Project No and Title: NCERA-101 Controlled Environment Technology and Use
Period Covered: 04-2018 to 04-2019
Date Reporting: 07/09/2019
Annual Meeting: April 14-17, 2019

Minutes of the 2019 NCERA-101 Business Meeting
April 14-17, 2019 Vaudreuil – Dorion, Quebec, Canada
Chateau Vaudreuil Hotel and Suites

To Dos

- Ramesh Kanwar urges the NCERA-101 to nominate this committee for a Research Excellence award by the USDA. Due date is November 19th, 2019
- Developing a mechanism or requirements for membership and format of future meetings to ensure adequate time for science presentations in light of the continually growing attendance at NCERA-101 meetings.
- Continuing education credits combined with re-wording the description of the NCERA-101 annual meeting activities to better position members to be eligible for continuing educations credits as well as certain federal institutions to approve travel to attend. (carry over from last year).
- Develop the artwork and plaque for the NCERA-101 Award for Significant Organizational Contributions to the Controlled Environment Sciences and award presented to NCSU and Duke University Phytotrons in commemoration of their 50th anniversary (carry over from last year)
- Station Reports

NIFA Summary – Steven J Thomson, National Program Leader

1. Capacity Grants - Hatch, McIntire-Stennis, Evans-Allen, etc. Quality of those is still variable but better than it has been. Even if your proposal is part of a multistate committee like this one, please do a good and thorough job on the write-up. Outline your methods well and show your "niche" within the larger program. I currently send back about 30% for improvements.
2. We have money allocated for a new program in Urban Ag. and Vertical Farming based on a push by the Administration, the Secretary of Agriculture, and the fact that we have been trying to get this done in a formal way for a while. Mathieu Ngouajio (Organic Farming) and I (Steve Thomson, Engineering programs) are set to co-lead this effort. I do not yet have details on amount of funding available and anticipated size of each grant. Stay tuned.
3. Notifications for the A1521 (Ag. Engineering, soon to be called "Engineering for Agricultural Production Systems") and A1531 Bioprocessing/Biological Engineering have been delayed due to medical emergency with my Program Specialist and mainly, the

GOV shutdown. If you submitted to A1521, notifications will be coming soon. I have already called PIs who are successfully funded.

4. A1531 panels just met, as we had to re-schedule 27 panelists into two panels due to the GOV shutdown. We are in the process of selecting the top proposals now. Funding rate for both A1521 and A1531 programs is about 9%.
5. The FACT panels just met also, and decisions will be made soon.
6. The AFRI RFA is scheduled to be out by late April or Early May. The Engineering Programs will have a deadline somewhere near Mid-July.
7. National Robotics Initiative (NRI) and Cyber-Physical Systems (CPS) programs (NIFA/NSF) are pretty much on schedule. Both programs had significant increases in number of proposals for 2019. Anticipated funding rate for both of these programs is 15%
8. I have been successful in expanding our footprint into the NSF Smart and Connected Communities realm, as NIFA funded one proposal, which was brought in from NSF. I funded this under the NIFA/NSF CPS program.
9. I'll attend and present at Indoor-Ag Con in Las Vegas May 21-23. Hope to see some of you there!

NCERA-101 Meeting Participants:

Peter Alem (Corteva Agrisciences), Mark Baker (Hettich Instruments), Sara Barjou (McGill Univ.), Daniel Bayley (Univ. of Guelph), Samuel Bilodeau (McGill Univ.), Mark Blonquist (Apogee Instruments), Joe Bocchiaro (Cornell Univ.), James Borden (EGC), A.J. Both (Rutgers Univ.), David Brault (INNO-3B Inc.), Tammy Brenner (Colorado State Univ.), Robin Brumfield (Rutgers Univ.), Bruce Bugbee (Utah State Univ.), Tristan Chauvin (McGill Univ.), Bobby Clegg (Syngenta Crop Protection LLC), Cristian Collado (North Carolina State Univ.), Jonathan Cuminotti (Corteva Agrisciences), Bruno D'Amico (Current, powered by GE),Ryan Dickson (Univ. of Arkansas), Quade Digweed (Agriculture & Agrifood Canada), Mike Dixon (Univ. of Guelph), Mike Doss, Eden Dubuc (Current, powered by GE), Michael Eaton (Cornell Univ.), Rob Eddy (Core Consulting Group), John Ertle (Ohio State Univ.), Adam Escobar, Christine Escobar (Space Lab Technologies LLC.), Bruno Faucher (Capital Greenhouse), Patrick Friesen (BioChambers), Ralph Frische (NASA), Gary Gardner (Univ. of Minnesota), Guillaume Gary (Gobeil Dion), Russ Gill (Gamble Technologies Ltd), Daniel Gillespie (Ohio State Univ.), Thomas Graham (Univ. of Guelph), Bernard Grodzinski (Univ. of Guelph), Kale Harbick (Cornell Univ.), Edward Harwood (Aerofarms), Dave Hawley (Fluence by OSRAM), Chris Higgins (Hort Americas), Brett Hilderman (Conviron), Nick Horsley (Hettich Instruments), Brandon Huber (North Carolina State Univ.), Henry Imberti (Percival Scientific Inc.), Benjamin Jayne (Inari Agriculture Inc.), Fei Jia (Heliospectra), Dave Johnson (LiCor Biosciences), Ramesh Kanwar (Iowa State Univ.), Meriam Karlsson (Univ. of Alaska), Dan Kiekhaefer (Percival Scientific Inc.), Hye-Ji Kim (Purdue Univ.), Connor Kiselchuk (Univ. of Guelph), Rebecca Knight (BIOS Lighting), Annika Elizabeth Kohler (Michigan State Univ.), Mary Jo Kopf (LI-COR Biosciences), Brian Krug (DuPont Pioneer), Chieri Kubota (Ohio State

University), Paul Kusuma (Utah State University), Dan Lee (Current, powered by GE), Wee Fong Lee (Ohio State Univ.), Mark Lefsrud (McGill Univ.), Gloria Lekai (LI-COR Biosciences), Joan Leonard (LLK Greenhouse Solutions), David Leroux (McGill Univ.), David Lewus (Rutgers Univ.), Peter Ling (Ohio State Univ.), Stephanie Linzer (Valoya), David Llewellyn (Univ. of Guelph), Leo Lobato (Karma Verde Fresh), Kyle Lucherini (Aurora), Sarah MacPherson (McGill Univ.), Jonathan Maisonneuve (Oakland Univ.), Tom Manning (Rutgers Univ.), Mahnaz Mansoori (McGill Univ.), Andie Marsh (Fluence by OSRAM), Gioia Massa (NASA - Kennedy Space Center), Erico Mattos (GLASE, Cornell Univ.), Neil Mattson (Cornell Univ.), Rhoda Maurer (Cornell Univ.), Penny McBride (Farmtech Society), Maureen McGuire (Andrew & Williamson), Matthew Mickens (Intravision Greens USA), Cary Mitchell (Purdue Univ.), Danielle Monfet (ETS-Montreal), Victorio Morello (McGill Univ.), Robert Morrow (Sierra Nevada Corporation), John Murphy (Stream Technologies), Matthew Nugent (Bionetics), Ellen Paparozzi (Univ. of Nebraska), JongSeok Park (Chungnam National Univ.), Morgan Pattison (Solid State Lighting Services, Inc), Robert Pauls (BioChambers Inc.), Brian Poole (LumiGrow Inc.), Lucie Poulet (NASA Kennedy Space Center), Reg Quiring (Conviron), Amilah Rasool (Univ. of Guelph), Sharon Reid (Conviron), Ilse Renner (Univ. of Minnesota), Brad Ricker (Univ. Wisconsin), Mark Romer (McGill University), Hannah Rüdel (Heliospectra AB), Sophie Rufyikiri (McGill Univ.), Erik Runkle (Michigan State Univ.), Nadia Sabeh (Dr. Greenhouse), Carole Saravitz (North Carolina State University), Kaelin Saul (NCSU), Rose Seguin (McGill Univ.), Erin Sharp (Valoya), Timothy Shelford (Cornell Univ.), Gregg Short (GShort.com LLC), Todd Smith (Duke University), Hans Spalholz (North Carolina State University), LaShelle Spencer (AECOM), Rob Spivock (Current, powered by GE), Michael Stasiak (University of Guelph), Jared Stoochnoff (Univ. of Guelph), Gary Stutte (SyNRGE), Wei Sun (BIOS Lighting), Steve Szewczyk (P.L. Lighting), Marc Theroux (BioChambers Inc.), Kenneth Tran (Microsoft Research), Andrew Turk (Bambu Vault), Jan Van Wagenen (Aerofarms), Geoffrey Weaver (Univ. Georgia), Raymond Wheeler (NASA - Kennedy Space Center), William Wheeler (Utah State Univ.), Tyler Wilson (Young Living Essential Oils), Philip Wiredu (McGill Univ.), Colin Woodford (Current, powered by GE), Xiangnan Xu (North Carolina State University), Sam Yavari (Conviron), Melanie Yelton (LumiGrow Inc.), Qinglu Ying (Univ. of Guelph), Neil Yorio (BIOS Lighting), Shuyang Zhen (Utah State University), Youbin Zheng (Univ. of Guelph).

