Project No and Title: NCERA-101 Controlled Environment Technology and Use
Period Covered: 09-2016 to 04-2017
Date Reporting: 23-May-2017
Annual Meeting: April 9-12, 2017

Minutes of the 2017 NCERA-101 Business meeting
April 9-12, 2017 Pacific Grove, California
Asilomar Conference Center

To Dos

- Reach out by Ramesh Kanwar to NIFA - Steven Thompson (new rep) replaced Dan Smoltz
- Continuing Education Credits - Greg Short, Mark Romer and Carole Saravitz, Mark Lefsrud
- Station Reports

NCERA-101 Meeting Participants:
George Adamson (Ontario Scientific), Lars Aikala (Valoya Oy), Peter Alem (Koch Biological), Sarah Baire (NASA), Bruk Belayneh (Univ. Maryland), Mark Blonquist (Apogee Inst), A.J. Both (Rutgers Univ.), Keri Bouchard (Conviron), Tracey Bradley (Heliospectra), Dave Bubenheim (NASA Ames), Bruce Bugbee (Utah State Univ.), Samuel Burgner (Purdue Univ.), Joseph Chiera (NCSU Phytotron), Christopher Choi (Univ. Wisc), John Clark (AgBiome), Bobby Clegg (Syngenta), Kristen Curlee (Dow Agrosciences), Mike Dixon (Guelph Univ.), Yurij Duda (Argus), Shuyler Duffy (Cornell Univ.), Jonathan Frantz (Pioneer), Gary Gardner (Univ. Minn.), Josh Gerovac (Fluence), Celina Gomez (Univ. Florida), Kale Harbick (Cornel Univ.), Ed Harwood (Aerofarms)), Dave Hawley (Guelph Univ.), Ricardo Hernandez (NCSU), Chris Higgins (HortAmericas), Lynn Hummel (Univ. Wisconsin-Madison), Allison Hurt (Mich. State Univ.), Henry Imberti (Percival Scientific), Murat Kacira (Univ. Arizona), Ramesh Kanwar (Iowa State Univ.), Bjorn Karlsson (Univ. Wisconsin-Madison), Meriam Karlsson (Univ. Alaska-Fairbanks), Daniel Kiekhaefer (Percival), Nick Klase (Fluence), Mary Jo Kopf (LiCor), Titta Kotilainen (NCSU), Mark Kroggel (Univ. Arizona), Chieri Kubota (Univ. Arizona), Paul Kusuma (Utah State Univ.), John Lea-Cox (Univ. Maryland), Mark Lefsrud (McGill Univ.), Yuan Li (Rutgers Univ.), Peter Ling (Ohio State Univ.), Alexander Litvin (Iowa State Univ.), Roberto Lopez (Mich. State Univ.), Tom Manning (Rutgers Univ.), Gioia Massa (NASA KSC), Neil Mattson (Cornell Univ.), Lucas McCartney (McGill Univ.), William Meng (Mich. State Univ.), Matt Mickens (NASA KSC), Cary Mitchell (Purdue Univ.), Bob Morrow (Orbitec), Mike Mucci (Guelph Univ.), Bill Mukanik (Conviron), Yujin Park (Mich. State Univ.), Morgan Pattison (SSLS Inc.), Rob Pauls (Biochambers), Eric Price (LiCor), Reg Quiring (Conviron), Sharon Reid (Conviron), Mark Romer (McGill Univ.), Matt Romeyn (NASA-KSC), Erik Runkle (Mich. State Univ.), Carole Saravitz (NCSU Phytotron), Greg Schlick (NASA-Ames), Flip Sheridan (Cycloptics), Todd Smith (Duke Phytotron), Wenzhan Song (Univ. Georgia), Rob Sorba (Conviron), Hans Spalholz (NCSU), Gary Stutte (NASA-KSC), Wei Sun (BIOS), Marc Theroux (Biochambers), Abhay Thosar (Philips Lighting), Viktor Tishchenko (Univ. Georgia), Marc van Iersel (Univ. Georgia), Kellie Walters (Mich. State Univ.), Caroline Wells (Heliospectra), Ray Wheeler (NASA-KSC), William Wheeler (Utah State Univ.), John Wierzchowski (EGC), Cameron Willingham (Vertical Harvest), Dave Wilson (NASA Ames),

Rachelle Winningham (Philips Lighting), Christopher Winterbottom (Sundance Berry Farms), Yang Yang (DOW Agrosciences), Melanie Yelton (Lumigrow), Zach Yohannes (AXP Technology), Neil Yorio (BIOS Lighting), Shuyang Zhen (Univ. Georgia).

Executive Officers:
Chair: Gioia Massa (NASA KSC), Vice-Chair: Bob Morrow (ORBITEC), Secretary: Mark Lefsrud (McGill University), Past-Chair: Carole Saravitz (NCSU Phytotron)

Business Meeting
April 10, 2017
Start 9:15

Minutes of meeting 2016 – Presented by Bob Morrow
Motion to Pass - Gary Stutte
Second - Henry Imberti
Passed

Attendance list from conference at end of this document – 110 attendances

Other Conferences
ASABE Annual Meeting, Spokane, Washington, July 16-19, 2017
Greensys 2017- Beijing China, Aug 20-24, 2017
ISHS –XXX International Horticultural Congress Istanbul, Turkey, Aug 12-16, 2018
NE 1335 Annual Meeting- Resource Management in Commercial Greenhouse Production – Lincoln, NE, June 29-30, 2017
American council on medicinally active plants June 20-22, 2017 Clemson, South Carolina
International Congress on Controlled Environment Agriculture (ICCEA), Panama City, Panama, May 17-19
American Society for Gravitational and Space Research, Renton, Washington, October 25-28, 2017
AHSA Annual Meeting, Waikoloa, Hawaii September 19-22.

Administration advisors report – Ramesh Kanwar
- Station reports are due 60 days after this meeting (June 12 is due)
- Nomination for Experiment Station section award suggestion would be a very good option – deadline for nomination Feb 28, 2018 (only 2-3 pages)
- Need to have a sub-committee set up
- 13 grad students funded for travel to conference
- Dave Bubenheim thank you for hosting this meeting
- International Permaculture Convergence, Hyderabad, India, Nov 27-Dec 2, 2017.

