Exhibit A
Statement of Work
Greenhouse Lighting and Systems Engineering (GLASE) Consortium
Agreement Numbers 107301 (Cornell) and 107303 (Rensselaer)

<u>Background:</u>

Rensselaer Polytechnic Institute (Rensselaer) and Cornell University (Cornell) have formed a Greenhouse Lighting and Systems Engineering Consortium (Consortium) to transform lighting and systems management in the greenhouse industry. New York's greenhouse industry is experiencing rapid growth, making quick and meaningful action key to ensuring that newly constructed greenhouses are designed to optimize energy-efficiency and enhance production opportunities and output potential. The core Consortium research members, Cornell and Rensselaer, form a unique New York State-located partnership of plant biologists, agricultural engineers, computer software control engineers, and lighting engineers, who together represent cross-cutting expertise on efficient greenhouse operation. This collection of expertise is unique nationally, as well.

The Consortium concept is an outgrowth of prior work in this technology area sponsored by NYSERDA. The Consortium intends to build on this work while developing progressively more advanced control systems that approach greenhouse operations as systems. It will increase awareness among the key market players of these systems, develop cross-cutting expertise, and provide training for teams of service providers. The Consortium is structured to become self-sustaining within seven years. To date, more than 30 potential participants have expressed interest in joining.

<u>Objectives:</u>

The goal is to transform lighting and systems management in the rapidly growing greenhouse industry by optimizing energy efficiency, crop yield and quality by performing research and demonstrations of improved prototypes, products and integrated systems for greenhouse lighting and control. The goal is also to establish a Consortium that will become financially self-sufficient by bringing together academia and marketplace knowledge and experience to increase the adoption of energy-efficient technologies in the greenhouse industry.

This type and level of system control in greenhouses has been made possible by the unique attributes of light-emitting diodes (LEDs), and has the potential to lead to electricity savings for lighting of up to 70 to 86% (depending on New York State climate zone). Greenhouses are particularly electricity-intensive compared to other buildings.

Project objectives by the end of 2022 include:

- Demonstrating technology adoption in at least 23 acres of NY greenhouses.
- Creating technology that can save up to 70% of a greenhouse's electricity costs for lighting.
- Determining how much value is added when crop-specific spectral distributions are used to increase crop yield, crop quality, desired morphology and biological efficiency.

- Developing four (4) new product concepts (e.g., higher efficiency tunable fixture formats with integrated dynamic wavelength control and application specific optical profiles (crop specific wavelength combinations), control software for light/shade/CO_2 that can modulate LEDs and three (3) new services (e.g. automated spectral control based on crop type and sensor inputs, light spatial and spectral uniformity assessment at commercial producers, new energy use tracking software, and efficiency performance metrics tied to optimal plant growth conditions).
- Filing up to eight (8) provisional patents by Rensselaer and/or Cornell regarding technology developed as part of GLASE.
- Creating a financially self-sufficient consortium with positive cash flow and 25 or more paying members.

Approach:

The Contractors for two parallel efforts are Rensselaer and Cornell, as specifically indicated in the tasks. Regardless of subcontracting or collaboration arrangements, each Contractor shall be solely responsible for the timely completion of all tasks and deliverables included herein that are attributed to the respective Contractors in the Milestone Payment Plan.

There are two agreements with identical Statements of Work. Agreement 107303 with Rensselaer will be in effect concurrently with Agreement 107301 with Cornell University. These two projects will be coordinated such that each specific task will be apportioned between Rensselaer, Cornell University, and Cornell's Subcontractors: Rutgers University and United States Department of Agriculture – Agriculture Research Service (USDA ARS). Roles and responsibilities are described in each task below. In general, Cornell University under NYSERDA agreement 107301, shall serve as the project lead and provide development of CEA control system software and pilot demonstrations, and coordinate with Rensselaer, Rutgers, and USDA ARS on data interpretation and project outputs. In general, Rensselaer, under NYSERDA agreement 107303, shall undertake development of lighting fixture concepts and collaborate with Cornell, Rutgers University, and USDA ARS on data interpretation and project outputs. In general Rutgers, as a subcontractor to Cornell University under NYSERDA agreement 107301 shall undertake the lighting fixture efficacy and distribution assessment and participate in national efforts to develop a standard label for horticultural lighting and collaborate with Rensselaer and Cornell University on data interpretation and project outputs. Also, in general, USDA ARS, as a subcontractor to Cornell University underr NYSERDA agreement 107301 shall undertake a number of the engineering and modeling tasks and collaborate with Rensselaer and Cornell University on data interpretation and project outputs.

Tasks:
In order to achieve the goals and objectives, the Contractor shall perform the following tasks as per the attached Milestone Payment Plan.

Task 1: Project Management

Subtask 1.1: Project Management

The Contractor (Cornell) shall collaborate with the Contractor (Rensselaer) to create a GLASE Leadership Team comprising the Academic Principle Investigators (APIs), one each from Rensselaer and Cornell University (Tessa Pocock from Rensselaer and Neil Mattson from Cornell) and the Consortium Executive Director (Director). The Director shall be responsible for communications with NYSERDA's Project Manager and the APIs shall be responsible for coordination of graduate and undergraduate students, project personnel, and subcontractors involved in the project, schedule, budget, and reporting. **Robert Karlicek from Rensselaer shall temporarily be assigned duties of Acting Director until the Director is selected in Task 10.1. Any change in the structure of the GLASE Leadership Team, or of key project personnel within GLASE shall be subject to prior approval by the NYSERDA Project Manager.** Such approval shall not be unreasonably withheld. The Leadership Team will make major decisions on project direction including corrective measures. Frequent discussions among the GLASE Leadership Team and the NYSERDA Project Manager will be encouraged, and quarterly review and planning meetings will be held among APIs and the Director.

The Director shall serve as the coordinator between all project participants, including coordination of written progress reports, conference calls, project review meetings, and other developments. For all meetings, the Director shall prepare a meeting agenda, take minutes, and describe key meeting results in the quarterly and final reports.

The Director shall arrange a **kickoff meeting** with NYSERDA, the APIs, and any other project participants, as appropriate, to discuss project scope and objectives, as well as time line, interim goals, and organizational and communications format, including a chart of key personnel and their assigned tasks.

The Director shall arrange **annual progress meetings (or more often, as necessary)** with NYSERDA, Cornell University, Rensselaer and any other project participants, as appropriate, to review the project scope and objectives, adherence to time line, interim achievements, identified problems, and any adjustments to project approach or future actions needed to achieve solutions.

The Director shall arrange a **wrap-up meeting** with NYSERDA, APIs, and any other project participants, as appropriate, at the end of the project to review problems and achievements and discuss future action and solutions.

1.1 Deliverables (payment milestones)

1.1.A. Kickoff meeting results: detailed responsibilities designations.
1.1.B. Annual Progress and wrap up meetings: arrangements, agenda, minutes.

Subtask 1.2. Reporting

Quarterly Reporting

The Director shall prepare and submit quarterly reports describing the progress of the project. Copies of the quarterly progress report shall be submitted to NYSERDA's Project Manager. Each quarterly report shall include a descriptive status report discussing progress and developments as to each Task, as appropriate, including any data or other specific information described under any Task Deliverable.

The Quarterly Progress Reports shall be in the following format:

- Title of project;
- Agreement number;
- Period of this report;
- Progress during reporting period;
- Planned progress in the future;
- Identification of problems;
- Planned solutions;
- Ability to meet schedule and reasons for slippage in schedule;
- Schedule -- percent completed and projected; and,
- Analysis of actual costs incurred in relation to the budget.

It is understood and agreed that NYSERDA and the GLASE Leadership Team are sharing the costs for the project work to be performed and that the cost share identified in the GLASE proposal and budget shall be readily available as described therein. (Cost-sharing will be in the form of unrecovered institutional overhead, defined as the difference between the overhead normally charged by Cornell and Rensselaer and the overhead agreed upon for work performed under this Agreement). Any change of cost share by either academic member of the consortium shall be subject to the prior written approval of NYSERDA.

It is anticipated that requests for payment as per the Milestone Payment Plan will be accompanied by a Milestone Payment Plan that indicates past paid milestones, current requested milestone payments, and percent complete on milestones in progress.

Final Report

The Contractor shall prepare and submit a final report documenting the results of the entire project, including all deliverables identified in the tasks, and photos of the technology, in accordance with Exhibit C. The final report shall contain all data, information, analysis and findings pertinent to this Agreement. The report shall be well organized, clearly written and free of grammatical or spelling errors. The final report shall describe the project thoroughly and contain a complete discussion of test results, data analysis, limitations of the study, research needs/data gaps, and conclusions. The technical report shall be written for readers with a high level of technical knowledge.

The final report shall contain an executive summary written for readers with some degree of technical knowledge but no particular expertise in this specific area, so that it can be distributed to a large readership, including policy analysts. The executive summary shall underscore the policy implications of the findings, highlight areas warranting additional research, and identify limitations of the study.

The final report shall clearly compare the features, upfront costs, operating costs, expected commercialized system lifespans, and benefits of each proposed device, control software, integrated system or other greenhouse system concepts developed by the Consortium relative to those of conventional products, and discuss, for each Consortium prototype, whether and in what situations it is expected to be economical for use in commercial greenhouse operation. The final report shall also calculate the amount of expected Statewide annual benefits that would be associated with implementation of the products in a range of commercial facility sizes and a range of CEA market sectors. The Final Report may include a qualitative or quantitative discussion of the potential for a positive change in crop value realized by a fresher, more nutritious product, and may include a discussion of the potential for heating and ventilation costs to be either positively or negatively affected by changes from business-as-usual lighting and control choices to GLASE products. Future research needs shall be outlined, including a prioritization of crops and markets earmarked for future study by the GLASE Consortium.

The Contractor shall also generate bullet points for several PowerPoint presentation slides that include information on the project goals and objectives, prototype systems developed, data collected, project results with conclusion, relevant pictures and diagrams, and acknowledgement of project participants and sponsors. The length of the final report is targeted to be 30 pages or less and the Contractor shall submit the following deliverables to the NYSERDA Project Manager in order to complete the final report:

1) At least one (1) outline shall be given to NYSERDA's Project Manager for review.

2) A first draft of the final report shall be given to NYSERDA's Project Manager for technical review, with at least 30 days allowed for review.

3) A second draft of the final report shall be prepared which conforms to the "Report Format and Style Guide" (the Guide contained in Exhibit E of the Agreement). The second draft shall address or incorporate questions and comments resulting from review of the first draft. The second draft shall be given to NYSERDA's Project Manager for technical review follow-up and for format review, with at least 30 days allowed for review.

4) A copy of the final report in compliance with Exhibit E shall be submitted to NYSERDA's Director of Technical Communications that shall adequately address NYSERDA's comments.

Annual metrics reports
On an annual basis, the Director shall submit, to NYSERDA's Project Manager, a prepared analysis and summary of metrics addressing the anticipated energy, environmental and economic benefits that are realized by the project. All estimates shall reference credible sources and estimating procedures, and all assumptions shall be documented. Both direct benefits resulting from the pilot operations and known indirect benefits resulting from market adoption shall be included (e.g., known market penetration into New York lettuce and tomato acreage, associated electricity savings, stage of commercialization for GLASE technologies, provisional patents filed, number of paying consortium members). Reporting shall commence the first calendar year after the contract was executed. Reports shall be submitted by January 31st for the previous calendar year's activities (i.e. reporting period). Please see Attachment A-1, Metrics Reporting Guide for additional metrics that you will be expected to provide and the reporting duration.

Coordination with NYSERDA's Outreach Contractors
The Contractor shall meet with, or provide project-related information to, NYSERDA's Outreach Contractors in the preparation of program-related materials as requested.

1.2 Deliverables
Quarterly progress reports.
Annual Metrics reports.
Final Report: Outline, first draft, second draft, final version.
Slide presentation.
Description of coordination with outreach contractors.

Task 2. Technology barriers addressed: Development of high efficiency dynamic LED systems (Rensselaer)

The Contractor (Rensselaer) shall develop high efficiency, multiple wavelength lighting systems suitable for research use. A 30% improvement over 1.7 umol/J for the final prototypes is targeted. Several key technology areas and approaches will be explored:

- Improved light extraction efficiency through the development and deployment of LEDs with higher refractive index encapsulants.
- Evaluation of the use of high refractive nanocomposites integrated with novel LED packaging technology to improve the thermal and optical performance of phosphor converted green LEDs.
- Improved thermal management for LED devices and modules through the application of advanced die attachments, novel thermally conductive module materials, and methods for integration of LED fixtures with greenhouse thermal management systems.
- A complete evaluation of air-cooled, water-cooled and hybrid cooling systems suitable for a wide range of greenhouse applications/structures that can be interfaced with the

integrated control systems developed in Tasks 6 and 7 to achieve wavelength and intensity management.

- The development of optical systems designed specifically for different types of greenhouse applications/spaces (e.g. seedling production areas vs. full-size plants) so that LED illumination is used as efficiently as possible.
- Evaluation of new forms of LED driver systems utilizing higher-efficiency wide bandgap semiconductor (GaN or SiC) electronics.

The goal of these research deliverables is 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.

Subtask 2.1. Improved High Refractive Index (RI) Encapsulants

The Contractor (Rensselaer) shall investigate suitable novel high index metal oxide nanoparticle structures that can be used in optical epoxy systems typically used for LED encapsulation.

