AFRI Foundation Program

Controlled Environment Indoor and Vertical Food Production Coordinated Research Conference

Program Priority A1102, “Foundational Knowledge of Agricultural Production Systems”

A Conference to Plan an Interdisciplinary Controlled Environment Indoor Agriculture R&D Roadmap and Coordinated Research Plan

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Executive Summary

The University of Arizona hosted the two-day Arizona CEA Conference sponsored by the U.S. Department of Agriculture that took place at the Biosphere 2 in Tucson, Arizona on September 9-11, 2019. A diverse group of stakeholders from industry, academia, and government sectors gathered to engage with the critical issues, both current and future, facing vertical and indoor food production systems. Discussions revolved around seven major thematic areas, established from the preceding workshop “Research and Development Potentials in Indoor Agriculture and Sustainable Urban Ecosystems” co-hosted by the USDA and U.S. Department of Energy (DOE) in June 2018: The themes were: **Economics, Production Systems, Engineering, Plant Breeding, Food Nutrition and Safety, Industrial Ecology in Closed Systems, and Pest Disease and Management.**

Summary Outcomes

There were two major outcomes from this conference, and one unexpected one:

- **(1)** Conference organizers prepared a final workshop report (this document) as well as a Summary Report) synthesizing outcomes from presentations and discussions at the conference for the CEA indoor food production industry in North America.The report is an integrated, cross-disciplinary, systems-based approach that integrates stakeholder needs and feedback to address challenges and to identify opportunities to grow the CEA Indoor food production industry sustainably and expand the U.S. agricultural economy.
- **(2)** A coordinated agricultural project (CAP) grant proposal addressing the thematic areas discussed in the CEA conference (not funded) was also prepared. This proposal was authored by conference organizers in collaboration with conference participants, with preparations for the submission begun during the final day of the conference.
- Seven topic areas, each with 'Challenges' and 'Opportunities' were the focus of Conference study. They represent the fundamental concepts for successful CEA operations, and are documented here and in the Summary Report
- (**unexpected)** A working group focused on the development of a comprehensive framework for best practices in design and operation for CEA enterprises was formed by conference participants: the Controlled Environment Agriculture Design Standards (CEADS). The CEADS project has since matured, officially incorporating in February 2021 and distributing the debut CEADS publication for external review in February 2021. The organization anticipates public release of CEADS v1.0 in later spring of 2021. More details on the CEADS project can be found in Appendix A-4.

Major Players in the Grant Project

Key Personnel Role

PD/Co-PD: Gene Giacomelli, PD, University of Arizona

Murat Kacira, Co-PD, University of Arizona

Joaquin Ruiz, Co-PD, Biosphere 2, University of Arizona

Key Collaborators:

Kai-Shu Ling, USDA-ARS

Sarah Federman, OSEC, Washington, DC

Steve Newman, Colorado State University

John Adams, Biosphere 2, University of Arizona

Kevin Bonine, Biosphere 2, University of Arizona

Participants and their institutional affiliations

Dr. Gene Giacomelli, University of Arizona, PD

- Dr. Murat Kacira, University of Arizona, Co-PD
- Dr. Joaquin Ruiz, Biosphere 2, University of Arizona, Co-PD
- Dr. Kai Ling, USDA-ARS, Charleston**, Key Collaborator**
- Dr. Steven Newman, Colorado State University, **Key Collaborator**
- Dr. Sarah Federman, USDA-OSEC, **Key Collaborator**
- Dr. Kevin Bonine, Biosphere 2, University of Arizona, **Key Collaborator**

- John Adams, Biosphere 2, University of Arizona, **Key Collaborator**

The following have agreed to be **Collaborators**:

- Dr. Joseph Munyaneza, USDA-ARS Beltsville
- Dr. Paul Zankowski, USDA-OSEC
- Dr. Kim Lewers, USDA-ARS Beltsville
- Dr. Alvin M. Simmons, USDA-ARS, Charleston
- Dr. John Stommel, USDA-ARS, Beltsville
- Dr. Matthew A. Cutulle, Clemson University
- Dr. Pat Wechter, USDA-ARS, Charleston
- Dr. Jinhe Bai, USDA-ARS, Fort Pierce
- Dr. Wojciech J. Janisiewicz, USDA-ARS, Kearneysville

A complete listing of conference attendees can be found in Appendix 2.

There were 41 non-profit, private industry, academic and stakeholder group members involved in meeting coordination and planning. They are listed in Appendix A-5.

FINAL REPORT

I. Scientific Background

In general, controlled environments for crop production include any closed or semi-closed structure (greenhouse, vertical farm in a reclaimed building, semi-portable container, etc) that provides the required crop growth conditions for successful plant or plant product production. These structures allow for successful production by means of climate control of the aerial environment and root zone environment, and may fully (Vertical Farm, container) or partially (greenhouse) replace the use of the solar radiation from the sun for plant growth and development. This report will use the following terms to describe this diverse set of systems used for crop production in controlled environments:

- *Controlled Environment Agriculture* (CEA) is the traditional name for growing within a structure, normally associated with a greenhouse.
- *Indoor Agriculture* (IA) is the current popular name for growing within a fully enclosed structure, requiring electrical lighting.
- *Urban Agriculture* (UA) is the application of CEA or Indoor Agriculture within the urban or peri-urban areas of highly populated locations.
- *Vertical Farm* (VF) is a fully enclosed structure, requiring electrical lighting, containing multiple layers for crop production.
- *Greenhouse* (GH) is a semi-closed structure primarily utilizing the sun for plant growth with the potential use of supplemental electrical lighting, with all production within one horizontal layer.

Much of the discussion that took place at the Az CEA Conference centered on applying the concept of *sustainability* to indoor and vertical food production systems. Recognizing the multi-faceted nature of these systems, and the diverse group of stakeholders involved in the CEA field, the sustainability and long-term viability of VF and IA systems in the agricultural industry is hinged on the concurrent economic, environmental, and social performance of these facilities.

II. Meeting Structure

The two-day conference was structured around seven thematic areas: *Economics*, *Production Systems*, *Engineering*, *Plant Breeding*, *Food Nutrition and Safety*, *Industrial Ecology in Closed Systems*, and *Pest Disease and Management*. These thematic areas were selected as most important based on our current understanding of the greenhouse as a complex system of both internal and external processes which combine to establish the components of the greenhouse system, to influence the efficacy of its operations, and ultimately to establish its level of sustainability. These topics were established from the preceding workshop "Research and Development Potentials in Indoor Agriculture and Sustainable Urban Ecosystems" in Washington D.C. co-hosted by the U.S. Department of Agriculture and U.S. Department of Energy in June 2018.

III. Thematic Topics

Economics focused on ways in which indoor crop production can be increased within urban areas to become an industry leader of the global agricultural market. People are increasingly looking towards controlled environment systems for ways that agriculture can be made more environmentally and socially sustainable while also addressing increased consumer demands for fresh, local, and high-quality produce. Despite this, there are many economic questions that need to be addressed regarding the scalability and long-term sustainability of these systems. Discussions within this thematic area focused on the following topics: (1) identification of the metrics of success in CEA systems from both an industry and community perspective; (2) the development of a pipeline to quantify environmental and social benefits of CEA in a Benefit-Cost Analysis framework; and (3) the scalability of CEA and IA systems. Additional points of consideration included the need to increase the productivity of CEA systems, promote rural prosperity, and maintain environmental health.

Production Systems focused on ways in which CEA production system processes can be enhanced through effective utilization of hand labor and automation as well as how innovative technological solutions can solve industry related challenges. CEA production systems range from basic high tunnel systems to fully insulated indoor operations that can produce crops on multiple levels; each type of production system has differing needs to be fulfilled to allow for maximum optimization of production. Discussions within this thematic area focused on the following topics: (1) the improvement of plant architecture to enhance crop productivity and reduce waste; (2) the improvement of logistics and enhancement of labor efficiency; and (3) the management of crops with integrated environmental controls, nutrient delivery, and automation. Additional topics of consideration included how CEA professional certifications can benefit the industry as well as ways that the industry can become more financially successful.

Engineering focused on ways in which robotics and automated systems can be integrated within CEA facilities to improve overall production. CEA facilities utilize technical expertise and extensive knowledge of both engineering and horticulture to allow for efficient year-round production of quality crops within a range of climates. Discussions within this thematic area focused on the following topics: (1) strategies to increase lighting efficacy and light use efficiency while reducing costs; and (2) the integration of innovative automated and robotic systems that minimize the need for labor inputs; and (3) the improvement of water use efficiency and cycling in growing systems within CEA facilities. Additional points of consideration included lighting system options, resource use optimization, wastewater management practices, and carbon dioxide regulations.

Plant Breeding focused on ways in which yield, transportability, and pest resistance can be increased within crop cultivars through effective breeding practices. CEA production can limit crop damage caused by pests and allow for shorter transportation distances; these potential benefits provide breeding programs with the opportunity to prioritize other traits that will benefit consumers as well as the production system overall. Discussions within this thematic area focused on the following topics: (1) the identification of plant traits that should be privileged in breeding programs for indoor farming; (2) the consideration of how CEA production systems can alter the structure of microbial communities associated with plants and growing media; and (3) the identification of a set of factors that make a crop a good candidate for indoor farming.

Additional points of consideration included the optimization of supplemental lighting, temperature, and nutrient conditions for specific plant breeds.

Food Nutrition and Safety focused on ways in which controlled environment facilities can utilize effective food safety protocols and increase the nutritional quality of crops. Both consumers and the agricultural industry are placing an intensified emphasis on the importance of food safety, transparency, and post-harvest practices to deliver a crop that consumers can trust. Additionally, the industry is continuously working to research and identify methods that can be utilized to improve the nutritional content, quality, and flavor of produce grown within controlled environment facilities. Discussions within this thematic area focused on the following topics: (1) the ways in which indoor growing conditions alter the microbial communities of plants and impact product quality and shelf life; and (2) the impacts of altered growing media and environmental conditions on food quality, flavor, and nutritional content of the crop. Additional points of consideration included the relationship between aromatics, flavor, and nutritional properties of CEA crops and ways that food safety protocols can be standardized.

Industrial Ecology in Closed Systems focused on how production system processes can become more environmentally conscious in terms of facility management and disposal practices. There are challenges in facilities' ability to balance necessary industrial processes with environmentally sustainable practices; to mitigate these challenges, industrial ecology seeks to develop processes that will reduce the amount of pollutants and material wastes generated. Discussions within this thematic area focused on the following topics: (1) how systems can be scaled and promoted such that products are economically accessible to all consumers; (2) how systems will function in urban and rural food sheds in terms of supply chain and job creation; and (3) the implications of systems for natural resource stewardship and climate. Additional points of consideration included proper facility disposal practices and utilization of efficient waste stream systems.

Pest and Disease Management focused on the importance of implementing effective and efficient management practices within controlled environment facilities. Although proper building designs and implementation of sterile protocols are important, they do not protect fully indoor growing systems from pests and diseases. Major outbreaks of pests or diseases pose a serious threat to controlled environment facilities and could prove to be detrimental to the business operation; it is therefore important to consider how risks can be minimized to the fullest extent possible. Discussions within this thematic area focused on the following topics: (1) identification of the major viral, fungal, and insect pathogens of CEA systems and best management practices that reduce reliance on chemical controls; and (2) the need for improvement of pest and disease management practices that do not harm beneficial insects and pollinators. Additional points of consideration included the importance of training personnel, implementing sterile protocols, and utilizing targeted pest management strategies.

Each of these thematic areas served as the topic of a keynote talk presented by **Invited Keynotes**, other complementary talks given by **Invited Speakers**, a **Panel Session** featuring a three-member panel with question/answer (Q&A) session, and a subsequent two-hour **Breakout Session**.

The **Invited Keynotes** were charged to offer an interdisciplinary discussion on the inter-related challenges of their topic in relation to other topics. As domain experts, they began the overview procedure for educating the audience with a 15-minute presentation to not only understand the importance of the topic within the controlled environment system, but also its relationship to the other topics. They were to bring focus to the influential factors of their topics to provide an overall appreciation of its complexity, then present a list of challenges that need consideration using clearly organized bullet points to enhance the following Q&As and discussions. Immediately following the keynote talk, the **Invited Speakers** provided a 10-minute presentation that attempted to bring focus to one or more critical aspects of the topic for subsequent discussions. Immediately following the invited speakers was a **Panel Session** featuring three panelists lasting for 30 minutes that was facilitated with questions prepared and proposed to the panel in advance for a Q&A interactive discussion with the entire audience and Invited Speakers. The invited keynotes, speakers, and panelists for each thematic area are described in Table 1.

Table 1. Az CEA Conference Invited Keynotes, Speakers, and Panelists for each of the 7 thematic areas covered at the meeting.