NIFA - Steven Thompson (new rep) replaced Dan Smoltz – reach out by Ramesh Kanwar

Membership report – Mark Romer
42 Annual Meeting – 2nd time in California
Thanks David's and all support
Bruce Bugbee support for the meeting

167 registered members
117 – different institutions
34 – states represented
11 countries represented
41 – Companies represented
Notes:
Gerry Deitzer – passed this year, 20 year member award member since 1988
Awards – 20 yr member award – 5 – 20 year awardees Meriam Karlsson, Bob Morrow, Reg Quiring, Jonathan Franz, Peter Ling

Web site report – Carol Saravitz
2 pointers to reach website
List of interest countries viewing the website are USA, UK, Canada, Russia, Netherlands, Australia, Germany, India, China
Unique page views- main page, meetings, pubs, members, activities, guidelines, meetings-past, officers, jobs
Traffic has increased by ~1/3
New website revamp, on the NC state ncera.phytotron.ncsu.edu – need to check up and will go live in next while
Additions for class use is suggested

AUSpheno travel grant – AJ Both (submitted grant and return of funds)
$50,000 grant – Dan Smoltz
Chieri Kubota – helped set it up
Committee to award – $3500 for graduate students, $1000 for everybody else
23 applications – on paper total award $48,700 but will pay out $44,000
No money has been paid yet

- Rutgers changes financial systems – now better
- Need to submit a W9 form with Social Security number – now straight
- Start date of grant was past meeting date – working to solve the issue

Write a short summary – based on 2 questions – do we need new guidelines for Phenomics

Greenhouse guidelines – AJ Both
Copies are available – 1900 copies in AJ office
Request copies from AJ, he will provide but you have to pay for shipping and handling
Send email in next couple of weeks
Or go and visit AJ to obtain

Instrument package and Financials – Bruce Bugbee
$20,000 is the treasury for NCERA-101
Instrument package report – unsure if used once this year
Graduate student funding for travel, so now moving to the university then fund student directly from the university

Student report update – Jonathan Franz
19 students requested travel – 13 were funded (partial support)

No poster completion – instead lightning talks (5 min)
Funding will go through Student University

Future meetings
Carol Saravitz – NCSU/Duke meeting 2018, April 14-17, 2018
Celebrate 50th year SEPAL anniversary (NC State Duke Anniversary Phytotron)
In downtown Raleigh, Sheraton downtown
See Phytotrons, and companies in the area
Commemoration of Dr Downs

Montreal in 2019 – Annual meeting

Election Secretary
Nominations - Neil Yorio
Motion to close nominations - Bruce Bugbee
Second Gary Stutte
Passed, Congratulations to Neil

New Business –
Greg Short – continuing education credit for engineering certification
Gary (minutes) – need to include station reports to highlight this need for continuing education credit
NCERA-101 – can approve this
Identify a topic/theme – highlight during a number of hours as part of this meeting
Request titles for their station reports (and focus areas)
Keep informal level of the conference
List major topics from from the station reports.
Need to change wording of the conference to meeting this level
Discuss with Greg Short, Mark Romer and Carole Saravitz, Mark Lefsrud and other as needed.

Update on LED standards to horticultural applications (ASABE Standards) - Neil Yorio

ES-311 Electromagnetic Radiation Application for Plants
ASABE (the American Society of Agricultural and Biological Engineers), an ANSI (American National Standards Institute) accredited standard development body, is currently developing three new standards for horticultural lighting systems. This effort arose from the recent emergence of LEDs as a commercially popular lighting system for plants as well as development of certain markets for controlled environment plant production.

The standard-writing committee (ES-311 Electromagnetic Radiation Application for Plants) consists of ~75 people from industry, academia and government, and is chaired by Jianzhong Jiao. Several members of NCR101 are part of the committee. The committee has been operating for the past 2 years.

The standards under development are aimed at providing a unified description of metrics, reference methodology for measuring and comparing lighting system characteristics and performance for horticultural applications. Three standards are being created:

1. Definition of Metrics of Radiation for Plant Growth (Controlled Environment Horticulture) Applications

    Status: Balloted and revised

2. Recommended Measures of Measurements and Testing for LED Optical Radiation Products for Plant Growth and Development

    Status: Balloted and undergoing revision

3. Performance Criteria for Optical Radiation Devices and Systems Installed for Plant Growth and Development

    Status: Still being drafted

<u>Passing of the gavel</u> Gioia Massa to Bob Morrow (now chair)

<u>Adjourned</u> 10:30am. (Bob Morrow)

Minutes respectfully submitted by Mark Lefsrud

Accomplishments (12 Reports)
(The complete station reports are available on the NCERA -101 website http://www.controlledenvironments.org/station_reports.htm)

1. New Facilities and Equipment

Dr. Roberto Lopez joined the faculty in the Department of Horticulture of Michigan State University (MSU) in March, 2016 as an assistant professor in the production of specialty crops grown in controlled environments. He has a 45% research, 30% teaching, and 25% extension appointment.

Dr. Garrett Owen was hired in the Department of Horticulture (MSU) as an Outreach Specialist in greenhouse production of floriculture crops and other specialty crops grown in controlled environments, primarily serving southeast Michigan. He has an 85% outreach and 15% research appointment.

Dr. Nemali joined the Purdue Horticulture and Landscape Architecture department in July 2016 as an assistant professor. He has responsibility for extension, research, and teaching activities related to controlled environment agriculture, which includes ornamentals and vegetables grown under protected culture. He has a Ph.D. from the University of Georgia focused on development of plant-uptake-based automated irrigation techniques using sensors and understanding the physiological responses of greenhouse crops to varying input (light, water, and nutrients) levels during production. Prior to joining Purdue, he worked at Monsanto company, USA for nearly 9 years as a controlled environment crop physiologist. His research at Monsanto significantly contributed to the commercialization of the first biotechnology-derived, drought-tolerant maize. His program at Purdue is focused on developing and making available affordable, robust, and feasible technologies and solutions that address current and future challenges and improve sustainability (i.e., reduce input waste, minimize environmental impact, and increase profits) in controlled environment agriculture.

Michigan State University has room renovations for the Controlled-Environment Lighting Laboratory (CELL; www.hrt.msu.edu/labs/cell) are nearly complete. The facility consists of two independently controlled and refrigerated growth rooms, each with 12 deep-flow hydroponic shelves. Sole-source lighting in CELL utilizes customized, state-of-the-art LED arrays developed in collaboration with Osram and Osram Opto Semiconductors. Computer software enables digital light control of individual shelves, allowing for temporal alternations of light quality and intensity. The facility is expected to be completed in April, 2017. Erik Runkle developed CELL for: Research on controlled-environment production of specialty food crops (such as leafy greens and herbs) and ornamentals (such as seedlings and cuttings); Demonstration of indoor growing systems to inform growers and capture the interest of students and the public; and Teaching applications for undergraduate students enrolled in relevant production courses in Horticulture at MSU.