NCERA-101 Meeting Industry Sponsors:
Apogee, Ball Horticultural Company, Bio Chambers Inc., BIOS Lighting, Consolidated Greenhouse Solutions, Conviron / Argus, Corteva Agriscience (Dupont Pioneer), Current, powered by GE, Environmental Growth Chambers, Gamble Technologies, Heliospectra, Hettich Instruments, HortAmericas, Licor, LumiGrow, Mexico Vertical Farm Association, Ontario Scientific, Percival, P.L. Light, Stream Technologies, Valoya

Executive Officers:
Chair: Mark Lefsrud (McGill University), Vice-Chair: Neil Yorio (BIOS Lighting), Secretary: Murat Kacira (University of Arizona), Past-Chair: Bob Morrow (Sierra Nevada Corporation)

Business Meeting
April 15, 2019
Start 8:19 am

Minutes of meeting 2018 – Presented by Mark Lefsrud
Motion to Pass – Dr. Bruce Bugbee
Second – Mark Romer
Passed unanimously

Attendance list from conference at end of this document – 155 attendees

Other Conferences
ASABE Annual International Meeting, Boston, Massachusetts, July 7-10, 2019
ISHS – IX International Symposium on Light in Horticulture, Malmo, Sweden, June 8-12, 2020
ASGSR - American Society for Gravitational and Space Research, Denver, Colorado, November 20-23, 2019
ASHS Annual Meeting, Las Vegas, Nevada, July 21-25, 2019
AERGC Annual Meeting, Colorado State University, July 8-11, 2019
Greensys2019, Angers, France, June 16-20, 2019
UK-CEUG Lincoln University, Lincoln England, September 19-20, 2019

Administration advisors report – Ramesh Kanwar

- Station reports in the NIMSS format are due 60 days after this meeting (June 15, 2019 is due) with special emphasis on impact statements included in the reports.
- Mid-term review of the NCERA-101 committee was successful.
- NCERA-101 submission of the multi-state excellence award was submitted, but due to administrative error was not entered into the system and thus not reviewed for nomination. Ramesh Kanwar offered to submit again for 2019 and make sure it gets submitted properly.
- Ramesh Kanwar reported that the NIFA representative would not be present at this year's NCERA-101 meeting, therefore no NIFA report presented to NCRA-101 committee.

Membership report – Mark Romer

- 44th Annual Meeting – 2nd time in Montreal.
- Tremendous thanks to Mark Lefsrud and his team for hosting the NCERA-101 meeting.
- Thanks to industry sponsors for supporting the meeting which helped defray meeting costs as well as support graduate student travel/participation.
- The committee established membership awards in 1992, and there will be four individuals receiving awards at this annual meeting. Requirements for award includes regular participation for at least 20 years, hosting a meeting, and serving on the executive team.

- Members receiving awards this year include Carole Saravitz, Erik Runkle, Gioia Massa, and Neil Yorio
- Other members eligible for awards include Marc Van Iersel and John Lea-Cox, both not in attendance this year but will be recognized at future meetings.
- Cary Mitchell was recognized as the longest tenured participant at this year's meeting.

166 - Registered members
122 – Institutions represented
32 – States represented
11 - Countries represented
44 – Companies represented

Web site report – Carole Saravitz

- The website receives about 15K page views, mainly consisting of visits to three pages; meetings, growth chamber handbook, and membership.
- Majority of visitors from US and Canada, but several other countries (India, UK, and China) make up a large contingent.
- Several website visitors looking for articles from the 1994 lighting conference (Madison, WI), warranting putting those articles back on the website.
- Ray Wheeler indicated that the lighting conference papers were published as a NASA Technical Memorandum and should be linked to website.
- Added link to NIMSS website on the NCERA-101 website.
- The NIMSS contact is Chris Hamilton, and she needs to be made aware of the NCERA award nomination presented by Ramesh.

ASABE Horticultural Lighting Guidelines Update – Mark Lefsrud

- PAFS - X653 co-sponsored by ASHRAE, focuses on HVAC requirement for controlled environment crop production facility design. Nadia Sabeh is chairperson for this committee.
- S640 – published standard.
- S642 - published standard.
- X644 - still in revision but expected to be published soon.

Controlled environment research data sharing – Erico Mattos

- Furthered the discussion from last year's meeting a need for a common format for data be investigated to aid in grant writing, particularly for USDA grants.
- Intent is to have a best practices/recommendation for sharing data among researchers
- Some committee members volunteered to work on this committee with Chieri Kubota, Erico Mattos, Melanie Yelton, Yang Yang among others.
- Committee will present their updates at the end of the station report session on Monday.

Standardized Labeling – Fei Jia, Heliospectra

- Indicated that the Design Lighting Consortia (DLC) has issued first draft of testing and performance requirements for horticultural lighting
- Draft input/comments are due May 30

- Supports the horticultural lighting facts label development

Instrument package and Financials – Bruce Bugbee

- $33,000 is the treasury for NCERA-101
- $26,000 received in sponsorships for the 2018 meeting
- Instrument package report – unsure if used once this year, but always available upon request
- Quantum sensors in the package are much improved
- Visit NCERA-101 website for more information on requesting instrument calibration package
- Graduate student funding for travel is now handled by USU

Student travel grant update – Ryan Krug

- Ryan Krug presents in Jonathon Franz's stead.
- 20 students applied for travel grants this year.
- 10 students received a travel grant from NCERA-101 ($800 per student).
- Awardees need to coordinate the transfer of their grant from Bruce Bugbee (Utah State University) to their home institutions.
- 22 graduate students presented at this year's meeting, with 18 during lightning talks and 3 additional poster presentations.
- All presentations were Lightning talks in addition to poster presentations.

Future meetings

- 2020 International Meeting hosted by Murat Kacira, University of Arizona, March 15-18 at the Marriott University Park Hotel. UK and Australasian groups invited to attend.
- 2021 Meeting hosted by Erik Runkle, Michigan State University in May for both nice weather and optimal time to visit production greenhouses and vertical farm facilities.
- 2022 Meeting hosted by Chris Currey/Iowa State University
- 2023 Meeting possibly another international NCERA-101. Leo Lobatto offered Mexico as a possible location.

Election Secretary

Motion to nominate Marc Theroux (BioChambers) by Mark Romer
Second Gioia Massa
Passed, Congratulations to Marc

New Business –

- Following on from last year, Gioia Massa discussed issue with both the continuing education credit for engineering certification and federal government justification for NCERA-101 attendance.
- Gregg Short suggests listing the department name as part of the sponsorship to justify education credits. Currently not on the NCERA-101 brochure or website. Needs to be updated.

- Discussion addressing the suggestion to increase the NCERA-101 executive members to a two-year post was dropped after justification it wasn't necessary with a growing group with several potential candidates to serve on the executive.
- Potential issue identified as a good problem to have in NCERA-101 attendance continues to grow.
    - Potentially a logistical problem if group gets too large too fast.
    - Problems could limit time available for scientific presentations and station reports.
    - The interest from the hemp and cannabis market may push attendance significantly higher.
    - Bruce Bugbee suggested moving to a model of a professional society – members submit abstracts for approval prior to be placed on the meeting agenda. This will limit the number of presentations and give more time to those presentations approved.
    - Keep focus on scientific presentations and not a trade show format.
    - Gregg Short indicated that the value of this meeting is to be presented fresh data, on the cutting edge of research and not out-dated, previously published data.
    - Ramesh Kanwar addressed the group by saying it is up to this committee to establish the format and structure of the meeting, so we are not restricted in how we accomplish this.
    - Gary Gardener also supported the idea in indicating that we are an informal group where information exchange is free and necessary time is needed to foster such a unique and open discussion platform.
    - Mark Romer indicated that there is no executive structure in place to support this and relayed some challenges with managing a larger conference. He discussed outlining the requirements to be a member of the NCERA-101, purging the membership roster for those not regularly attending, etc.
    - Membership at large was asked to think about these challenges and offer suggestions.

Passing of the gavel:

Mark Lefsrud to Neil Yorio (now chair)

Adjourned 1:30pm. (Mark Lefsrud)

Minutes respectfully submitted by Neil Yorio

Agenda Item to be included in next year meeting

- Motion by Mark Romer to create a new NCERA-10 award – The NCERA-101 Award for Significant Contributions to the Controlled Environment Sciences
- Much discussion on working and eligibility of the award by the committee
- Motion tabled until after lunch break. Motion amended by executive committee and approved by Mark.

- Presented amended motion after lunch break, seconded by Neil Yorio, and passed by committee
- First recipients to be NCSU and Duke Phytotrons in commemoration of their 50th anniversary
    - Description of new award is as follows:

Title: NCERA-101 Award for Significant Organizational Contributions to the Controlled Environment Sciences

Criteria

An organization that has been deemed by the NCERA101 to have had a significant impact on the field of controlled environment science. Criteria would include aspects such as significant facilities, publications and/or significant technological advances developed in the field of controlled environments for plants. The award shall be decided by the NCERA-101executive committee and presented at the annual meeting.