Thematic Area	Invited Keynote	Invited Speaker	Panelists
Economics	**Nate Storey** (Plenty Unlimited, Inc., CSO)	**Dr. Simone Valle de Souza** (Michigan State University, Assistant Professor)	1. **Jennifer Harris** (AmHydro, CEO) 2. **Robert Colangelo** (GreenSense Farms, CEO) 3. **Jim Pantaleo** (Indoor AgCon, Indoor Vertical Farm Operator)
Production Systems	**Dr. Steve Newman** (Colorado State University, Professor)	**Morgan Pattison** (Solid State Lighting Services, Inc., President)	1. **Dr. Neil Mattson** (Cornell University, Associate Professor) 2. **Dr. Celina Gomez** (University of Florida, Assistant Professor) 3. **Dr. James Atland** (USDA-ARS, Research Leader)
Engineering	**Dr. Murat Kacira** (University of Arizona, Professor)	**Erico Mattos** (GLASE, Executive Director)	1. **Ralph Fritsche** (NASA, Senior Project Manager) 2. **Fei “Jeff” Jia** (Heliospectra, Technical Solutions Manager)

			3. **Tharindu Weeraratne** (AutoGrow, Director of Crop Science and Agronomy)
Plant Breeding	**Dr. Gail Taylor** (University of California-Davis, Professor & Department Chair of Plant Sciences)	**John Reich** (The Foundation for Food and Agriculture Research, Scientific Program Director)	1. **Jennifer Boldt** (USDA-ARS, Research Horticulturist) 2. **Paul Gauthier** (Princeton University, Assistant Professor) 3. **John Stommel** (USDA-ARS, Research Leader)
Food Nutrition and Safety	**John Finley** (USDA-ARS, National Program Leader)	**Bai Jinhe** (University of the District of Columbia, Research Plant Pathologist)	1. **Penny McBride** (FarmTech Society, Vice Chair) 2. **David Bubenheim** (NASA, Senior Research Scientist)
Industrial Ecology of Closed Systems	**Mario Cambardella** (Atlanta City Government, Urban Agriculture Director)	**Sabine O’hara** (University of the District of Columbia, Professor)	1. **Corine Wilder** (Fluence Engineering, Vice President of Global Commercial Operations) 2. **Mark Lefsrud** (McGill University, Associate Professor) 3. **Weslynne Ashton** (Illinois Institute of Technology, Associate Professor)
Pest and Disease Management	**Kai-Shu Ling** (USDA-ARS, Research Plant Pathologist)	**Michael Bledsoe** (Village Farms, Vice President of Food Safety and	1. **Karin Tiftt** (Greenhouse Vegetable

		Regulatory Affairs)	Consultants LLC., Consultant for Integrated Pest and Disease Management) 2. **Joseph Munyaneza** (USDA-ARS, National Program Leader) 3. **Alvin Simmons** (USDA-ARS, Research Entomologist)

All attendees participated in at least one afternoon **Breakout Session** offering more comfortable round table-type conversation that included the Invited Keynotes, Invited Speakers, and Panelists for each breakout session topic. These sessions brought together 12-15 conference attendees for a detailed interpretation of the selected topic in which participants engaged in respectful and thoughtful dialogue surrounding common issues in controlled environments and indoor agriculture facilities. The participants in each Breakout Session are shown in Table 2. From each session, a **scribe or recorder** volunteer from the group of graduate students took 5 minutes to report to the entire reconvened conference at the end of each day on the key findings of their respective session (Appendix A-1). Approximately 80 active participants at the conference attended one of these Breakout Sessions. The sessions aimed to provide a consensus within each group of the influential factors, the specific problem statements that need to be resolved or understood, the potential research options/routes to realizing solutions, and the possibilities for synergy/collaborative efforts with other thematic groups.

The **Economics** Breakout Session was led by University of Arizona graduate students Bekah Waller, Robert Heintz, and Justin Chang. The participants identified the following challenges: (1) the relationship between capital expenditures and operational expenditures is going to change as automation increases; (2) the carbon costs associated with CEA; and (3) the energy, labor, and rent costs required for operation of CEA facilities.

These issues were discussed in detail, and the group formulated solutions and recommendations that can potentially be used by facilities to mitigate some of the extensive operational costs often associated with CEA. These recommendations included the following: (1) consider siting as a critical factor prior to constructing a CEA facility to mitigate energy costs; (2) consider the energy sources available within each state; (3) utilize nutrient water and condensate recycling; and (4) implement on-site water treatment facilities. Following the discussion of these challenges and proposed solutions, the group shifted focus to additional economic related issues and topics facing the CEA industry. These topics included the following: (1) quality issues around maintenance of live plants in grocery stores; (2) implementation of “state grown” programs; (3) conceptions of what consumers think about CEA produce; and (4) the impact of automation on CEA facilities.

The topics discussed in the Economics session **interacted with other Breakout Session themes** such as: (1) costs associated with automated technologies; (2) top costs associated with CEA facilities; and (3) renewable and efficient energy sources. The conversation regarding the relationship between capital and operational costs for CEA enterprises is tied to the development and application of automated technologies in CEA facilities, a theme that was discussed at length in the Production Systems and Engineering Breakout Sessions. Additionally, the conversation regarding the top costs for CEA facilities (i.e. labor and energy) ties in with the Industrial Ecology of Closed Systems Breakout Session discussion, which focused on the need to integrate renewable energy sources and more resource-use efficient systems into CEA facilities.

The **opportunities** identified for facilities to utilize in the future included: (1) implement on-site water treatment systems; (2) utilize nutrient water and condensate recycling; (3) consider siting as a critical factor prior to constructing a CEA facility to mitigate energy costs; and (4) consider the energy sources available within each state.

The **Production Systems** Breakout Session was led by University of Arizona doctoral student Ying Zhang. The participants identified the following challenges: (1) a need for more opportunities for collaboration and partnerships between players in the CEA industry; (2) a need for new tools for nutrient management; (3) a need to bridge the gap between industry and academia; and (4) determining whether LED lighting is the answer, or just a trend. These issues were discussed in detail, and the group formulated solutions and recommendations that can potentially aid in enhancing the efficiency and innovation of production systems. These recommendations included the following: (1) implement consistent testing processes with accurate result interpretations; (2) create events that facilitate interaction between industry and academia; (3) lobby for more ARS and other USDA funds and research; and (4) conduct more Environmental Manipulation Research for LED vs HPS lighting. Following this discussion of these challenges and proposed solutions, the group shifted focus to additional production system related issues and topics facing the CEA industry. These topics included the following: (1) CEA professional certifications; (2) central food standards as they relate to CEA; (3) developing a protocol to find what spectrums of light to use for LEDs in CEA facilities; and (4) robotics and mechanization.

The topics discussed in the Production Systems session **interacted with other Breakout Session themes** such as: (1) LED and HPS lighting systems; and (2) the efficiency of automated systems. The conversation regarding the effectiveness of LED and HPS lights and energy efficiency is tied to degradation and lifetimes of LED lighting systems, a theme that was discussed at length in the Engineering Breakout Session. Additionally, the conversation regarding evaluating the efficiency of automation as compared to manual labor ties in with the Economics Breakout Session discussion, which focused on the need to evaluate the costs associated with automation, technology, and robotics within CEA facilities.

The **opportunities** identified for facilities to utilize in the future included: (1) identify ways in which the industry can utilize university research; (2) create events that facilitate interactions between industry and academia; (3) create and regulate industry best practices, standards, and protocols; (4) facilitate free information exchange; (5) utilize consistent testing processes with accurate result interpretation; and (6) utilize real time nutrient evaluations and adjustments that are reliable and consistent.

The **Plant Breeding** Breakout Session was led by Charles Parrish, a University of Arizona Graduate student, and Magda Pancerz, Director of Research and Development at Cedar Valley Farms. The participants identified the following challenges: (1) the need to separate greenhouses from other forms of indoor production facilities; (2) the defining of appropriate time frames for crop traits of interest; and (3) the competition in plant breeding efforts amongst indoor and outdoor agricultural operations. The Plant Breeding discussion group formulated solutions and recommendations that can potentially be used by CEA facilities in the future to increase and improve production, quality, nutritional value, and other crop attributes that are important to both growers and consumers. These recommendations included the following: (1) consideration of the unique breeding needs of each crop cultivar; (2) the prioritization of the desired architectural aspects of the crop; and (3) the enhancement of screening and validation procedures for plant cultivars through partnerships with large-scale growers. Following this discussion of these challenges and proposed solutions, the group shifted focus to additional plant breeding related topics and issues facing the CEA industry. These topics included the following: (1) pollination challenges with flowering and fruiting plants; and (2) difficulty in determining the timelines for performing breeding in specific crop types.

The topics discussed within the Plant Breeding session **interacted with other Breakout Session themes** such as: (1) considering how to optimize the nutritional value and flavor of a crop; and (2) increasing pest and disease resistance for viral vectors. The conversation regarding improving the nutritional value and flavor of a crop is tied to the relationship between microbial communities to crop flavor and post-harvest quality, a theme that was discussed at length in the Food Nutrition and Safety Breakout Session. Additionally, the conversation on improving upon crop pest and disease resistance ties in with the Pest and Disease Management (IPM) Breakout Session discussion, which focused on the need to integrate biological, chemical, and cultural methods of pest and disease management.

The **opportunities** identified for facilities to utilize in the future included: (1) consider the unique breeding needs of each crop cultivar; (2) place priority on the desired architectural aspects of the crop; and (3) partner with full-scale growers as an option for large-scale screening and validation.

The **Food Nutrition and Safety** Breakout Session was led by University of Arizona graduate student Allie Allgeyer. The participants identified the following challenges: (1) a lack of industry standards and best practices for indoor farming; (2) the need to source clean seeds and plants; (3) differing protocols are required for greenhouses and fully indoor systems; and (4) the need for standardization of food safety protocols. These issues were discussed in detail, and the group formulated solutions and recommendations that can potentially be used by CEA facilities to increase the effectiveness of food safety protocols as well as crop quality. These recommendations included the following: (1) create a standard protocol for growth chamber hygiene; (2) obtain lab analyses on clean seeds and identify sanitizing treatment options; and (3) create standards that all CEA systems are required to meet. Following this discussion of these challenges and proposed solutions, the group shifted focus to additional food nutrition and safety related topics and issues facing the CEA industry. These topics included the following: (1) approaches to standardization; (2) defining quality in terms of nutrition; (3) identifying how lighting treatments can be used to maximize the nutritional content of crops; and (4) discussing how food nutrition can vary with shelf-life. Future research topics that were discussed included: (1) standards on nutritional quality for CEA crops; (2) the effect of indoor agricultural environments on the nutritional shelf life of produce; and (3) developing an understanding on the effects of microbial communities on the growth, nutrition, quality, and handling of indoor agriculture produce.

The topics discussed within the Food Nutrition and Safety session **interacted with other Breakout Session themes** such as: (1) breeding for disease and pest resistance; and (2) energy and nondestructive technology developments. The conversation regarding production and breeding for diseases and pest resistance is tied to precision genetics and breeding methods, a theme that was discussed at length in the Pest and Disease Management session. Additionally, the conversation regarding energy and nondestructive technology developments for safety, quality, nutrition, and disease ties in with all of the topic sessions considering technology is a growing instrumental component of CEA facilities.

The **opportunities** identified for facilities to utilize in the future included: (1) create a standard protocol for growth chamber hygiene; (2) obtain lab analyses on clean seeds; (3) identify seed sanitization methods; and (4) create end-point standards that all systems are required to meet.

The **Industrial Ecology of Closed Systems** Breakout Session was led by University of Arizona Graduate student KC Shasteen. The participants identified the following challenges: (1) improper disposal practices can lead to salt buildups in the ocean; (2) inedible crop waste disposal practices lead to production of greenhouse gases like carbon dioxide and methane; (3) energy limits are being implemented to encourage electrical efficiency; and (4) regulations for CO2 levels are being placed below where scientific has shown them to be harmful. These issues were discussed in detail, and the group formulated solutions and recommendations that can potentially be used by CEA facilities in the future. These recommendations included the following: (1) encourage community building, safety practices, and consumer health; (2) implement production and capture of bio-gas for fuel and biochar for fertilizer; (3) utilize renewable energy sources or encourage CEA facilities to generate their own energy; and (4) encourage thermal energy storage and off-peak power usage. Following this discussion of these major challenges and proposed solutions, the group shifted focus on additional industrial ecology related topics and issues facing the CEA industry. These topics included the following: (1) discussion on whether greenhouses should still count as CEA; (2) low income groups in food deserts are missing opportunities; and (3) cannabis laws could negatively impact other types of CEA.

The topics discussed within the Industrial Ecology of Closed Systems session **interacted with other Breakout Session themes** such as: (1) resource use efficiency and renewable energy sources; and (2) the need for standardization of CEA protocols. The discussion regarding increasing resource use efficiency is tied to utilization of renewable energy sources for water and energy, a theme that was discussed at length in the Engineering session. Additionally, the discussion regarding the need for standardization within all aspects of CEA ties in with the Food Nutrition and Safety Breakout Session, which focused on the need for development of standards that CEA facilities should be held to as well as the need for differing protocols within greenhouses and full indoor systems.

The **opportunities** identified for facilities to utilize in the future included: (1) encourage community building, safety practices, and consumer health; (2) implement production and capture of bio-gas for fuel and biochar for fertilizer; (3) utilize renewable energy sources or encourage CEA facilities to generate their own energy; and (4) encourage thermal energy storage and off-peak power usage.

The **Engineering** Breakout Session was led by Wythe Marshall, an anthropologist at Harvard and Cornell University. The participants identified the following challenges: (1) engineering and degradation challenges of LED lights; (2) the potential need for a new database system within CEA facilities; (3) consideration of how Artificial Intelligence (AI) can be deployed so that sufficient data is collected while being cost-effective; and (4) consideration of plant responses to light and water and how this information can be used to increase yield, quality, flavor, and nutritional value of the crop. These issues were discussed in detail, and the group formulated solutions and recommendations that can potentially be used by CEA facilities in the future to effectively integrate automated systems and robotics to improve overall production. These recommendations included the following: (1) increase research on the engineering aspects of LED thermal-load issues; (2) develop data using a research greenhouse to test significant parameters for production; based on this data, low-cost, easy-to-use sensors can be designed for growers; (3) demonstrate need and raise investment for a national greenhouse database; and (4) develop benchmarks and standards for lighting, energy, and resource use. Following this discussion of these challenges and proposed solutions, the group shifted focus to additional engineering issues facing the CEA industry. These topics included the following: (1) extensive costs for integrated control systems and technology; (2) lack of uniformity in sensors used by CEA facilities; and (3) differing engineering requirements amongst CEA space facilities, greenhouses, and vertical farms.