The University of Georgia Photobiology research. van Iersel's Horticultural Physiology Lab (hortphys.uga.edu) has set up a dark room for photobiological studies, mainly used to study the effects of light intensity and spectrum on chlorophyll fluorescence and to determine leaf absorptance. For chlorophyll fluorescence studies, we have multiple LED lights available, including red/blue LED, white LEDs, and an LED light with control over ratios and intensities of red, blue white, and far-red light. Fluorescence measurements are collected using a mini-PAM fluorometer (Walz, Germany). For leaf absorptance measurements, we use a combination of a Unispec spectrometer (PP Systems) for reflectance and spectroradiometer (Apogee Instruments) for transmission. Leaf absorptance is calculated as the fraction of light that is not transmitted or reflected.

The University of Georgia Chlorophyll fluorescence-based biofeedback system**.** Inside a Conviron E15 growth chamber, we have upgraded a system that can measure chlorophyll fluorescence and quantum yield of photosystem II and calculates electron transport rate. The system can autonomously adjust the light level to achieve a user-define electron transport rate. The initial setup used four white, 100-W LED modules controlled using pulse-width modulation (rapid on/off control of the LEDs, with intensity determined by the fraction of time that LEDs are on during an on/off cycle). We now have installed new LED lights (combination of red, blue, white, and far-red LEDs, donated by PhytoSynthetix, LLC) that provide a much more uniform light coverage. These lights are controlled using current control (*i.e.*, true dimming), which has eliminated almost all noise in chlorophyll fluorescence and light measurements. The setup can be used to test the effect of different lighting strategies on the plant's light use efficiency. The system can measure and maintain specific quantum yields of photosystem II or electron transport rates by adjusting the light intensity as needed.

The University of Georgia Spectral and intensity effects of LED light on plant growth. We have outfitted a room with six LED lights that provide independent control over the intensity of red, blue, white, and far-red light (donated by Aurora). This setup is used to study spectral effects on leaf elongation, light interception, photosynthetic physiology, and crop growth.

The University of Georgia Adaptive lighting control of LED lights in the greenhouse. Based on the adaptive lighting controller described by van and Iersel and Gianino (2017), we have developed a system to test different supplemental lighting approaches. The system can implement five different lighting approaches (including one unlit control treatment). Five quantum sensors are used to measure the light level in each of the five treatments. A datalogger can then send a signal to the LED lights (SpydrX, Fluence BioEngineering) to adjust their light output. This allows for excellent control of light levels at the canopy level.

Kennedy Space Center continued to rent several walk-in and reach-in chambers at Space Life Sciences Lab (SLSL), and in addition have been using two reach-in chambers with red-blue LED lamp fixtures at the SSPF building at Kennedy Space Center. Larry Koss, our electro-mechanical lead has completed a retrofit of a large Thermotron walk-in chamber for growing plants in O&C Building on the main campus of Kennedy Space Center. Larry added banks of T8 fluorescent lamps and has set up his Opto-22 based monitoring and control system. We will also be purchasing five Percival walk-in chambers (6 ft X 8 ft) and two reach-in chambers that will be located at the SSPF facility of Kennedy Space Center, adjacent to several new plant-focused lab areas under development. Anticipated completion of this new facility is Summer 2017. A plant processing area has been established in the SSPF building and testing in this space has commenced with LED arrays, a grow tent, and two small reach-in chambers operating.

KSC purchased a Decagon SC-1 porometer for stomatal conductance measurements. It is much smaller than our Li-Cor steady state porometer, and has a built in data logger. Additional equipment purchased in the establishment of the plant processing area includes a large capacity Thermo Scientific forced air oven, a Gilson sieve shaker with sieves for sorting substrate particle sizes, a Wiley tissue mill, a Li-Cor LI-3100C leaf area meter, and Li-Cor quantum meters, an Apogee spectroradiometer, an Atago portable refractometer, a Minolta SPAD meter, a FLIR C2-pocket sized thermal Imaging system, a Heliospectra RX30 lamp, and other standard analytical equipment. ORBITEC retrofitted 6 Biomass Production Systems for Education (BPSe) with LED light-caps to mimic the Veggie system. Several new LED lighting systems have been purchased, including 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).

University of Guelph, a new ‘WhiteBox’ growth chamber was added to our collection and now houses four 600 x 2400 mm benches of 7 channel multispectral and addressable LEDs (UV through far red) as well as four 400 x 2600 mm benches of fixed wavelength purple and green Intravision Blade LEDs.

University of Guelph, the ion specific optrode system has seen continued development and is now reduced in size, with operation controlled by a Raspberry Pi with touch screen interface. The system has been field tested in Chile and will soon see implementation in the EDEN ISS Antarctic greenhouse. In collaboration with PlantForm Corporation, plant infiltration equipment has been installed and is used for vector insertion and therapeutic cancer drug production. A prototype whole plant photosynthesis chamber equipped with seven-channel multispectral LEDs was acquired and installed. Additional Ocean Optics spectrometers were acquired.

The University of Arizona: A 100m^2 greenhouse bay was renovated by Myles Lewis (Arizona Vegetable Growers) and Dr. Gene Giacomelli, to provide intensive workshops on hydroponic lettuce production. The UA-CEAC established a new multi-tier vertical farm based research, education, extension and outreach facility (UAg Farm) (750 ft2). The project (PI Kacira) was funded by Water, Environmental and Energy Solutions program, an in part by UA-CEAC facilities maintenance funds, along with in-kind support by industrial collaborators Illumitex, IndoorHarvest, HortAmericas. The goal of the project and this program is to conduct engineering and science based research to address challenges and help advancing technology and crop production applications with indoor growing under artificial lighting, to provide experiential educational opportunities for students, to educate and inform growers and public on indoor growing systems.

The University of Arizona: Kacira Lab custom designed, built and implemented a data acquisition and graphical user interface system, in the indoor vertical farm facility (UAg Farm), that enables real-time monitoring of key environmental variables including air temperature, relative humidity, CO2, light intensity from aerial environment and pH, electrical conductivity, dissolved oxygen from nutrient solution as well as monitoring of resource use (e.g. energy, water, CO2), while controlling CO2 injections. A custom design Dash Board also serves as graphical user interface for the system operators to access these monitored and recorded variables for improved system and operational managements and resource use.

