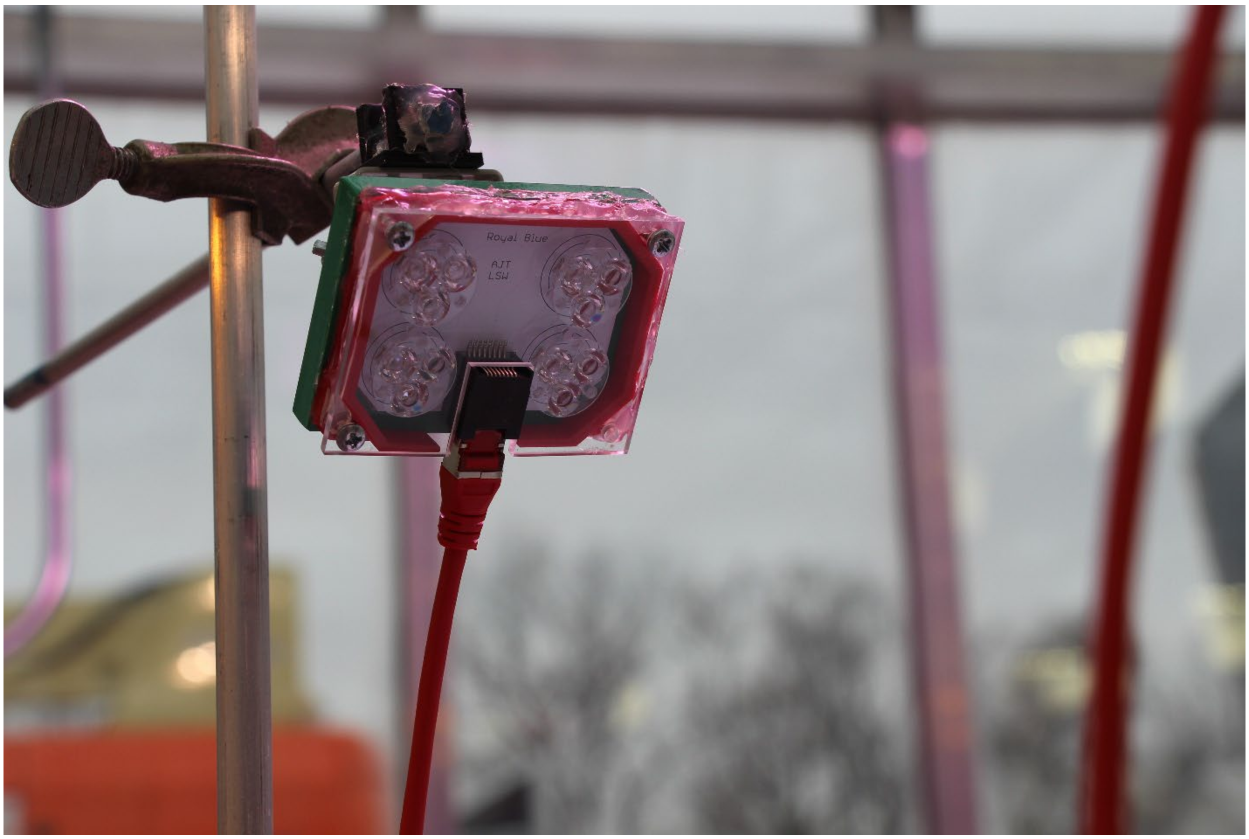
4.12.5 Key Outcomes

The Alpha Model was successfully designed and tested, with results documented in a separate performance report. Minor circuit issues were identified during Alpha testing, leading to improvements such as optimization of the charge pump and filter frequency.

Figure 18. Sensor Measuring Chlorophyll Fluorescence of Plants

GLASE researchers developed a handheld sensor to monitor a key indicator of plant health: chlorophyll fluorescence.

RPI photo



The Beta Model incorporated these design improvements and was completed and tested in 2024.

Testing showed that the Beta unit functioned well over long durations, providing reasonable chlorophyll fluorescence data. A design flaw related to the charge pump's inability to deliver adequate negative current was discovered and addressed with an external power supply, validating a more robust solution.