2.1 Deliverables (Payment milestones)

2.1.A. Report on demonstration of suitable chemical modification of high index metal oxide nanoparticles that can be incorporated in commercial LED encapsulant epoxies.

Subtask 2.2. Green LED Development

The extent to which green LED plays a role in plant growth needs research. Green LED efficiency lags far behind blue and red LED efficiencies, so its cost effectiveness also needs improvement.

The Contractor (Rensselaer) shall compare phosphor converted LED efficacy with direct green LED efficacy and quickly assess lettuce nutrient density and growth performance of the broad green emission associated with phosphor converted green LEDs with narrower band green direct emitting LEDs.

If phosphor converted (PC) LEDs show comparable or better performance for plant growth, nanocomposite conformally coated phosphor converted LEDs shall be fabricated and assessed for operating efficacy improvement relative to conventional phosphor converted green LEDs. In contrast, if direct emission green LEDs show better performance (biomass efficacy, nutrient efficacy than PC LEDs, the direct emission green LEDs with the highest efficacy shall be selected for the final prototypes.

Testing shall be conducted on at least three spectral compositions on red and green lettuce, including three replicates for each cultivar using a one-month growth cycle. Baseline biomass efficacy (g/kWh) and nutrient density efficacy (µg nutrient/kWh) shall be calculated for crops grown under the research prototype.

The research prototype shall be assembled and tested early in the project. The test results from the research prototype shall be used to determine which wavelengths are needed for each cultivar and how much output is needed from each wavelength. This spectral data information shall be used in Subtask 2.6 for the development of future prototypes that are exploring hardware efficiency, including which and how many LEDs are needed in a commercial light system.

2.2 Deliverables (Payment milestones)

2.2.A. Lettuce: Results of comparative assessment of lettuce growth and nutrient density with green direct emission LEDs and green phosphor converted LEDs (including testing of at least three spectral compositions on red and green lettuce; three replicates for each cultivar, using a one-month growth cycle). Baseline biomass efficacy (g/kWh) and nutrient density efficacy (µg nutrient/kWh) results for crops grown under the research prototypes.

Subtask 2.3. Improved Thermal Management

LED thermal management is well known to play a strong role in the efficacy and lifetime of LED systems, and this is particularly true for horticultural lighting requiring use of thermally sensitive red and far-red LEDs.

The Contractor (Rensselaer) shall attempt to improve the thermal performance of horticultural lighting fixtures by reducing the number of thermal barriers in the design of the fixture, and by using state of the art die attachments, heat sinks, and thermal transport components. Because heating and cooling of greenhouses represents a significant use of energy, the thermal design of the LED fixture needs to be integrated into the heating/cooling strategies of the greenhouse. Depending on the lighting format and greenhouse design, it is anticipated that both air-cooled and water-cooled LED fixtures will be employed to minimize fixture energy use.

The Contractor (Rensselaer) shall create a process for evaluating thermal performance for commercial fixtures. Thermal performance evaluation shall include measurement of thermal impedance from the temperature measured at the LED semiconductor P/N junction to the ambient temperature.

The Contractor (Rensselaer) shall use the thermal performance evaluation process to establish baseline thermal performance values for at least two state-of-the-art horticultural LED fixtures. The evaluation shall include a mechanical teardown in order to perform a thermal pathway analysis highlighting potential areas of improvement. The thermal pathway analysis may include preparation of a thermal flow diagram that shows thermal impedances from the LED diode to the ambient temperature. Additional thermal performance evaluations may be performed periodically on new LED fixtures as they become available in the marketplace.

The Contractor (Rensselaer) shall assemble air-cooled thermal management systems that utilize low-cost vapor plates and/or heat pipes to create efficient and compact LED fixtures (with improvements relative to current state-of-the-art fixtures as defined in the baseline testing) and evaluate their thermal performance.

These air-cooled systems shall also be evaluated with regard to cost, size (light blocking footprint), and weight.

At least one prototype fixture with an improved air-cooled thermal management design shall be prepared for further evaluation in Subtask 2.6.

2.3 Deliverables (Payment milestones)

2.3.A. Process for evaluating thermal performance for new commercial fixtures.

2.3.B. Report on baseline thermal performance values for at least two state-of-the-art horticultural LED fixtures, including a thermal pathway analysis that highlights potential areas of improvement.

Subtask 2.4. High efficiency wide bandgap LED drivers

The Contractor (Rensselaer) shall strive to develop advanced drivers that are more efficient than current drivers and capable of integrating better modulation of the dynamic and spectral control systems used in horticultural lighting fixtures. The Contractor (Rensselaer) shall consider recent breakthroughs in novel power electronic components that were based on wide bandgap semiconductors. The Contractor (Rensselaer) shall document improvements to driver size, overall weight and driver efficiency.

The Contractor (Rensselaer) shall analyze the designs of up to three (3) currently available LED driver systems available for horticultural lighting. The analysis shall include the power conversion efficiency, power factor correction, power density (which pertains to size and weight) and suitability for novel spectral control needed as part of Subtasks 3.2, 3.3, and 3.4.Based on lessons learned from the comparative analysis, the Contractor (Rensselaer) shall design at least one version of an improved wide bandgap semiconductor LED driver system (estimated energy savings relative to conventional Si-based LED drivers range from 10 to 20%) suitable for the fixture design and operation improvements needed in Subtasks 3.2, 3.3, and 3.4.

The Contractor (Rensselaer) shall construct and test at least one of the design versions of a wide bandgap semiconductor LED driver system that offers at least 10% efficiency improvement. Testing shall include measurements of power conversion efficiency, power factor correction, power density (which pertains to size and weight) and an analysis of suitability for novel spectral control as needed in Subtasks 3.2, 3.3, and 3.4. The Contractor (Rensselaer) shall prepare the driver for implementation on one or more of the lighting fixtures in Task 2.6.

2.4 Deliverables (Payment milestones)

2.4.A. Report on the comparative design advantages of currently available LED driver systems available for horticultural lighting, particularly as it applies to power conversion efficiency, power factor correction, power density and suitability for novel spectral control needed as part of Tasks 3.2, 3.3, and 3.4.

2.4.B. Report on the design of an improved driver technology suitable for fixture design and operation improvements needed in Subtasks 3.2, 3.3, and 3.4.

2.4.C. Test results from at least one version of a wide bandgap semiconductor LED driver system that offers improved performance.

Subtask 2.5. LED Fixture design and testing (three phases)

New lighting fixtures needed to reduce the overall carbon footprint of greenhouse operations shall be developed in three phases, with the initial phase designed to match current performance (spectral coverage, irradiance color uniformity, operating efficiency, programmability, potential for dynamic wavelength control and ease of integration with green house control systems) of the best commercially available systems.

The first phase shall serve as a research fixture for demonstration of engineering and biological performance enhancements developed in other parts of Task 2, or as required in order to achieve optical and efficiency performance by other tasks in the program. In the first phase, the Contractor (Rensselaer) shall use the air-cooled prototype developed in Subtask 2.3 and the driver developed in Subtask 2.5 to develop a Phase I prototype fixture that will serve as a reference design for the evaluation of future fixture requirements and efficiency improvements. The Phase I prototype(s) shall be used by Cornell and Rensselaer APIs as a multi-wavelength, adjustable research grade fixture to determine the optimum spectral composition of future prototypes for lettuce, tomatoes and strawberries in Task 3, and will also be used in Task 5 as appropriate. The Phase I prototype(s) may be assembled by a third party (to be determined). The number of Phase I prototype(s) assembled shall be sufficient for the APIs at Cornell and Rensselaer to independently cover three 1.2 x 1.2 m (4 x 4 ft) areas.

The Contractor (Rensselaer) shall test the Phase 1 prototype with respect to the following key performance parameters, and project potential energy savings:

- Spectral coverage (fixture irradiance versus wavelength)
- Irradiance uniformity at the plant (quality of color mixing)
- Operating efficiency (µmol/kW)
- Irradiance profile (polar plot of intensity versus distance and angle)
- Crop performance (Tasks 3-8).

As was done for the Phase 1 prototype, the Contractor (Rensselaer) shall report on designs for Phase 2 prototypes that include new performance capabilities as a result of GLASE research and/or materials/devices that become available as the result of continuing commercial development. As the prototype design becomes ready, it will be evaluated for plant testing as described in Tasks 3 and 5 as appropriate and as time allows.

The Contractor (Rensselaer) shall also work with appropriate IAB members to commercialize elements of at least one prototype in commercially available (or precommercial) fixtures suitable for testing in the pilot tests described in Task 8.4, and ultimately for commercial sales.

The evaluation of the Phase 2 prototype shall compare results to the baseline (Phase 1) performance as well as the best systems commercially available at that time, to include an assessment of its role in meeting the overall carbon footprint commitments of the total GLASE program. Results from the performance of Phase 2 commercial prototypes shall be used by the GLASE Consortium as a spin-off platform for sustainability. The Contractor (Rensselaer) shall prepare reports at the end of years 5 and 6 on the status of fixture commercialization and intellectual property (IP).

2.5 Deliverables (Payment milestones)

2.5.A. Design of the Phase 1 prototype fixture that will serve as a reference design for the evaluation of future fixture requirements and efficiency improvements, and as a multi-wavelength, adjustable research grade fixture for GLASE plant research.

2.5.B. Results of performance testing for the Phase 1 prototype.

2.5.C. Design of the Phase 2 prototype fixture that will include new performance capabilities as a result of GLASE research and/or materials/devices that have become available as the result of continuing commercial development.

2.5.D. Results of performance testing for the Phase 2 prototype.

2.5.E Year 5: Report on fixture commercialization status and IP.

2.5.E Year 6: Report on fixture commercialization status and IP.

Task 3. Spectrum/irradiance optimization and plant sensing (Rensselaer)

Subtask 3.1. Define combinations of wavelengths for optimal crop growth

It is now apparent that the spectral combinations (recipes) for different crop species are unique and the wrong 'recipe' can be detrimental to the crop at hand. The APIs at Cornell and Rensselaer shall narrow down the infinite recipe combinations that are available using LEDs.

The Contractor (Rensselaer) shall develop unique crop-specific spectral combinations and photon flux densities (PFD) using LED prototypes that were developed in GLASE Task 2 as sole source lighting (no sunlight). Both static and dynamic spectral combinations shall be tested, with the ultimate goal of improving crop quality while saving energy. The first step in developing crop specific spectra shall be to use the Phase I prototype developed in Subtask 2.6 to conduct light response curves under the individual LED channels (colors). Photosynthetic efficiency and water use efficiency shall be monitored using infra-red gas analysis (IRGA) to determine the saturation PFDs for each wavelength. (It is expected that driving the LEDs at currents that do not go beyond the saturation point of photosynthesis will save energy.) These saturation points shall be collected for lettuce, tomatoes and strawberries and the data shall be used to draft the specifications for prototypes in Subtask 2.6). The data shall also be incorporated into the design of the greenhouse experiments that use both solar and supplemental light.

Photochemical efficiency of the crop plants shall be measured using pulse amplitude modulated chlorophyll fluorescence (CF).

Based on the PFD saturation points, at least four spectral combinations shall be tested on each of the three crops (lettuce, tomato, strawberry). Three to five replicates shall be performed in series for each crop at the various wavelength combinations to ensure statistically meaningful results. Both static and dynamic light protocols shall be used (whereby the spectral combinations are changed based on time of day or plant developmental stage).

The Contractor (Rensselaer) shall conduct the trials described above in environment-controlled growth chamber experiments. Lettuce shall be assessed under at least four spectral combinations from germination to harvest (using a one-month crop cycle with three replications for red cultivars and three replications for green cultivars). Tomato and strawberry shall be assessed under at least four spectral combinations for three to four months (from transplanting to first fruit). Statistical analysis shall be performed for the replicates.

Crop performance shall be assessed as morphology (height, number of leaves, internode length), biomass (fresh and dry weights of leaves and stems), health (appearance and chlorophyll concentrations) as well as photosynthetic and photochemical efficiencies. Photosynthetic and water use efficiencies shall be measured with an infrared gas analyzer (IRGA) and include CO_2 quantum efficiency (f CO_2), maximum photosynthetic capacity (P_{max}), stomatal conductance (gs), transpiration rates (E; water loss), and water use efficiency (WUE). Photochemical efficiencies shall be measured using CF™ techniques and include the maximum photochemical quantum yield of photosystem II (Fv/Fm), the effective photochemical quantum yield of photosystem II (Y(II)), photochemical quenching (qL and qP; light energy use in photosynthesis) and non-photochemical quenching (NPQ; absorbed light energy lost through heat dissipation). Commercially available lighting fixtures shall be used as controls. The rate of electricity use and total electricity consumption for lighting for each crop and replication shall be logged along with environmental data (ambient CO_2 concentration, temperature, relative humidity). Spectral distributions and PFD shall be monitored weekly.

3.1 Deliverables (payment milestones)

3.1.A. Lettuce, tomato and strawberry: Data tables and calculations for the photosynthetic light saturation points under the individual wavelengths (monochromatic light). Specifications for wavelength and PFD combinations generated from this data set (to be evaluated in in 3.1.B through 3.1.D). Report describing light response curves and saturation PFDs.

3.1.B. Lettuce: Evaluate crop performance in red and green lettuce cultivars grown under spectra specified from 3.1.A. results:

3.1.B.1 Data tables and environmental data reported for first one-month crop cycle for each cultivar.

3.1.B.2 Data tables and environmental data reported for second one-month crop cycle for each cultivar.
3.1.B.3 Data tables and environmental data for third one-month crop cycle for each cultivar. Statistical analyses for the three replicates.