The University of Arizona: A 20-foot long standard shipping container was retrofitted by the Cuello Biosystems Engineering Laboratory as a modular vertical farming unit for educational purposes, sponsored by The University of Arizona Green Fund. Dubbed the Arizona Green Box, the unit contains vertically stacked hydroponic cultivation systems built by a group of participating students, called “Cats in the Green Box.” Through this project, an original vertical farming cultivation system specifically designed for vertical farming, the V-Hive Green Box, has just been prototyped and for which a patent disclosure has just been submitted.

The CAMLab at Purdue University continues to develop the Minitron III controlled-environment/crop-cuvette system that will measure gas-exchange rates of hydroponic crop stands in the same environmental conditions as those under which they are grown. The recirculating hydroponic root system is compartmented separately from the flow-through cuvette headspace, the height-adjustable cuvette compartment is capped with a dimmable LED light array, and cuvette temperature is maintained by an external temperature-controlled recirculating bath pumping coolant through a heat exchanger in the cuvette plant-growth space. The cuvette space has recirculating fans for air mixing, temperature sensors, a quantum light sensor, computer-controlled air-flow rate through the cuvette space, and injection and control of CO_2. Return air from the cuvette flows through an infrared gas analyzer (IRGA), and CO_2 differential between sample air and cuvette bypass air going through a reference cell is used, along with air-flow rate and plant-growth area, to determine photosynthetic rate as a function of crop stage, light intensity or spectrum, CO_2 concentration, and/or cuvette temperature. The computer-controlled and monitored controlled-environment/gas-exchange system is anticipated to be routinely functional by fall, 2017.

New Equipment at Purdue University include: Aris TopView Multi-Spectral Imaging Station , Apogee SS-110 Spectro-radiometer, Decagon NDVI/PRI Spectral Reflectance Sensors, Campbell Sci. CR300 Dataloggers, Campbell Sci. CS615 EC/Temp/VWC sensor, Decagon Pro-Check handheld Datalogger, Apogee Infrared Radiometer, FLIR-One Infrared Camera.

North Carolina State University is building a 200,000 sq. ft. Plant Science Research Complex that will be completed by 2021. The facility will have 30,000 sq. ft. of controlled environment rooftop greenhouses with 10,000 sq. ft. being biosafety level 3 compliant as well as multi-user area with growth chambers. Faculty labs and offices will be located throughout the facility and there will be leasable corporate lab and startup suites available for corporations. An atrium collaborative space and multi-user labs will also be included.

SNC/ORBITEC has added several new employees and will be expanding to a third building in 2018.

A new controlled environment plant growth facility is nearing completion at Fluence. The new facility consists of eight climate-controlled walk in growth chambers. Each chamber has temperature and humidity control with four chambers being equipped with CO_2 injection systems. Temperature and relative humidity data will be collected with a Campbell Scientific CR1000 data logger with EE181-L air temperature and relative humidity probes mounted in aspirated radiation shields.

2. Unique Plant Responses

Automating determination of optimal light levels for different crops. The University of Georgia have developed a system that can automatically determine optimal light levels for a specific plant and then maintain those light levels. The system start with a light level of 100 µmol/m2/s and increase this by 25 µmol/m2/s every 15 minutes. The electron transport rate (ETR, a proxy for photosynthesis) is measured at each light level and the increase in ETR in response to the increase in light intensity is calculated. When the increase in light no longer results in a user-specified increase in ETR, the system returns to the previous light level and maintains that light level for the rest of the photoperiod. The light can be kept on either for a pre-determined amount of time, or when a specific integrated electron transport rate has been reached. Ultimately, the optimal light level for a specific crop should not merely depends on physiological measurements, but also account for the value of the crop and electricity prices.

The University of Georgia performance of the biofeedback system, using hellebore as a model plant. Initially the system gradually increases the light level and measures the corresponding change in the electron transport rate (ETR). Once the optimal light level has been identified, based on only a small increase in electron transport rate in response to an increase in light, the biofeedback system maintains that light level for a specific amount of time or until a threshold integrated electron transport rate has been, at which time the light is turned off automatically. The University of Georgia adaptive lighting in greenhouses can result in energy-efficient supplemental lighting for the propagation of roses in greenhouses. We compared five different lighting treatments (sun only, 82 µmol/m2/s of supplemental lighting for 14-hr/day, and adaptive lighting with thresholds of 50, 150, and 250 µmol/m2/s). In the adaptive lighting treatments, the LED lights were controlled to provide just enough supplemental light to prevent the light level at the canopy from dropping below the thresholds. The 50 µmol/m2/s adaptive lighting treatment resulted in similar root and shoot growth of rose cuttings as sun light only (because it provided little supplemental light). The 150 µmol/m2/s adaptive lighting treatment increased root growth about 25% more than 14-hr/day of supplemental light, but with similar energy use. The 250 µmol/m2/s adaptive lighting treatment used almost twice as much energy as 14 hr/day of supplemental lighting, but increased root weight three times as much. Adaptive lighting with 150 or 250 µmol/m2/s thresholds increased root growth with 25-50% greater energy efficiency that standard supplemental lighting.

The University of Georgia development of an efficient method for screening of sorghum phosphorus efficiency and evaluation of root morphology and architecture under controlled P-concentration. A phenotype screening and selection method for tolerance to low-phosphorus stress conditions was developed at the Georgia Envirotron. Methodology that uses P-loaded alumina as a phosphorus buffer in quartz sand culture (Coltman et al., 1982) was modified to perform efficient, economical, high throughput sorghum screening for P-efficiency under controlled nutrition conditions. The solid-phase sand-alumina culture system provided stable, diffusion-limited, slow-release conditions with varying P availability to plants. This technique provided better media conditions control and reproducibility compared to a complex soil systems and, at the same time, better mimicked natural conditions compared to hydroponic cultures. Sorghum was selected due to its wide range adaptability to abiotic stress (such as drought and barren soil). Significant genetic variation in tolerance to abiotic stress exists in sorghum germplasm and cultivars. Simulated incremental plant responses to the six different P concentrations comparable to those found in soil proved the effectiveness of the technique and allowed to select low-P and close to optimal-P phosphorus concentrations of 3-5µM and 40-50µM PO_4^{3-} respectively. The sand-alumina culture medium was used to screen 6 sorghum varieties including those presumably efficient at low-phosphorus stress conditions. Sand-alumina medium revealed promising abilities for studying root development and architecture. It allows to apply nondestructive *in situ* electrical capacitance tomography (ETC) method for monitoring root development with greater accuracy due to media and plants consistency. The developed media also allows limited disturbance during root separation from the medium, preserving the intact root system architecture and allowing 3D imaging and subsequent root architecture analysis. This method demonstrated a good example for screening sorghum and other plant species growing in soils with low-P availability. The identified materials may be used in plant breeding programs for development of cultivars with high phosphorus use efficiency.