The topics discussed within the Engineering session **interacted with other Breakout Session themes** such as: The conversation regarding engineers not placing significance on the costs of operation in CEA facilities is tied to the extensive costs of automation, rent, energy, and water, a theme that was discussed at length in the Economics session. Additionally, the conversation regarding the cost of transportation for goods and products and proper siting of CEA facilities ties in with the Ecology of Closed

Systems Breakout Session which focused on differing costs, regulations, and availability of resources depending on the state.

The **opportunities** identified for facilities to utilize in the future included: (1) increase research on the engineering aspects of LED thermal-load issues; (2) develop data using a research greenhouse to test significant parameters for production; (3) demonstrate need and raise investment for a national greenhouse database; and (4) develop benchmarks and standards for lighting, energy, and resource use.

The **Pest and Disease Management (IPM)** Breakout Session was led by Magda Pancerz (Cedar Valley Farms) and University of Arizona Graduate student Charlette Bonner. The participants identified the following challenges: (1) one infected plant can destroy the entire crop system; (2) diseases are not being addressed when yields are still sufficient to the grower; and (3) difficulty in identifying sources of infection. These issues were discussed in detail, and the group formulated solutions and recommendations that can potentially be used by CEA facilities in the future. These recommendations included the following: (1) develop more efficient scanning methods for pest detection; (2) consider utilizing beneficial organisms as biocontrol; (3) search for new, non-chemical methods of plant protection (biological and chemical); and (4) incorporate pest killing LED lights. Following this discussion of these major factors of concern and proposed solutions, the group shifted focus to additional pest and disease management issues facing the CEA industry. These topics included the following: (1) difficulty in evaluation of pest and disease issues when treatments are proactive and preventative; (2) numerous vectors of disease; and (3) challenges in sanitation of CEA facilities.

The topics discussed within the Pest and Disease Management session **interacted with other Breakout Session themes** such as: The conversation regarding utilization of LED lights to reduce pesticides and kill pests is tied to the efficiency of LED lighting systems in CEA facilities, a theme that was discussed at length in the Engineering session. Additionally, the conversation regarding maintaining healthy microbiomes ties in with the Food Nutrition and Safety Breakout Session, which focused on utilizing microbial communities as indicators of food safety and the need to conduct more research on how microbial communities affect flavor and post-harvest qualities of produce.

The **opportunities** identified for facilities to utilize in the future included: (1) develop more efficient scanning methods for pest detection; (2) consider utilizing beneficial organisms as biocontrol; (3) search for new, non-chemical methods of plant protection; and (4) incorporate pest-killing LED lights.

Thematic Area	Discussion Leaders	Recorder(s)	Participants
Economics	1. Bekah Waller 2. Robert Heintz 3. Justin Chang	Robert Heintz	1. Robert Heintz 2. Nate Story 3. Nick Matelero 4. Bekah Waller 5. Justin Chang
Production Systems	Ying Zhang	1. David McKinney 2. Ying Zhang	1. Matt Cutulle 2. Oscar Monje 3. Steve Newman 4. Remi Naasz 5. Joe Swartz 6. Karla Garcia 7. James Atlant 8. Celina Gomez 9. Austin Smith 10. Stacy Tollertson 11. Morgan Pattinson 12. Joshua Craver 13. Neil Mattson 14. Meriam Karlsson 15. Matthew Denten 16. Brady Sinclair
Engineering	Wythe Marshall	Wythe Marshall	1. Gene Giacomelli 2. Murat Kacira 3. Erico Mattos 4. Ralph Fritsche 5. Dinah Dimapilis

			6. Dung Duong 7. Tharindu Weerante 8. Matt Bergen 9. Genhua Niu 10. Shumin Wang 11. Bob Morrow 12. Fei “Jeff” Jia 13. Kale Harbick 14. Dave Hanson 15. Wythe Marschall
Plant Breeding	1. Charles Parrish II 2. Magda Pancerz	1. Charles Parrish II 2. Magda Pancerz	3. Paul Gauthier 4. Magdalena Pancerz 5. Ray 6. Gail 7. Patrick 8. Jennifer 9. Joanne 10. Charles 11. Brad 12. Paul Zankowski 13. Phil Sadler
Food Nutrition and Safety	Allie Allgeyer	Allie Allgeyer	1. Gioia Massa 2. Michele Spencer 3. Sarah Federman 4. John Finley 5. Jinhe Bai 6. Ryan Barelme 7. Allie Allgeyer 8. Gary Stutte 9. Chiara Amitrano
Industrial Ecology of Closed Systems	KC Shasteen	KC Shasteen	1. Matt Liotta 2. Weslynne Ashton 3. Jess Buncheck 4. Barry Pryor

			5. Prim Wilder 6. Fenton Williams 7. Kitt Ferrel-Poe 8. Mario Cambardella 9. Mark Lefsrud
Pest and Disease Management	1. Madga Pancerz 2. Charlotte Bonner	Magda Pancerz Charlotte Bonner	UNAVAILABLE

IV. Meeting Personnel, Collaborators, and Participants

The AzCEAC was primarily organized by Dr. Gene Giacomelli, PD (University of Arizona), Dr. Murat Kacira, Co-PD (University of Arizona), and Dr. Joaquin Ruiz, Co-PD (University of Arizona).

Key collaborators involved in meeting coordination and planning included Dr. Kai Ling (USDA-ARS), Dr. Steve Newman (Colorado State University), Dr. Sarah Federman (USDA-OSEC), Dr. Kevin Bonine (University of Arizona), and Dr. John Adams (University of Arizona)

The non-profit, private industry, and stakeholder group members involved in meeting coordination and planning included the following: Ed Hardwood (Aerofarms), David Rosenberg (Aerofarms), Nate Storey (Plenty Unlimited), Robert Colangelo (Green Sense Farms), Jim Pantaleo (Sananbio-UA-Oasis Biotech), Chaz Shelton (Merchant’s Garden), Jennifer Frymark (Gotham Greens), Myles Lewis (Arizona Vegetable Company), Robert Brot (WGVA), Chris Higgins (HortAmericas), Austin Smith (GRODAN), Ron DeKok (Signify), Ken Gerhard (GVC), Karen Tifft (GVC), Jenny Harris (AmHydro), Mike Briotta (FarmTec), Remi Naasz (Premier Tech Horticulture), Wil Lammers (Rider-Hortimax), John Provens (Argus Control), Dung Duong (Fluence), Neil Mattson (CEA Cornell), Lee Frankel (Coalition for Sustainable Organics), Nicola Kerslake (Newbean Capitol). A letter of support was received from the NCERA-101 Committee, whose executive leadership includes: Ramesh Kanwar (Iowa State University), Mark Lefsrud (McGill University), Neil Yorio (BiosLighting), Mark Romer (McGill University), Eric Runkle (NASA-Kennedy Space Center). A letter of support was also received from the NE-1335 Committee, whose members include: R. Dickson - (Chair, University of New Hampshire), R. Brumfield (Rutgers University), C. Kubota, (Ohio State University), R. Gates (University of Illinois Urbana-Champaign), A.J. Both (Rutgers University), P. Ling, (Ohio State University), C. Gomez (University of Florida), R. Rhodale (University Connecticut) S. Burnett (University of Maine), H-J. Kim (Purdue University), Ellen Paparazzi, (University of Nebraska-Lincoln), Ricardo Hernandez (North Carolina State University).

The total number of attendees at the conference was 108 (see Appendix A-2 for list of attendees and institutional affiliations).

V. Conference Activities

The program began with a tour of a commercial research and development facility in Marana, AZ operated by Bayer Crop Sciences. The leadoff tour to an extremely modern high-tech greenhouse helped to set the stage for the interdisciplinary and complex nature of operational CEA plant production systems. All of the diverse attendees were introduced to not only their area of expertise, but to all other areas of expertise by the 2-hour tour. It also provided for a re-introduction of former, and an introduction of new, professional friends at the start of the conference, which led to the end-of-day welcome reception dinner and further mixing of the attendees. Then immediately at the start of the first session of the next day, everyone was comfortable, ready, and willing to actively participate.

The conference concluded with a tour of the UA-CEAC campus research facilities and a BBQ. This ending tour offered the attendees upfront experiences of numerous types of greenhouse structures, a vertical farm research facility, and numerous plant growing systems and nutrient delivery systems for production of various types of leafy green and fruiting vegetable crops.

One outcome of the Az-CEA Conference was the development of a pre-proposal for a coordinated agriculture project (CAP) to the NIFA-Specialty Crop Research Initiative (SCRI) program. The grant proposal meeting took place during the conference on the morning of Thursday, September 12, 2019 at the Lodge on the Desert hotel in Tucson. Based on the discussions of the conference topics and from the interactions between the conference attendees, the contributors began drafting a submission of the pre-proposal document that was due October 15, 2019. The proposal was titled “CEA-CAP: Optimizing controlled environment production systems to improve productivity, profitability and quality of tomatoes” with PI Kai Ling (PD, USDA-ARS), Murat Kacira (co-PD, University of Arizona), John Stommel (co-PD, USDa-ARS), Alvin Simmons (co-PD, USDA-ARS), Jinnhe Bai (co-PD, USDA-ARS), Simone Valle de Souza, (co-PD, Michigan State University), Steve Newman, (co-PD, Colorado State University) along with key personnel (co-PIs): Dr. Jennifer Boldt (USDA-ARS, Toledo, OH); Dr. Joshua K. Craver (Assist. Professor, Colorado State University); Dr. Gene Giacomelli (Professor, University of Arizona); Dr. James Giovannoni (USDA-ARS, Ithaca, NY); Dr. James Harnly (USDA-ARS, Beltsville, MD); Dr. Wojciech Janisiewicz (USDA-ARS, Kearneysville, WV); Dr. Jesusa Legaspi (USDA-ARS, Tallahassee, FL); Dr. Peter Ling (Assoc. Professor, Ohio State University); Dr. Zachary Lippman (Professor and HHMI Investigator, Cold Spring Harbor Laboratory, NY); Dr. Joe Masabni (Professor, Texas A&M University); Dr. Genhua Niu (Professor, Texas A&M University); Dr. Erdal Ozkan (Professor, Ohio State University); Dr. Dilip Panthee (Assoc. Professor, North Carolina State University); Dr. Anne Plotto (USDA-ARS, Fort Pierce, FL); Dr. Anissa Poleatewich (Assist. Professor, University of New Hampshire); Dr. James N. Roemmich (USDA-ARS, Grand Forks, ND); Dr. Fumi Takeda (USDA-ARS, Kearneysville, WV); Dr. W. Pat Wechter (USDA-ARS, Charleston, SC); and Dr. Heping Zhu (USDA-ARS, Wooster, OH) with 22 industry collaborators provided support letters for the proposal submission. The proposal was not selected for funding. The team decided to re-evaluate and revise for re-submission.

I. Post-conference activities - Survey of Attendees

A post-conference survey comprised of 25 questions was prepared with the intent to better understand the experiences gained by the attendees. The survey was distributed to all 108 conference attendees and resulted in 52 responses. Overall the survey feedback was positive, with 100% of respondents indicating that the conference met expectations (73% strongly agree, 27% somewhat agree). The seven thematic areas of the conference were deemed appropriate overall (77.08% strongly agree, 20.83% somewhat agree, 2.08% neither agree nor disagree), and there was relative agreement that the selected speakers provided content and information that was relevant to the attendees backgrounds (70.21% strongly agree, 23.40% somewhat agree, 4.26% neither agree nor disagree, 2.13% somewhat disagree).

In terms of specific topics discussed within the conference, many agreed that the LED research presented will change how they conduct their own LED research (72.92% strongly agree, 25.00% somewhat agree, 2.08% somewhat disagree). Many attendees agreed that the format of the thematic sessions, keynote presentations, invited speaker presentations, panel presentations, and discussions were effective (66.67% strongly agree, 29.17% somewhat agree, 2.08% neither agree nor disagree, 2.08% somewhat disagree). Nearly all survey respondents agreed that the overall discussions in each thematic area yielded valuable information, were in-depth and interesting, and consisted of appropriate and relevant topics. General agreement was seen for responses on whether the afternoon breakout sessions were of value and allowed attendees to provide their input while also learning from others (70.83% strongly agree, 27.08% somewhat agree, 2.08% neither agree nor disagree). Respondents were asked to suggest other topics that should have been incorporated as themes of the conference; their suggestions included the following themes: microbiology, data analytics, marketing, and desalination and wastewater treatment. Regarding the program overall, respondents offered the following suggestions for improvements: (1) shorter presentations to allow for longer breakout sessions; (2) more diverse presenters who can offer different perspectives; and (3) the incorporation of CEA growers feedback into meeting discussions and activities.

With regard to pre-conference activities, there was strong agreement among those attendees who attended the Bayer greenhouse tour that it played an important role in the conference. Responses were nearly the same when asked for thoughts on the importance of the tour and BBQ at the Controlled Environment Agriculture Center at the University of Arizona; many agreed that the facility tours and BBQ event facilitated great networking discussions and allowed for relationships to be developed amongst the attendees.

There were somewhat scattered responses on the importance of the post-conference grant writing session, however many people who were in attendance agreed that it was useful (40.43% strongly agree, 14.89% somewhat agree, 4.26% neither agree nor disagree, 4.26% somewhat disagree, 36.17% did not participate). Responses were also scattered regarding thoughts on the effectiveness of the grant writing session, however the majority remained in agreement that the format was effective (23.40% strongly agree, 23.40% somewhat agree, 6.38% neither agree nor disagree, 4.26% somewhat disagree, 2.13% strongly disagree, 40.43% did not attend).