3.1.C Lettuce: Photosynthetic and photochemical performance measurements in red and green lettuce cultivars grown under spectra specified from 3.1.A results.
3.1.C.1 Data tables and environmental data reported for first one-month crop cycle for each cultivar.
3.1.C.2 Data tables and environmental data reported for second one-month crop cycle for each cultivar.
3.1.C.3 Data tables and environmental data for third one-month crop cycle for each cultivar. Statistical analyses for the three replicates.
3.1.C.4 Lettuce: Final crop performance report.

3.1.D Tomato: Evaluation of crop performance in tomato plants grown under spectra specified from 3.1.A. results.
3.1.D.1 Data tables and environmental data reported for first four-month crop cycle.
3.1.D.2 Data tables and environmental data reported for second four-month crop cycle.
3.1.D.3 Data tables and environmental data for third four-month crop cycle. Statistical analyses for the three replicates.

3.1.E Tomato: Photosynthetic and photochemical performance measurements in red and green lettuce cultivars grown under spectra specified from 3.1.A results.
3.1.E.1 Data tables and environmental data reported for first one-month crop cycle.
3.1.E.2 Data tables and environmental data reported for second one-month crop cycle.
3.1.E.3 Data tables and environmental data for third one-month crop cycle. Statistical analyses for the three replicates.
3.1.E.4 Tomato: Final crop performance report

3.1.F. Strawberry: Evaluate crop performance in strawberry plants grown under spectra specified from 3.1.A. results.
3.1.F.1 Data tables and environmental data reported for first four-month crop cycle.
3.1.F.2 Data tables and environmental data reported for second four-month crop cycle.
3.1.F.3 Data tables and environmental data for third four-month crop cycle. Statistical analyses for the three replicates.

3.1.G. Strawberry: Photosynthetic and photochemical performance measurements in red and green lettuce cultivars grown under spectra specified from 3.1.A results.
3.1.E.1 Data tables and environmental data reported for first one-month crop cycle for each cultivar.
3.1.E.2 Data tables and environmental data reported for second four-month crop cycle.
3.1.E.3 Data tables and environmental data for third four-month crop cycle. Statistical analyses for the three replicates.

Subtask 3.2. Determine narrow regions of the spectrum that contribute to nutrition in leafy greens (Rensselaer)

The Contractor (Rensselaer) shall quantify the nutrient density in lettuce leaves grown under the LED spectra determined in Subtask 3.1. Anthocyanins (red pigments) shall be analyzed spectrophotometrically while carotenoids shall be quantified using high performance liquid chromatography (HPLC). Data shall be compiled as mg/mg fresh weight of produce.

3.2. Deliverables (payment milestones)

3.2.A. Lettuce: Data tables and statistical analyses for anthocyanin and carotenoid densities (mg/mg fresh weight) for plants grown under the selected spectra determined in 3.1.

Subtask 3.3. Automation of dimming in growth chamber studies (Rensselaer)

The Contractor (Rensselaer) shall test and improve a chlorophyll fluorescence detector engineered and assembled at Rensselaer. In-house proof of concept has been established under cool white fluorescent lighting and validation of this prototype against a commercially available detector, the Walz PAM 2500 (http://www.walz.com) shall be conducted under LED lighting systems in controlled environment growth chambers. Physiological set points for optimal f, CO_2, WUE, Y(II) and NPQ shall be specified from the data collected in Subtask 3.1. Physiological set points shall be continually monitored and any deviations shall be detected and processed remotely using the Center for Lighting Enabled Systems & Applications (LESA) detector and a cloud-based data acquisition system. The benefits on crop growth, quality, and energy use using the automation of dimming or brightening spectral regions based on physiology shall be evaluated. Red and green lettuce cultivars shall be used for detector validation studies from germination until harvest for one-month crop cycles with at least three replicates for each cultivar.

3.3 Deliverables (payment milestones)

3.3.A. Develop first prototype modular detector and validate in growth cabinets

3.3.B. Set up communication protocols between detector and multi-channel LED systems and evaluate their ability for adaptive lighting

3.3.C Analyses of the effects of automated dimming/brightening lighting on biomass, nutrient density and photosynthetic and photochemical efficiencies

3.3.C.1 Data tables for first one-month crop cycle for each cultivar.

3.1.C.2 Data tables for second one-month crop cycle for each cultivar.

3.1.C.3 Data tables for third one-month crop cycle for each cultivar. Statistical analyses reported for the three replicates and summary of the rates of electrical energy use for lighting.

3.3.D. Report on benefits of automated dimming on crop growth, development and energy use.

Subtask 3.4. Automation of dimming in greenhouse studies (Rensselaer and Cornell)

The Contractor (Rensselaer) shall collect one year of baseline data on hourly changes in sunlight spectrum (wavelength composition) and irradiance in a greenhouse. The greenhouse shall be a glass greenhouse located at Cornell University that does not have supplemental lighting. The LESA spectral acquisition system (spectroradiometer) shall be calibrated by Contractor (Rensselaer) prior to installation and connected to a datalogging system. The Contractor (Cornell) shall monitor the spectral acquisition a minimum of three times weekly to ensure the system has power and is logging hourly data. The data shall be transmitted by the Contractor (Cornell) to the Contractor (Rensselaer) electronically once weekly.

Based on the baseline data on hourly spectral fluctuations (collected in Subtask 3.4.C) and an evaluation of the automated dimming in the growth chambers (Subtask 3.3.D) the Contractor (Cornell) shall update basic Light and Shade System Implementation (LASSI) control software to include:

1) functionality to dim an LED light system in real-time (at a minimum, a 10-minute interval or less) in response to sunlight <u>irradiance</u> fluctuations. Dimming shall occur to a target irradiance value selected specifically for each of the three plant species examined (lettuce, tomatoes, and strawberries); and,

2) functionality to adjust in real-time (at a minimum, a 10-minute interval or less) in response to sunlight <u>spectral</u> fluctuations to achieve a stable light spectrum (at a minimum, a stable ratio of light in the range of red [600-700 nm]:blue [400-500 nm]).

The version of LASSI with both updates shall be referred to as "real-time LASSI."

The Contractor (Cornell) shall install two LED lighting systems in adjoining research greenhouse spaces at Cornell University. Each system shall light a minimum 200 square foot production area. The two LED lighting systems shall be controlled by basic LASSI and real-time LASSI (as developed in subtask 3.4.D/E), respectively.

The Contractor (Cornell) shall then conduct greenhouse experiments for a minimum of three (3) months for each of the three plant species (lettuce, tomatoes, and strawberries)

Lettuce shall be assessed from the stage of transplanting to harvest (1 mo./crop cycle with 3 replications) and tomato and strawberry shall be assessed for the three (3) months from transplanting to initial fruit harvest. Plants shall be assessed for morphology (height, width, and visual observations), developmental stage (vegetative, flowering, fruiting), and biomass (fresh weight and dry weight of stems, leaves, and fruit). Electricity usage for lighting for each crop and replication during the three-month experimental period shall be logged, and compared for the basic LASSI and real-time LASSI treatments.

3.4 Deliverables (payment milestones)

3.4.A. Calibrate and update LESA spectral acquisition system (Rensselaer)

3.4.B. Install spectral acquisition system in a glass greenhouse house at Cornell with no supplemental lighting (Rensselaer)

3.4.C. Collect and compile into data tables one year of hourly spectral data from the glass greenhouse at Cornell (Rensselaer)
3.4.D. Demonstration of modified LASSI control software algorithm to incorporate real-time adjustment to sunlight irradiance fluctuations (minimum frequency ten-minute interval) dimming to a constant irradiance value (PPFD) (Cornell).
3.4.E. Demonstration of modified LASSI control software algorithm to incorporate real-time adjustment to a stable spectral ratio (minimum frequency 10-minute interval to a stable red [600-700 nm]:blue [400-500 nm] ratio) (Cornell).
3.4.F.1-3. Lettuce: evaluate supplemental light electricity use, plant morphology, developmental stage, and biomass comparing current LASSI to LASSI implementing real-time dimming and spectral ratio (3.4.D/E):
3.4.F.1 Data tables and statistical analysis reported for the first one-month crop cycle (Cornell).
3.4.F.2 Data tables and statistical analysis reported for the second one-month crop cycle (Cornell).
3.4.F.3 Data tables and statistical analysis reported for the third one-month crop cycle (Cornell).
3.4.G. Tomato: evaluate supplemental light electricity use, plant morphology, developmental stage, and biomass comparing current LASSI to LASSI implementing real-time dimming and spectral ratio (3.4.D/E). Data tables and statistical analysis reported for three-month growth cycle from transplant to initial fruit harvest stage (Cornell).
3.4.H. Strawberry: evaluate supplemental light electricity use, plant morphology, developmental stage, and biomass comparing current LASSI to LASSI implementing real-time dimming and spectral ratio (3.4.D/E). Data tables and statistical analysis reported for three-month growth cycle from transplant to initial fruit harvest stage (Cornell).

Task 4. Energy Efficacy and Radiometry

The Contractor (Cornell) shall direct Cornell's Subcontractor Rutgers to perform the activities in Task 4 as indicated.

Subcontractor (Rutgers) shall conduct lamp testing on three (3) to five (5) commercial lamps designed for horticultural applications. In addition, Subcontractor (Rutgers) shall conduct lamp testing on advanced prototypes described in Subtasks 2.3 and 2.6 that are provided to Contractor Cornell by Rensselaer for submission to Subcontractor (Rutgers).

Testing shall include: efficacy (using a two-meter integrating sphere), spectral output (300-1,000 nm), and PAR distribution (at a horizontal plane at one or more distances below the lamp). Reports on commercial lamp testing shall be prepared twice per year in years 1through 5. Reports on Rensselaer prototype lamp testing shall be prepared by Subcontractor Rutgers in years 1through 4.

As part of the Final Report at the end of the project, Subcontractor Rutgers shall prepare an evaluation that compares results of commercial lamps (non-cooled integrating sphere) with advanced lamps developed at Rensselaer and provided to Contractor Cornell by Rensselaer and/or by commercial testing laboratories when available. As part of the evaluation, a measurement protocol shall be developed for lamps that are specifically intended for horticultural applications. This protocol shall be prepared for publication and submitted to an appropriate journal. For this topic, a report on preliminary work shall be prepared, then a draft, then a final report.

Light distribution in tall plant canopies (e.g. tomato, pepper) shall be measured using spherical PAR sensors. Measurements shall be conducted by Rutgers and at locations with representative crop stands (e.g., at one of the participating research facilities and/or at a commercial operation). Based on the measurements, Rutgers shall collaborate with Cornell to evaluate the results and develop recommendations for how a greenhouse lighting system can be used most effectively to realize optimum plant response in terms of lamp design, lamp placement, and suitable lamp output characteristics. For this topic, an outline of preliminary work shall be prepared, two interim reports and a final report.

Towards the end of the research tasks, Cornell, Rensselaer and Rutgers shall collaborate on a report that Rutgers prepares. The report shall describe and compare energy and cost impacts for various lighting systems used for plant growth applications, including a comparison of business-as-usual lighting choices with improved lighting systems developed by GLASE. For this topic, an outline of preliminary work shall be prepared, three interim reports, and a final report.

4 Deliverables (Payment milestones)

1. Annual lamp test reports for commercial lamps designed for horticultural applications (3-5 total).
   4.1.A.1. Year 1: First lamp test report (3-5 total for the year).
   4.1.A.2. Year 1: Second lamp test report (3-5 total for the year).
   4.1.A.3. Year 1: Third and more lamp test reports (3-5 total for the year).
   4.1.B.1. Year 2: First lamp test report (3-5 total for the year).
   4.1.B.2. Year 2: Second lamp test report (3-5 total for the year).
   4.1.B.3. Year 2: Third and more lamp test reports (3-5 total for the year).
   4.1.C.1. Year 3: First lamp test report (3-5 total for the year).
   4.1.C.2. Year 3: Second lamp test report (3-5 total for the year).
   4.1.C.3. Year 3: Third and more lamp test reports (3-5 total for the year).
   4.1.D.1. Year 4: First lamp test report (3-5 total for the year).
   4.1.D.2. Year 4: Second lamp test report (3-5 total for the year).
   4.1.D.3. Year 4: Third and more lamp test reports (3-5 total for the year).
   4.1.E.1. Year 5: First lamp test report (3-5 total for the year).
   4.1.E.2. Year 5: Second lamp test report (3-5 total for the year).
   4.1.E.3. Year 5: Third and more lamp test reports (3-5 total for the year).
2. Lamp test reports for prototype lamps designed by Rensselaer as needed.
   4.2.1. Year 1: Lamp test report(s) for Rensselaer prototype(s)
   4.2.2. Year 2: Lamp test report(s) for Rensselaer prototype(s)
   4.2.3. Year 3: Lamp test report(s) for Rensselaer prototype(s)
   4.2.4. Year 4: Lamp test report(s) for Rensselaer prototype(s)

3. Measurement protocol for lamps designed for horticultural applications.
   4.3.1. Report on preliminary work on a measurement protocol for lamps used for horticultural applications
   4.3.2. Draft measurement protocol for lamps used for horticultural applications
   4.3.3. Final measurement protocol for lamps used for horticultural applications
4. Report on the light distribution patterns observed in a tall plant canopy such as tomato and how the lighting system can be used most effectively to realize optimum plant response.
   4.4.1. Outline of preliminary work on light distribution patterns observed in a tall plant canopy such as tomato and how the lighting system can be used most effectively to realize optimum plant response
   4.4.2. Interim report I on light distribution patterns observed in a tall plant canopy such as tomato and how the lighting system can be used most effectively to realize optimum plant response
   4.4.3. Interim report II on light distribution patterns observed in a tall plant canopy such as tomato and how the lighting system can be used most effectively to realize optimum plant response
   4.4.4. Final report on light distribution patterns observed in a tall plant canopy such as tomato and how the lighting system can be used most effectively to realize optimum plant response
5. Report comparing energy and cost impacts of various lighting systems designed for horticultural applications.
   4.5.1. Outline on preliminary work on comparing energy and cost impacts of various lighting systems designed for horticultural applications.
   4.5.2. Interim report I on comparing energy and cost impacts of various lighting systems designed for horticultural applications.
   4.5.3. Interim report II on comparing energy and cost impacts of various lighting systems designed for horticultural applications.
   4.5.4. Interim report III on comparing energy and cost impacts of various lighting systems designed for horticultural applications.
   4.5.5. Final report on comparing energy and cost impacts of various lighting systems designed for horticultural applications.