KSC continue to grow, propagate, and pollinate genetically engineered plum (*Prunus domestica)* trees with overexpressed FT1 flowering gene (developed by the ARS at Kearneysville, WV). The plants do not have any cold-period dormancy requirements for flowering, which is an advantage as a potential space crop. We have been able to grow fruit from the several of the lines, but have been fighting thrips in these studies, which is new challenge for our growth chamber testing. Larry Koss has built several load cell platforms to track weight changes associated with watering event and transpiration. Although still to be fully investigated, early testing of plant response to different light spectra has shown an enhancement in photosynthesis in response to UVA in some species. The addition of UVA light to CEA production of quinoa seedlings improved field transplant success and yield at harvest.

Preliminary screening of Chinese cabbage (*Brassica rapa* cv.Tokyo Bekana) in growth chambers at KSC using peat/arcillite media incorporating controlled-release fertilizer with capillary-wicking irrigation, cool-white fluorescent lighting at a PPFD of 400 µmolm^{-2}s^{-1} and 400 µmolmol^{-1} CO_2 indicated that cultivar to be particularly productive and a top candidate for growth in the 'Veggie' plant-growth unit on the International Space Station (ISS) for astronaut pick & eat activity. However, when grown at Purdue in Veggie analogues in controlled environment conditions on the ground mimicking ISS environmental conditions (except for microgravity), growth impairment and multiple symptoms of stress occurred, which have not been observed for other salad species (viz. lettuce, radish) on the ground or on ISS.

Old technique with new application: Normalized difference vegetation index (NDVI) measurements were found to be correlated with supplemental light-use efficiency of plants. Petunia plants were exposed to drought stress to purposefully lower light use efficiency by lowering photosynthesis. Under drought stress, plants reflected relatively more incident red light from supplemental lighting as measured by a lower NDVI value. In addition, NDVI measurements were found to be more useful under artificial lighting than under sunlight conditions.

Crop growth rate of several bedding plant seedlings, lettuce and tomato were non-invasively measured using top view image station. The image station fluorescence signal from the canopy as a mask to detect plant edges in the image and automatically calculates pixel area, which was further highly correlated to total leaf area and shoot dry weight. This technique offers a rapid way to detect plant responses to environment using imaging technique.

We are currently testing the use of canopy reflectance to estimate crop N status. Our preliminary results are very promising and suggest a potential use of calculating relative greenness index (intensity of green pixels in the image) and relative reflectance of red waveband to NIR waveband in estimating canopy N status. We use MultiSpec software to convert images to grayscale and calculate intensity of pixels in the image after exposure to a particular wavelength of light in the TopView Image Station. Our goal is to develop Smartphone based Apps to measure canopy N status in greenhouse plants.

We are currently using image-based approach to measure daily crop growth rate and required nutrient solution concentration for hydroponic lettuce. This approach seems promising as we adjust fertilizer EC based on N demand of the crop and not on a target level. Our preliminary results indicate that higher lettuce biomass can be produced by adjusting nutrient solution concentration based on crop growth rate compared to maintain a target EC. This approach has potential use in plant factories where it is difficult to manually monitor plants. Cameras have potential use in these production systems.

Joshua Craver, a Ph.D. student working with Dr. Nemali (graduate committee member) and Drs. Lopez and Mitchell (co-advisors), identified that higher fraction of blue light (50:50) in the spectrum increases photosynthesis rate of plants by increasing light saturation point, electron transport rate and mesophyll conductance in plants. Josh measured A-PPF and A-Ci curves on petunia seedlings grown under 90:10 (red: blue) or 50:50 (red: blue) light treatments using LED lights in a growth chamber. His research shows that total leaf area and biomass are higher under higher red light treatment as these plants preferentially allocated more biomass to leaf growth and thereby, intercepted more light than 50:50 (red:blue) treatment. This result emphasizing the importance of total light interception, and not the rate of photosynthesis *per se*, on dry matter accumulation and plant growth. An interesting finding in his research was that plants grown under 50:50 (red:blue) treatment showed preferential biomass partitioning to the root system, and may have potential benefit for stress tolerance. Moreover, plants in this treatment were found to be compact, a trait that is appealing to customers.

Fluence performs internal research and collaborates with partners from academia and the controlled environment agriculture (CEA) industry. The focus of our research is to determine the influence of light intensity and spectral light quality on the growth, development, and phytochemical concentration of multiple plant species. We have found the following unique plant responses this past year: Increased biomass accumulation when leafy greens were grown under broad spectrum LEDs as compared to narrow band (Red:Blue) LEDs in sole-source lighting environments; Phytochrome photoequilibrium (PPE) influenced flowering of long-day and short-day bedding plant species; Light intensity influenced anthocyanin accumulation and plant morphology of microgreens.