The survey questions then began to address attendees thoughts on the logistics of the conference; there was nearly complete agreement that the registration cost to attend the conference was appropriate (70.83% strongly agree, 10.42% somewhat agree, 10.42% neither agree nor disagree, 2.08% somewhat disagree, 6.25% not applicable). Responses were very similar when asked if local arrangements were sufficient for attendees needs (64.58% strongly agree, 16.67% agree, 10.42% somewhat agree, 8.33% neither agree nor disagree). A free response question was provided for attendees to comment on the local arrangements or accommodations; some of the feedback included comments on the excellent food, satisfaction with Biosphere 2 as the venue, and great interactions with the organizing committee and venue staff.

Lastly, survey questions were provided to gather information on the attendees backgrounds, gender, and role at the conference. There were a large variety of responses when asked for attendees current roles and positions with a fairly even divide between people in industry and people in academica (25% university faculty, 20.83% government researcher, 31.25% CEA industry professional, 4.17% graduate student, 18.75% other). The positions categorized as “other” included: (1) consultant; (2) government administrator; (3) industry association; (4) Food Safety Projects Coordinator for the Arizona Department of Agriculture; (5) Research Staff; (6) Manufacturer; and (7) postdoctoral researcher. Survey responses regarding the gender of the attendees were fairly evenly split (54.17% male, 33.33% female, 2.08% other, 10.42% choose not to answer). Attendees roles at the conference were highly varied (49.21% participant; 3.17% breakout session scribe, 23.81% panel speaker, 4.76% invited speaker, 7.94% keynote speaker, 7.94% organizing committee, 3.17% other). The roles categorized as “other” included: (1) speaker at the lightning talks; and (2) PI of the NIFA grant for the conference.

II. Post-conference activities - CEADS Initiated

Another important and unexpected outcome of the conference was the formation and development of a working group focused on developing a comprehensive set of guidelines for the design of CEA facilities - the Controlled Environment Agriculture Design Standards (CEADS). Beginning with a handful of conference attendees from government, academia, and industry sectors, the group identified 7 ‘domains’ (i.e. topic areas) deemed critical in determining the success or failure of CEA enterprises. These domains include the following: Crop Quality, Profitability, Automation & Labor, Materials & Waste, Equity & Localness, Utilities, and Integrated Pest Management. These domains represent the structure of considerations and thoughtful discussion topics for the development, design or evaluation of a controlled environment system, and were logical outcomes of the discussions and ideas exchanged at the AzCEA Conference at Biosphere 2. The collaborative structure of the meeting helped to inspire those attending to move forward with the development of a procedural framework of inter-related information by which controlled environment systems can be generically defined. From this CEADS effort may arise a lasting framework for benchmarking and improving the CEA facility design and operation, for the benefit of all future controlled environments such as greenhouses, VF, and other systems and technologies.

The CEADS project is led by a 5-member Leadership Team. Matt Liotta (formerly Agrify) serves as President, Charles H. Parrish II (UbiQD) serves as the Chief Financial Officer, Rebekah Waller (The University of Arizona) serves as Secretary, with Dr. Weslynne Ashton (Illinois Institute of Technology), Dr. Gary Stutte (syNRGE LLC.), and Jess Bunchek (NASA Kennedy Space Center) as Leaders. The CEADS Advisory Board members contribute their expertise and networks toward the development of the standards and its implementation in the CEA industry. The CEADS Advisory Board includes David Kessler (Agrify), Mark Lefsrud (McGill University), Brady Nemeth (Fluence by OSRAM), Tharindu Weeraratne (Autogrow), Gene Giacomelli (The University of Arizona), Penny McBride (Second Chances Farm, LLC.), Charles Wu (Nexem), and Simone Valle de Souza (Michigan State University).

The CEADS standards establish a comprehensive framework of best practices and industry benchmarks in the design and operation of CEA facilities, aligned with the economic, environmental, and social dimensions of sustainability. CEA enterprises can utilize CEADS to guide the entire planning, design, construction, and operation phases of their growing facilities, promoting long-term business success and a more resilient CEA industry overall. The central mission of the CEADS project is to enable growers to become leaders in the CEA industry through recommending standard best practices for the design and operation of CEA enterprises. The initial version of the CEADS standards - CEADS v0.9 - was completed in January 2021 and subsequently distributed for external review. Many of the External Reviewers of CEADS v0.9 were attendees of the Az CEA Conference. The external review process will conclude by mid-March 2021, and with this feedback the group aims for a publication of the CEADS v1.0 slotted for May 2021. A CEADS One-Pager document (Appendix X) and Reference Guide for CEADS v0.9 (Appendix X) provide more information on the project.

Following the success of the conference with an abundance of confirmed information to organize and present, and with the development of Controlled Environment Agriculture Design Standards (CEADS) as a living outgrowth of the conference, two undergraduate student interns were hired by UArizona-Controlled Environment Agriculture Center to help prepare the final report and to help the development of the CEADS document.

III. Discussion

The discussions and ideas exchanged at the Az-CEA Conference, both in the plenary sessions as well as the Breakout Sessions, highlighted the diverse array of challenges and opportunities that exist for widening the scope of indoor and vertical food production systems. The ultimate goal of these discussions was to identify factors that could increase the sustainability of CEA enterprises as advances in growing technologies enables the CEA industry to play new and increasingly important roles in agriculture going forward. The structure of the meeting, the stakeholders and participants involved, and the thematic areas selected by the conference organizers indicated an understanding that the viability of indoor and vertical food production systems going forward is a question of economic, environmental, and social dimensions that demands multi-disciplinary and multi-stakeholder collaboration. The dynamic discussions that took place within each Breakout Session were useful in both highlighting the granularity of the issues involved in CEA, VF, and UA as well as identifying overlap and intersection between these issues. A major theme throughout the discussions was the need for research to increase understanding of the challenges faced by indoor and vertical farms. This research effort should leverage the strengths of both the private sector and academic and government bodies in collaborative projects. Related to the identified need for more research activity is the need for increased transparency and dissemination of information within the CEA industry at large. At many points in the Breakout Sessions participants pointed to the lack of a widely accessible and centralized information source that could guide indoor and vertical farm managers in making operational and business decisions. CEA is a relatively young field, and the IA and VF sub-fields are even younger. There is strong interest in developing standardized protocols for the design, operation, and research of these systems that can both enable meaningful benchmarking of performance for existing facilities as well as promote earlier success for new CEA facilities being built. It was from this call for standardization at the Az-CEA Conference and similar meetings that preceded it that the CEADS initiative was born, and why the project has already received the support and interest it has from across the CEA industry.

IV. Conclusions and future directions

Developing sustainable and strategic plans to feed the future in the face of growing global challenges will require interdisciplinary vision and innovation on a grand scale. These growing global challenges include climate change, which is creating unpredictable growing conditions and increased aridity in many parts of the world[1], continued and increasing water scarcity in agriculture, insufficient agricultural land to meet growing global food demands and soaring global populations that are becoming increasingly urbanized[2]. Addressing these grand challenges to feed the future will require innovative, integrative and interdisciplinary solutions that draw on both historical and current approaches such as traditional plant breeding and modern gene editing technologies, or develop strategies to reduce global food waste, as well as forward thinking and out-of-the-box innovation.

The controlled environment agriculture (CEA) implemented as indoor agricultural food production systems may offer innovative technological solutions to solve such problems. In recent decades, there have been major expansions as a result of significant increased investments into controlled environment facilities within the US. The available technology, much from international sources and the relatively docile US greenhouse industry, provided the promise of more food products from controlled environments;

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[1] Elbehri, A., Challinor, A., Verchot, L., Angelsen, A., Hess, T., Ouled Belgacem, A., ... & Walker, R. (2017). FAO-IPCC Expert Meeting on Climate Change, Land Use and Food Security: Final Meeting Report. *Rome: FAO and IPCC*.

[2] Sauer, C. (2008). *The morphology of landscape* (pp. 108-116). Routledge.

however, the producers and operators were numerically unprepared to meet the demand of the rapidly developing industry.

The influx of investment into CEA resulted in considerations of inexperienced but well-financially backed facilities to begin production, leading to facilities that were not optimally designed or operated. A noteworthy positive was the great interest to establish CE as a supplemental production avenue to complement field production agriculture, while the negative aspect was the lack of sufficient experience and knowledge entering the industry. This new generation of young ‘farmers’ enthusiastically joined production agriculture with a mild awareness of hydroponics but no experience or knowledge of controlled environments. Despite the overall lack of familiarity with the industry, people were willing to work hard for production to ultimately experience success. The key motivating force and source of enthusiasm was the ability to integrate newly affordable LED lighting into the Urban Agriculture market. Additionally, excitement over CE food production has since created immense opportunities for those who were unable to enter farming previously.

This lack of experience on part of the new generation of CEA growers was also compounded by the lack of established best practices for crop production in these novel indoor facilities. The remarkable advances in indoor agriculture technology in the past decade must be complemented by the establishment of a widely accepted knowledge base for how to operate these facilities optimally.

The Az-CEA conference was in part an effort to bring a large group of people to consider the unique aspects of plant production in indoor facilities and ways in which scientific laws of physics and biology are incorporated into these operations. The conference effectively served as an educational experience that demonstrated the need for new information to continuously enter the industry; people within a variety of backgrounds were able to provide unique perspectives and knowledge on ways in which the industry can evolve to become more efficient.

APPENDICES

A-1. Conference Breakout Session Summaries

A-1-1. Economics Breakout Session

Recorder: Robert Heintz

Date: September 10, 2019

Participants: N/A

Issue #1: Quality issues around the maintenance of live plants in grocery stores
Solutions/Discussion: Create new qualitative categories to differentiate products, develop common food safety standards, agree upon CEA pre-harvest and post-harvest data

Issue #2: Consumer thoughts on CEA produce need to be better understood
Solutions/Discussion: Utilize blockchain technology, market food as safe, hygienic, etc., refrain from mentioning hydroponics in marketing, dedicate market shelf space for AZ grown products, consider that state grown products can command a premium price

Issue #3: Consider what parts of the production process are best suited to automation
Solutions/Discussion: Difficulty in finding venture capital and bank loans due to low CEA profit margins, strong economy has increased labor costs, many positions are offered part-time only

Issue #4: Consider how the relationship between capital and operational expenditures will change with increased automation

Solutions/Discussion: Automation is perceived as taking jobs from the community, automation can lower prices for consumers, CEA brings high skilled jobs

General Discussion Points

- Consider state grown programs (produce grown from a particular state). Locally grown produce can procure a competitive advantage and a smaller environmental footprint
- Producers seem focused on quality. Market analysis suggests distributors have different needs than suppliers. For suppliers that sell to large chains stores, quality is defined by the buyers
- Grocery stores do not have good, well qualified produce managers
- A romaine outbreak killed five people; this catastrophe raised questions on transparency in agriculture
- CEA food safety commission is an important organization; Indoor Ag-Con should host some food safety guideline organizations to raise standards
- 70% of interviewed people said they would pay a premium for organic food, but what they said they would pay was half of the actual price of organic food
- Consider near term solutions offered using blockchain technology
- Consider that value added by CEA production will vary from state to state
- Automation/robotics is an expensive start-up cost and a luxury of large companies
- Consider if large companies that do produce packaging can take over branding of CEA products
- Consider if the federal government would offer crop insurance to CEA growers
- Aquaponics can be problematic; elegant, but not profitable
- Research question: consider the impact of vertical farms in opportunity zones (economic development zones)

Key Questions for the FDA

1. Will the FDA do an audit? What will they do with the information?
2. What subsidies can be offered to CEA/Vertical farm growers

General Topics

Energy

- Labor, rent and energy are the highest costs. EPRI Electric Power Research Institute found that CEA growers conserve water and should get a differential rate for irrigation water supplied from the municipal water supply. A national agriculture rate for irrigated water should be supplied. Costs are location dependent.
- Difficulty in installation of photovoltaics in facilities that are leased
- Siting is critical; it is cost prohibitive to locate indoor farms in urban areas
- CEA benefits the local community and should have subsidized property costs

Carbon Costs in CEA

- Carbon costs are becoming lower
- Consider the externalities and environmental impacts of CEA
- Consider what energy sources are available within each state

Yield as it Relates to Capital Expenses

- More inexpensive renewable energy is being developed
- Nutrient water and condensate recycling are benefits of CEA
- On-site water treatments can save costs
- Building code issues contribute to capital expenditures
- Vertical farms should seek agricultural zoning to save on cost

Unit Economics as it Relates to the Need for Indoor Farming

- Field agriculture may have reached a national limit
- Macroeconomic case for urban farming
- High unit costs of CEA need to be addressed; find ways to reduce costs
- CEA needs to create more brand value
- Organic has less added value than CEA technology

Impact of Automation on CEA and Vertical Farming

- LED efficiency gains are shifting cost curves
- Need for a common metric to measure productivity
- Vertical farming presents challenges when quantifying yield
- Vertical farms have small environmental footprints and large yields
- “Starbucks effect” may hit CEA
- Total consumption may increase with costs
- A few large players may attract people to the industry; may increase speciality market as well
- Decommodification will result from differentiated high quality produce
- Consumers can be conditioned to pay more for quality produce

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A-1-2-1. Production Systems Breakout Session (Day 1)

Recorders: David McKinney & Ying Zhang
Date: September 10, 2019
Participants: Matt Cutulle, Oscar Monje, Steve Newman, Remi Naasz, Joe Swartz, Karla Garcia, James Atland, Celina Gomez, Austin Smith, Stacy Tollertson, Morgan Pattison, Joshua Craver, Neil Mattson, Meriam Karlsson, Matthew Denten, Brady Sinclair