Eligibility

University, government or commercial facilities or organizations working in the area of controlled environments.

Appendix A:

NCERA-101 Membership Summary …… April 2019

Mark Romer, *Membership Secretary*

Membership Number .....March 2018 166

March 2019 171

- Additions 12
- Deletions.....7
- Net Gain (Loss) 5

Membership Composition	Institutions	Members
• Phytotrons & Controlled Environment Facilities	10	13
• University Departments, Agr. Exp. Stations	59	85
• Government Organizations & Contractors	10	10
• Industry Representatives	46	63
Total Number of Institutions / Members	**125**	**171**

Total Number of Countries 9

Total Number of US States 33

New Institutions :

- Canada
  Intravision Light Systems Inc.
- USA
  University of Wisconsin,
  Department of Plant Pathology
  Colorado State University,
  Horticulture and Landscape Architecture
  Oakland University,
  Mechanical Engineering Department
  Consolidated Greenhouse Solutions

Appendix B:

Accomplishments (19 Reports)
(The complete station reports are available on the NCERA -101 website https://www.controlledenvironments.org/station-reports/)

1. New Facilities and Equipment

At the Purdue University, supplemental lighting system was updated for one of the shared teaching/research greenhouse bays that measures 9.1 m x 12.2 m. Existing 1000 W magnetic-ballast-powered high-pressure sodium fixtures were removed and 630-W broad-spectrum LEDs (FluenceBioengineering, VYPRxmPlus and PhysioSpec Greenhouse) were mounted at a rate of 1:1 9.5 feet above bench top. This design maintained a uniform irradiation field of 125 µmol/m²/s PAR. Additionally, drivers have been wired to provide two independent dimming circuits for research utilization. In addition, decoupled aquaponic systems were installed at Purdue HLA Greenhouse facilities, which can be scaled up to commercial aquaponics. The aquaponic systems consist of 3 aquaponic units, including three fish-rearing tanks (200 gallons each) to feed 12 nutrient-film technique (NFT) systems. The total water volume in each aquaponic unit (fish tank, sediment tank, biofilter, water reservoir, and four hydroponic nutrient containers) is 650 gallons. The sediment tank captures most suspended solids from the fish tank. After passing through the sediment tank, aquaculture wastewater flows into the biofilter filled with biomedia and then the water reservoir, where wastewater from the fish tank is optimized for plant crop production and recirculated within the hydroponic unit.

At the University of Guelph, a second PS-1000 whole plant photosynthesis system was acquired from CONVIRON. Both of the original BlueBox walk-in photosynthesis growth chambers are now equipped with Intravision LED systems, replacing the previous 7,800 Watts of HPS and MH lamps that were on each box. Three CONVIRON PGC-Flex growth chambers equipped with seven channel Intravision multispectral LED arrays were installed in our satellite laboratory in Napanee, Ontario. This laboratory is located within a secure licenced cannabis production facility. The new chambers will soon be employed in the investigation on the environmental effects on cannabis growth, development and biochemistry. A ‘new to us’ HPLC was acquired and will be used for the measurement of vitamins in plant tissue related to vertical farming initiatives. A new controlled environment building dedicated to the study of medicinal plants (cannabis) is in the design phase. The building will house over 30 controlled environment spaces consisting of both walk-in and reach-in growth chambers and a roof-top greenhouse.

Cornell installed new quantum sensors connected to a microcontroller which interfaces with the Argus Titan environmental control system. Four adjoining greenhouse sections have been equipped with. The microcontroller runs a modified Light and Shade System Implementation (LASSI) algorithm (Albright et al., 2000) which controls light (HPS) and shade decisions to achieve a constant daily light integral (DLI). Two of the greenhouse sections are being equipped

with CO2 enrichment capabilities from liquid CO2. The sections are being used to determine DLI and CO2 yield and fruit quality impacts on tomatoes and strawberries.

Kennedy Space Center continue to use Heliospectra RX30 LED lighting systems for many of their studies. The fixtures provide nine, selectively dimmable LED wavelengths 380, 400, 420, 450, 520, 630, 660, 735 nm, and white (~5700 K). They also continue to use four dimmable, 6500 K white LED arrays from BIOS Lighting (Melbourne, FL) and five custom 1:1 red/blue LEDs arrays from AIBC International (Ithaca, NY). Matt Mickens completed experiments with the Artificial Sunlight Research Module (ASRM) from Specialty Lighting of Holland that employs all LEDs to closely simulate the solar spectrum from near UV, through PAR, to the far-red region. They have tested OSRAM PHYOFY preproduction lights and have ordered several of PHYTOFY RL lights for testing. These are currently being installed. A new LI-6800 portable leaf photosynthesis system was purchased, and both LaShelle Spencer and Lucie Poulet have been trained in operating this instrument.

At Michigan State, a portable spectrometer (LI-180) was purchased to measure photon flux density from 380 to 780 nm in 1-nm increments, as well as several other parameters. An MC-100 chlorophyll concentration meter was purchased, to quantify chlorophyll, CCI, and SPAD. One existing walk-in growth chamber was retrofitted with RAY66 Fluence LED fixtures, CO2 injection, and four Apogee ST-100 thermistors. To expand greenhouse hydroponic research capacity, 7 modular deep flow hydroponics systems were built.

Ohio State installed new growth chambers (two walk-in rooms each with 90 ft2) were installed in the basement of Howlett Hall Greenhouse Complex, Department of Horticulture and Crop Science. Inside each growth chamber, there will be four independent units of movable growing systems with three tiers with selected lighting system. This facility will provide ample space to examine different experiments studying light qualities, intensities, CO2 as well as relative humidity A mini VF unit ‘Veggie Box’ was installed in the head house of Howlett Hall Greenhouse Complex. This is a modular, all-in-one, commercial unit originally imported from Japan (Sankyo Frontier, Japan). This 60 ft2 footprint, highly insulated and contained structure is equipped with a four-tiered re-circulating hydroponic production system (total production area 50 ft2), LED lighting (300 or 600 umol m-2 s-1), nutrient pH and EC controller, CO2 controller, as well as A/C condensation water recovery system. A new greenhouse research complex (Controlled Environment Food Production Research Complex) has been planned to be built in Columbus campus. A new leaf gas exchange measurement system (CIRAS3, PP System) was acquired.

New Jersey purchased a LI-COR spherical quantum sensor (LI-193) and accompanying datalogger (LI-1500). They plan to evaluate the light environment in tall canopies (e.g., vine crops) by comparing the output of the spherical quantum sensor with that of regular quantum sensors.

At University of Arizona, the faculty [Dr. Gene Giacomelli], staff [Tilak Mahato, Neal Barto] and students of the UA-CEAC [University of Arizona-Controlled Environment Agriculture Center] and the Agricultural & Biosystems Engineering Department at CALS [College of Agriculture & Life Sciences] worked closely with industry contacts Stephanie Boe and Jason Licamele [2018 - 2019] of Bayer Company to establish a new plant production procedure for growing corn in the greenhouse to develop the breeding lines required for developing new varieties of field corn, and to replace the less efficient, current practice of field production. An Ebb & Flood hydroponic nutrient delivery system was created, tested and demonstrated to successfully produce mature seed corn plants with healthy ears with many viable seed kernels. Many crop cycles have been completed substantiating the consistency of the successful procedures. As a result, the company has invested in the design and construction of a 7-acre [2.7 hectare] seed corn production facility, including a 87,000 square foot [8000 square meter] processing lab and office facility, will begin operations in Fall 2019 in Marana, Arizona
A 24 x 30 greenhouse and recirculating nutrient delivery system has been in operation since 2018 at the roof top of the Student Union Memorial Center (SUMC) to produce fruiting crops for delivery to the Student Pantry for all food insecure UA students. Established by Center Director Todd Millay, the facility has been managed by CEAC personnel in conjunction with student employees. CEAC. Industry support through hardware donations and financial assistance has been provided by AutoGrow, Grodan and PolyTex Greenhouse Co. The UA-CEAC recently established a new 1100 ft2 educational and research facility with an NFT system (PI Kacira) growing leafy greens. The NFT system and funding for operations were provided by American Hydroponics (AmHydro) company. The facility has been also part of the CEAC's outreach program activities.

At Rutgers, Yuan Li continues to work on the effects of soluble Silicon amendments used for hydroponically grown leafy greens.

The Center for Lighting Enabled Systems and Applications (LESA) includes a Plant Research Lab which supports GLASE activities at Rensselaer Polytechnic Institute. The facility is equipped with a general purpose hydroponics system and 5 environmental growth chambers (Conviron A1000). Three of those chambers are retrofitted with custom LESA-designed advanced multi-wavelength (400nm, 420nm, 450nm, 520nm, 660nm and 735nm), dynamically adjustable LED lighting systems and real-time, remote chlorophyll fluorescence sensors developed at LESA (Urschel and Pocock, 2018). The Plant Research Lab is equipped with an infrared gas analyzer (PP Systems, CIRAS-3), multiple spectrometers (Ocean Optics, JAZ and STS), a PAM Fluorometer (Walz PAM-2500), along with standard analytical test and laboratory equipment

BIOS Lighting added two new products to the Icarus® Product Line in response to industry demand. The first product is a durable, broad spectrum, high efficacy greenhouse fixture, called the Icarus Ti. The second is a cost-effective, commercial-grade, light-weight vertical farming fixture called the Icarus Li. More details can be found at the company website: www.bioslighting.com.