3. Accomplishment Summary

- Rutgers University continues to evaluate a variety of lamps for light output, light distribution and power consumption using our 2-meter integrating sphere and a small dark room. A variety of outreach presentations on high tunnel construction, greenhouse lighting, energy consumption, and electrical safety have been delivered at local and out-of-state venues. A $50K travel grant was secured from the USDA to help support travel expenses of NCERA-101 members who attended the 5th International Controlled Environment Meeting (AusPheno) in September 2016 in Australia.
- Erik Runkle and Roberto Lopez at MSU organized and convened the ISHS 8th International Symposium on Light in Horticulture (http://www.lightsym16.com) in East Lansing, MI from May 22 to 26, 2016. There were 250 participants from 25 countries, 52 oral and 78 poster presentations, and 26 sponsors from leading lighting, growth chamber, and horticultural companies. The proceedings was peer-reviewed and published as Acta Horticulturae volume 1134 and contains 56 articles (http://www.actahort.org/books/1134).
- MSU Ph.D. student Yujin Park and Erik Runkle evaluated the influence of including far-red radiation in sole-source lighting on ornamental seedling growth and subsequent flowering under different intensities of blue radiation and total photosynthetic photon flux. In general, inclusion of far-red radiation increased stem elongation, leaf expansion, and biomass accumulation and in some species, also promoted subsequent flowering. A moderately high intensity of blue radiation attenuated the effects of FR radiation on stem elongation but minimally influenced flowering.
- MSU Ph.D. student Qingwu (William) Meng and Erik Runkle assessed the usefulness of far-red radiation for indoor seedling production of leafy greens and herbs. When far-red light was added to red and blue light, it promoted leaf expansion and biomass accumulation but reduced leaf pigmentation.
- MSU M.S. student Mengzi Zhang and Erik Runkle investigated responses of two cultivars of potted poinsettia grown in a greenhouse under different end-of-day lighting treatments. Generally, end-of-day lighting promoted extension growth of poinsettia and low-intensity far red radiation was less effective at inhibiting flowering than red+far red lighting.
- MSU Ph.D. student Kellie Walters and Roberto Lopez evaluated the impact of carrier water alkalinity and air temperature at application on the efficacy of plant growth regulator ethephon sprays. High carrier water alkalinity ($> 150\ mg \cdot L^{-1}$) and/or high air temperatures (>23 ºC) reduced chemical efficacy.
- MSU M.S. student Allison Hurt and Roberto Lopez assessed plug quality of ornamental seedlings propagated under supplemental and photoperiodic lighting providing varying light intensities and qualities. Root dry mass increased and stem extension decreased under supplemental lighting from either HPS or LEDs than under photoperiodic lighting with or without far red radiation.
- MSU M.S. student QiuXia Chen and Ryan Warner utilized a genetic mapping population in *Petunia* to identify chromosomal regions (QTL) that control important plant quality traits including development rate, branch number, flower production, flower size and internode length. Additionally, the influence of temperature on these traits was evaluated and used to understand potential genotype by environment interactions underlying the control of these traits.
- The University of Georgia has developed a control system for LED lights that automatically determine the optimal light level for different crops, based on user-provided input. Once the

optimal light level has been determined, the system can then maintain that light level for a user-specified amount of time or until a user-specified total daily amount of electron transport has been achieved.

- The University of Georgia has shown that ‘adaptive’ control of supplemental lighting results in more energy-efficient stimulation of root growth of cuttings than standard supplemental lighting. Adaptive lights provide just enough supplemental light to reach user-specified threshold. Because of that, they provide most of the supplemental light when there is little sun light and plants can use the supplemental light most efficiently. This technology has the potential to provide great cost savings to propagators.
- The University of Georgia developed a novel screening technique to select for genotypes with high P-efficiency and to quantify root architectural and morphological responses to P availability. The method uses quartz sand and P-loaded alumina and is well suited for phenotyping and breeding for high P-efficiency.
- Gioia Massa continued to oversee the “validation” testing with Veggie plant growth systems on the International Space Station (ISS), which included a third trial with red romaine lettuce, and the first test with Chinese cabbage. Gioia has a 3-yr NASA grant to conduct the first official plant testing with Veggie (with leafy greens and dwarf tomato in 2018). Ray Wheeler and Mary Hummerick at KSC, Bob Morrow at ORBITEC, and Cary Mitchell at Purdue are Co-Is on the grant along with other Co-Is from Johnson Space Center focusing on food and behavioral health. Matt Romeyn in our group leads this research at KSC and continues to run ground studies as we prepare for flight. In particular, we are testing a different water delivery systems called PONDS, which holds a container of solid growth media (e.g., arcillite) that is surrounded by a small reservoir of water. Air permeable patches on the sides of the reservoir allow O_2 to diffuse into the water. But we need to test the system on parabolic air flights to observe behavior of the water in freefall.
- KSC completed a series of tests using mini-bioreactors to recover soluble nutrients from dried, inedible plant biomass. These tests did not show much improvement on recovery of soluble nutrients compared to previous tests with continuously stirred-tank bioreactors (CSTRs), but dropping the pH of the solution (adding acid) improved recovery of elements like Ca, P, and Mg. As part of this study, we did some calculations that estimate about 90 kg / yr of fertilizer would be required to grow enough food for one person, and would be interested in anyone else’s data or publications on fertilizer needs to sustain certain levels of productivity in CEA systems.
- Matt Mickens completed his first growth comparison of lettuce under white LEDs supplemented with various narrow-band LEDs of red (635 nm), blue (460 nm), green (525 nm), and far red (745 nm). The white LED control treatment had a ~2800 K color temp. A sixth treatment utilized a Heliospectra light fixture with LEDs at 425, 525, 660, and 733 nm. Using a PPF of about ~200 µmol m^{-2} s^{-1} with an 18-h photoperiod, we saw the best overall growth for lettuce with the Heliospectra LEDs and the White plus far red. After a chamber relocation, we encountered some problems of very aggressive algal (maybe cyanobacteria) growth on the soil surface of pots and in standing water in trays during a follow-up study. Seedlings in that study were severely stunted?! Has anyone else every seen this when a lot of algae growth occurs? We cleaned the humidifiers and heat exchange coils in the chamber to reduce possible sources of the algae.
- Kacira lab designed and help implementing a vertical air flow and distribution system work in with industrial collaborator, to be used in a multi-tier vertical farm system for transplant

production, with improved climate uniformity and providing desired air current speeds for the production.