Issue #1: Need to bridge the gap between industry and academia

Solutions/Discussion: Apply translational research to the real world, identify barriers to the industry’s ability to adopt university research, evaluate economic thresholds on an individual basis, identify the cost benefit analysis of switching out technology, increase communication between industry, academia, and the general public, create events that facilitate interaction between industry and academia, promote verified models, research industry specific needs

Issue #2: Need for more CEA association

Solutions/Discussions: Create dialogue between academia, industry, and suppliers to communicate needs, share technology, research, experience, mistakes, design pilot programs, and training, lobby for more ARS and other USDA funds/research, create and regulate industry best practices, standards, and protocols, build public-private partnerships, facilitate free information exchange, share expenses for industry development, share new product development from suppliers, lobby for an organic CEA definition and certification

General Topics

CEA Professional Certifications

- Put trained people into the industry
- Build a foundation of skilled labor
- Implement training courses for professionals
- Collaborative curriculum between academia and industry
- Implement an apprenticeship program to help employees gain experience
- Give another level of experience to associate or certificate level employees

Combined CEA Research Facility

- Modeled in the Netherlands: multi-institutional full-scale production research facility
- Central data compilation and analysis for industry to utilize
- Verifiable information center
- Translational research center to apply university protocols in the industry
- Knowledgeable resource to evaluate products available in the market
- Research technology for practicality, time savings, and value compared to hand

labor
- Trial and share information on equipment and compare to current knowledge
- Build resources for extension
- Create specialized protocols on a species basis
- Establish trials for new varieties and genetics in real world application

Environmental Manipulation Research

- Combine knowledge from equipment providers, academia, and supplies to look at every manipulatable factor
- Light
  - LED vs HPS
    - Consider the HPS heat effect for northern growers, when or how to transition from HPS to LEd, and whether LED is the answer, or just a trend
  - Physiology
    - Consider how plants respond to specific light spectrums
    - Sole source vs. supplemental lighting
  - Nutrient Management
    - Lab testing to optimize specific and accurate nutrient management
    - Real time nutrient evaluation and adjustment
- Nutrient film or tissue sample measurements
    - New tools are needed
  - Robotics and mechanization

        - Evaluate automation vs manual labor
    - Consider scale differences, pest control, energy efficiency, and seed to harvest, to post harvest and storage
    - Evaluate the appropriate relationship of all of the technologies

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A-1-2-2. Production Systems Breakout Session (Day 2)

Recorder: David McKinney

Date: September 11, 2019

Participants: Matt Cutulle, Oscar Monje, Steve Newman, Remi Naasz, Joe Swartz, Karla Garcia, James Atland, Celina Gomez, Austin Smith, Stacy Tollertson, Morgan Pattison, Joshua Craver, Neil Mattson, Meriam Karlsson, Matthew Denten, Brady Sinclair

Research Priorities (in order of importance)

1. Committee or Organizational Body to Follow Up Conference
    a. Evaluate opportunities for the industry
    b. Find contributors willing to collaborate
    c. Pull from existing associations/committees to help make decisions
    d. Model off existing organizations (greenhouse, nursery, etc.)
    e. Pose solutions, get feedback, give growers the result desired
    f. Identify need for standard(s) improvements
2. Center of Excellence for Controlled Environment Agriculture
    a. Focus in translational research, skilled workforce training, testing and trailing of equipment and plant varieties
    b. Public-private funding cooperative
    c. Demonstrate automation for all scales

d. Central information base for standards/best practices and data analysis/interpretation

e. Evaluate existing infrastructure

f. Indoor specific breeding center and possible robotics development

g. Opportunities for internships and apprenticeships

3. The industry needs to develop a protocol to identify what light spectrums to use for LEDs

a. Develop a unified framework with rapid processes for testing

4. The industry needs new tools for nutrient management

a. Real time nutrient evaluation and adjustment that is reliable and consistent b. Consistent testing process with accurate results interpretation is needed c. More research lab interpretation to develop more expertise in the U.S. d. Bank of modern nutrient standards

e. Develop industry standards to be more proactive for environmental impact of wastewater

i. Begin by teaching about closed nutrient delivery systems

5. Central food safety standards as it related to CEA

a. Standards for system materials (e.g. PVC, food grade plastics, fittings) b. Handling and best practices as it relates to scale

c. Research needed in systems microbiology and minimizing contamination **General Discussion Points**

- Scale based systems efficiency evaluation protocol

○ Identify areas for improvement on a facility specific basis

○ Standard operating procedure audit process

○ Share standard operating procedure for training purposes

○ Find bottlenecks where automation is a possibility

    - Help the industry to be more financially successful
    - Feasibility studies for scales and automation
    - Help smaller growers

A-1-3. Plant Breeding Breakout Session

Recorder: N/A

Date: September 11, 2019

Participants: N/A

General Discussion Points

- There is a strong need to separate greenhouses from indoor production ● Indoor production as complete artificial light environments
- Utilizing germplasm resources and genotyping plants for architectural changes
- Search for plant traits that save space with simultaneous reduction of non-edible parts (less leaves with higher chlorophyll content)
- Search for plant traits that are sweet with higher nutritional values and a long shelf life ● Use rootstocks to provide root resistance to diseases and plant growth reduction

Project Goals

Focus on Solanaceae family, such as pepper, tomato, and eggplant

- Architecture for high yield and harvest index
- Robotics ready
- Consider flavor, especially for tomato production
- Intumescence edema (so far, UV is the only suppressant- looking for a plant with more resistance)

- Increase disease resistance
- Highest harvest index to determinate varieties
- Consider possible uses of inedible biomass: mushroom production, anaerobic digestion, and combined heat and power

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Food Nutrition and Safety Breakout Session

Recorder:

Date: 9/10/2021

Participants: Gioia Massa, Michele Spencer, Sarah Federman, John Finley, Bai Jinhe, Ryan Barelme, Chiara Amitrano, Allie Allgeyer, Gary Stutte

General Topics

Safety Challenges

a. Communicating to consumers regarding food safety issues

b. Certification for large growers vs. small growers, field vs. soilless culture c. Lack of industry standards and best practices for indoor farming

  i. Solution: create a standard protocol for growth chamber hygiene

d. Question of applicability of GHP-GAP Certification

  i. USDA Agricultural Marketing Service owns GHP-GAP certifications ii. Entry level food safety audit- large operations have more complicated ones iii. Consider if this is immediately applicable to CEA or if more standards/protocols are needed

e. Sourcing clean seeds and plants

  i. Get lab analysis on clean seeds

  ii. What is considered clean, and what sanitizing treatment should be used?

f. Lack of evidence for efficacy of probiotic amendments to indoor growing systems

g. Where do you look for evidence of pathogenic activity in different crops?

  i. Proxies that can be used to detect plant infections and stress

Nutrition Challenges

a. Lack of understanding and consensus on post-harvest handling of crops for CEA

b. Lack of flavor and quality in CEA grown crops, specifically tomatoes

c. Lack of understanding over the sharing of nutrients between plant community and microbial community in a CEA production system

d. Marketing of nutritional content of crop has been shown to be a consumer deterrent

  i. Case study of kale- cultural phenomenon, advertised as “superfood”

e. Space-based diet-specific nutritional needs

  i. Antinutrients- high levels of iron/calcium undesirable- grow iron deficient plants?

f. Lack of understanding in the effect of light qualities and quantities on crop nutritional quality

g. Making nutritious foods accessible

Future Research Questions/Topics

1. What should CEA industry specific food safety standards and protocols for production systems look like?
2. CEA specific industry specific standards and protocols for post-harvest practices? 3. Standardized and accessible education and training programs on CEA food safety
4. Post-harvest best practices for maintaining crop flavor/nutritional profile

a. How does food nutrition vary and change with shelf life?

5. Standards on nutritional quality for CEA crops
    a. How can we measure and quality the nutritional content of CEA crops? b. How does this quality compare to field grown crops?
    c. How can producers effectively market this information to consumers?
6. What is the relationship between aromatics, flavor, and nutritional properties of CEA crops?
    a. How can these be improved?
    b. How can this translate into wholesale value for the producer?
7. Interactions of plant and microbial communities in CEA production systems, especially with regard to distribution and sharing of nutrients
8. How can lighting treatments be used to maximize crop nutritional content?

Overarching Ideas

- Lack of industry standardization in CEA
- Lack of knowledge of microbial ecosystems in indoor systems
- Marketing of highly fortified crops to consumers
- Education and training in indoor agriculture
- Proxies for crop nutrition and safety
- Effects of CEA-specific environmental factors affect health and nutrition of crops

A-1-4. Food Nutrition and Safety Breakout Session (Day 2)

Recorder: N/A

Date: September 11, 2019

Participants: N/A

General Topics

How do we standardize?

a. Does this require R&D or the USDA to set standards?

i. Research on microbial communities in CEA and how to manage them ii. What is required to clean a facility of a contaminant?

iii. R&D to discover whether contamination in the field or CEA is worse?

b. What standards is CEA held to?

c. Studying the history for risk assessment, studying existing industry standards

d. Greenhouse and fully indoor systems will require different protocols

i. Do we create end-point standards that all systems are required to meet? Which allows for flexibility in methods for varying facilities?

e. Post-harvest will be a relatively easy time to catch contaminants (worker safety)

f. Design parameters for facilities: water needs to be X amount sterile, other baseline criteria

g. Heavy metals, allergens, microbial loads all make it unsafe and research needs to identify what levels of these are acceptable?

Nutrition

1. How does nutrition vary with shelf life?

a. Consider the economic value of this; not enough research in this area 2. What is quality defined as?

a. Field grown comes from a variety of environments

b. Standards of nutritional content may not reflect flavor/aromatics

c. How can variety packs of food be standardized?

3. Consider how standards will affect nutritional value

4. How can lighting treatments be utilized to maximize crop nutritional

content? a. Consider if more funding is needed in this field

5. Microbes/plants need trace metals for their physiology- consider the interactions between the two
    a. How does the microbial community affect flavor and post-harvest qualities? b. Microbes can be beneficial- do we want a sterile product?
    c. Microbial communities indicate whether something is safe to eat

or not 6. Is year-round production leading to a lack of diversity in human's diets?

7. Labeling- we need to better understand what consumers want
    a. "No need to wash" or "indoor grown"
    b. Needs to add value
8. Do we want to draw attention to the fact that vegetables are being industrialized like wheat and corn?

Research Questions

1. What is the effect of indoor agricultural environments on the nutritional shelf life of produce?
2. What is the effect of the microbial community on the growth, nutrition, and quality and handling of indoor agriculture?

Overarching Ideas

- Improving nutrition and food safety through:
    - Energy, pathogens, breeding, safety
    - Production, nutrition
    - Marketing, economics, nutrition
        - Labeling
    - Nondestructive technology developments for safety, quality, and disease

        - Blockchain- how are plants tracked in a system?
    - Production and breeding for diseases and pest resistance

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A-1-5-1. Industrial Ecology of Closed Systems Breakout Session (Day 1)

Recorder: KC Shasteen

Date: September 10, 2019

Participants: Matt Liotta, Fenton Williams, KC Shasteen, Kitt Farrell-Poe, Jess Buncheck, Weslynne Ashton, Prim Wilder, Mario Cambardella, Mark Lefsrud

General Topics

Permit Programs

a. Energy limits to encourage electrical efficiency instituted in MA
    i. Limit can be mitigated by using renewable energy or energy generated by the facility
    ii. A more effective policy could be based on regulating efficiency of watts/kg of produce rather than per unit area
    iii. Other states are pursuing similar laws
    iv. HVAC regulations in CA require by law for systems to vent air outdoors when conditions are favorable to conserve energy. This can be problematic for indoor farms that are seeking closure and recycled atmospheres
    v. Some laws may not be effective in certain climates
    vi. Sensible policies are more complex than simple limits and arbitrary rules
    vii. Industry can be resistant to government interference that fails to recognize strengths of CEA (e.g. high water use efficiency)
    viii. Cannabis industry may cause blanket regulations for other types of

CEA ix. Consider reducing regulations on those who are just entering the market x. Encourage thermal energy storage and off-peak power usage

Waste Stream Efficiency

a. Some greenhouses use drain to waste systems; this is exemplary of wasteful practices in CEA that should be discouraged
b. Even with fully recirculating systems, eventually water must be refreshed and old water disposed of
c. Reverse osmosis systems produce high concentration brine waste that is too much to be disposed of; the waste can be reduced to salts with enough energy

Disposal Practices

a. There are sites where disposal into the ocean would produce no harmful effects
    i. Some places may cause salt build ups if flow through the water in the area is not optimal (.e.g a sea with a small outlet)
    ii. Open field agriculture has to deal with salt build ups
    iii. Sustainable disposal practices are valued amongst land stewards and conscientious consumers
b. Inedible crop disposal practices
    i. In CA, waste is incinerated (producing CO2)
    ii. In Canada, waste is sent to a landfill (producing methane)
    iii. Alternative methods are producing and capture of bio-gas and biochar

Standardization

a. A standards organization could provide a “CEA approved” logo- may be useful to consumers and policy makers
    i. Need to agree on definitions and metrics for good practices
    ii. Need to consider the wants of consumers, industry, and regulators
b. Worthwhile values: community building, safety, health

Change of name for “CEA”

a. Issue: the lowest tech greenhouses and the highest tech indoor farms are grouped in this label

b. Perhaps a name can be given based on the degree of closure of the facility or based on the degree of sustainable land practices

c. Need for an industry standard and party validation of the standard so that no one industry member can define the regulation to benefit themselves

d. Organization would focus on: safety, locality, energy, water, waste, sustainability, equity, symbiosis, and nutrition