With Heliospectra AB's move to new headquarters in Gothenburg, Sweden, the Heliospectra Plant Lab now features a 14 m2 propagation room and 63 m2 of growth room with 12 standardized units, one Conviron A1000 climate chamber and a vertical farming system. There is also a new 15m2 development lab for the helioCORE light control system and software. Heliospectra introduced a new series of SIERA light bars which offers 50-watt, fully dimmable LED fixtures for vertical farming and tissue culture/cloning applications. The SIERA series includes five different spectra variants including Indoor Production, Propagation, High Blue, Red and Grafting/Healing light treatments. Heliospectra is conducting commercial crop trials with SPISA in Sweden using the SIERA series for propagation of herbs and leafy greens in greenhouse and indoor environments. In 2018 and 2019, Heliospectra continued collaborations with Chalmers University on image recognitions and crop control parameters as part of a larger research focus on spectral light sensing.

HortAmericas has a demonstration greenhouse located on the state fairgrounds just feet from the historic Cotton Bowl. The hydroponic production systems include: (2) floating rafts systems, (1) organic raised bed, (2) nutrient film technique (NFT) systems, multiple multilayered ebb-n-flow growing systems, (3) separate dutch bucket systems and room for expansion. Each of the production systems utilizes unique technology designed to work both operationally and economically in a medium-tech greenhouse. Each of the production systems includes the technology systems with LED grow lights from powered by GE, LED grow lights from OSRAM, wireless sensor technology from 30MHz, a nanobubble generator from Moleaer, custom-built, multilayered grow racks from HortAmericas for germination, propagation and microgreen production.

Valoya's headquarters in Helsinki are equipped with a growth chamber where their plant biologist team has ongoing trials to further develop our capacity in photobiology.

LumiGrow expanded research lighting installation at Cabrillo College (Aptos, CA) with newest LumiGrow TopLight and sensor technology to an additional 225 m2 (2,450 ft2), bringing total lighting research and teaching space to 630 m2 (6,800 ft2). They deployed tunable far-red prototype fixtures at Michigan State University to study the effects of dynamic far-red spectrum on ornamental flowering.

2. Unique Plant Responses

Purdue determined that plant grown in aquaponics perform better at a higher flow rate (HFR, 2 L/min, 1/5th to 1/10th of conventional flow rate) than at low flow rate (LFR, 0.7 L/min). Water-quality parameters were improved and associated with a higher growth rate and the total fresh and dry weight of crops grown at HFR. HFR-improved growth was more prominent in shoots than in roots and increased fish growth rate, biomass, and feed-conversion efficiency. The leaf greenness (SPAD value) and photosynthetic rate (Pn) of crops grown at HFR were significantly higher than those at LFR. Regardless of supplemental light source (HPS lamps, R + FR LEDs), greenhouse high-wire tomato plants grown with low EC (1.8 μS/cm) maintained total dry weight, total fruit dry weight, dry weight per fruit, and DMR of the fruit to the levels of those

grown with high EC (2.8 μS/cm). High EC promoted dry matter accumulation only in roots and dry matter partitioning from leaves to roots. Fruit harvest date was not affected by the reduction in EC. Notably, low EC improved the intensity of aroma regardless of light treatment, and tomatoes grown with HPS lamps and high EC or R + FR LEDs and low EC had a higher DOL score in sweetness, saltiness, and acidity compared to their counterparts.

At University of Guelph study, the addition of sub-canopy lighting in cannabis improved yield and normalized the THC and CBD profiles in the plant canopy. Nicotiana benthamiana plants grown under low light conditions showed an increased target protein response in transgenic biosimilar drug production trials.

In an experiment at Cornell, screening four strawberry cultivars for yield and Brix by PhD student, Jonathan Allred, a two-fold difference in yield was found based on cultivar. Unfortunately, the highest yielding cultivar had the lowest Brix content. In experiments with tomato 'Merlice' in Plexiglas mini chambers under T5 fluorescent lights, the plants were quite sensitive to edema, a physiological disorder which causes blisters on the underside of leaves. The low UV light and humidity in the chambers may be cause of the disorder. In collaboration with GLASE at Cornell University, responses to strawberry and tomato to CO2 enrichment under varying daily light integrals have been examined. The research takes place in 4 Plexiglas mini growth chambers under T5 Fluorescent lights for 10 to 15 days during the vegetative growth stage for tomato and early flowering stage for strawberries. For tomato, cultivar 'Merlice' has exhibited quite severe edema symptoms (a physiological disorder due to insufficient UV light or sometimes associated with excessive humidity/water imbalances). The disorder has limited our ability to detect plant growth responses, but the chambers were used to screen tomato cultivars for sensitivity to edema. For both species, photosynthesis light and CO2 response curves have been collected.

Kennedy Space Center completed a series of tests to grow different leafy crops in controlled environments with or without supplemental far-red lighting. These included chard, wasabi mustard amara mustard, shungiku (an edible crysanthemum), several radicchio spp., several escaroles, sorrel, pak choi, red mustard, kale, red Russian kale, as well as lettuce. They are in the process of analyzing the data, but in general, species with distinct stems and internodes showed more elongation with supplemental FR (as expected), while heading plants (lettuce, escarole, radicchios) showed greater leaf expansion with FR. The Pak Choi cv. Extra Dwarf showed no difference.

Ohio State investigated species specific responses (growth and nutrient uptake) to pH lower than conventional range. Basil plants can be grown without showing growth reduction or nutrient disorder up to pH 4.0 (Gillespie and Kubota, unpublished).

Kacira Lab at University of Arizona evaluated various daily light integrals (DLI) (9-17 mols/m2/day with 2 DLI increments) with LED lighting (with 80% red, 15%blue and 5% green) under CO2 setpoints ranging between 400-1300 ppm with experiments at UA-CEAC vertical farm facility (UAg Farm) to determine effects on yield and quality of lettuce (variety Fairly),

and for energy savings in indoor multi-tiered vertical farming setting. The most optimal conditions for energy savings were achieved at 11DLI range and at 850 ppm CO2 levels.

Sierra Nevada Corporation/ORBITEC conducted studies with potato crop. The studies showed that potatoes can grow well in soilless culture systems and are even grown in aeroponic systems commercially to produce seed stock. Challenges are primarily related to the large size of potato plants in traditional growing systems. They are investigating the growth of a red skin potato variety (cv. Norland) in a salad crop production module consisting of eight, one cubic foot growing zones. This module uses an aeroponics water and nutrient delivery system. During preliminary testing, we found that by constricting the shoot volume we could constrain an individual potato plant while still allowing tuber initiation and development. While not as productive as standard growth systems, they were able to produce over 14 tubers in a one cubic foot growing area over about 100 days, equivalent to 112 tubers in an eight cubic foot growing module. This provides the potential to grow potatoes, which require relatively little processing, as part of a salad crop diet architecture for hybrid life support.

Ida Fällström and the Heliospectra Plant Lab team focused in-house crop trials on the effect of Far-Red on tomato seedlings, basil, mustard, and multiple varieties of microgreens and lettuce. Comparing broad spectrum LEDs (containing blue and red) with a Far-Red enriched spectrum and end of day Far-Red treatments, the Plant Lab work demonstrates that Far-Red can 1) significantly increase plant biomass in herbs and lettuces; 2) elongate the stems in herbs and microgreens to facilitate trimming and packaging at commercial harvest; 3) enhance color or finish of produce; and 4) achieve taller plants with thicker stem diameter in tomato seedlings.

Up to 2019 Valoya has conducted more than 500 plant trials, either independently or in collaboration with various research institutes and universities. The most prominent recent research points to unique plant responses in *Cannabis sativa* L. Next to morphological and developmental plant responses, the light spectrum and light intensity also regulates the extent of protective plant responses. Those responses are linked to stress inducing conditions, which activate the biosynthesis of secondary metabolites. Plants sense stressful light environments, such as short wavelength irradiation or high photon flux, respectively through photoreceptors, which activate the defense response by complex signal transduction pathways. Valoya research suggested a close link between the expression level and profile of certain secondary metabolites and the proportion of blue photons in an ultra-wide (380-780 nm) light spectrum. A direct comparison between spectra with and without supplemented blue photons showed that in medicinal cannabis a higher content of secondary metabolites (THC) was obtained in light conditions with elevated amounts of blue photons. Next to the spectrum response, the effect of light intensity was investigated. In medicinal cannabis an increase in yield and flower yield was correlated to increasing irradiation levels during flowering phase. The light spectrum had a larger effect on secondary metabolite accumulation and profile than light intensity. Another noted success for Valoya in 2018 was the promotion of the speed breeding technique. Recently, scientists have published new breeding methods such as a SSD and speed breeding to increase the genetic gain per year. Both methods have in common utilizing light conditions (spectrum and photoperiod), to push crops toward a faster generative growth. This enables them to double generation cycles per year for important spring crops. The shared lighting conditions including

spectrum and daily light integral (DLI) provide important data to exploit the approach in winter crops or to transfer the methods into a greenhouse setting. Thereby, the natural light needs to be supplemented with a flowering inducing spectrum until DLI and photoperiod of the specified light conditions are achieved.