Task 5. Carbon dioxide enrichment studies

The biomass response of lettuce to irradiance and CO_2 concentration has been previously reported. A mathematical equation to determine the "virtual DLI" (daily light integral) response of lettuce has been previously incorporated into a Cornell patented extended version of LASSI (CO_2 LASSI) which simultaneously controls CO_2 enrichment and supplemental lighting to optimize for a reduced need for supplemental lighting. The mathematical equation that correlates DLI and CO_2 concentration to the resulting virtual DLI relies on crop-specific equations modeling CO2/DLI interactions.

The Contractor (Cornell) shall evaluate the response of tomatoes and strawberries to DLI and CO_2 enrichment to determine their crop-specific equations modeling CO2/DLI interactions for the "virtual DLI" equation in the same manner as was done for lettuce. Experiments shall be conducted at Cornell in controlled environment chambers whereby four (4) DLI by four (4) CO_2 concentration treatments (resulting in an anticipated 16 treatment combinations) are imposed. Strawberry and tomato seedlings shall be grown for 10 days in each of the anticipated 16 treatment combinations. Each treatment condition shall be replicated in time twice for an anticipated total of 32 treatments each for strawberry and tomato.

Near the conclusion of each treatment period, plants shall be assessed for photosynthetic parameters (PSN, stomatal conductance, transpiration rates, and WUE), morphology (height, width, and visual observations) and biomass (fresh weight and dry weight of stems and leaves). Nonlinear regression shall be used to determine the equations modeling CO_2/DLI interactions. CO_2 LASSI software shall be updated to allow for user selection of crop-specific equations modeling CO_2/DLI interactions; and the software will be pre-programmed with default equations for lettuce (existing), tomatoes (deliverable 5.A) and strawberries (deliverable 5.B).

5. Deliverables (payment milestones)

5.A. Tomato: equations modeling interactions for DLI and CO_2 concentration versus biomass. Data tables and statistical analysis reported for photosynthetic parameters, morphology, and biomass in response to anticipated up to 16 DLI/CO_2 treatments applied and replicated in a controlled environment chamber for a 10-day treatment period.

5.B. Strawberry: equations modeling interactions for DLI and CO_2 concentration versus biomass. Data tables and statistical analysis reported for photosynthetic parameters, morphology, and biomass in response to anticipated up to 16 DLI/CO_2 treatments applied and replicated in a controlled environment chamber for a 10-day treatment period.

5.C. Demonstration of the updated CO_2 LASSI software that allows user selection of equations modeling interactions for DLI and CO_2 and with pre-programmed default equations for lettuce (existing) tomatoes and strawberries.

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

Subtask 6.1. Validation of CO_2 LASSI in research greenhouses for tomato and strawberry.

The addition of tomato- and strawberry-specific equations modeling CO2/DLI interactions to CO_2 LASSI based on growth chamber experiments (Task 5) shall be further validated through demonstrations with tomato and strawberry during the early fruiting stage in research greenhouses at Cornell University. (a lettuce-specific equation was developed previously.)

The Contractor (Cornell) shall install basic LASSI (control treatment) and CO_2 LASSI software and CO_2 supplementation capability (experimental treatment) in adjacent research greenhouses.

The control treatment shall consist of a greenhouse section (approximately 400 square feet of crop production area) with lighting control from basic LASSI. In an adjoining greenhouse, the experimental treatment for tomatoes and strawberries shall consist of a similarly sized greenhouse section with both lighting and CO_2 enrichment controlled from CO_2 LASSI, using crop-specific equations modeling CO2/DLI interactions for the tomatoes and strawberries. The luminaire type will be the same in both greenhouses as treatment of interest is basic LASSI vs. CO_2 LASSI. It is anticipated that high pressure sodium (HPS) luminaires will be used as the supplemental lighting source for both greenhouses.

The Contractor (Cornell) shall conduct the adjacent control and experimental greenhouse experiments in parallel for a minimum of three (3) months each for tomatoes and strawberries from the stage of transplanting until the plants spend a minimum of one month during the fruit harvest stage.

Plants will be assessed using standard morphology (height, width, and visual observations), developmental stage (vegetative, flowering, fruiting) and biomass (fresh weight and dry weight of stems, leaves, and fruit) measurements. During the experimental period, for each treatment (basic LASSI [control] and CO_2 LASSI [experimental]) daily electricity usage for lighting and weekly CO_2 usage shall be logged during the experimental period.

The Contractor (Cornell) shall evaluate data collected during the experimental period for the strawberries and tomatoes, (including supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass), and compare the results from the basic LASSI to the CO_2 LASSI that implemented crop-specific equations modeling CO2/DLI interactions. Data tables shall be prepared and statistical analysis performed for the three-month growth cycle from transplant through early fruit harvest stage.

6.1. Deliverables (payment milestones)

6.1.A. Installation of basic LASSI and CO_2 LASSI software and CO_2 supplementation capability in adjacent research greenhouses.

6.1.B. Test results (data tables) for tomato using CO_2 LASSI software, CO_2 supplementation capability, and tomato-specific equations modeling CO2/DLI interactions in research greenhouses, including the evaluation of supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass comparing basic LASSI to CO_2 LASSI during the three-month growth cycle from transplant through early fruit harvest stage.

6.1.C. Statistical analysis and report from 6.1.B.

6.1.D. Test results (data tables) for strawberry using CO_2 LASSI software, CO_2 supplementation capability, and strawberry-specific equations modeling CO2/DLI interactions in research greenhouses, including the evaluation of supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass, and data tables and statistical analysis comparing basic LASSI to CO_2 LASSI during the three-month growth cycle from transplant through early fruit harvest stage.

6.1.E. Statistical analysis and report from 6.1.D.

Subtask 6.2. Validation of energy efficient LEDs with CO_2 LASSI in research greenhouses for lettuce, tomato and strawberry

The Contractor (Cornell) shall conduct research on lettuce, tomatoes, and strawberries to demonstrate the combined benefits (in terms of biomass efficacy, defined as crop yield in grams (g) per kWh electricity) of integrating new energy-efficient LED luminaires (with design features as optimized as described in Tasks 2 and 3, anticipated to be supplied by Rensselaer or a commercial industry partner implementing the optimized designed features) and with the most updated version of LASSI, called "real-time LASSI," (implementing to the extent practical the real-time dimming and spectral ratio as described in subtask 3.4, crop-specific equations modeling CO2/DLI interactions as described in task 5 and additional upgrades as described in subtask 7.4 (if available).

The Contractor (Cornell) shall install basic LASSI (control treatment) and real-time LASSI software, CO_2 supplementation capability and energy efficient LED luminaires (experimental treatment), for lettuce, tomatoes and strawberries in adjacent research greenhouses. (It is anticipated the Subtask 6.1 installation will simply be upgraded with the improved software and luminaires and expanded to include the lettuce crop.)

For each crop (lettuce, tomatoes and strawberries), the control treatment shall consist of a greenhouse section (approximately 400 square feet of crop production area) lit with HPS luminaires with lighting control from basic LASSI. In adjacent greenhouses, the experimental treatment for each crop shall consist of a similarly sized greenhouse section lit with LED luminaires that implement the optimized design features developed by Rensselaer (as per the research prototype developed in Subtask 2.2 and additional developments in Tasks 2 and 3 as appropriate) and with CO_2 supplementation and with the most updated version of LASSI (real-time LASSI).

The Contractor (Cornell) shall then conduct the adjacent greenhouse experiments in parallel for a minimum of three (3) months (or three (3) crop cycles, whichever is shorter) for lettuce and five (5) months each for tomatoes and strawberries from the stage of transplanting until the tomatoes and strawberries spend a minimum of two months during the fruit harvest stage. Lettuce crop cycles are defined as occurring from transplant through the mature (5 ounce) head stage.

Plants will be assessed for the standard morphology, developmental stage, and biomass measurements as previously described. Electricity usage for lighting and CO_2 usage shall be logged daily (electricity usage) and weekly (CO_2 usage) for the basic LASSI (control) and real-time LASSI (experimental) treatments during the experimental period.

The Contractor (Cornell) shall evaluate data collected during the experimental period for the lettuce, strawberries and tomatoes, (including supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass), and compare the results from the basic LASSI to the real-time LASSI. Data tables shall be prepared and statistical analysis performed for the growth cycles described above from transplant through fruit harvest stage.

6.2. Deliverables (payment milestones)

6.2.A. Installation of basic LASSI and real-time LASSI software, lighting systems (1 HPS array and 1 new LED array) and CO_2 supplementation capability (1 greenhouse) in adjacent research greenhouses at Cornell University.

6.2.B. Test results (data tables) for real-time LASSI software, CO_2 supplementation capability, and energy-efficient LEDs for lettuce in research greenhouses, including the evaluation of supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass, comparing basic LASSI (with HPS) to real-time LASSI during the three months (or three growth cycles from transplant through mature (5 ounce) head stage, as described).

6.2.C. Statistical analysis and report from 6.2.B.

6.2.D. Test results (data tables) for real-time LASSI software, CO_2 supplementation capability, and energy-efficient LEDs for tomato in research greenhouses, including the evaluation of supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass comparing basic LASSI (with HPS) to real-time LASSI during the five-month growth cycle from transplant through fruit harvest stage.

6.2.E. Statistical analysis and report from 6.2.D.

6.2.F. Test results (data tables) for real-time LASSI software, CO_2 supplementation capability, and energy-efficient LEDs for strawberry in research greenhouses, including the evaluation of supplemental light electricity usage, CO_2 usage, plant morphology, developmental stage, and biomass comparing basic LASSI (with HPS) to real-time LASSI during the five-month growth cycle from transplant through fruit harvest stage.

6.2.G. Statistical analysis and report from 6.2.F.

Task 7. Engineering and modeling

The Contractor (Cornell), with assistance from their subcontractor, USDA ARS, shall perform all work in Task 7. Tasks utilizing assistance from USDA ARS are indicated as such.

Subtask 7.1. Integrated energy simulation engine

Previous work at Cornell funded by NYSERDA resulted in development of two simulation engines for modeling energy use in greenhouses: GEM and modified EnergyPlus. Each has different methodologies and capabilities. For example, in addition to modeling greenhouses, modified EnergyPlus can also model plant factories. A single unified software architecture that merges the capabilities of the two engines would better facilitate the completion of GLASE tasks. To that end, the two engines shall be benchmarked against each other by running simulations of one or more identical greenhouse building model(s). The causes of any output discrepancies shall be determined and documented, and the anticipated approach to address discrepancies in the unified architecture shall be discussed. Software development shall be undertaken in order to create an integrated energy simulation engine with unified architecture that encapsulates the capabilities of both engines. Virtual Grower 3 (VG3) is a software tool developed by ARS that simulates energy consumption of greenhouses. However, the calculations in the current version are based on steady-state models. Through a partnership with USDA-ARS, GLASE will support the development of the next generation Virtual Grower (VG4) and expand its modeling milestones capabilities. There are many planned upgrades for VG4, including updating the hourly energy simulation engine to incorporate a dynamic model known as the ASHRAE heat balance method, the industry standard for energy modeling calculations. With these upgrades in place, VG4 will be able to produce research-grade energy models that are suitable for satisfying multiple GLASE objectives. This subtask shall be supported by Cornell's subcontractor, USDA ARS.

A demonstration of the simulation outputs from the integrated energy simulation engine with unified architecture shall be conducted for the NYSERDA Project Manager.

7.1 Deliverables (payment milestones)

7.1.A. Description of greenhouse building model(s) that will be used in the benchmarking process.

7.1.B. Report detailing simulation outputs of each engine, GEM and modified EnergyPlus, for each of the identical building model(s), discussion of discrepancies, and discussion of how it is anticipated that discrepancies may be addressed when the unified architecture is completed.

7.1.C. Demonstration of simulated outputs from Virtual Grower – A greenhouse model will be constructed and simulated in multiple ASHRAE climate zones in order to demonstrate the capabilities of the new engine. The models will incorporate building geometry, internal loads such as evapotranspiration and supplemental lighting, and external loads such as conduction, solar radiation, and ventilation.

Subtask 7.2. Improve energy simulation engine

It is possible to improve the energy simulation engine developed in Subtask 7.1 in various ways: raytracing, semi-closed models, and gas modeling. This subtask shall be supported by Cornell's subcontractor, USDA ARS.