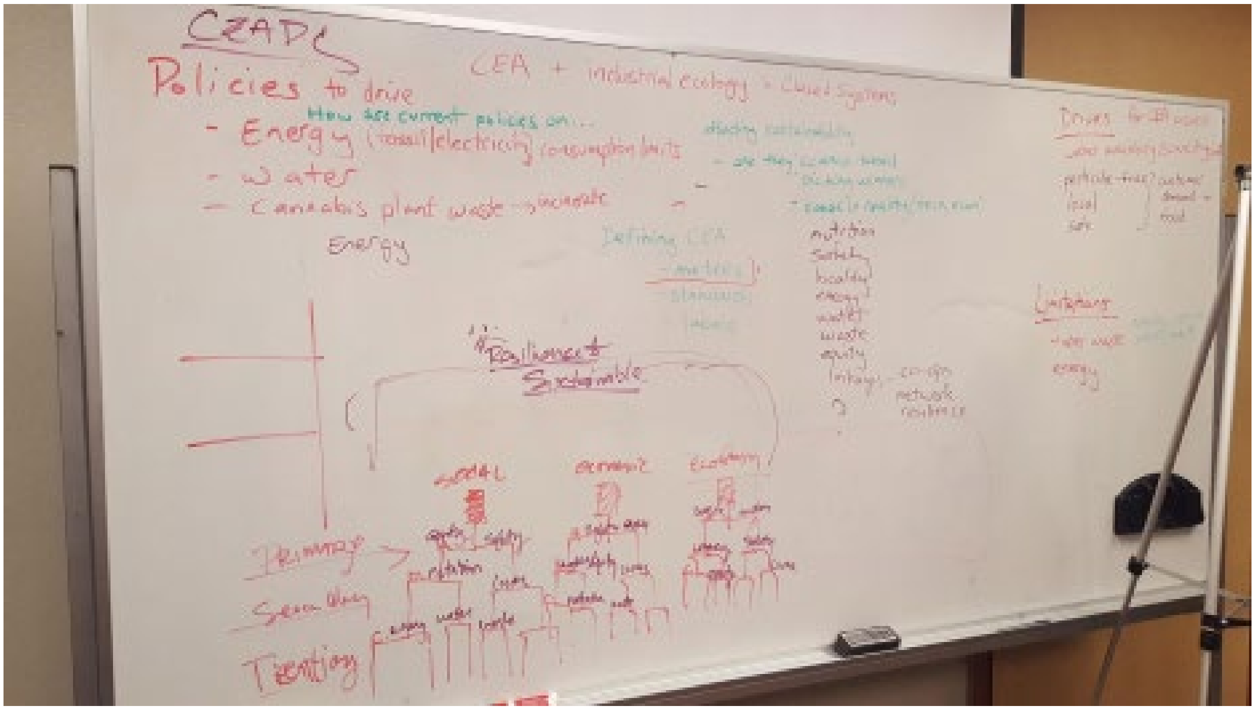
  i. Potential new ideas for an organization name: CEAsphere, BLEAD, SEAD, LEAD…

  ii. Group decides on CEADS: Controlled Environment Agriculture Design Standards **Regulations**

a. CO2 regulations are placed below where scientific evidence has shown them to be harmful

General Discussion Points

- Group produced a 3 way venn diagram with social, economic, and ecological titles ○ Pillars of certification
  - ○ Equity is connected to social and ecology, local is connected to social and economics, and waste is connected to economics and ecology
- Group produced a tiered tree with major categories, tiers, and area of focus (see below)



A-1-5-2. Industrial Ecology of Closed Systems Breakout Session (Day 2)

Recorder: KC Shasteen

Date: 9/11/2019

Participants: Matt Liotta, KC Shasteen, Weslynne Ashton, Jess Buncheck, Barry Pryor, Prim, Wilder

General Discussion Points

- Equity
    - Low income groups are missing opportunities
    - Cannabis laws could impact other types of CEA
    - Employment opportunities and good stewardship such as sourcing material with attention to ethical practices

- Linkages/symbiosis/connections/networking
    - Linking a business, either its products or waste streams, with other businesses to increase sustainability, reduce ecological footprint, or create added value for the product
        - Enriching CO2 using atmosphere from a brewery or heating a greenhouse using waste heat from a power plant
- Consider sustainability/resilience as a fourth pillar of the disease triangle
- Should greenhouses still count as CEA?
    - These structures lack the control that an indoor farm has
    - They moderate the environment, not control it

Action Points

1. List criteria for the standard and define the terms
2. Assess a metric for each category
3. Build a point or tier system for the metric and try to use it to make judgements about various examples of CEA practices in the industry
4. Item 0: assess interest from people at the conference and gather their names for inclusion in future actions
5. Item 1: schedule meetings and invite participants from academia, industry, and government
6. Item 2: assign leadership and organizational structure
7. Item 3: apply for funding grants for the organization and detail a plan of action for creating the standard

CEADS Discussion

a. Need to construct a planning grant proposal to support the effort of creating a system/standard for CEADS

b. City planning organizations may want to lend support

c. Possible criteria for the standard: nutrition, safety, locality, energy, water, waste, equity, symbiosis, IPM, innovation, automation, labor, land, footprint, loop closure
d. Stakeholders for points of actions: Matt Liotta, Weslynne Ashton, Jess Buncheck

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A-1-6-1. Engineering Breakout Session

Recorder: N/A

Date: September 11, 2019

Participants: Gene Giacomelli, Murat Kacira, Erico Mattos, Ralph Fritsche, Dinah Dimapilis, Dung Duong, Tharindu Weerante, Matt Bergen, Genhua Niu, Shumin Wang, Bob Morrow, Fei "Jeff" Jia, Kale Harbick, Dave Hanson, Wythe Marschall

General Topics

LEDs

1. Industry is close to the asymptote of LED performance. There are engineering challenges with installation
    a. Consider the lifetime of LED lights; is there a loss?

    b. Fixtures around LEDs break

    c. Lifetime of LED fixtures is dependent on thermal. If kept low, LEDs can last hundreds of thousands of hours- LEds don't die, they just degrade

    d. Horticulture requires a certain level of light

2. Degradation is higher than expected
3. Greenhouse environments are harsh on Led lights due to salts,
sun, etc. 4. Packaging of LED lights is an issue
5. Engineering thermal load issues for LED lighting systems
6. HPS bulbs should be replaced every year to maintain light output
7. Move to sensors rather than becoming burned out on LED lights

8. Consider the importance of economics
9. Climate controls can reduce operational costs of greenhouses by making real time adjustments of climate factors like lighting, CO2, etc.

Wavelength

1. How can the right wavelength be defined? Is it a challenge?
    - a. If a specific wavelength is not defined, it is not possible to replicate tests or use data
    - b. Groups are working on developing standards
        - i. Define what is considered blue light
        - ii. AJ Both at Rutgers University has proposed a more rigid definition for wavelength in scientific papers
2. Average users- when BML was founded, users could choose between 1.5 billion combinations of light spectra- most growers want to be told what spectrum to use
    - a. Uniformity is key amongst growers
    - b. Growers are using what is normal, not what is best. Market potential is winning out

Breeding for Light

1. Further research is needed on how plants are responding. Biomass is one thing, increasing yield is another. Consider quality, flavor, nutrition, and plant response to water
    - a. Counterpoint: breeders should be the ones to fix the plants
2. What is the cost of plant breeding?
    - a. It is an optimization issue. Under broad spectrum, a plant will grow, and narrow bands lead to tweaks
3. Breeding towards automation
4. Add parameters on the end of the plant cycle
5. Some people can grow under artificial light and tune lights; others can not.

Polyethylene high-tunnel grower versus fully automated glass grower?

  a. Cannabis is roughly $1000 per square foot per year; specialty food is $10; tomato is $7; field you're down to $4 or 5. Engineering has to hit an ROI.
  b. Great to have things that can only work with cannabis, but to make it useful for food, has to bring $1000 per fixture down to $200. HPS is $140 per fixture in bulk. LEDs aren't going to be that cheap. How much electricity savings are facilities really getting? Squeeze every penny out of the total system to provide the technology to everyone.

Integrated Control Systems

a. Integration challenges

  i. Mainly a cost problem; how can enough AI be deployed for facilities to get the data they need while still being cost effective?

1. There is a gap between research and production controls

2. Temp, humidity, HVAC engineering that needs to be done

3. How can sensors be cost effective enough to improve data yield and plant yield?

4. Nutrient analysis needs further research; no improvements in recent years ii. Quantum sensors are good, expensive but high quality.

Plants-Sensing and Controlling

a. Non traditional sensors: Mar Van Lersel a UGA is looking at fluorescence as sensors

  i. Plants respond to CO2; they are going to change their photosynthetic efficiency ii. Same thing with nutrition, needs to be monitored with sensors that are effective

b. What should facilities do with this data?

  i. Control systems differ per customer- it is assumed that all needed sensors are available, but this is not certain

ii. Red Hawk Precision: hyperspectral sensors mounted on a drone for large greenhouses

iii. NASA is deploying a hyperspectral sensor for plant health; what is to be done with this data? What target parameters are meaningful? How much time will it take to get something into space that is meaningful?

1. Autogrow is using static sensors of plant leaves NDVI
2. NASA has to do it with uni gravity and then deploy microgravity with different radiation

c. Standards: difficult to consider that recalibrations will be necessary within AI systems i. Spectrums change throughout the day

d. Lack of uniformity in photometrics

i. The more variables that need to be changed, the less generalizable it will be

ii. Need granularity, take a picture, do a chemical analysis

iii. Photometrics are meant for field application; a certain distance is needed

1. All LEDs are lambertian- 1:1 ratio is the rule of thumb. Optic lenses will change these projections
2. Consider distance of canopy to LEDs

iv. Designers can decide to tilt lights, light inter-canopy. There are many standards for this distance, but not short applications

1. Flat-plane integration? At a specific distance?
2. Can be done in a lab for one fixture, but application distance must be known
3. Should distance be standardized for indoor facilities

a. No, a suite of techniques for mapping is needed

Smart Sensors/Non Traditional Sensors

a. Inline sensors for nutrients: ion-specific (membrane) sensors- Korea seems to be the most advanced

i. Phytofarms used to use them, but never has much lock with it because of high maintenance needs. If calibration isn't possible, it isn't good.

ii. Customers would like this idea

iii. Alternatives are flame photometry, big instruments, tissue analysis, spot checking…

iv. An engineering solution hasn't been created for smart sensors yet

v. Indoor agriculture needs this type of technology, not outdoor agriculture

vi. Iowa state created an ion-specific sensors, however it may not be robust enough vii. Miniature spectrum fluorimeters, small scale flow cytometers, etc.

Sensors for Microbes

a. Consider different CEA production methods: space, greenhouse, VF

i. In space, the only different requirement is gravity independence and robustness

b. There is a valley of death between things in the lab and products that come out commercially

i. How sensitive can sensors be? How many parts per billion?

ii. Can sensors look at microbes that are precursors to biofilm? Yes

iii. Canadian company is chipping genes of microbes, looking for pathogens

iv. Gas chromatography are created to find dangerous compounds in air- would be nice to apply this to water if possible

v. The technology exists but is not being brought to market

c. For space, biofilm buildup is important

i. Biofilm can consume nutrients or release CO2

ii. Oil industry has answers for biofilms, but not for agriculture

Developing New Sensors

a. A list needs to be created of sensors needed by the horticulture industry

b. GLASE will propose a national greenhouse database: starting with lighting and moving on to other topics, data will be collected from different growers to identify points of improvement. One issue is that growers may not be transparent

  i. How can farmers live without these sensors?

  ii. GLASE will provide quantification of data

c. Direct plant sensors, new measurements of biochemistry, are needed. Currently, the industry must wait until harvest to track sugars and other chemicals

  i. Hyperspectral can be used to do BRIX

  ii. Even people growing the same crop for the same organization have different needs based on their goals and expertise

d. Start with Big Data

  i. Simple continuous sensors are going to be easier to deploy

1. Current commercial scale sensors: CO2, air, EC/pH, leaf temp, leaf wetness

  ii. Need to integrate modeling to interpret data with AI. Develop a model to help detect abnormalities before they are visible to humans

  iii. Need something to share data automatically

  iv. Need to standardize how data is shared within the industry as well as how data is formatted

    1. Same thing with GLASE, guidelines are needed

  v. How can growers be convinced to use a new plant or buy a new sensor? People have to want to use the sensor and see the benefits

    1. For growers, how much ROI is needed for what is being produced? For space, the issue is limited by physical space and limited resources

Standardizing Sensors

a. Changing just some spectrum will change the plant visibly. Standardization is needed towards white light because it is more visible. There is a lot of variation amongst cultivars and species

   i. ASAB, DLC, and Intertech are looking into these standards. Engineers will follow what is suggested- a proposal should be created

b. It is important to pay attention to averages of temperatures- leaf temperatures differ significantly due to cloud cover

c. Necessary light sensors: light, water, nutrients and other salts, other toxins, pathogens in the water

d. Types of sensors: fluorimeters, ion-selective, microbial, CO2

A-1-6-2. Engineering Breakout Session (Day 2)

Recorder:

Date: September 11, 2019

Participants: Murat Kacira, Dave Hanson, Kale Harbick, Erico Mattos, Fei Jia, Phil Sadler, Bob Morrow, Shumin Wang, Dung Duong, Matt Bergen, Genhua Niu, Tharindu Weerarante, Wythe Marschall

General Topics

Test Facility (Biosphere 3) for Benchmarking

a. Focus should be on making solutions affordable for farmers. Hyperspectral is expensive and very technical. One suggestion is to set up a 1-2 acre research greenhouse and test what parameters actually matter in terms of production.