3. Accomplishment Summary:

- At Purdue, several factors critically affect aquaponic crop production, including key nutrient elements, accumulation of harmful compounds, nutrient-management practices, water-flow rate, and pH of the aquaponic solution, which information will contribute to the successful operation of aquaponics. And, intracanopy LED supplemental lighting, an energy-efficient light source, promotes earlier and higher yield of greenhouse tomato, reduces water and fertilizer usage, and produces higher quality tomato fruit than does conventional HPS lamps.
- EDEN ISS, an EU 2020 Antarctic 'greenhouse' project coordinated by the German Space Agency and involving a large consortium of European, Canadian and American partners completed its first mission. CESRF provided the hydroponics and control systems. The system produced 77 kilograms of fresh lettuce, 51 kilograms of cucumbers and 29 kilograms of tomatoes, along with a number of other herbs and leafy greens, the majority of which were fed to the overwintering crew at Germany's Neumayer III Station.
- CESRF BlueBox technology has been licensed to Intravision Group AS who are building our next generation whole plant photosynthesis chamber, the PS2000.
- At CESRF, patent submission for Regenerative in situ Electrochemical Hypochlorination process in support of a commercialization plan. Developing an electrochemical advanced oxidation system for in situ processing of 'organic' fertilizers to improve nutrient availability. And, Tomatosphere, a free science outreach program available throughout North America, is now in its 20th year.
- At Cornell, PhD student, Jonathan Allred determine response of day-neutral strawberries to greenhouse supplemental lighting and CO_2 enrichment. In an ongoing winter experiment plants are lit to 15 $mol \cdot m^{-2} \cdot d^{-1}$ under either HPS or LED fixtures and compared to an ambient light treatment. Yield during winter was 150-200% greater for lit plants. Brix was also greater in lit berries. Early results indicate that berry size (fresh weight) was 15-20% higher than ambient or HPS. M.S. student, Erica Hernandez, compared response of 13 lettuce cultivars to HPS or LED supplemental lighting in a greenhouse NFT system. Between lighting treatments there were no significant yield differences, however, cultivars varied greatly in harvestable yield. Some subtle differences in plant morphology (height) and color (for red leaf lettuce) were found between treatments. Biomass efficacy was estimated as the harvestable fresh weight divided by estimated electricity usage by lights (in kWh). In the small experimental area, biomass efficacy under LEDs was 140% greater than the old magnetic ballast single ended LED fixtures. M.S. student, Dylan Kovach, is determine the influencing of tomato 'Merlice' yield to daily light integral. Photosynthesis light and CO_2 response curves have been collected and will be compared to the growth and fruiting. M.S. student, Renyuan Mi, is conducting experiments to optimize the growth of baby leaf hemp which is used as an edible salad green

or in nutritional shakes. Cultivars used for grain or fiber have been tested. Experiments are determining the impact of seeding density, organic/conventional fertilizer, and seed size. M.S. student, Jiaqi Xia, is developing hydroponic production techniques for succulent edible ice plant (*Mesembryanthemum crystallinum*). The plant is salt tolerant and experiments are underway to determine plant and consumer sensory response to increasing sodium chloride treatments. Along with Cornell economists, Miguel Gomez and Charles Nicholson, we completed a study to estimate the economic and environmental costs of lettuce production in field in CA vs. in greenhouses or vertical farms in Chicago and New York City. The scope of the supply chain encompassed production through to distribution to a wholesale market. The chapter is forthcoming in in Food Supply Chains in Cities: Modern Tools for Circularity and Sustainability, (E. Aktas and M. Bourlakis, eds.), Palgrave Macmillan.

- At the Kennedy Space Center, Ye Zhang and Matt Romeyn continued to oversee some of the "validation" testing with Veggie plant growth systems on the International Space Station (ISS), which mixed crop tests with two types of lettuce and mizuna, continuous production in two veggie units, and the addition of new crops, Red Russian Kale, Dragoon lettuce, Wasabi mustard and Extra Dwarf pak choi.
- Gioia Massa has a 3-yr NASA grant to conduct the first official plant testing using Veggie (with leafy greens in 2019 and dwarf tomato in 2020). Ray Wheeler, Mary Hummerick, Matt Romeyn and LaShelle Spencer at KSC, Bob Morrow at Sierra Nevada, and Cary Mitchell at Purdue are Co-Is on the grant along with several Co-Is from Johnson Space Center focusing on food and behavioral health. The focus of this research is to assess fertilizer and light quality impacts on crop growth, nutrient content, and organoleptic appeal. We have worked closed with Florikan Inc. to assess different controlled release (CR) fertilizer combinations. Two sets of mizuna will be grown in Veggie plant pillows, one grown for 28 days and the second for 56 days with repetitive harvesting. Tomatoes will be grown in the Passive Orbital Nutrient Delivery (PONDS) growing system. A modified version of this hardware will be tested on ISS soon.
- Mary Hummerick and LaShelle Spencer along with super undergraduate and graduate interns, grew several growth chamber tests with lettuce, mizuna, radish, dwarf tomato and dwarf peppers to assess their microbial counts, and compared these to similar vegetables purchases in local grocery stores. The intent of these studies was to establish some baseline or "norm" for acceptable microbial counts and food safety considerations for edible space crops. In general, plants grown in the controlled environment chambers were lower in microbial counts than similar crops purchased at grocery stores, and in all cases, the levels of microbes could be dropped by treating the leaves or fruits with ProSan, a citrate based sanitizing agent. Colleagues at Johnson Space Center will use the data to develop a risk assessment for fresh produce grown in space.
- Matt Romeyn, Oscar Monje, LaShelle Spencer and Larry Koss, along with new team member and former intern Jacob Torres continue to compare different watering techniques that might be considered for space applications (primarily looking at systems for µ-gravity operations). These challenges are not new but we want to establish some baseline data for a possible new NASA mission to develop a "deep-space gateway", which would be positioned somewhere near the moon and provide a staging point for lunar surface or Mars transit

missions. The Gateway would only be "manned" for perhaps 1-2 months out of a year, so the ability to have autonomous operations, start-up, and shut-down would be an important consideration.

- LaShelle Spencer, Matt Romeyn, Ray Wheeler and some super interns completed a set of studies where leaf vegetables were grown at 400, 1500, 3000, and 6000 ppm CO_2 to study growth and development, and stomatal conductance across a range of CO_2. For the first tests at 400, it became very difficult to hold the set point due to CO_2 pollution in the surrounding room and humans coming and going in the chamber. We later added CO_2 scrubbing systems from Percival, which contain multiple trays with color-indicating NaOH coated pellets. This worked quite well for holding 400, even with one person in the chamber. But you need to be sure the pellets are changed when they are exhausted. Larry Koss of the KSC group put an acrylic "window" on the scrubbing box to allow easy viewing of the pellets.
- Matthew Mickens completed his Postdoctoral Fellowship in August, 2018, and accepted a position as Operations Manager, Indoor Vertical Farming with Intravision Greens, Inc. in Newark, NJ.
- Lucie Poulet was selected as a NASA Postdoctoral Fellow and began working at KSC in January, 2019, on a project entitled "Modeling plant growth and gas exchanges in various ventilation and gravity levels."

- At Michigan State, led by Ph.D. candidate Jose Llera in Engineering, a multi-objective evolutionary algorithm (NSGA-II) is used to evolve the setpoints for microclimate control in a greenhouse simulation with two objectives: minimizing variable costs and maximizing the value of the tomato crop yield. Results show that the evolved setpoints can provide the grower a variety of improved solutions, resulting in greater profitability compared to prior simulated results. Post-doctoral researcher Yujin Park and Erik Runkle determined whether early flowering of petunia under a mint-white LED could be attributed to greater green radiation or far-red radiation. The results suggest that early flowering was caused by a relatively small amount of far-red radiation that is emitted by the mint-white LED. Ph.D. candidate Qingwu Meng evaluated the efficacy of green radiation (LEDs with peak emission of 521 nm) at regulating flowering of ornamentals during truncated short days in the greenhouse. Increasing the green photon flux density from 0 to 25 $\mu mol \cdot m^{-2} \cdot s^{-1}$ as a 7-h day extension accelerated flowering of all long-day plants and delayed flowering of all short-day plants. Ph.D. student Kellie Walters and Roberto Lopez evaluated the influence of light intensity, average daily temperature, and carbon dioxide concentration on consumer preference of sweet basil. consumers preferred basil grown under 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ compared to 100, 400, or 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$ because these samples had a less bitter taste, milder aftertaste, deeper green color, crisper texture, more moderate flavor, and more pleasant aroma. Consumers indicated no differences in flavor between the CO_2 treatments. However, they preferred the appearance, texture, and color of basil grown under higher temperatures (26 or 29 to 35 °C) compared to 23 °C. Ph.D. student Kellie Walters and Roberto Lopez quantified the influence of temperature and daily light integral (DLI) on growth and development of greenhouse-grown dill, parsley, purple basil, sage, spearmint, and watercress to develop temperature response curves. M.S. student Charlie Garcia and advisor Roberto Lopez evaluated the photoperiodic responses of coriander 'Santo', oregano 'Greek', dill 'Bouquet', lavender 'Bandera Pink', watercress, spearmint 'Spanish', and

marjoram. Lavender, oregano, spearmint, and watercress can be classified as long-day plants. M.S. student Charlie Garcia and advisor Roberto Lopez evaluated the interaction between light intensity and photoperiod, and the influence on the growth and development of 'Genovese Basil' 'Sweet Thai', 'Red Ruben', 'Nufar OG', 'Holy Basil', and 'Lime Basil'. Flowering of all cultivars was hastened under a 16-h photoperiod. M.S. student Charlie Garcia and advisor Roberto Lopez quantified the effects of supplemental light quality on cucumber, tomato, and pepper transplants for high-wire production, in an effort to optimize transplant production. Most responses were generally species-specific. However, the most compact transplants were those grown under a ratio of 75:25 red:blue radiation.