Raytracing is a mathematical technique used in computer graphics that allows rendering of photorealistic scenes, and in computational physics to model optical systems. In greenhouses, solar rays striking a pane of glass may be absorbed, reflected, or refracted. This process continues many times until a photon is ultimately absorbed for photosynthesis, absorbed as heat, or refracted out of the greenhouse. Similar processes occur for supplemental light rays. Raytracing shall be applied to optical modeling in greenhouses in order to improve the way the energy simulation engine simulates thermal energy modeling and the modeling of shading from the structure and the luminaires.

Previous work at Cornell included development of semi-closed greenhouse models. A semi-closed greenhouse uses a small mechanical cooling system at certain times of the year to remove latent heat, thereby reducing ventilation and waste of supplemental CO_2. The previously developed semi-closed greenhouse models shall be improved by simulating complicated heating, ventilation, and air conditioning (HVAC) systems that allow waste heat to be dumped into the greenhouse, or employ heat exchange technologies such as an enthalpy wheel.

Energy simulations for greenhouses typically employ a single thermal zone for the air and assumes the air is well mixed, so that properties such as temperature, flow, CO_2, and humidity are homogeneous. Improvements shall be made to the energy simulation engine that allow modeling of non-homogeneous air masses. These may include improvements to the modeling of gas flow, sensible heat, latent heat, and/or CO_2 distribution. This shall be accomplished by employing techniques such as computational fluid dynamics (CFD) or dynamic thermal zone subdivision.

One or more demonstrations of the simulation outputs from the integrated energy simulation engine with raytracing capability, semi-closed greenhouse model features, and/or improved gas modeling shall be conducted for the NYSERDA Project Manager.

7.2 Deliverables (payment milestones)

7.2.A. Demonstration of raytracing capability showing differences in output with feature enabled.

7.2.B Demonstration of semi-closed greenhouse models in Virtual Grower with simulation outputs – A semi-closed greenhouse operates with a hybrid HVAC system: inexpensive evaporative cooling in the summer, and mechanical cooling in shoulder seasons. This facilitates more efficient CO2 supplementation by minimizing ventilation cycles. Semi-closed greenhouse models will be simulated in various climates within Virtual Grower.

Subtask 7.3. Construct baseline energy models for pilot facilities

An energy audit is a procedure used to help establish a baseline of energy consumption before improvements are made. This procedure shall be applied to the facilities identified in Task 8 for the pilot studies and shall include a site visit, interviews with facility staff, analysis of building plans or blueprints if available, and measurement of infiltration and other parameters according to well-known audit protocols such as ASHRAE Procedures for Commercial Building Energy Audits, and documentation of existing HVAC and lighting systems types and energy usages.

An analysis of utility data shall be performed using at least three previous years of electricity and heating fuel bills, if available, and correlated with available weather data. Using the results of the energy audit, energy models shall be constructed that simulate energy consumption in the building. The energy models shall be run, compared with the utility data, and analyzed to see if there is agreement between the model and the data.

The models shall be tuned as baseline sensor data is collected and incorporated during the pilot study.

7.3 Deliverables (payment milestones)

7.3.A. Energy audit report of baseline energy consumption including building parameters and utility data analysis.
7.3.B. Description of energy models.
7.3.C. Report including simulation outputs and assessment of agreement with utility data.
7.3.D. Report detailing tuning of energy models using baseline sensor data from pilot.

Subtask 7.4. CO_2 LASSI improvements

Previous work at Cornell demonstrated how CO_2 LASSI could be used to optimize energy costs using off-peak electricity rates. This work shall be extended to optimize costs using Day Ahead Market Pricing, in which electrical utilities provide hourly rates for the upcoming 24-hour period. This subtask shall be supported by Cornell's Subcontractor, USDA ARS.

LASSI was originally developed to employ an algorithm that used heuristic light and shade rules based on climate. Previous work at Cornell provided a slight performance increase that improved on the original algorithm by employing a trajectory model that could simultaneously optimize reductions in energy cost and revenue from plant sales. This technique shall be extended to CO_2 LASSI and then real-time LASSI, with CO_2 cost included among the optimized quantities.

Most of the previous work with CO_2 at Cornell has focused on lettuce crops. With the completion of Task 5, CO_2 LASSI shall be simulated with tomato and strawberry crops as well.

One or more demonstrations of CO_2 LASSI with capabilities to address Day Ahead Market Pricing, a trajectory control algorithm, and/or CO_2 control simulation of tomato and strawberry crops shall be conducted for the NYSERDA Project Manager. The demonstrations shall be repeated with real-time LASSI once the CO_2 LASSI demonstrations in this Subtask are completed.

7.4 Deliverables (payment milestones)

7.4.A. Demonstration of Day Ahead Market Pricing applied to CO_2 LASSI.
7.4.B. Demonstration of trajectory control algorithm for CO_2 LASSI.
7.4.C. Demonstration of CO_2 control simulation of tomato and strawberry crops using CO2 LASSI.
7.4.D. Demonstration of Day Ahead Market Pricing applied to real-time LASSI.
7.4.E. Demonstration of trajectory control algorithm for real-time LASSI.
7.4.F. Demonstration of CO_2 control simulation of tomato and strawberry crops using real-time LASSI.

Subtask 7.5. Devise and simulate integrated control system for lights, shade, CO_2, temperature, humidity

Lights, shade, CO_2, temperature, and humidity are tightly coupled in CEA (controlled environment agriculture) buildings. Previous work at Cornell has focused on controlling the first three. An integrated control system shall be developed that allows control of lights, shade, CO_2, and HVAC while optimizing costs, such as electricity, heating fuel, and CO_2. To that end, a predictive algorithm for ventilation shall be developed that incorporates indoor and outdoor conditions, including weather. This subtask shall be supported by Cornell's Subcontractor, USD ARS.

A demonstration of the predictive algorithm for ventilation that incorporates indoor/outdoor conditions shall be conducted for the NYSERDA Project Manager.

7.5 Deliverables (payment milestones)

7.5.A. Demonstration of predictive algorithm for ventilation that incorporates indoor/outdoor conditions.

Task 8. Pilot/Demonstrations

Pilot studies shall be performed by the Contractor (Cornell) in two New York State facilities, anticipated to be approximately 6,000 and 20,000 ft^2. **All of the subtasks, deliverables, and milestone payments in Task 8 apply to both the small 6,000 ft^2 and the large 20,000 ft^2 pilot studies**. The Contractor (Cornell) shall allow NYSERDA to validate energy savings if requested.

Subtask 8.1. Pilot selection and baseline data collection

The Contractor (Cornell) shall identify a suitable New York State facility for use in the pilot study. Each facility should have the following characteristics:

- Commercial CEA greenhouse currently producing vegetable or hemp crops
- Although the exact sizing is not as critical as other factors, the pilot studies shall occur in one small and one large pilot. The facilities are anticipated to be approximately 6,000 square feet available for demonstrations in the small pilot and 20,000 square feet in the large pilot. Some demonstrations are anticipated to be conducted in the entire facility, others in independently-controlled portions of a facility. If possible, facilities with separate zones shall be sought in order to facilitate parallel demonstrations.
- Plans to install new LED supplemental lighting from a third party manufacturer, willingness to consider choices that substantially incorporate energy efficient lamp design as developed in Task 2 (as described in Subtask 8.4)
- Hardware capabilities to allow for real-time LASSI control
- Shade system installed if growing lettuce or other light-sensitive crops
- HVAC system installed
- Capable of tracking daily yield data and energy data

- Currently supplementing CO_2 to no higher than 400 ppm
- Tight enough building envelope to make higher CO_2 supplementation practical

The Contractor (Cornell) shall draft a sample letter of intent the facility owner may use, detailing the responsibilities of the facility owner, and provide it to the facility owner. The Contractor (Cornell) shall obtain a letter of intent from the facility owner that indicates an understanding of their responsibilities and their willingness to participate in the pilot study.

Data loggers that can collect sensor data for light, CO_2, temperature, humidity, and HVAC system operation shall be installed by the facility and data collection procedures developed and implemented. Procedures for collecting daily crop yield data and other economic benefit data, if available, from the grower shall be established and implemented. This information will be much more detailed than can be obtained from previous utility bills as described in Subtask 7.3. Local weather data sources shall be explored, and if necessary, a weather station shall be installed at the pilot facility. Weather data collection procedures shall be developed and implemented before baseline data collection begins.

Baseline data collection shall be performed for one year. An analysis shall be performed on this one year of sensor, yield, and utility data from the pilot, and normalized with local weather data. This analysis, combined with the three years of prior utility data as detailed in Subtask 7.3, will be used to provide a high-quality baseline energy model with which to compare further phases of the pilot as well as to calculate energy savings.

8.1 Deliverables (payment milestones)

8.1.A.1 Letter of intent from facility owner agreeing to participate in small pilot study.
8.1.A.2 Letter of intent from facility owner agreeing to participate in large pilot study.
8.1.B.1 Report on data logger installation at small pilot and procedures for collecting data logger data and daily crop yield data, as well as weather data procedures.
8.1.B.2 Report on data logger installation at large pilot and procedures for collecting data logger data and daily crop yield data, as well as weather data procedures.
8.1.C.1 Report from small pilot including analysis of one year of baseline sensor, crop yield, and utility data and normalization with weather data and energy usage.
8.1.C.2 Report from large pilot including analysis of one year of baseline sensor, crop yield, and utility data and normalization with weather data and energy usage.

Subtask 8.2. Basic LASSI Pilot

Basic LASSI control software shall be installed by each facility, and tested by the Contractor (Cornell) using previously developed protocols to ensure proper operation. Sensor, crop yield and utility data will continue to be collected for a period of one year. The data shall be normalized with weather data and compared with the baseline. Energy savings shall be calculated.

The APIs shall collaborate with each other to prepare one or more case studies based on Subtask 8.2 small and large pilot facility results that translate scientific findings into a fashion that is useful to greenhouses considering the use of LED lighting or energy control systems. Each case study shall include descriptions of the product and how it can be used, calculations for lighting needs, the relative pros and cons of the product compared to business-as-usual methods, benefits, knowledge gaps, estimated capital and operating costs, and estimates of return on investment to the end-user, including assumptions (e.g. product lifespan, climate zone) in the case study itself or in an appendix as appropriate. Because costs of new products may be speculative, estimated costs may include price ranges. The case studies shall be written at a reader level appropriate to the *New York Times* Science section and use graphical illustrations and photographs where possible to most clearly convey what is known.

8.2 Deliverables (payment milestones)

8.2.A.1 Installation of basic LASSI software at small pilot facility.
8.2.A.2 Installation of basic LASSI software at large pilot facility.
8.2.B.1 Report from small pilot including one year of sensor, crop yield, and utility data, normalization with weather data, and comparison with baseline, and energy savings.
8.2.B.2 Report from large pilot including one year of sensor, crop yield, and utility data, normalization with weather data, and comparison with baseline, and energy savings.
8.2.C..1. Publish case study that includes Subtask 8.2 small pilot results.
8.2.C..2. Publish case study that includes Subtask 8.2 large pilot results.

Subtask 8.3. CO_2 LASSI Pilot

CO_2 LASSI control software shall be installed by each facility, as well as CO_2 supplementation capability if necessary. The control system shall be tested by the Contractor (Cornell) using previously developed protocols to ensure proper operation. Sensor, crop yield and utility data will continue to be collected for a period of one year. The data shall be normalized with weather data and compared with the baseline. Energy savings shall be calculated.

The APIs shall collaborate with each other to prepare one or more case studies based on Subtask 8.3 small and large pilot facility results that translate scientific findings into a fashion that is useful to greenhouses considering the use of LED lighting or energy control systems. Each case study shall include descriptions of the product and how it can be used, calculations for lighting needs, the relative pros and cons of the product compared to business-as-usual methods, benefits, knowledge gaps, estimated capital and operating costs, and estimates of return on investment to the end-user, including assumptions (e.g. product lifespan, climate zone) in the case study itself or in an appendix as appropriate. Because costs of new products may be speculative, estimated costs may include price ranges. The case studies shall be written at a reader level appropriate to the *New York Times* Science section and use graphical illustrations and photographs where possible to most clearly convey what is known.

8.3 Deliverables (payment milestones)

8.3.A.1 Installation of CO_2 LASSI software and CO_2 supplementation capability at small pilot facility.

8.3.A.2 Installation of CO_2 LASSI software and CO_2 supplementation capability at large pilot facility.

8.3.B.1 Report from small pilot including one year of sensor, yield, and utility data, normalization with weather data, and comparison with baseline, and energy savings.

8.3.B.2 Report from large pilot including one year of sensor, yield, and utility data, normalization with weather data, and comparison with baseline, and energy savings.

8.3.C.1 Publish case study that includes Subtask 8.3 small pilot results.

8.3.C.2 Publish case study that includes Subtask 8.3 large pilot results.

Subtask 8.4. Real-time (10-minute interval) LASSI Pilot

New LED luminaires that were developed and designed by engineers and plant physiologists at Rensselaer and Cornell (the research prototype developed in Task 2.6 and additional developments in Tasks 2 and 3 as appropriate) shall be purchased by each pilot facility described in Subtask 8.1, assembled by a third party as directed by the APIs at Cornell and Rensselaer, and, as described in Tasks 2 and 3, shall be installed by each pilot facility described in Subtask 8.1. Though the LED technology will be continuously improving through an iterative R&D cycle during Tasks 2 and 3, the APIs shall, in advance of the pilot, choose a consistent set of luminaires and control software for the one-year duration of the pilot. The control systems at each pilot facility shall be upgraded to real-time LASSI as described in tasks 3.4, 5, and 7.5. Luminaires and the control system shall be tested using previously developed protocols to ensure proper operation. Sensor, crop yield, and utility data will continue to be collected for a period of one year. The data shall be normalized with weather data and compared with the baseline. Energy savings shall be calculated.