- Kacira Lab enhanced design of the multi-wavelength based optical density sensors to serve as in-situ sensor unit, for algae biomass growth and health monitoring in real-time. A neural-networks based predictive model was developed aiming to timely indicate anomaly in growth and health of algae and help making corrective actions to prevent algae crushing or saving the biomass by harvesting.
- UA CEAC organized the 16th Greenhouse Crop Production and Engineering Design Short Course (April 3-7, 2017) with 100 participants. 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.
- Online non-credit professional course 'Greenhouse Plant Physiology and Technology' was offered in October - December, 2016 (9 weeks, 29 enrollment).
- One-day private strawberry training was offered to 4 individuals during the 2016/2017 season.
- One-day private custom training was offered to 9 individuals during the 2016/2017 season
- Organized and hosted National Greenhouse Manufacturers Association (NGMA) Annual Meeting tour at UA-CEAC which included professional interaction and introduction of all CEA students with the 50 companies represented. April 11th, Tucson, AZ
- The Cuello Biosystems Engineering Laboratory successfully tested the hydrodynamic characteristics and algae biomass production in the Accordion Air-Loop Bioreactor, the third in the series of the Lab's patented Accordion Photobioreactors
- Cuello and the Association for Vertical Farming (AVF) have agreed to launch the Vertical Farming Global Sustainability Registry Network (or Vertical Farming SURE Network), whose aims include (1) to enable Vertical Farming companies and institutions to voluntarily self-report their own yearly Vertical Farming sustainability achievements; (2) to provide each participating Vertical Farming company or institution due recognition for its annual effort in helping the Vertical Farming industry collectively reach its significant sustainability potential and goals; (3) to provide each participating Vertical Farming company or institution due recognition for its effort in furthering or fulfilling its corporate social responsibility (CSR) in advancing environmental, economic and social sustainability; (4) to record, monitor, analyze and publish development trends in sustainability-based productivities among various types of Vertical Farms that make up the global Vertical Farming industry; and, (5) to provide annual guides and recommendations for the various types of Vertical Farms in the industry to help further advance their sustainability-based productivities. The Vertical Farming SURE Network is scheduled for formal launching later this year.
- Several different cultural and/or environmental stressors seem to be present in the ISS-mimicked growth-chamber environment that may have contributed to growth inhibition and chlorosis/necrosis of Chinese cabbage 'Tokyo Bekana'. Systematic research to eliminate them one by one failed to alleviate all stress symptoms. Incremental improvements typically were seen as stress candidates were varied. Chronically high CO_2 mimicking what is present on the ISS has emerged as a major candidate stressor, but LED spectral composition, polymer-coated fertilizer ratios and dose, and even the arcillite growth medium *per se* all loom as potential contributors to the growth reduction of this sensitive Chinese cabbage cultivar seen under ISS-normal environments and Veggie growth conditions at 1 x g.

- NCSU Phytotron staff has completed an Energy Conservation project renovating the facility/growth chamber/greenhouse cooling system, facility electrical system and growth chambers. We have also added a full-service Plant Transformation Laboratory (PTL) to our facility on the third floor. The PTL was constructed using 2 lab spaces: one that was formerly used as a Plant Pathology lab & the other was a Phytotron staff research lab. We relocated the Phytotron research lab by renovating a room used for miscellaneous incubators. A new incubator room was constructed on the first floor using part of the newly renovated mechanical room to create the extra space.
- SNC/ORBITEC will continue 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).
- SNC/ORBITEC continues to work with the Kennedy Space Center (KSC) to support the Veggie plant-growth system hardware that is on-board the ISS. A second Veggie unit should be transported to the ISS later this year.
- SNC/ORBITEC also continues to support KSC in the development of the Plant Habitat system for plant research aboard the International Space Station. When flown, this system will be the largest plant growth system put in space to date. It should fly this year (2017). Delivery of Plant Habitat flight components was made to KSC for transport to the ISS on Orbital Sciences and SpaceX spacecraft.
- SNC/ORBITEC is completing development of a Zero-G Mass Measurement Device (ZGMMD) that will launch to ISS this year. The ZGMMD will provide for mass measurement of rodents on the ISS, but can also measure the mass of other specimens such as plant tissues.
- SNC/ORBITEC continues to work with Commercial Crew Integration Capabilities partners for development of human Life Support and Thermal Control systems.
- Shenandoah Growers, the largest retail grower of organic herbs in the United States, recently deployed thousands of Fluence LED systems in its state-of-the-art vertical farm and greenhouse facilities. With the new Fluence lighting systems, Shenandoah Growers boosted crop yield and quality while reducing land, water and fertilizer resources.
- AeroFarms have a patented, reusable cloth medium for seeding, germinating, growing, and harvesting. Our growing cloth medium is made out of BPA-free, post-consumer recycled plastic, each taking 350 (16.9 oz.) water bottles out of the waste stream. This is but one example of how we are progressing in sustainability. The cloth can be fully sanitized after harvest and reseeded with no risk of contamination. Acting as a barrier between the mist and the plants, the cloth allows us to harvest a clean, dry and ready to eat product.
- AeroFarms facility at on Rome St. in Newark, NJ is producing and selling crops locally. The reception in the stores has been overwhelming. The scaling of our technology is represented by grow towers that are twelve levels high making us 130 times more productive than outdoor agriculture. More facilities are in the works.
- 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. This greenhouse heating research has resulted 2 patent applications on the removal of particulate matter from flue gas. Test of this system has has shown that up to 97% of all soot produced can be removed using this system and when in its default (failure mode) over 70% of the soot can be removed. The system combines an electrostatic chamber and a cyclone section that allow for extended operation of the traditional air filter. This design allows for

the soot free exhaust gas to then be treated in the catalytic system and used to heat and provide CO_2 for improved production in the greenhouse. Stability of the system has been very good with up to 7 days of continuous operation possible with longer term testing required. We are continuing this research and are entering into an option agreement with an industry partner to build a commercial unit.

- Macdonald Campus of McGill University 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 we have begun to add in amber LEDs to the red and blue mixture with improved production of lettuce plants. We are expanding this research to include Arabidopsis and tomato plants and are hopeful have published results in the coming year.
- Macdonald Campus of McGill University have continued to a tropical greenhouse design called the NVAC, with test units build at campus, inside a greenhouse and at Barbados. The data collected from the NVAC in a greenhouse has been used to quantify air movement and temperature control of the system and determine operation ranges. The combined data from these 3 systems are being combined and published results are expected in the next year.
- Macdonald Campus of McGill University is continuing the design of a northern greenhouse is continuing with further testing and improvements required. We have successfully grown a crop of lettuce and had fruit set on tomato plants inside the unit. We have recently submitted a LOI to create a northern food security network and are hopeful on its success to allow the project to move forward.

4. Impact Statement

Nationwide, Extension 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 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%.

Far-red radiation can improve both plant shoot and root growth in vertical farms. A moderate addition of far red promoted red leaf lettuce yield by 17% to 48% and increased basil root growth by 18% to 26%. Faster growth rates with far-red radiation can reduce production time, potentially increasing the harvestable yield and thus, grower profitability. Growers can also use far red to customize crop appearance, such as shape and color, based on consumer and market preferences.

Plant height of poinsettia can be increased by adding red and/or far-red radiation at the end of the day. This technique can potentially substitute for chemical treatments to increase plant height. It can also help growers meet specific height targets at flowering and thus, increase the quality and marketability of potted poinsettia.

Including far-red radiation in sole-source lighting of ornamental seedlings increased biomass and leaf area, and in some crops, accelerated flowering (by 7-12 days). Results will better inform growers about the merits of far-red radiation, and interactions with blue radiation, when plants are grown under sole-source lighting.