- The Macdonald Campus of McGill University is researching means to use biomass for heat and carbon dioxide enrichment in controlled environments with a focus on greenhouses. The system combines an electrostatic chamber and a cyclone section that allow for extended operation of the traditional air filter. The electrostatic chamber has been very successful with removal of soot occurring for over 7 days with removal efficiency remaining above 85%, with peak removal at 97%. We have patented the technology and are looking for industrial partners to allow this technology to reach the marketplace. They are continuing our light emitting diode research. This project is to determine the proper wavelengths and ratios of light emitting diodes to maximize production. This research is ongoing, but they have tested amber (peak at 595 nm) LEDs to the red and blue mixture with improved production. Also, they have tested Arabidopsis, tomato, and lettuce plants with over 50% increase in the yield when using amber light directly. A cooling system for a greenhouse called the NVAC was developed. Testing is ongoing with Sprung Structures in Calgary to commercialize this technology, with testing continuing at site. The design of a northern greenhouse is continuing with further testing and improvements required. They have successfully grown a crop of lettuce and had fruit set on tomato plants inside the unit. Research is ongoing with collaboration with northern partners and have completed a research project using chicken manure as a fertilizer source for a hydroponic lettuce production facility. McGill tested a porous concrete for plant growth. They tested the porous concrete using different concentrations of Hoagland's solution with the slag based porous concrete. The double Hoagland treatment porous concrete had similar dry mass values as the rockwool treatment. This research has been patented and we are attempting commercial scaling of the technology.
- Ohio State organized the 2019 Greenhouse Management Workshop led by Peter Ling and Chieri Kubota with 48 participants (including 19 online). This year's focus was 'Root-zone optimization in hydroponics and substrate-based culture systems' covering both ornamental and vegetable crops. A new workshop series "Basics of the Greenhouse Environment for K-12 Educators" was first offered in 2018. The workshop was organized by Uttara Samarakoon, Kimberly Sayers, and Peter Ling with 24 participants. A 5 one-day private workshops were offered to 7 parties to learn basics of physiology and technologies of soilless strawberry and tomato production.
- At University of Arizona, UA-CEAC, in collaboration with American Hydroponics (AmHydro), established a research and outreach greenhouse with nutrient film technique-based hydroponics system. The experiments continued to evaluate yield and quality of three lettuce varieties under two different EC levels (1.8 and 1.2 dS/m) and with chilled and non-chilled nutrient solution conditions.

- Kacira Lab at UA-CEAC continued evaluated yield and quality of lettuce crop in floating raft based hydroponics system in a multi-tiered indoor vertical farm research facility (UA-CEAC UAg Farm) under six different DLIs (9-17) and six CO2 concentrations (400-1300 ppm) to evaluate resource use efficiency and potentials for energy savings.
- Established the first continuously recirculating hydroponic system for fruiting crops (tomato, cucumber, sweet pepper) at University of Arizona, (SUMC) Rooftop Greenhouse. Giacomelli in collaboration with Dr. Stacy Tollefson. Located, owned and financially supported by the Student Union Memorial Center (SUMC), Todd Millay, Director.
- Kacira Lab developed a simulation model that evaluates energy generation of organic photovoltaic film (OPV) integrated to a greenhouse roof as covering material, crop yield and economic profit under various OPV film coverage ratios and deployment alternatives.
- Evaluation of wavelength altering properties of quantum dots in plastic film for the improvement of lettuce plant production. NASA-STTR for UbiQD, Inc, Los Alamos, NM. Giacomelli in collaboration with Dr. Matt Bergren, UbiQD
- Kacira (co-PI), in collaboration with K. Chief (PI) et al., within NSF-NRT funded project titled "Indigenous Food, Energy, and Water Security and Sovereignty" continued to educate a cohort graduate students on novel and sustainable off-grid production of safe drinking water, brine management operations, and controlled environment agriculture systems to provide technical solutions for communities, currently with Navajo Nation, challenged to have access to fresh produce and safe drinking water. The project collaboration included educational and training programs for technical staff members and intern students, on controlled environment agriculture (CEA) systems, hydroponic crop production, sensors and controls in CEA, with onsite visitations at the Navajo Nation, as part of Tribal College and University Program, and within UA-CEAC annual greenhouse crop production and engineering short courses and intensive workshops.
- UA-CEAC continued to provide educational opportunities on CEA for new farmers through its 18th Annual Greenhouse Engineering and Crop production Short Course (~80 participants, 15 exhibitors). UA-CEAC Intensive Workshops on education of growers producing hydroponics leafy greens (Dr. Stacy Tollefson, Instructor) and tomato crops (Myles Lewis, Instructor) in controlled environments. (~40 participants).
- University if Arizona SUMC Roof Top Greenhouse weekly community tours (10 – 15 guests) established with Todd Millay, Director SUMC and Dr. Stacy Tollefson. Providing 25+ kg fresh veggies to the UA Student Pantry for food challenged students. Providing internship experiences for operations of RTGH for 2 students
- A day long workshop was organized by LiCor company with Mary Jo Kopf at the CEAC in University of Arizona with 30 participants including students, staff.
- Kacira at UA-CEAC mentored an undergraduate student who designed and evaluated a low cost vapor pressure deficit sensing unit integrated with a microcontroller, and two undergraduate students evaluating crop yield and quality under various DLIs and CO2 enrichment levels with lettuce crop in an indoor vertical farming system, and two undergraduate students helped evaluating lettuce crop yield and quality in NFT based hydroponic system.
- Undergraduate students, Chris Patzke and Devon Valdivia completed 6-month and 4-month internships with Dr. Stacy Tollefson at UA-CEAC, respectively, for the development and operations of the SUMC Rooftop Greenhouse.

- Rutgers continue to evaluate a variety of lamps for light output, light distribution and power consumption using our 2-meter integrating sphere and a small darkroom. They evaluated the spectral output of a variety of lamp technologies (INC, CFL, CMH, HPS, and LED) and compared various waveband ratios with sunlight. Research continues with a comprehensive evaluation of ventilation strategies for high tunnel crop production. They are working on the evaluation of energy use in commercial greenhouses and comparing the information to model-based predictions. A variety of outreach presentations on the engineering aspects of high tunnels, greenhouse production, and energy consumption have been delivered at local and out-of-state venues.
- GLASE researchers at Rensselaer Polytechnic Institute (RPI) have designed and built two dynamic research LED modules designed for crop cultivation in CEA systems in growth chambers and greenhouses. The LED modules designed for growth chambers have six individually programable wavelengths which can operate in either analog or pulse width modulation (PWM) modes and are capable of high speed pulsed operation. The LED modules designated for greenhouses were designed by Lumileds and have the same wavelengths as the growth chamber modules. On a complementary effort GLASE researchers at RPI have completed the basic design of a gallium nitride (GaN) based high efficiency power supply for horticultural LED fixtures. The new power supply will be integrated into the two dynamic research LED modules.
- GLASE researchers at RPI developed a new remote chlorophyll a fluorescence (ChlF) sensing device capable to provide direct, remote, real-time physiological data collection for integration into tunable LED lighting control systems, thereby enabling better control of crop growth and energy efficiency. Data collected by this device can be used to accurately model growth of red lettuce plants. In addition to monitoring growth, this system can predict relative growth rates (RGR), net assimilation rates (NAR), plant area (PA), and leaf area ratio (LAR).
- GLASE researchers at Cornell University are developing equations modeling interactions of daily light integral (DLI) and CO2 concentration versus photosynthetic parameters, morphology and biomass for tomatoes and strawberry. These equations will be used to simultaneously control CO2 enrichment and supplemental lighting to optimize light use efficiency in CEA systems.
- GLASE researchers have implemented the Lighting and Shade System Implementation (LASSI) in two commercial greenhouses (Sustainable Aqua Farms (SAF) Produce, Berlin NY and Wheatfield Gardens, Buffalo NY). GLASE researchers are already working on the next generation lighting control named Day Ahead Market (DAM) LASSI. DAM LASSI is currently programmed in Matlab and is being developed into a usable controller written in Python running on a Raspberry Pi controller. Future improvements include the incorporation of CO2 supplementation to the lighting control algorithm and the validation against traditional LASSI.
- GLASE researchers at Rutgers University have performed energy efficacy and radiometry
- measurements in two commercial horticultural LED fixtures. Results were presented under the proposed horticultural lighting label format (AJ Both et al, 2017). The team is now developing a protocol to test a water-cooled horticultural LED fixture inside an iterating sphere.
- Sierra Nevada Corporation-SNC/ORBITEC is continuing work on the development of Exploration Life Support Salad Crop production as an early stage implementation of hybrid

life support systems (combination of bioregenerative and physical-chemical life support technologies). Current efforts include development of aeroponic and nutrient film technique (NFT) hydroponic systems for use in the space environment as a way to significantly reduce the mass, power, and volume of plant nutrient delivery systems while maintaining good plant productivity. This work consists of three components, a series of parabolic flights investigating aeroponic and nutrient film technique systems for use in microgravity, a technology demonstration experiment on the ISS looking at these same parameters, and development of a ground based high fidelity prototype with >6 m2 of growing area for testing NASA identified salad crops.