Based on that data, develop low-cost, easy-to-use sensors for growers

   i. Compare performance of sensors

b. Is it worth considering standards? Need to consider who would manage the standards.

c. Benchmarking needs to be focused on- it ties in a lot with the greenhouse database (GLASE). Beyond lighting, it can be applied to energy and resource use in general. Can be used to compare energy usage within different facilities.

d. Important to define biomass- it is automatically included in the resource use efficiency equation. Do growers care about dry weight?

e. Computational fluid dynamics is more complicated- it gets right to the problem of airflow and is a good tool for quantifying and qualitatively evaluating

f. It would be difficult for a research grant to establish something so complicated with so many sensors

   i. Researchers need to have access to data generated by farms to integrate multiple data sets

g. Consider centralized test beds to collect multiple sets of data

Modeling Energy Prices

a. The industry has a patchwork for energy regulations- it is very complex, even for an expert to analyze the cost structure of energy

b. Cheap natural gas is available right now, but it likely won't always be c. How much energy needs can be met using solar? Perhaps all of it?

d. Geothermal and co-gen may have a lot of potential- especially in terms of saving on costs e. Models need to be varied with real world data

   i. Vertical farms do not provide much data- a system needs to be anonymous to encourage growers to share data

   ii. Being able to correlate data over a whole grow season or year is important iii. If a greenhouse database is funded by the USDA, growers may be more willing to participate

            1. More people would need to be interested in the idea for the USDA to fund it

Populating Databases, Validating Models

- a. The Caliber Project tests lighting facts for LEDs used by facilities. They verified numbers that facilities were putting out there. No longer operating because they ran out of funding
    - i. Manufacturers do not publicize all their information- there is more information for domestic than horticulture. People need to pay for photometry information
- b. Lighting Facts for horticulture is needed- people are working on this
- c. Is there a need for a new database, or can the industry pull from an existing database?
    - i. As long as outcomes are the same, the industry can define how to collectively tap into another resource
    - ii. Must be simple for growers to adopt- on the other hand, many people agree that the growers are not responsible for handling the database
    - iii. A new benchmarking tool is needed
    - iv. Consider that anonymity is key
- d. Benchmarking and energy collection could be the goal. Get data from real facilities and couple it with modeling
    - i. Portfolio Manager is used in the commercial world to compare buildings ii. Many people do not want to be honest on the input of market data, but everyone wants the output

1. They will be paying for something that everyone lied to produce

    - iii. Stakeholders need the participation of energy companies and lighting manufacturers
    - iv. Market research studies are accurate overall

CEA: A New Phytotron

- a. How many benchmarking facilities? Will facilities have one HVAC system and one lighting system? Is it a multiple environment?

  i. Multiple systems from high to low tech. The location is a significant factor strategy can be compared when the site, layout, and climate is known

b. Evaporative pads can be used in AZ but not in GA

c. Driving down cost of overall technology, including sensors. How to engineer the best technology at a level that can be adopted.

  i. A system needs to be engineered that is cost effective

d. Like a cyclotron: a user facility that people apply to every year

e. Help everyone who participates in the industry and show transparency on how tax dollars are spent

f. UW Biotron rents space off to the industry for a higher fee to do material testing

g. Testing plant varieties for CEA: a facility like this would be able to test 100,000 tomato lines, looking to dwarf varieties from different accessions, looking for the 20 that may work, breeding them for commercial production. It is a resource for everyone

h. Consider a phenomics lab for plant nutrition and food safety testing

i. Automation should be a secondary thing. It is easy to automate a system that is relatively stable. In some cases it can be a parallel effort, but it usually is not. When the size of plants to harvest is changed, automation of robotic harvesting becomes an issue.

  i. Controls go hand-in-hand with sensors

j. How much will automation cost? Grant and other money for this exists; the low ranges are $65 million, the high are $100 million+. It depends on what the facility wants to include

  i. The bayer greenhouse was 7 acres, $100 million, including labs

    1. $400/square foot

  ii. High-tech research greenhouses are $300/square foot. As the scale goes up, price goes down

  iii. Bayer facility is not fully censored, they do not have microclimate sensors

k. Location: AZ and NM need to be considered as important locations for greenhouses

  - i. Somewhere northern and somewhere southern- somewhere sunny and somewhere cloudy
  - ii. Has to be associated with good people and good universities

l. Maybe the goal is one system that can be put in multiple locations with a lifetime of 20 years

  - i. Upgrades and modifications can be done

ii. Facilities can identify a grand but quantifiable goal, a la Human Genome Project

    1. Need to know which sensors will bring down cost first

Testing Hardware

a. Are crop-specific sensors wanted?

  - i. Should work on multiple crops with economic value

b. Instrument packages: come up with interesting sensors and loan them out to industry people to test out

  - i. Quantum sensors would be purchased and a nominal fee would be needed to ship them to facilities
  - ii. Either be funded through rental fees or self-funded

c. Covering materials

  - i. Luminescent solar concentrator: changes how the greenhouse behaves and condensation patterns

d. Not much work being done in the U.S. for coloring materials

  - i. Saves money on beneficials

Light Control

a. A lot of people are trying to get rid of solar and go with electric or total light control

b. Commercial companies do not have a lot of good options for light control

Materials Testing

a. Getting commercial growers to do testing is a big risk. If it goes poorly as R&D, it can ruin a facility

b. Universities used to do testing for facilities

Overlaps

a. Synergy with economics- sometimes engineers do not pay much attention to the costs b. Nutrition: controlled by light

c. Food safety: sensors provide useful data

d. Industrial ecology: costs of transport of goods/products. Siting near talented students vs. helping people in a food desert

e. Plant breeding: canopy architecture and spectrums.

  i. Seed banks

  ii. Holistic crop models

  iii. Collaborating with academia

A-1-7-1. IPM Breakout Session

Recorder: N/A

Date: September 10, 2019

Participants: N/A

General Topics

Precision agriculture

a. AI drones for spraying

  i. Limitation for vining crops

        ii. Cadillac of AI spray: detect insect, determine which insect, spray accordingly b. Use drones to release beneficial insects?

  c. Lasers to prune off diseased insects?

    i. Ohio State tried, but did not obtain grant money

LEDs

- a. LEDs to reduce use of pesticide
- b. Combining technology in vertical agriculture- incorporate pest-killing LEDs c. Philolux

Sprays/Pesticides

- a. IR-4 expansion to biological controls
    - i. Needs to be easier to study in CEA
- b. Consider market differentiation

Seed Testing and Treatment

- a. Hand treatments, treatments other than heat

Healthy Microbiomes

- a. Testing irrigation water for microbes present
- b. How to build up microbial resilient community
- c. How long does adding microbiological components affect the rest of the community? d. How do LEDs influence the microbial community?
- e. Reusing substrates- increase microbial community and therefore improve plant defense against disease?
- f. Addition to silicone to irrigation
- g. Issues: difficult to evaluate when treatments are proactive and preventative

Production of Secondary Metabolites

- a. Flavonoids- boost production in plants via quercetin powder
    - i. Can increase reproductive behavior in ladybugs, which is biological control

        for many pests
    ii. Aphids can be repelled from plants, pushing away from plant but pulling in natural enemies
    iii. Honeybees can also be benefitted

Genetics and Breeding

a. Conventional for resistance

b. Enhanced interactions between plant and bio control

c. CRISPr

    i. Manipulated pests

    ii. Plants

d. Are pollinators needed?

    i. Mechanical pollination

    ii. Pollination without bees leads to smaller fruits- vibrating leads to less seeds in fruits and less fruit drop

    iii. Crop dependant

A-1-7-2. IPM Breakout Session (Day 2)

Recorder: N/A

Date: September 11, 2019

Participants: N/A

General Discussion Points

- There is a challenge for facilities to stay clean

- Clavibacter as a leading challenge; viroids- phytosanitation issues, spread by aphids; rugose virus in seed material
- Additional mechanical transmission or with pollen, one infected plant can destroy the entire crop production system
- Growers are staying silent about issues, making it difficult to identify the source of infection
- Sanitation and certified seeds
- Many growers do not care about diseases as long as yield is good
- Spot treatments, automated scouting, improved scanning methods
- Increase tolerance of varieties
- Symptoms on the leaves but yield does not have to be effected
- Immunity build into the crop-plants ca recover
- Plant irradiation during the night killed undesirable microbes but did not kill the plants themselves- what about beneficial organisms as biocontrol?
- Give options to growers, provide technology and information
- Utilize gene editing technology CRISPr- silencing genes, no transgenic modifications ● Boost immunity

A-2. Conference attendees and institutional affiliations.

Participant Name	Affiliation	Position
Adams, John	University of Arizona	Deputy Director Biosphere 2
Allen, Lee		Freelance Journalist
Allgeyer, Allie	University of Arizona	Graduate Student
Amitrano, Chiara	University of Naples Federico II	Graduate Student
Ashton, Weslynne	Illinois Institute of Technology	Associate Professor
Atland, James	USDA-ARS	Research Leader
Baez, Arturo	USDA-ARS	Biological Science Lab Technician
Bai, Jinhe	USDA-ARS	Research Plant Physiologist
Bartelme, Ryan	University of Arizona	Postdoctoral Researcher
Barto, Neal	University of Arizona	Research Specialist
Bergren, Matt	UbiQD	Chief Product Officer
Bledsoe, Michael	Village Farms	Vice President of Food Safety and Regulatory Affairs
Boe, Stephanie	Bayer Crop Science	Engagement Lead
Boldt, Jennifer	USDA-ARS	Research Horticulturist
Bonine, Kevin	University of Arizona	Director Biosphere 2
Bonner, Charlotte	University of Arizona	Graduate Student
Brandt, Rosemary	University of Arizona	Media Relations Manager
Budenheim, David	NASA	Senior Research Scientist

Bunchek, Jess	Kennedy Space Center	Plant Scientist
Burgess, Shane	University of Arizona	Vice President for Agriculture, Life and Veterinary Sciences
Cambardela, Mario	City of Atlanta	Urban Agriculture Director
Ceaser, David	Agritecture	Lead Agronomist
Chung, Justin	University of Arizona	Graduate Student
Colangelo, Robert	Green Sense Farms Holdings, Inc.	CEO/Founding Farmer
Craver, Joshua	Colorado State University	Assistant Professor
Cutelle, Matthew	Clemson University	Assistant Professor
Denten, Matthew	Mastronardi Produce Ltd.	Assistant Grower
Dickens, Megan	Bayer Crop Science	Protected Culture Production Lead
Dimapilis, Dinah	NASA	Project Manager
Dragony, Megan	University of Arizona	CEA Program Coordinator
Duong, Dung	Fluence Engineering	Chief Innovation Officer
Farrell-Poe, Kitt	University of Arizona	Department Head of Agricultural and Biosystems Engineering
Federman, Sarah	Plenty	Research Scientist
Finley, John	USDA-ARS	National Program Leader
Fritsche, Ralph	NASA	Senior Project Manager
Garcia, Karla	HortAmericas	Technical Advisor
Gauthier, Paul	Princeton University	Assistant Professor
Gellenbeck, Sean	University of Arizona	Graduate Student

Gernhart, Ken	Greenhouse Vegetable Consultants	Director
Giacomelli, Gene	University of Arizona	Professor
Gomez, Celina	University of Florida	Assistant Professor
Groose, Robin	University of Wyoming	Associate Professor (retired)
Gruener, Raphael	University of Arizona	Professor
Harbick, Kale	USDA-ARS	Research Agricultural Engineer
Hardwood, Edward	AeroFarms	CSO
Harris, Jennifer	Cornell	HR Generalist II
Heintz, Robert	University of Arizona	Graduate Student
Heward, Samantha	University of Arizona	Graduate Student
Jacobson, Stewart	Arizona Department of Agriculture	Food Safety Projects Coordinator
Janisiewicz, Wojiech	USDA-ARS	Research Plant Pathologist
Jia, Fei “Jeff”	Heliospectra AB	Technical Solutions Manager
Kacira, Murat	University of Arizona	Professor
Karlsson, Meriam	University of Alaska Fairbanks	Professor
Lebate, Joanne	USDA-ARS	Molecular Biologist
Lefsrud, Mark	McGill University	Associate Professor
Legaspi, Jesusa	USDA-ARS	Research Entomologist
Lewis, Myles	Arizona Vegetable Company	Grower
Licamele, Jason	Bayer Crop Science	Discovery & Optimization Lead
Ling, Kai	USDA-ARS	Research Plant Pathologist