The APIs shall collaborate with each other to prepare one or more case studies based on Subtask 8.4 small and large pilot facility results that translate scientific findings into a fashion that is useful to greenhouses considering the use of LED lighting or energy control systems. Each case study shall include descriptions of the product and how it can be used, calculations for lighting needs, the relative pros and cons of the product compared to business-as-usual methods, benefits, knowledge gaps, estimated capital and operating costs, and estimates of return on investment to the end-user, including assumptions (e.g. product lifespan, climate zone) in the case study itself or in an appendix as appropriate. Because costs of new products may be speculative, estimated costs may include price ranges. The case studies shall be written at a reader level appropriate to the *New York Times* Science section and use graphical illustrations and photographs where possible to most clearly convey what is known.

8.4 Deliverables (payment milestones)

8.4.A.1 Installation of new luminaires and upgrade control software at small pilot.

8.4.A.2 Installation of new luminaires and upgrade control software at large pilot.

8.4.B.1 Report from small pilot including one year of sensor, crop yield, and utility data, normalization with weather data, and comparison with baseline, and energy savings.
8.4.B.2 Report from large pilot including one year of sensor, crop yield, and utility data, normalization with weather data, and comparison with baseline, and energy savings
8.4.C.1 Publish case study that includes Subtask 8.4 small pilot results.
8.4.C.2 Publish case study that includes Subtask 8.4 large pilot results.

Task 9 Training, outreach and technology transfer

Subtask 9.1 Training
Short courses describing new CEA technology and GLASE results shall be developed by the Cornell and Rensselaer APIs and given at Cornell, anticipated to be in years 2, 4 and 6. Course offerings shall be open to both growers and other industry participants. Short courses shall be a minimum of one day in duration. Early courses may focus on general principles of lighting and energy efficiency in CEA systems appropriate for a variety of stakeholders, including growers, lighting manufacturers and others interested in CEA. Later courses may include training specifically for lighting manufacturers or service providers.

To the extent possible, course materials shall provide consistent messaging and delivery among Subtask 9.1 course offerings and Subtask 9.2 webinars, and focus on the knowledge, expectations, and needs of the audience. As applicable, course materials may incorporate the use of approved course content from Cornell and/or Rensselaer and may incorporate the use of hands-on exhibits and demonstrations. Course outlines shall be submitted to NYSERDA's Project Manager for review and approval in advance of course offerings. If the courses are taught by someone other than the APIs, staff resumes shall be submitted prior to the courses to NYSERDA's Project Manager for review and approval.

The number and variety of course offerings shall expand over time as GLASE progresses. Annual updates shall be offered, anticipated to be at the existing biannual Cornell CEA Advisory Committee meetings (which are conducted independently of this agreement).

Short courses are part of the Marketing Plan developed in Subtask 9.5 and shall serve as a portal for new members. The number of attendees (Consortium members and non-members) at training events shall be recorded and submitted to NYSERDA's Project Manager. Attendees shall be asked to complete a training evaluation form, and names and contact information shall be collected and used as appropriate to provide consortium updates and for potential consortium member recruitment as described in Membership Outreach, Subtask 9.5. Short courses shall be used in the consortium development plan and shall serve as a portal for new members. The APIs shall work with NYSERDA to explore ways to provide education credits to course attendees.

To supplement the short course curriculum, the APIs at Cornell and Rensselaer shall mentor undergraduate and graduate students in horticulture and engineering programs, as appropriate.

9.1 Deliverables (payment milestones)

9.1.A. Resumes as applicable, short course outline, materials and attendance report for Year 2.
9.1.B. Resumes as applicable, short course outline, materials and attendance report for Year 4.
9.1.C. Resumes as applicable, short course outline, materials and attendance report for Year 6.
9.1.D. Report on mentoring activities (ongoing in progress reports).

Subtask 9.2 Webinar series

A periodic webinar series shall be developed by the Cornell and Rensselaer APIs and offered jointly by Cornell's and Rensselaer's APIs every other year (out of phase with the short courses) to facilitate information transfer to reach New York participants as well as a national audience. Two of the webinars are anticipated to be led by Cornell and one by Rensselaer as indicated. The topics are anticipated to include 1) Light basics, (Cornell) 2) Best horticultural practices (Rensselaer) and, 3) Energy savings and calculations (Cornell). Results from the GLASE research efforts shall be presented in the webinars wherever applicable. The series shall have a minimum of three (3) hours of training (which may be offered on the same day or as part of a multi-week series). The webinar series may evolve and expand over time as GLASE progresses. The webinar offerings shall be open to both growers and other industry participants (ex: service providers, lighting manufacturers and suppliers).

To the extent possible, webinar materials shall provide consistent messaging and delivery among Subtask 9.1 course offerings and Subtask 9.2 webinars, and focus on the knowledge, expectations, and needs of the audience. As applicable, course materials shall incorporate the use of approved course content from Cornell and/or Rensselaer and incorporate the use of hands-on exhibits and demonstrations. Webinar presentations shall be submitted to NYSERDA's Project Manager for review and approval in advance of webinars.

The number of attendees (Consortium members and non-members) at training events shall be recorded. Attendees shall be asked to complete a training evaluation form, and names and contact information shall be collected and used as appropriate to provide consortium updates and for potential consortium member recruitment. Webinars shall be used in the consortium development plan and shall serve as a portal for new members.

9.2 Deliverables (payment milestones)

9.2.A. Webinar materials and attendance report for Year 1.
9.2.B. Webinar materials and attendance report for Year 3.
9.2.C. Webinar materials and attendance report for Year 5.

Subtask 9.3. Information transfer

Cornell and Rensselaer shall establish a joint website describing the GLASE Consortium and associated in-house research and activities. Where appropriate Cornell and Rensselaer shall each link their broader webpages to the GLASE webpage.

The Contractor shall work with NYSERDA and/or NYSERDA's outreach contractors to ensure that the web site has the functionality to transfer project information in an easily accessible manner and that it meets all applicable New York State Handicapped Accessibility Standards. The project description shall include appropriate acknowledgments and disclaimers for NYSERDA. The Contractor shall use Google Analytics to collect information about who is viewing and/or downloading data from the Contractor's website by tracking the users uniform resource locator (URL), requesting information from the users or other methods as appropriate.

Any web-based information and applications development, or programming delivered pursuant to the contract or procurement, will comply with New York State Enterprise IT Policy NYS-P08-005, Accessibility of Web-Based Information and Applications as such policy may be amended, modified or superseded, which requires that state agency web-based information and applications are accessible to persons with disabilities. Web-based information and applications must conform to New York State Enterprise IT Policy NYS-P08-005 as determined by quality assurance testing. Such quality assurance testing will be conducted by NYSERDA and the results of such testing must be satisfactory to NYSERDA before web-based information and applications will be considered a qualified deliverable under the contract or procurement. Questions concerning this policy may be directed to OFT, Strategic and Executive Services (SES) Bureau (518) 473-0234, Attn: Accessibility Program Manager. Or visit OFT at www.oft.state.ny.us.

Any web-based information and applications development, or programming delivered pursuant to the contract shall conform to requirements of the New York State Office of Cyber Security Policy P03-002 and any amendments thereto, to maintain the security of and to prevent unauthorized access to Information that is maintained in electronic form on the Contractors 'systems.

The APIs from each university, with support from the other, shall prepare at least two (2) scientific manuscripts describing results from the project for submission to a peer-reviewed journal. Based upon discussion and written approval from NYSERDA's Project Manager, the "Open Access" publication of peer-reviewed papers may be substituted for some of the Final Report.

The APIs from each university, with support from the other, shall prepare at least two (2) trade journal articles describing results from the project for submission to a CEA or agricultural journal.

The APIs from each university, with support from the other, shall prepare, at least annually, a slide presentation describing results from the project suitable for presentation at a technical conference.

The APIs or their direct research support staff or graduate students will present results from the project at academic meetings at least once annually.

Throughout the project, the APIs and Rutgers shall collaborate on outreach efforts to assist in national efforts to develop, promote, and refine a newly proposed lamp label, including dissemination of basic information about lamps designed for horticultural applications. Outreach materials for growers may include information regarding eye safety as it relates to LED lighting. Annual reports on these outreach efforts shall be prepared in years 1-4 (Reports I – IV).

9.3 Deliverables (payment milestones)

9.3.A. Establishment of project webpage.

9.3.B. Peer reviewed journal articles (2).

9.3.C. Trade journal articles (2).

9.3.D. Presentations at academic meetings (min. 1 per year).

9.3.E. Report on Outreach efforts to assist in national efforts to develop, promote, and refine a suitable proposed lamp label.

- 9.3.E.1. Year 1: Report I on Outreach efforts to assist in national efforts to develop, promote, and refine a suitable proposed lamp label
- 9.3.E.2. Year 2: Report II on Outreach efforts to assist in national efforts to develop, promote, and refine a suitable proposed lamp label
- 9.3.E.3. Year 3: Report III on Outreach efforts to assist in national efforts to develop, promote, and refine a suitable proposed lamp label
- 9.3.E.4. Year 4: Report IV on Outreach efforts to assist in national efforts to develop, promote, and refine a suitable proposed lamp label

Subtask 9.4 Industry Surveys

The Director shall work with the APIs and the SAB (developed in Subtask 10.2) to develop and conduct annual Consortium membership satisfaction surveys. The Director shall report on results, including who and how many are participating in the GLASE Consortium. The annual survey may include self-reporting from GLASE manufacturing members on sales of products.

The Director and APIs shall assist NYSERDA as it conducts baseline and longitudinal CEA surveys of New York. These surveys will attempt to determine some or all of the following information:

- The total number of potential industry manufacturing members and CEA growers that exist in New York, and total CEA acreage in New York.
- How many and which manufacturers are participating in commercialization of GLASE products or intend to do so in the future.
- How many and which growers are implementing various GLASE practices, and with which products and which crops or market sectors.

- The total square footage of production using GLASE practices, and the estimated statewide energy savings associated with that, (accounting for varying energy savings associated with specific crops and products).

NYSERDA surveys may also include questions regarding product lifespans, crop production yields, grower and manufacturer perceptions of perceived barriers and benefits of the Consortium or CEA products, willingness to participate in the Consortium and/or willingness to adopt new products or technologies.

In particular, the APIs shall assist NYSERDA in interpretation of NYSERDA's CEA survey information, and help NYSERDA explore ways to measure other important parameters of success such as the growth of manufacturing companies or grower's companies, as well as national trends, This assistance may involve updating Cornell's existing market rate adoption model if requested to by NYSERDA.

Assistance shall also include provision of mailing lists of potential survey respondents.

To supplement the information from the NYSERDA surveys, the Director shall gather market characterization data from CEA trade associations and USDA as available.

9.4 Deliverables (payment milestones)

9.4.A. Member Satisfaction Survey.
9.4.B. Member Satisfaction Survey results.
9.4.C. Update to market rate model if requested.

Subtask 9.5 Membership Outreach

The Director shall work with the SAB and the APIs to develop a Marketing Plan to market GLASE nationally and internationally. This plan should be designed to increase membership, maximize value to members, attract funding, increase recognition of GLASE and members, and help to attract CEA businesses, suppliers and vendors to NY.

The Marketing Plan shall include tasks, milestones, and responsibilities, and be incorporated into the costs for the Financial Sustainability Plan developed in Task 10.2. The Marketing Plan shall be updated annually, indicating progress towards goals, and any strategy changes, and provided to NYSERDA's Project Manager for review.

Specifically, the Marketing Plan shall include discussion of progress and planned work towards developing strong relationships with key organizations that are critical to the success of CEA technologies, including trade associations, manufacturers, end-users, federal funding programs, research laboratories, and members of the financial community.

The Marketing Plan shall evolve over time to include a variety of activities appropriate to the maturity of the Consortium. Activities may include assisting members with finding strategic partners, networking, building relationships among the CEA community, information dissemination on funding opportunities for members, development and maintenance of supply chain or resource databases, participation in events such as the Subtasks 9.1 training and Subtask 9.2 webinars to raise awareness, promotion of member achievements, mentoring activities, and Consortium member meetings to discuss new technologies, trends, and commercialization opportunities. Marketing may occur through phone and webinars, face-to-face meetings, symposia, or conferences. It is anticipated to include facilitating introductions between and among GLASE members and vendors or other in-state or national market players. It shall include maintenance of a database of current and potential members, which may include a knowledge base of member capabilities. In addition to Subtask 9.3 information dissemination activities, information dissemination could be through distribution of periodic news updates to members and interested parties, coordination with NYSERDA programs for agriculture including Energy Audits, or coordination with NYS Department of Agriculture & Markets, the New York CEA trade association, NYSERDA Science Advisors and Cornell Cooperative Extension as appropriate.

The Marketing Plan shall address ways the Consortium could help NYS economic development agencies attract manufacturers and growers to New York, and how outreach materials will address the advantages of GLASE generated products while comparing them to competing lighting products in a tactful manner.

The mix of market participants in the Consortium shall be assessed annually to determine if outreach strategies must be updated to attract more members from specific market sectors.