- SNC continues to work with the Kennedy Space Center (KSC) to support the two Veggie plant growth systems that are on-board the ISS.
- The Advanced Plant Habitat that SNC delivered to the Kennedy Space Center is operating on the ISS to support a wide range of microgravity plant research. This system is the largest plant growth system put in space to date.
- The SNC Mass Measurement Device developed to support animal and plant sciences is now operational on the ISS.
- SNC continues to work with Commercial Crew Integration Capabilities partners for development of human Life Support and Thermal Control systems for space habitats. During the last year SNC completed a full scale mockup of its Large Inflatable Fabric Environment, designed for long-duration human activity in lunar orbit, as a potential component for NASA's planned moon-orbiting Gateway architecture. This Gateway vehicle is designed to support a 1,100-day mission orbiting the moon. It also can support deep space missions. The module can accommodate up to four astronauts at a time, who would typically be on board for missions of 30 to 90 days per year.
- In order to quickly determine lighting requirements, BIOS Lighting is preparing lookup tables and manuals for the sales team and will eventually release these to the public. For example, simulations were conducted to compare the light intensity for six common vertical farming racking applications using the new Icarus Li. These were generated for two different light bar densities in a 4 x 8 ft racking system (8 and 16 bars per rack), and for four different racking system set-ups for light installations and simulated for distances at 12-36" above canopy. The results were compared to theoretical light capture and allow for improved customer light level predictions. Below are a sampling of the vertical rack set-up drawings, tabular data and charts to be released in the future.
- In 2018 BIOS Lighting presented on VoltServer Digital Electricity as a safer alternative to traditional electrical wiring in CEA environments. The system works by centralizing power and AC/DC conversion into a subsection of the grow facility and then sending it in packets along an ethernet cable requiring a return signal between each packet. This year BIOS configured fixtures with transmitters and worked with VoltServer on a large lighting installation in California. Based on the innovative nature of the project, SMUD became involved and is in the process of writing a report.
- BIOS Lighting worked with a company called Soleil to install mesh network lighting control in a commercial grow facility outside Portland, OR. Soleil uses HD-IoT (high density internet of things) technology and BIOS incorporated this into the Icarus Gi2, allowing light intensities to ramp on and off which resulted in a significant decrease in energy load to HVAC.
- BIOS Lighting is designing custom supplemental lighting for a greenhouse outside Dallas, TX. The greenhouse uses a unique vertical farming operation for leafy greens. Without supplemental lighting, the tall towers create light limiting striation along each row; in amounts depending on row location, cloud cover, time of day, and time of year. BIOS took light density measurements at different days

and light scenarios and built simulation models to determine the light maps. BIOS also installed a set of new Icarus Li fixtures and data is being collected on the effects within the greenhouse with the extra supplemental light.

- Heliospectra continues work with Dr. Youbin Zheng and his research associate David Llewellyn at the University of Guelph on LED control systems, collaborating with Greenbelt Microgreens of Ontario, Canada in 2018 to develop crop-specific lighting strategies for arugula. The installation demonstrated the performance of dynamic, real-time LED light response and the helioCORE DLI and On-Target PPFD controllers in the commercial production environment.
- Heliospectra also supports the work of Dr. Brande Wulff at John Innes Research Centre and Dr. Lee Hickey at University of Queensland to develop academic speed breeding protocols. John Innes Research Centre is using the helioCORE™ light control in glasshouses in Norwich, United Kingdom. The speed breeding research team established a 22-hour photoperiod with helioCORE control of supplemental lighting for seed to seed wheat generation cycles of 8 to 9 weeks.
- Heliospectra's Engineering and Development teams completed simulations and analysis of both static spectrum LEDs (basic on/off function) and adjustable spectrum LEDs (supported by helioCORE control) to evidence~24% potential reduction in energy consumption using the adjustable or tunable spectrum LED technology
- LumiGrow had SmartPAR sensor-actuated DLI control commercially deployed at over a dozen locations. Total customers using smartPAR for spectral lighting strategies up to over 150. New high-intensity greenhouse TopLight fixture received UL and UL Canada certification, IP 67 rating and pending listing on DLC Horticultural Lighting qualified product list. During winter 2018-19, smartPAR DLI controlled fixtures supplemented solar light to within 2% of the target 18 mol·m-2·s-1 DLI on greater than 90% of days at Harrow Research and Development Centre.
- Valoya's continued focus on plant biology research and collaboration with the scientific community has resulted in 12 academic articles being published in 2018 which used Valoya's LED solutions to advance our collective understanding of the field. One of these papers was the first comparative study of effects of HPS versus LED lighting on morphology and cannabinoid content of Cannabis sativa L. Additionally Valoya hosted its first LEDs & Innovators Conference 2018 during the GreenTech exhibition which aimed to disseminate knowledge to the wider public on the latest implementations of the LED technology in crop science, vertical farming and professional cannabis cultivation fields.

4. Impact Statements:

- Purdue generated new knowledge on nutrient profiles in the wastewater derived from ingested fish feed and nutrient dynamics during the production, which is critical to develop nutrient management guidelines in aquaponics and improve crop yield and quality. Furthermore, the research also identified optimal light environment (red plus far-red LEDs) for high-wire greenhouse tomato production, which produces a higher yield and better flavor than HPS lamps to a degree that consumers find more acceptable. This will contribute to the development of production guidelines of greenhouse tomatoes to improve yield and flavor.

- Cornell with industry outreach presented at 17 New York State, 3 out-of-state, and 3 webinars reaching to more than 400 participants. Two industry conferences were organized including a floriculture Field Day and a greenhouse lighting workshop. Five undergraduate students were mentored in greenhouse research projects. One of which is being presented at the National Conference for Undergraduate Research.For head lettuce in greenhouses, only subtle effects of LED vs HPS light source were found, which is promising in that adoption of new lighting technology can

focus on other metrics (energy efficiency, initial and operating cost, longevity, light distribution). Cornell with adoption of LED fixtures demonstrated reduced electricity usage by 60% compared with magnetic ballast HPS fixtures that had been used for several thousand hours.

- Thanks to many hard-working colleagues at KSC, Sierra Nevada Corp., numerous universities, and the controlled environment plant research community, their reach was successfully extended to the International Space Station with a second Veggie plant growth unit and now the Advanced Plant Habitat (APH). The APH is the largest plant growth chamber ever flown (~0.2 m2 growing area) and completed its first peer-reviewed science test with Arabidopsis, with a second test with radish coming up soon. APH uses porous metal-ceramic watering tubes embedded in trays of arcillite, and provides a well-controlled, closed environment that will allow tracking of whole canopy photosynthesis, respiration, and transpiration. As with the prior Astroculture and BPS chambers flown in space, the humidity is condensed and recycled back to the plants. Lighting is provided by a range of narrow-band along with white LEDs, and can provide up to ~800 µmol m-2 s-1 at the plant level. Initial validation tests in APH using Apogee dwarf wheat and Arabidopsis thaliana were recently completed and follow on testing is planned.
- In the production of vegetable crops inside Michigan State University (MSU) greenhouses, the environment influences crop growth (including the harvestable yield) as well as the amount of energy consumed to maintain desired air temperatures. Information generated in the greenhouse simulations compare the trade-offs that exist between fruit yield of tomato and input costs for heating. The research developed a greater understanding of the roles of far-red radiation (700 to 800 nm) on growth of leafy green vegetables as well as growth and subsequent flowering of ornamentals. There are compelling reasons to include far-red radiation in a sole-source lighting spectrum. A common misconception is that green radiation (500 to 600 nm) is less (or not) useful to plants for photosynthesis, and that green light is not perceived as a long-day stimulus. MSU demonstrated that many plants perceive a low intensity of green radiation when delivered for a prolonged (e.g., hours) period of time during an otherwise long night. Light intensity and temperature can influence sweet basil secondary metabolite production and flavor. MSU demonstrated that altering the growing environment influences taste and have identified consumer preferences. By understanding and modeling the effect of temperature and DLI on culinary herbs, growers can conduct cost-benefit analysis to increase profitability and group plants with similar light and temperature responses in a common environment. Lavender, oregano, spearmint, and watercress can be classified as long-day plants. This information is of great benefit for many greenhouse growers who struggle to maintain herb crops such as vegetative. Growers can use the information to modify practices and prolong their harvest period. MSU demonstrated that the addition of green radiation to supplemental lighting containing red and blue radiation can promote leaf expansion and biomass accumulation of vegetable transplants.
- The Biomass Production Laboratory at McGill University has shown that plant growth using LED light from 595 nm is very beneficial for plant growth with both fresh and dry mass over 50% higher than any other single LED wavelength we have tested. The studies are ongoing with industry partners to improve on this result and add in other wavelength to improve the lighting system further.
- In August 2018, Ohio State launched an online monthly forum ‘Indoor Ag Science Café’ to serve as a non-competitive communications platform for indoor farmers and relevant stakeholders. The Café has been communicated by various media and blogs, in some cases reaching more than 1,600 readers. During each Café forum. The Café provide a short presentation (recorded and shared in YouTube) and then discuss production and business obstacles (but these portions are not recorded). Thus, the Café have received tremendous encouragement from participants, and the Café stakeholder membership has quickly increased (from 47 to over 200 members presently), serving as a very effective engagement method with industry stakeholders.