Plans were made to redesign the system into a slightly larger (still handheld) prototype suitable for extended testing and future deployment. Project delays occurred due to staffing challenges, including the layoff of the lead engineer and graduation of a key student researcher, halting further development.

4.12.6 Impact Assessment on the Industry

This research demonstrated that a compact, affordable, and effective chlorophyll fluorescence monitoring tool is within reach, which could benefit early stress detection in greenhouse and CEA systems.

However, due to halted development, the technology has not yet been deployed in production settings. The foundational work, especially identification of design needs and field feasibility, lays important groundwork for future innovation in this area and informs the industry about both the promise and technical hurdles of deploying such tools.

4.12.7 Future Research Needs

The CFPS system requires redesign to integrate a dedicated negative power supply and improved housing for a handheld prototype.

Further testing in commercial and research greenhouse environments is needed to evaluate durability, usability, and data quality over extended periods.

Additional work could explore how CFPS data integrates with existing greenhouse management systems or automated decision-support platforms.

A comprehensive assessment of market viability, manufacturing costs, and potential partnerships is necessary for commercialization.

5. Other Industry Outcomes

The New York Greenhouse Technology Research, Outreach, and Education project delivered additional outcomes to accelerate adoption of efficiency greenhouse technologies and develop the CEA industry workforce.

5.1 Summit

The GLASE Summit is an annual event that convenes researchers, growers, and industry leaders to exchange knowledge, explore cutting-edge technologies, and advance sustainability in controlled environment agriculture (CEA). Each Summit features grower and research panels, networking opportunities for GLASE members, and focused discussions on key industry challenges. The 2022 Summit in Ithaca, NY, and the 2023 Summit in Leamington, ON, drew 64 and 68 attendees, respectively, with themes centered on Efficiency & Sustainability in CEA (2022) and Greenhouse Energy Resilience (2023). The 2024 Summit in Montreal, Canada, saw record attendance with 90 participants and highlighted innovations in Dynamic Lighting. These events have supported the adoption of energy-efficient practices, fostered cross-sector collaboration, and strengthened the GLASE community.

Figure 19. Speakers at the 2024 GLASE Summit

Right to left: Gretchen Schimelpfenig (GLASE Executive Director), Bob Jones (Chef's Garden, Ohio), Holly Counter Beaver (Finn & Roots, Vermont), and Denis Lavoie (Cytech Corbin, Quebec).

GLASE photo

The 2025 Summit was co-located with the CEAg World Conference and Expo in Durham, NC and featured six sessions totaling four hours of continuing education on the topics of circular CEA systems, lighting for crop nutrition, scaling CEA pilots, benchmarking greenhouses, CEA codes and standards, and CEA training models. In 2026, GLASE partnered with Indoor Ag-Con to facilitate a job lounge on the expo floor.

5.2 Short Courses

The GLASE Virtual Short Course series has served as a cornerstone of the consortium's educational programming, offering in-depth instruction on key technical topics in CEA. Launched in 2021 with a focus on Plant Lighting, the inaugural Short Course drew 222 registrants and generated $42,825 in gross income. Subsequent courses on Climate Control (2023) and Greenhouse Systems (2024) attracted 239 and 99 registrants, respectively. Each multi-week course featured expert speakers from academia and industry, covering modules such as lighting, humidity, irrigation, and autonomous controls. A survey conducted following the 2021 Short Course found that over 80% of grower participants planned to implement new practices in their operations as a result of the course, including changes to lighting layout, climate control strategies, and sensor use.

In 2025, GLASE adapted this successful model and launched CEA Works, an online, on-demand training platform hosted on Teachable, designed to provide greater accessibility and flexibility for learners across the CEA sector. The first four CEA Works courses offer students over 16 hours of instruction and assessments in Overview of CEA Crop Production, Root Zone Environment Management, Plant Physiology of CEA Crops, and CEA Business Planning 101.