Improving ethephon spray efficacy can improve the control of flowering, branching, and plant growth for greenhouse growers. However, ethephon spray efficacy is significantly reduced by both high air temperatures at application and high carrier water alkalinity, which can cause the final spray solution pH to be higher than recommended. With increased efficacy comes the potential for lower chemical inputs and higher quality plants.

Increased leaf area and internode elongation under photoperiodic lighting providing red+white+far-red light can give growers the perception that seedlings production time is reduced. However, seedlings under photoperiodic lighting or ambient light can be delayed by one and two weeks, respectively, compared to those produced under supplemental lighting.

Molecular markers useful for breeding new petunia cultivars with improved traits were identified. Specifically, markers that could help develop cultivars with reduced production time sensitivity to temperature, improved branching habit, and greater floral production were developed.

Electricity costs for supplemental lighting can be a major cost for greenhouses. The adaptive lighting system, developed in the Horticultural Physiology Lab at the University of Georgia, can greatly reduce energy use by automatically dimming the lights in response to increasing sun light. This results in more energy-efficient stimulation of growth: for rose cuttings, adaptive lighting promotes root growth 100 to 150% more efficiently than standard supplemental lighting. The Veggie vegetable production system has been operating on the International Space Station (ISS) for more than 2 years. The passive, capillary based watering systems is still causing some issues (insufficient or excess water). A third crop of red romaine lettuce and a first crop of Chinese cabbage plants were grown and the astronauts were allowed to eat the leaves.

Thanks to many hard working colleagues at KSC, ORBITEC, and numerous universities, the plant controlled environment and CEA community have successfully extended their reach to the International Space Station with the Veggie plant growth unit. A second Veggie unit is also being sent to ISS to double the capability and allow for greater experimental flexibility. NASA and ORBITEC have built an even larger (0.2 m^2), more highly controlled plant research chamber with over 180 sensors called the Advanced Plant Habitat, or APH, which will be launched in the next few months. The APH is going to be the largest plant growth chamber ever flown and will be utilized to understand plant growth in space that will help us here on Earth and as we move forward to Mars and beyond.

The Controlled Environment Agriculture lab at Purdue University is developing sensors to remotely measure crop growth, plant N status, and crop light use in greenhouses. Our approach is to conduct the discovery work using state-of-the art equipment and use the generated algorithms and techniques to develop affordable and robust technologies (ex: Smartphone Apps with embedded software for analysis) that can be broadly disseminated to industry and research professionals. We have established algorithms to non-invasively measure crop growth rate (based on shoot dry weight) and leaf area using imaging technique. We obtained promising results to develop remote sensing techniques for crop N and light use efficiency measurements.

The NCSU Phytotron by growth chamber usage for all growth chambers in 2016 was 91% of the recommended optimal occupancy, or 73% of maximal occupancy (Table 1). For 2016, total A-chamber (2.4 m width x 3.7 m depth x 2.1 m height) usage was 82% maximal occupancy. Usage of B-chambers (2.4 m width x 1.2 m depth x 2.1 m height) was at 82% and C-chambers (1.2 m width x 0.9 m depth x 1.2 m height), 69% for the year. Lower usage of C-chamber was due to on going renovations of the chambers. Fifty-seven different projects were conducted in the Phytotron during 2016 by faculty and students from 11 departments (Table 2). The Crop Science Department used the largest amount of space in 2016 (more than 23%, for 12 different projects). The Plant Pathology Department used 9.1% of the space for 7 projects, Plant and Microbial Biology used 8.8% of the space for 8 projects, and Horticultural Science used over 5% for 6 projects. During 2016, 37% of the growth space in the Phytotron was used to grow soybeans (Table 3). Research with other agronomic crops included cotton (9%), tobacco, (3.6%) and corn (5%). Research on Arabidopsis used 7% of growth space, ornamentals, 6%, turfgrass, 4.5% and the 'Demonstration' category (1%) included space for plants grown for display during tours of the facility.

Chinese cabbage cv. Tokyo Bekana appears to be a very sensitive indicator species of environmental stress that unexpectedly reacted negatively to multiple ISS-normal stressors, possibly in a synergistic way. Because the few other salad species that have been grown in space have not reacted negatively to the ISS cabin environment, 'Tokyo Bekana' may be a valuable indicator species for plant-growth stressors in space, known or unknown, compared to Earth-normal growth conditions in which it has been shown to thrive.

SNC/ORBITEC 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 protected agriculture systems.

SNC/ORBITEC is developing 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/ORBITEC will continue to develop environmental control technologies for space based biological and physical-chemical life support systems, technologies that may have applications for terrestrial environmental control systems.

SNC/ORBITEC is using 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.

Fluence Bioengineering LED-based lighting systems are designed to provide high levels of photosynthetically active radiation (PAR) ideal for commercial cultivation and research applications. From sole-source lighting to supplemental greenhouse lighting, we custom tailor our light spectrum and form-factors to optimize plant growth and increase yields while consuming less energy and reducing operating costs versus legacy technologies.

AeroFarms is the commercial leader in indoor farming. We grow without sun or soil in a fully-controlled indoor environment. We have optimized our patented aeroponic growing system for faster harvest cycles, predictable results, superior food safety and less environmental impact. A significant development has been technology that allows our plant scientists to monitor more than 130,000 data points every harvest. With over 20 harvests per year, learning is rapid and revision is on target. The plant scientists are constantly reviewing, testing and improving our growing system using predictive analytics to create a superior and consistent result. With remote monitoring and controls in place, we have minimized the typical risks associated with traditional agriculture.

The biomass heating group at McGill University has identified methods to utilize both the heat and carbon dioxide that result from the combustion process. This research has developed a method to remove the soot from the exhaust gas streams. A patent has been filed that describes a system to remove the soot and allow for a cleaner exhaust gas before conversion and removal of the noxious gases with the catalytic conversion system. Testing of the unit is ongoing and have signed an option agreement with an industry partner.

Light emitting diodes are slowly replacing all supplemental lighting systems in greenhouses, growth chambers and urban agricultural systems. Our research has been to determine the optimum wavelength of light for plant production and we have begun to alter light composition by adding amber wavelengths to the red and blue LEDs with improved production of the lettuce.

5. Published Written Works

In addition to the efforts described above, the NCERA 101 group reported 72 publications. The publication list below is compiled from the NCERA-101 station reports, and does not include publications 2017 Annual Report NCERA-101 Controlled Environment Technology and Use from members not submitting reports. In addition to the publications listed here, the NCERA-101 members reported numerous presentations at scientific and non-peer reviewed publications.

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