The Director shall work with the SAB and the APIs to implement the Marketing Plan. As a first step, the Director shall formalize relationships with those who have previously expressed interest in joining the GLASE Consortium. Large national/international luminaire manufacturers who can assemble and market novel luminaires shall be targeted for membership, as shall attendees at trainings and webinars conducted as part of Subtasks 9.1 and 9.2.

The Marketing Plan shall incorporate case Studies developed in Task 8 and other outreach materials developed in Task 9 to inform constituents of benefits of GLASE products, including energy savings and other opportunities.

The Contractors (Rensselaer and Cornell) shall collaborate with NYSERDA's Director of Communications to prepare any press release concerning this agreement and any such activity shall be in accordance of Section 16, Publicity, of this Agreement. As such, Contractors shall notify NYSERDA, in advance, of media interviews, and credit NYSERDA as appropriate.

It is anticipated a joint press release will be issued announcing the GLASE Consortium. The Director shall prepare and issue additional approved press releases regarding GLASE updates as appropriate.

9.5 Deliverables (payment milestones)
Marketing plan and annual updates to the plan.
Press releases – GLASE announcement approved.
Press releases – GLASE announcement issued.
Consortium member meetings – Held in parallel to the Annual updates and the Cornell CEA Advisory Committee meetings (which are conducted independently of this agreement).

Task 10 Consortium Development and Operation

Subtask 10.1 Complete Consortium Organization Structure
The Acting Director defined in Subtask 1.1 (with assistance from the Director, when hired and as appropriate) shall define the organizational structure of the Consortium, including preparation of an organization chart, job descriptions and responsibilities for organizations and key personnel. This subtask shall include a description of the roles and key members of the APIs, the Leadership Team, and the Scientific Advisory Board (SAB), the Industry Advisory Board (IAB) as well as the reporting structure within and among each of these organizational components. Job descriptions for the Director and APIs shall also be completed.

The Acting Director shall submit the proposed recruitment plan, organizational structure, job descriptions and responsibilities to the NYSERDA Project Manager for review and approval. The ideal candidate for Director would have business, fundraising, and/or Consortium experience, an understanding of the research, agriculture or horticulture experience, intellectual property, and university structures, as well as a holistic view of the relevant markets and industries, an understanding of what activities are needed to launch a product to commercialization. It is understood that the Director position will be a role that evolves over time as the Consortium matures.

The Contractor (Cornell), shall review applications, interview, select, and hire a Director according to Cornell hiring protocols. NYSERDA's Project Manager and the Contractor (Rensselaer) shall participate in the evaluation of the short-listed candidates for the Director position. The recruiting process should be competitive, and processes for checking at least three references for the preferred candidate should be documented prior to extending an offer of employment.

10.1 Deliverables (payment milestones)
10.1.A. Organizational structure, including organization chart, job descriptions and responsibilities descriptions for all positions defined in the organizational chart.
10.1.B. Recruitment plan and evidence the recruitment of the Director has begun.
10.1.C. Signed employment contract for Director.

Subtask 10.2. Recruit and empanel the Scientific Advisory Board (SAB) and conduct a "Voice of the Customer" (VOC) survey
The Director and the APIs shall coordinate with the NYSERDA Project Manager to suggest SAB members. An SAB comprising three (3) appointees shall be submitted to the

NYSERDA Project Manager for review and approval. The Director shall prepare commitment letters for the SAB members to sign, detailing their responsibilities, including participation in biannual meetings, and reimbursement procedures for their expenses. Travel expenses for SAB members shall be minimized through use of webinars where feasible. SAB expenses shall be reimbursed by the Contractor (Rensselaer) for one member and by the Contractor (Cornell) for the other two members. The Director shall submit the draft letter to NYSERDA for review, and obtain a signed letter from each member. The Director shall direct the SAB to meet (in person or via web meeting) at least biannually to review GLASE progress and future research plans in relation to goals, metrics, and outcomes. The Director shall arrange SAB meetings, prepare SAB meeting minutes, and invite the NYSERDA Project Manager to attend (or call into) SAB meetings.

The Director, APIs, and Contractors Rensselaer's and Cornell's support staff shall design a VOC exercise that includes completing a marketing overview of GLASE research plans, segmenting industry into key parts of the current Controlled Environment Agriculture (CEA) supply chain (to be formally identified as part of this exercise), identifying key topics of interest to each market segment, and exploring GLASE Consortium Industry Fee membership levels (by market segments, to be defined in the supply chain evaluation).

The Leadership Team shall prepare an up-to-date supply chain evaluation for the VOC exercise that identifies roles and relationships within the supply chain, lists representative members, and estimates NYS market sizes for various CEA market sectors.

The Leadership Team, with assistance from the SAB, shall request assistance from key actual or potential Consortium industry members to outline the complete set of baseline VOC questions and target audiences who will be recruited as part of the VOC exercise.

The VOC supply chain evaluation, baseline questions and target audiences shall be submitted to NYSERDA's Project Manager for review and approval.

The Leadership Team, shall conduct the VOC exercise, document the responses, and assess the results in terms of how they may impact GLASE research tasks and educational outreach.

10.2 Deliverables (payment milestones)

10.2.A.1 Signed commitment letters from approved SAB appointees.

10.2.A.2 SAB meeting minutes.

10.2.B. An up-to-date evaluation of the greenhouse CEA supply chain, showing roles, relationships within the supply chain, a list of representative members, and approximate NYS market sizes.

10.2.C. Document outlining the complete set of baseline VOC questions and target audiences who will be recruited as part of the VOC exercise.

10.2.D. Report documenting VOC responses and assessment of impact on GLASE research and educational outreach.

Subtask 10.3. Structure the Industry Membership Program

The Director and the APIs shall develop and complete a formal Industry Membership Agreement, including fee structure, membership duration, structure of the Industry Advisory Board (IAB), model Intellectual Property (IP) Agreements, and other rights/privileges of GLASE industry members, including access to training, participation in meetings, and the extent of access to APIs and support staff. Membership and fee structures to be considered may include provisions for stakeholders in different market sectors or business sizes, differing rates for new or early members versus membership renewals, or other additional benefits for early membership.

The Intellectual Property Agreements are anticipated to cover, at a minimum, testing arrangements and research projects, both with and without background IP. IP policies should be structured in a way that makes IP negotiations as streamlined and efficient as possible.

The Industry Membership Agreement shall be submitted to NYSERDA's Project Manager for review and approval.

The Director shall prepare Industry Membership letters for each industry member to sign, detailing their rights and responsibilities under the Industry Membership Agreement as described above. The Director shall submit the draft letter to NYSERDA for review, and obtain a signed letter from each member that includes member contact information.

The Leadership Team shall use the Marketing Plan developed in Subtask 9.5 to recruit paying industry members into the Consortium, as well as other members as appropriate. Twenty-five paid memberships are targeted by 2022.

The Leadership Team shall select members of the IAB with input from the individual member companies.

The Director shall collect signed membership letters and payments from the members and distribute the funds according to the Financial Sustainability Plan and Consortium bylaws developed as part of Subtask.10.4.

The Director shall, on a quarterly basis, report on industry and other membership status in the Consortium, member and prospective member contact information, membership fees paid and names of IAB representatives.

10.3 Deliverables (payment milestones)

10.3.A.1 Industry Membership Agreement outlining Industry Membership responsibilities and rights, access to GLASE intellectual property and membership fee structure.
10.3.A.2 IAB membership.
10.3.B. Shell Industry Membership letter.

10.3.B.1 – B.5 Proof of membership (signed agreements and fee payment) for each of first five GLASE Industry Members (flat fee as indicated in the Milestone Payment Plan).

10.3.B.6 – B.25. Proof of membership (signed agreements and fee payment) for each of next twenty GLASE Consortium Industry Members (decreasing over time for each member as indicated in the Milestone Payment Plan).

10.3.C. GLASE industry membership status, membership fees paid and names of IAB representatives. (as part of Subtask 1.2 Quarterly Reporting).

Subtask 10.4 Financial Sustainability Plan and Consortium Maintenance

The Director shall develop a Financial Sustainability Plan during 2017 that addresses the future financial viability of the Consortium. It shall contain business plan elements to maximize the value proposition of membership. The Financial Sustainability Plan shall include specific objectives, milestones, target dates, and tasks over the 7-year period. Within six months of hiring, the Director shall provide a schedule to the NYSERDA Project Manager that outlines the Financial Sustainability Plan.

An annual update shall be prepared (with input from the APIs as needed), indicating progress towards goals and any strategy changes, and provided to NYSERDA's Project Manager for review. In particular, the Year 5 annual update to the Financial Sustainability Plan shall include a comprehensive review of past and forecasted non-NYSERDA funding and an analysis of how the Consortium scope and objectives may need adjusting to achieve financial sustainability beyond the end of NYSERDA funding. The Financial Sustainability Plan prepared in the final year shall include a discussion of research needs, including what crops or applications will be a future focus of the Consortium in the near-term.

As part of the Financial Sustainability Plan, sources of non-NYSERDA funding, which may include fee-based services, federal and foundation funding, industry sponsored research, conference fees, and royalty revenues, shall be identified and mechanisms created to obtain it. The Financial Sustainability Plan shall support appropriate dues levels based on other funding coming in.

The Financial Sustainability Plan shall include a discussion of the commercialization status of research and development conducted in previous tasks, including IP development and/or adoption/commercialization by Consortium industry members of products based on improvements. The Financial Sustainability Plan shall identify key points in product development where manufacturers would be interested in collaboration on commercialization activities, as well as tactics to use to recruit their participation in collaborations, and ultimately to encourage their adoption of prototypes and concepts into product lines. Tactics to inform growers of the value of GLASE products shall also be delineated. The Financial Sustainability Plan shall identify the percentage of external income targeted towards achieving sustainability through collaborative research.

As part of the Financial Sustainability Plan, and to an increasingly greater extent as the Consortium progresses, the Director shall explore ways to shift the funding and focus from primarily research activities to include a progression of commercialization activities by 2022, including the pros and cons of when and whether the Consortium may transform into a 501.3c entity or another non-academic form. As part of the Financial Sustainability Plan, the Director shall prepare annual Consortium operating budgets for NYSERDA's Project Manager to review. The Director shall consider pursuing the Entrepreneur in Residence or other NYSERDA business assistance programs, as appropriate.

The Financial Sustainability Plan shall consider Consortium mechanisms, appropriate to the maturity of the Consortium that encourage financial self-sufficiency of the GLASE Consortium. In later years, while the Consortium considers how to transform into a stand-alone entity, such as a 501.3(c) organization, this may include features such as reward structures that encourage Directors or others to increase membership. The results of the Marketing Plan developed in Subtask 9.5 shall be used to develop an annual marketing budget for the Financial Sustainability Plan that is appropriate for the stage of Consortium maturity and financial self-sufficiency. (Funding for marketing in early years is anticipated to occur as part of the outreach activities described in Task 9).

The Director shall also develop Consortium by-laws, insurance needs, and operational policies, including IP, licensing, and legal components. Since the maturity of the Consortium will evolve over time, periodic updates to the policies will be prepared as necessary.

Because the research and best practices for CEA are rapidly evolving, in year 6 of the program, the Director shall submit a Readjustment Plan to readjust milestones in the Milestone Payment Plan based on unspent milestones, changes in markets and/or lessons learned. The Readjustment Plan shall include a justification for the changes as well as an updated Milestone Payment Plan. Changes to the Milestone Payment Plan that involve reallocating less than 10% of the remaining NYSERDA funding among existing milestones to change their value may be submitted as a revised Milestone Payment Plan and accompanying justification for the requested revisions to the NYSERDA Project Manager for approval at his or her discretion.

Until such time as the Consortium becomes a standalone entity, the Contractor (Cornell), with input from the Contractor (Rensselaer), shall prepare a written performance plan for the Director and update it annually. The APIs, with input from the NYSERDA Project Manager, shall review the Director's performance annually against the performance plan. The Director's review should take into account factors such as success in obtaining non-NYSERDA funding for the Consortium, value provided to members, membership growth, or other factors.

10.4 Deliverables (payment milestones)

Financial sustainability plan and annual updates, including commercialization status of research.
By-laws, insurance needs and operational policies.
Consortium operating budget and annual update.
Readjustment plan.

Task 11 – Machine Learning and Data Analytics in CEA

Subtask 11.1 Data collection on plant and environmental data of winter 2020-2021 CO_2 LASSI experiments

While massive environmental data sets from controlled environment studies (and commercial facilities) are open available (data collected every 1-10 minutes across several months), they are not typically aggregated coincident with plant sensor data and are rarely made publicly accessible for further analysis by others. A recent initiative by GLASE investigators and other controlled environment academics has established the CEA Open Data project https://ceaod.github.io/ which defines data structures and serves as a repository for the public to download CEA data sets. However, currently there are only three crop data sets and these do not have real time plant sensor data. The Contractor (Cornell) shall collect and aggregate data from the winter 2020-2021 planned experiments at Cornell University in four adjacent greenhouses (tomatoes/strawberries with CO_2 LASSI vs. LASSI). The data shall be processed and uploaded to the CEA Open Data project, and the Contractor (Cornell) shall use their experiences to encourage other researchers to share data. The data shall be publicly available to encourage academics and private industry to develop machine learning (ML) and data analytics tools for CEA. From the four greenhouse sections, the environmental data shall be collected at a 5 minute intervals and include: inside temperature, outside temperature, inside relative humidity, outside relative humidity, outside global radiation, outside light spectra (from FUSSY), inside photosynthetic photon flux density (PPFD), and status of lamps, shade curtains, vents, and fans. Plant data shall be collected at a 5-15 minute interval and include: chlorophyll a fluorescence (SASSY), plant water status (either by sap flower sensors or soil moisture sensors), and weekly harvest data. Data from a minimum 3 month time period shall be processed and uploaded to the CEA Open Data project. Following uploading, the Contractor (Cornell) shall compile lessons learned from collecting and processing data and shall prepare a tutorial (document, slides, or recorded webinar). The Contractor (Cornell) shall reach out to a minimum of 10 academic colleagues to share the tutorial and encourage data sharing. The Contractor shall offer assistance to colleagues processing and uploading data and shall check in after three months to check on data submission status and further encourage submission.