5.3 IAB

The GLASE Industry Advisory Board (IAB) played a key role in supporting the consortium's mission and financial sustainability through annual membership fees. In 2023–2024, membership revenue totaled $53,162. In 2024–2025, membership revenue totaled $57,880. Broader economic challenges in the CEA sector impact a membership-based model for consortium financial sustainability. Instability in the indoor farming industry, inflationary pressure on greenhouse projects, and growing competition among technology providers as well as internal staffing transitions, made member retention and recruitment more difficult. In 2026, GLASE closed out the original IAB focused on the 2017-2025 NYSERDA research. Manufacturer partnerships continue to focus on applied research with Cornell CEA faculty and students.

5.4 Workforce Development

The rapid growth of the CEA industry has outpaced the availability of standardized training and workforce development opportunities. As new technologies and sustainable practices become increasingly integral to CEA operations, there is a pressing need to equip current and future workers with the skills required to operate, manage, and innovate within these systems. Despite the high demand for qualified labor, the industry lacks unified educational pathways and recognized standards for competencies. To address this gap, initiatives like GLASE's online CEA Works training and Greenhouse Course Catalog provide accessible, science-based curricula that support both foundational learning and advanced technical training. These resources represent essential steps toward building a skilled, adaptable workforce and fostering consistency across the CEA sector.

GLASE expanded into youth agriculture workforce development with the E-GROW program in collaboration with partners in New York, Pennsylvania, Virginia, and Wyoming. In 2026, the GLASE online classroom will expand to include an E-GROW library of tools and resources for middle and high school students.

Appendix A. Detailed Description of the Scope Tasks

A.1 Task 1 Description: Project Management – GLASE

Establish and manage a collaborative leadership structure between Cornell University Rensselaer Polytechnic Institute (RPI), and Rutgers University to oversee the GLASE project, ensuring effective coordination, communication, scheduling, reporting, and strategic decision-making in alignment with NYSERDA's objectives, oversight, and funding.

A.2 Task 2 Description: Development of high-efficiency dynamic LED systems

Develop high efficiency, multiple wavelength lighting systems suitable for research use. A 30% improvement over 1.7 μmol/J for the final prototypes is targeted to reduce, to a practical level, the electrical energy consumption used by LED lighting in greenhouse applications. LED fixture development will be rolled out in three phases of successive improvements as core LED packaging, thermal management, optical systems and driver technologies are developed by GLASE and/or its industry members who are adapting GLASE technology for commercial LED greenhouse lighting products.

A.3 Task 3 Description: Spectrum/irradiance optimization and plant sensing

The objective of Task 3 is to develop and optimize crop-specific LED lighting strategies that improve energy efficiency and plant performance in controlled environments. Through a combination of laboratory and greenhouse experiments, RPI (in collaboration with Cornell) will define ideal spectral combinations and photon flux densities (PFDs) for lettuce, tomato, and strawberry using advanced sensing and automation technologies. This includes determining light saturation points, measuring photosynthetic and photochemical responses, assessing nutritional content in leafy greens, and developing real-time adaptive lighting controls. The ultimate goal is to enhance crop yield, quality, and sustainability while minimizing energy use.

A.4 Task 4 Description: Energy efficiency and radiometry

Evaluate and compare the performance of commercial and prototype horticultural lighting systems to inform more energy-efficient and effective lighting strategies for controlled environment agriculture. Led by Rutgers under Cornell's direction, this task involves rigorous testing of lamp efficacy, spectral output, and light distribution using standardized radiometric methods. The team will assess how different lighting technologies perform in real-world crop scenarios, particularly in tall plant canopies, and develop measurement protocols tailored for horticultural applications. The findings will guide optimal lamp design and placement and quantify the energy and cost benefits of advanced GLASE-developed lighting systems over conventional approaches.

A.5 Task 5 Description: Carbon dioxide enrichment studies

Develop crop-specific models that quantify the interactive effects of light (DLI) and carbon dioxide enrichment on plant growth in tomatoes and strawberries, building upon prior work conducted with lettuce. Through controlled experiments at Cornell, these models will generate equations describing CO_2/DLI interactions, which will be incorporated into the CO_2 LASSI software platform. This updated tool will enable optimized, crop-specific control of supplemental lighting and CO_2 enrichment in controlled environments, supporting more efficient energy use, and improved crop productivity.