- At the North Carolina State University Phytotron, usage for all growth chambers in 2018 was 99% of the recommended optimal occupancy, or 81% of maximal occupancy. For 2018, total A-chamber (2.4 m width x 3.7 m depth x 2.1 m height) usage was 77% maximal occupancy. Usage of B-chambers (2.4 m width x 1.2 m depth x 2.1 m height) was at 98% and C-chambers (1.2 m width x 0.9 m depth x 1.2 m height), 82% for the year. Fifty-six different projects were conducted in the Phytotron during 2018 by faculty and students from 8 departments. The Department using the largest amount of space in 2018 was Plant Pathology & Entomology (23%, for 19 different projects). The Crop Science Department used 15.8% of the space for 13 projects, Plant and Microbial Biology used 11.4% of the space for 9 projects, and Horticultural Science used 13.6% for 5 projects. During 2018, 29.4% of the growth space in the Phytotron was used to grow soybeans. Research with other agronomic crops included cotton (5.7%), tomato, (6.3%) and corn (3.1%). Research on Arabidopsis used 2.4% of growth space, strawberries, 5.2%, and turfgrass, 5.9.

- At Rutgers, Nationwide, Extension and NRCS personnel and commercial greenhouse growers have been exposed to research and outreach efforts through various presentations and publications. It is estimated that this information has led to proper designs of controlled environment plant production facilities and to updated operational strategies that saved an average sized (1-acre) business a total of $20,000 in operating and maintenance costs annually. Greenhouse energy conservation presentations and written materials have been prepared and delivered to local and regional audiences. Greenhouse growers who implemented the information resulting from our research and outreach materials have been able to realize energy savings between 5 and 30%.

- University of Arizona-CEAC organized the 18th Greenhouse Crop Production and Engineering Design Short Course (March 2019) with ~80 participants (representing 20 US states, 5 countries, 3 continents). Hands-on workshops were given to attendees during the short course. These workshops included demonstrating hydroponics crop production and systems basics, greenhouse sensors and instrumentation basics with theory and practical use. Ten graduate students, and five undergraduate students [by Kacira] and 5 graduate students, 9 undergraduate students (by Giacomelli) were mentored in CEA systems such as greenhouse, growth rooms and indoor vertical farming-based research projects at UA-CEAC. In University of Arizona research at experimental scale, consideration of various DLI and CO2 concentration injection combinations could help achieving energy savings, and the CFD models developed at UA-CEAC research could help improving environmental uniformity with alternative air distribution system hardware and designs and environmental control strategies in indoor vertical farm-based operation. In Arizona, using the controlled environment changed the future in the development of new varieties of field corn for animal feed. Stefanie Boe, Monsanto/Bayer Company's Community Relations/Site Enablement Lead stated that: "CEAC has been an instrumental partner in developing the necessary technology and capacity to conceive and build our new $100M Marana, Arizona Greenhouse Complex, creating 40 - 60 new local jobs which range from HVAC engineers to plant biologists, and access for others within the company." The Marana facility represents a highly automated greenhouse hydroponic crop production system for the continuous yearly production of seed corn for breeding new varieties. Future benefits to the farmer include new breeding lines, developed up to 3 years faster (7 rather than 10 years), that ultimately create new corn varieties with attributes farmers will need, such as drought or salt tolerance to meet the effects of climate change. Given that the Monsanto/Bayer Company supplies 70% of the world's feed corn production our science and engineering technology will be affecting billions of dollars of the global agricultural economy. This new system recycles all its irrigation water and nutrients for seed corn production, Unused water was captured and stored for a future watering cycle, using 80% less water per crop cycle than previous. Furthermore, with recycling, there is no discharge to the environment of waste water or plant nutrients. The closed environment of the greenhouse makes IPM [Integrated Pest Management] highly effective for control

of pests and diseases, reducing pesticide use by 70% compare to the current open-field seed corn production systems. Space utilization will increase 7-fold compared to current open-field seed corn production systems.

- From April 2018 to April 2019, GLASE has signed 21 industrial members; established a new website (https://glase.org); published 8 newsletters to an audience of 500+ people; hosted 2 webinars (Funding Opportunities for CEA Energy Efficiency and A proposed horticultural lighting label) to an audience of 170+ people; hosted 1 Industry Talk (Effects of lighting on phenolics production in crops cultivated in CEA systems); hosted the 1st GLASE meeting (Guidelines for new Controlled environment Agriculture energy-efficient technology adoption) to an audience of 130+ people on November 5th in Ithaca, NY. In March 2019 GLASE has disclosed its first Intellectual Property filed at RPI entitled Remote Plant Chlorophyll Fluorescence Monitor (U.S. patent app. #62/802,886 filed 2/8/2019). A low cost (< $400) fluorescence sensing device is described that provides remote, real-time chlorophyll fluorescence data collection for integration into tunable LED lighting control systems, thereby potentially enabling energy efficiency and better control of crop growth. Data collected by this device can be used as a proxy for mean growth dynamics of target plants. In addition to monitoring growth, this system could predict relative growth rates, net assimilation rates, plant area and leaf area ratio.

- Sierra Nevada Co./Orbitec is working toward development of hybrid life support systems for space applications, integrating biological and physical/chemical technologies. SNC is advancing the technology of controlled environment systems to meet the performance and quality needs of long duration space applications. Some of this technology may be transferable and scalable to terrestrial protected agriculture systems. SNC continues to develop LED lighting configurations and control strategies for plant and human lighting applications to provide increased lighting system utility for aerospace and gravitational biology applications. SNC continues to use its space biology controlled environment work and human life support work to spark interest in high school and college students in controlled environment technology and STEM.

- AeroFarms using their internal analysis and that of Rutgers Dr. James Simon's biochemistry lab and Dr. Beverley Tepper's sensory lab, they were able to document methods to alter color, taste, texture, and phytochemicals. In the next year of the project, we are focusing on 3-4 of the most interesting stressors. Their studies will expand knowledge of control range and will combine multiple stressors towards creating bespoke growth algorithms that can make our produce more attractive, nutritious or tasty.
- BIOS Lighting is addressing several problems in CEA. First and foremost, by creating manuals with lookup tables and charts, growers can quickly estimate lighting requirements and needs for optimal productivity. This is important because oftentimes the lighting requirements and lighting layout in controlled environmental agriculture are unique to the grower, operation, and facility. Having this information as a manual allows for quick reference for lighting design, electricity use calculations, and estimated ROI. Additionally, by partnering with innovative technology partners like Soleil for HD-IoT and VoltServer for digital electricity, BIOS Lighting is ensuring a position on the cutting edge of CEA Agricultural technology, without needing to do the specialized development work, with focus on quality lighting products and solutions.
- Heliospectra collaborates with leading research institutions, scientific agencies and commercial growers to further the technical development, knowledge transfer and market adoption of LED lighting technologies and light control systems. Heliospectra's customer applications identify opportunity for businesses to standardize yields year-round, ensure highest quality crops and maintain consistent nutritional profiles and implement dynamic light control/response to reduce energy consumption by~40%.

- In LumiGrow research, it was shown that ornamental perennial species Leucanthemum, Phlox, and Rudbeckia had increased branching and flower number when grown under 90 µmol·m-2·s-1 compared to those grown under photoperiodic lighting and Phlox grown under 90 µmol·m-2·s-1 from LEDs flowered 9 days earlier compared to those grown under HPS lamps at a similar intensity. During the transplant phase, under a DLI of 16 mol·m-2·s-1, lettuce growth increased as the photoperiod was increased from 16-hr to 24-hr. Providing Kalanchoe blossfelidana with 85 µmol·m-2·s-1 during the long-day and short-day phases results in increased flower number and more compact plants compared to lighting during the long-day phase alone.
- Valoya introduced wide (full / continuous) spectra to the market and continue to build our brand around high quality light which has thus far resonated with customers in more than 50 countries including 8 out of 10 world's largest agricultural companies.

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