11.1 Deliverables (payment milestones)

11.1.A. Data tables from three months of environmental and plant data from four greenhouse sections that were uploaded to the CEA Open Data project.

11.1.B. Tutorial for submitting to CEA Open Data project with guidance on data structure, cleaning/ processing, and submission.

11.1.C. List of ten academic colleagues (outside of GLASE) where the tutorial was shared and support provided for data processing/submission. Notes from the follow up with the colleagues that occurred three months after initial support.

Subtask 11.2 Predicting of ventilation using ML and data analytics

Greenhouse ventilation is used to control temperature and relative humidity within the greenhouse environment. The timing of ventilation is important to avoid conditions that would reduce plant performance but also to reduce the need for unnecessary heating. Better prediction of ventilation events can reduce unnecessary heating costs but also better inform the timing of CO_2 enrichment (it is undesirable to add CO_2 close in time to ventilation events because the added CO_2 will be vacated from the greenhouse and wasted. An existing GLASE Task 7.5.A uses an empirical modeling approaching using ASHRAE heat balance method to predict ventilation based on indoor/ outdoor conditions. In this subtask, the Contractor (Cornell) shall develop an alternative method to predict ventilation events using ML. The data sets from 11.1.A shall be used as training data sets for ML to predict ventilation based on temperature and relative humidity set points. It is anticipated that ML may reveal patterns not found in empirical modeling on unexpected relationships between the environment and ventilation (for example, light spectrum data from SASSY may end up correlating with sunny vs. cloudy weather which may give a better prediction than data on global radiation or outdoor temperature; data on plant water status may correlate to humidity which also affects ventilation). Following the training data set usage, a new several day data set shall compare ventilation predictions from the ML model vs. the 7.5.A model.

11.2 Deliverables (payment milestones)
11.2.A. Demonstration of a machine learning algorithm to predict greenhouse ventilation trained on data from 11.1.A.
11.2.B. Report comparing performance of ML algorithm (11.2.A.) to empirical model (7.5.A.) for predicting ventilation using a new greenhouse data set.

Subtask 11.3 Analysis of Environmental and plant data from CEA Open Data project

The experimental CEA setup at Cornell University allows for a collection of large amounts of environmental and plant data. To ensure that data is valid and can be used for ML, the raw data need to be preprocessed. Each reading for every sensor needs to be time-stamped and verified so that the value of the reading is in the defined interval. Because the output of the SASSY system is timestamped spectral power distributions (SPD), additional steps for this type of data analysis need to be taken – the quantitative (intensity) and qualitative (spectrally resolved photon flux density) lighting parameters need to be extracted. The Fourier transform of SASSY data could reveal frequencies of light fluctuation. The data from the Rensselaer custom-built plant fluorescence measurement system, FUSSY, need additional preparation steps as well. The Contractor (Rensselaer) shall establish a preprocessing protocol for the collected data from the SASSY and FUSSY systems. The Contractor (Rensselaer) shall identify the dynamics of the fluorescence change by examining the differentiation of relative FUSSY readings. Additionally, the Contractor (Rensselaer) shall examine the chlorophyll *a* fluorescence response to temporal fluctuations in the photon flux density. To detect various potential malfunctions (anything that compromised the validity of the recorded data), this type of data preprocessing needs to be conducted on a weekly basis. The Contractor (Rensselaer) shall establish a cloud-based data storage infrastructure with build in data import functions to be able to store the raw environmental and plant data. The Contractor (Rensselaer) shall preprocess the data sets received and store the well-structured CEA environmental and crop data in the database for ML analysis.

11.3 Deliverables (payment milestones)
11.3.A. Python code for data preprocessing.
11.3.B. Cloud-based data storage infrastructure with build in data import functions
11.3.C. Database of well-structured CEA environmental and crop data for ML analysis.

Subtask 11.4 Using ML tools to analyze correlations between environmental data and plant data

CEA environmental parameters directly affect biological processes of the plants. For instance, the particular combination of controllable parameters such as artificial lighting, temperature, CO2, and humidity could result in the highest plant biomass; however, it is hard to identify which of those parameters has the biggest impact and which ones are less important. On the other hand, the dynamics of natural lighting, which is the environmental parameter we have limited abilities to control, also effect the same biological processes of the plant. The ability to understand the correlations between environmental data and plant photosynthetic efficiency would allow the creation of feedback control that would result in energy savings or increased plant growing productivity. To identify these types of correlations the Contractor (Rensselaer) shall create the ML models. The Contractor (Rensselaer) shall also examine the information from the models to identify any correlations between the environmental parameters and propose a new strategy to control the environmental parameters that would optimize growing productivity and energy savings.

11.4 Deliverables (payment milestones)
11.4.A. ML model that could be trained using 11.3.C data
11.4.B. Identification of the correlations.
11.4.C. Proposal of the strategy to control environmental parameters.

Task 12 – Responses of Hemp to Light and CO2

Subtask 12.1 Determine the response of hemp to daily light integral and CO2

Hemp grown for CBD (cannabidiol) in full compliance with state and federal regulations (i.e. <0.3% THC along with meeting full licensing requirements) has become a new commercially important greenhouse crop in New York State, the U.S., and for the two GLASE Pilot locations. More information is needed on the response of this crop (yield and CBD content) to daily light integral (DLI) and CO2 so that LASSI lighting algorithms and their derivatives can be fully applied to hemp to improve electrical efficacy outcomes (i.e. g of CBD per kWh electricity).
The Contractor (Cornell) shall conduct a series of experiments to determine a DLI/CO2 equation for two CBD hemp cultivars, similar to our previous work with tomatoes and strawberries. Two hemp cultivars shall be grown in a greenhouse under four DLI treatments (ex: 15, 20, 25, 30 mol·m-2·d-1) to determine response (flower yield and CBD content) to light. Plants from the experiment shall be used to establish a preliminary CO2 LASSI equation (as in previous strawberry / tomato work) using leaf photosynthesis measurements (with a combination of 6 light intensities and 3 CO2 concentrations). The equation shall be

incorporated into the existing Greenhouse Energy Model (GEM) tool. A greenhouse experiment shall then be conducted to validate the CO2 LASSI equation whereby plants shall be grown in two adjacent greenhouses, one greenhouse shall have HPS lights and be controlled by basic LASSI, while the other greenhouse shall have HPS lights and CO2 enrichment capability where light and CO2 is controlled by CO2 LASSI. Data shall be collected on flower yield, CBD content, and electricity usage.

12.1 Deliverables (payment milestones)
12.1.A. Response of hemp (yield and CBD content) to four DLI treatments.
12.1.B. CO2 LASSI equations for two CBD hemp cultivars using light and CO2 response curves from leaf photosynthesis meter.
12.1.C. Demonstration of CO2 LASSI simulation for CBD Hemp using the Greenhouse Energy Model (GEM) tool

12.1.D. Greenhouse validation of CO2 LASSI equation for CBD hemp

Subtask 12.2 Determine the response of hemp to red:blue light ratio

Very little information is available in the scientific literature on the impact of light quality on hemp. Anecdotal evidence suggests that higher blue light can be used to keep plants shorter (desirable in greenhouse environments) and that higher blue light may impact cannabinoid product (CBD or THC). With CBD hemp, it is desirable to promote higher CBD accumulation, however, if the same treatment also causes THC concentration to be higher that may be undesirable if it passes the 0.3% threshold. If our research demonstrates that a specific red:blue ratio is desirable then real time (RT) LASSI can be used to complement the sun to adjust red and blue output from lamps to achieve a stable red:blue ratio from day to day and season to season. The Contractor (Cornell) shall conduct a greenhouse experiment with four light quality treatments: 90:10 red:blue; 60:40 red:blue; white LED; and HPS. Data shall be collected on flower yield and content of CBD and THC. The results shall be used to implement a RT CO2 LASSI equation to optimize CBD content for greenhouse hemp. The equation shall be implemented and demonstrated using the GEM tool.

12.2 Deliverables (payment milestones)
12.2.A. Greenhouse experiment on the effect of red:blue ratio on hemp yield and CBD content
12.2.B. Demonstration of a RT CO2 LASSI equation for CBD hemp

EXHIBIT E ***(5/26/20)***

ADDITIONAL COVID-19 TERMS AND CONDITIONS FOR ALL NYSERDA AGREEMENTS

In response to the ongoing COVID-19 pandemic, beginning in March 2020, Governor Cuomo issued a series of Executive Orders addressing various categories of business activities, including, but not limited to, construction, manufacturing, administrative, and professional services. In addition, Empire State Development (ESD) was authorized to develop *Guidance for Determining Whether a Business Enterprise is Subject to a Workforce Reduction Under Recent Executive Orders*. Although much of NYSERDA's clean energy efforts involve construction activity, NYSERDA engages in many other activities that are affected by State COVID-19 directives and requirements.

The State has also established a series of metrics required to begin a phased reopening plan. The phase-in plan prioritizes businesses considered to have a greater economic impact and inherently low risks of infection for the workers and customers, followed by other businesses considered to have less economic impact, and those that present a higher risk of infection spread.[1] Pursuant to Executive Order 202.31 and "NY Forward," New York will reopen on a regional basis as each region meets the criteria necessary to protect public health.

For New York State regions and approved activities that have been deemed reopened pursuant to the State's Regional Monitoring Dashboard, and in light of the paramount importance placed on health and safety at this time, NYSERDA hereby directs and requires that NYSERDA contractors performing clean energy activity pursuant to a NYSERDA contract or program to comply with all Executive Orders addressing the COVID-19 pandemic, and in all events, NYSERDA contractors are expected to continue to comply with all relevant State, federal and local rules. All contractors are also accountable for staying current with any updates to these requirements. COVID-19 related guidance and references can be found on NYSERDA's website at: https://www.nyserda.ny.gov/ny/COVID-19-Response, and is hereby deemed incorporated herein, as may be updated from time to time.

Phase I of reopening does include all construction activity. All NYSERDA contractors specifically engaging in construction activity are required to, without limitation, adhere to and attest to the New York State Department of Health (NYS DOH) *Interim Guidance for Construction Activities During the COVID-19 Public Health Emergency* prior to commencing

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[1] In accordance with ESD's current Essential Business Guidance and subject to all relevant health and safety requirements, NYSERDA is hereby allowing its contractors performing program work pursuant to a NYSERDA contract or program to undertake the following activities on a Statewide basis:

-electric power generation and storage-related development, construction, operation or maintenance, except with respect to new solar projects on residential sites (which residential projects must continue to follow the regional reopening);

- electric vehicle (EV) charging station installation, operation and maintenance at commercial and government sites; and

_ activity by a single worker who is the sole worker on a project site.

work on NYSERDA clean energy construction projects. The attestation is embedded within the Guidance Document and NYSERDA advises that contractors maintain a copy of such attestation for their records. Also, as included in the NYS DOH Construction Guidance, for all contractors performing construction activities, completed safety plans must be conspicuously posted on a project site. The State has provided a template to assist in developing Business Safety Plans, which is available through the NY Forward website as well as NYSERDA's COVID-19 webpage. While these plans are not required to be submitted to NYSERDA or a State agency for approval, they must be retained on the premises of the business or construction site and must made available to the NYS DOH or local health or safety authorities in the event of an inspection.

In accordance with Executive Order 202.31, business activities may only commence for New York State regions that have been deemed reopened and is limited to only those activities approved for reopening. For state regions and activities that remain on PAUSE, or for reopened areas that revert back to PAUSE, NYSERDA continues to direct a pause in work until that region is re-opened for all NYSERDA contractors performing program activity pursuant to a NYSERDA contract or program, requiring in-person presence at a project site, that is not explicitly permitted under State directives or guidance.

During this time of uncertainty, NYSERDA is committed to working collaboratively with its Contractors to address contractual obligations when performance under the contract may be suspended or delayed due to COVID-19-related limitations in business activity that are beyond the reasonable control of either NYSERDA or the Contractor.

NYSERDA takes health and safety issues of its contractors and program participants very seriously and will strictly enforce compliance with Executive Order 202.31, and any relevant subsequent Executive Orders, and this guidance, as well as existing contractual obligations that require NYSERDA's contractors to comply with all general and special Federal, State, municipal and local laws, ordinances and regulations that may in any way affect the performance of agreements executed with NYSERDA. Accordingly, non-compliance may give rise to disciplinary action, which may include, without limitation:

- orders to stop work;
- immediate termination of the Agreement;
- a determination of ineligibility to participate in one or more NYSERDA program efforts, on either a temporary or permanent basis;
- reporting of non-compliant activity to enforcement authorities, including but not limited to the NY Forward online complaint submission form, which will result in investigation and, if credible, enforcement.

This guidance supersedes all previously issued guidance and shall be deemed to modify any applicable provisions in any NYSERDA contract, program rule, guideline, manual, solicitation or other applicable document or agreement.