A.6 Task 6 Description: Greenhouse experiments with energy efficient lighting and control systems

The goal of Task 6 is to validate the effectiveness of CO_2 LASSI software, which integrates crop-specific CO_2 and DLI interaction models, by comparing its performance to standard LASSI lighting control in side-by-side greenhouse experiments with tomatoes and strawberries. Through replicated trials in research greenhouses at Cornell, the task will assess differences in plant growth, development, resource use, and productivity under CO_2-enriched versus standard lighting control conditions. This validation will demonstrate the potential energy and productivity benefits of integrating CO_2-responsive lighting control in greenhouse production systems.

A.7 Task 7 Description: Engineering and modeling

Develop and improve energy simulation tools that support more accurate, dynamic modeling of greenhouse systems and facilitate better decision-making for energy efficiency. Cornell and its subcontractor, USDA ARS, worked to unify and enhance existing simulation engines, develop next-generation capabilities in Virtual Grower, and model new control strategies for lighting, CO2, HVAC, and shading systems. The task also included constructing baseline models for pilot facilities and extending tools like CO2 LASSI to optimize costs under real-time and day-ahead energy pricing. These efforts lay the groundwork for integrated modeling and control platforms that support research-grade simulations and commercial application in controlled environment agriculture.

A.8 Task 8 Description: Pilot demonstrations

Conduct comprehensive pilot studies in a range of New York State commercial controlled environment agriculture facilities, varying in size from small to large operations, to evaluate advanced LED lighting and energy control systems. These pilots will include baseline data collection, installation and testing of lighting control software called LASSI, and progressive upgrades leading to real-time control integration, while continuously monitoring crop yield, energy use, and environmental conditions. The collected data will be analyzed and adjusted using local weather information to measure energy savings and improvements in crop productivity. The results will be summarized in case studies that provide useful information for industry stakeholders about the advantages, costs, and practical considerations of implementing energy-efficient controlled environment agriculture technologies.

A.9 Task 9 Description: Training, outreach, and technology transfer

Design and implement a comprehensive training, outreach, and technology transfer program that facilitates the adoption of energy-efficient lighting and systems practices in CEA by translating research into actionable knowledge, engaging key stakeholders across academia and industry, and building a community of informed practitioners through accessible education and communication platforms.

A.10 Task 10 Description: Consortium development and operation

Establish and operationalize the GLASE Consortium by defining its organizational structure, recruiting leadership and advisory boards, developing an industry membership program, and creating a comprehensive Financial Sustainability Plan. This task ensures the Consortium has a clear governance framework, effective recruitment processes, member engagement strategies, and a path toward long-term financial viability.

A.11 Task 11 Description: Machine learning and data analytics in CEA

Demonstrate the utility of machine learning tools applied to greenhouse climate modeling based on large data sets and to promote researcher adoption of the CEA Open Data (CEAOD) platform to share large environmental and crop data publicly to aid further research in machine learning applied to CEA.

A.12 Task 12 Description: Response of Hemp to Light and CO_2

Determine the light quantity and quality (spectrum) response of cannabinoid hemp (i.e. hemp grown for secondary compounds such as CBD or CBG in full compliance with state and federal regulations, licensed and with less than 0.3% THC). Further by understanding hemp responses to DLI and CO2, hemp specific equations will be incorporated into LASSI versions to improve energy efficiency of greenhouse supplemental lighting. In addition, understanding CO2 and light quantity and quality effects on hemp yield and secondary compounds will add to knowledge and grower best practices for supplemental lighting of this emerging crop.

A.13 Task 13 Description: Development of Chlorophyll Fluorescence Point and Shoot (CFPS) Monitor

Develop a low-cost, handheld chlorophyll a fluorescence monitoring device capable of early detection of plant stress. This included designing, testing, and refining both Alpha and Beta models, evaluating functionality in a controlled setting, and preparing units for field testing and potential commercialization.