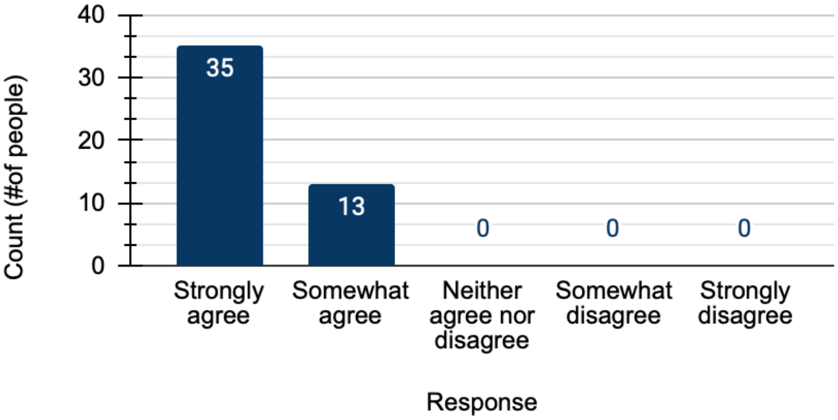
Lingard, Matthew	Bayer Crop Science	Marana, AZ Site Lead
Liotta, Matt	Agrify	Chief Technology Officer
Mahato, Tilak	University of Arizona	Research Assistant
Marschall, Wythe	Harvard University	Graduate Student
Massa, Gioia	Kennedy Space Center	Project Scientist
Mattos, Erico	GLASE	Executive Director
Mattson, Neil	Cornell University	Associate Professor
McBride, Penny	FarmTech Society	Vice Chair
McCreedy, Glenn	Inara	Founder and CEO
McKinney, David	Colorado State University	Graduate Student
Monje, Oscar	Kennedy Space Center	Research Scientist
Montoya, Steven	Crop One	Senior Vice President
Morrow, Robert	Sierra Nevada Corporation	Principal Scientist
Munyaneza, Joseph	USDA-ARS	National Program Leader (Specialty Crops)
Naasz, Remi	Premier Tech Horticulture	Scientific Expert Director
Newman, Steven	Colorado State University	Professor
Niu, Genhua	Texas A&M	Professor
O’Hara, Sabine	University of the District of Columbia	Professor & PhD Program Director
Pancerz, Magdalena	Cedar Valley Farms	Director of Research and Development
Pantaleo, Jim	Indoor AgCon	Indoor Vertical Farm Operator
Parrish, Charles	University of Arizona	Graduate Student

Pattinson, Morgan	Solid State Lighting Services	President
Pawar, Sangita	University of Arizona	Vice President of Operations
Poleatewich, Anissa	University of New Hampshire	Assistant Professor
Pryor, Barry	University of Arizona	Professor
Ranger, Christopher	USDA-ARS	Research Entomologist
Reich, John	Foundation for Food and Agriculture research	Scientific Program Director
Riddick, Eric	USDA-ARS	Research Entomologist
Ruiz, Joaquin	University of Arizona	Professor
Sadler, Phil	Sadler Machine Co.	CEO
Sanchez, Pedro Andradre	University of Arizona	Associate Specialist in Agricultural Biosystems Engineering
Shasteen, KC	University of Arizona	Graduate Student
Shelton, Chaz	Merchant’s Garden AgroTech	CEO
Simmons, Alvin	USDA-ARS	Research Entomologist
Sinclair, Brady	Backyard Farms	Grower
Smith, Austin	Grodan	Commercial Account Manager
Spencer, LaShelle	Craig Technologies	Scientist
Stommel, John	USDA-ARS	Research Leader
Storey, Nate	Plenty	Co-Founder and CSO
Stutte, Gary	Kennedy Space Center	Principal Investigator
Swartz, Joe	AmHydro	Vice President
Taylor, Gail	UC Davis	Professor and Department Chair

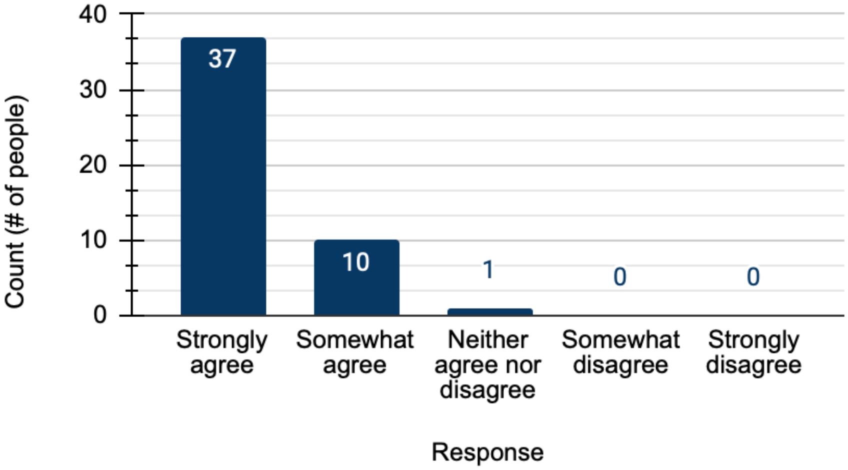
		of Plant Sciences
Tifft, Karin	Greenhouse Vegetable Consultants, LLC.	Consultant for Integrated Pest and Disease Management
Tollefson, Stacy	University of Arizona	Professor
Valle de Souza, Simone	Michigan State University	Assistant Professor
Wahlgren, Bradley	Bayer Crop Science	Science Fellow
Waller, Rebekah	University of Arizona	Graduate Student
Wang, Shumin	National Institute of Biomedical Imaging and Bioengineering	Program Director
Weeraratne, Tharindu	WayBeyond Ltd.	Director of Crop Science & Agronomy
Wetcher, Patrick	USDA-ARS	Research Plant Pathologist
Wheeler, Raymond	NASA	Plant Physiologist
Wilder, Corinne	Fluence Bioengineering	Vice President of Global Commercial Operations
Williams, Clinton	USDA-ARS	Soil Scientist
Zankowski, Paul	USDA Office of the Chief Scientist	Agricultural Science Advisor
Zhang, Ying	University of Arizona	Graduate Student

A-3. Post-conference survey responses

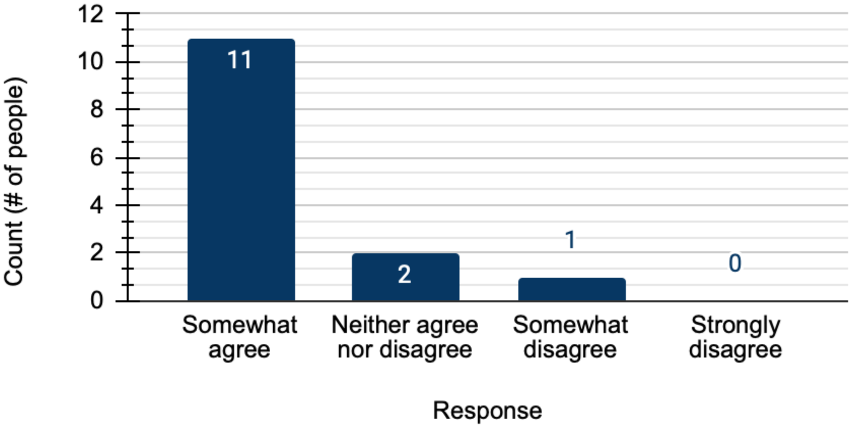
The conference as described in the announcements met my expectations



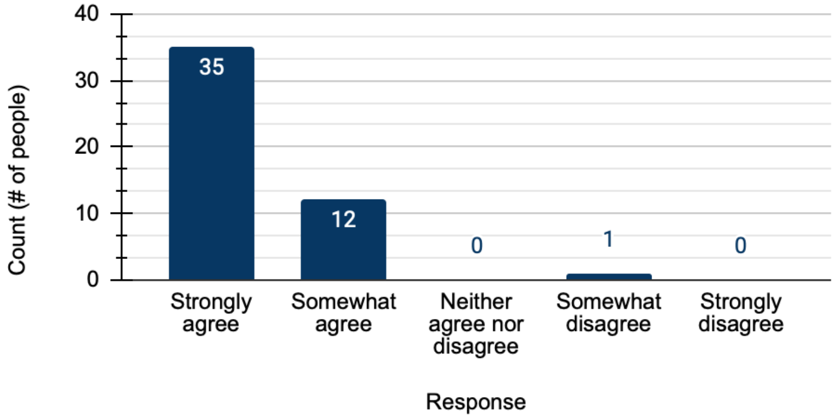
The conference themes were appropriate



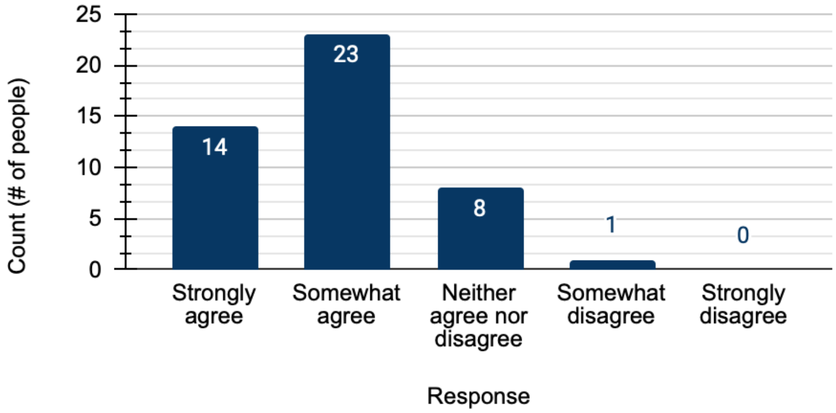
The speakers provided content and information on CEA that was relevant to my work or studies



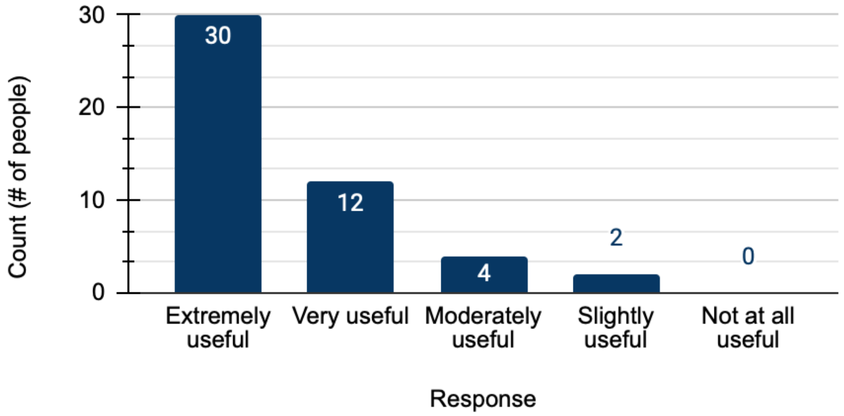
The LED research presented by the speakers will change how I conduct my own LED research



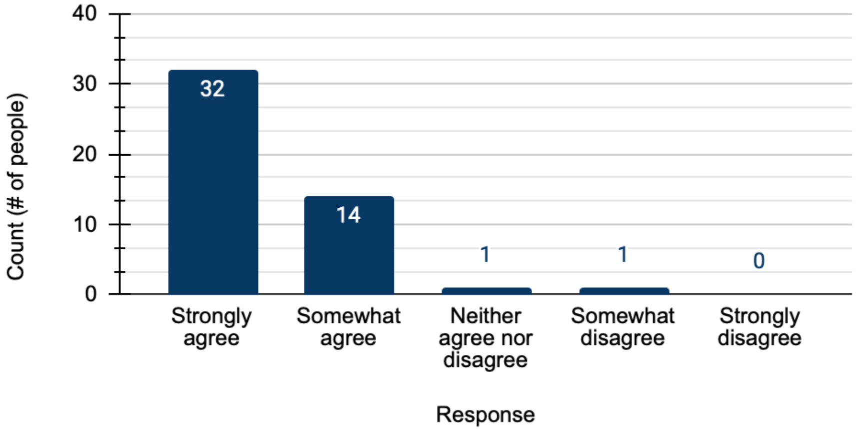
The CEA content presented by the speakers will change how I conduct my own CEA research



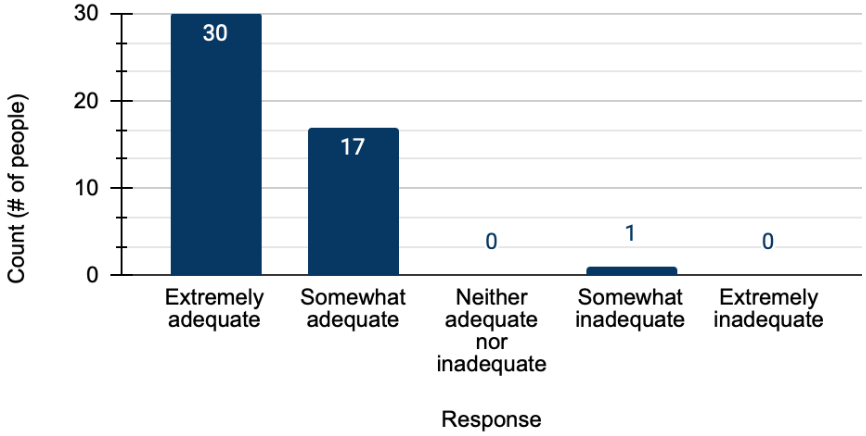
The CEA content presented by the speakers will be useful to the industry



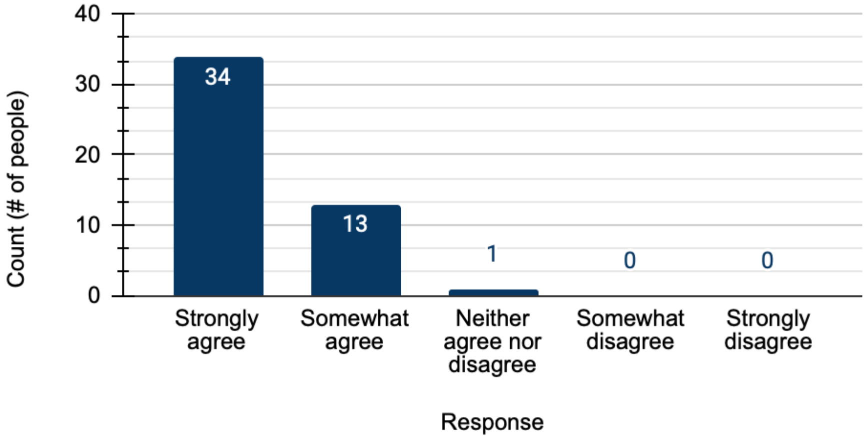
The format of the thematic sessions, keynote, invited speakers, panel presentations, followed by discussion, was effective



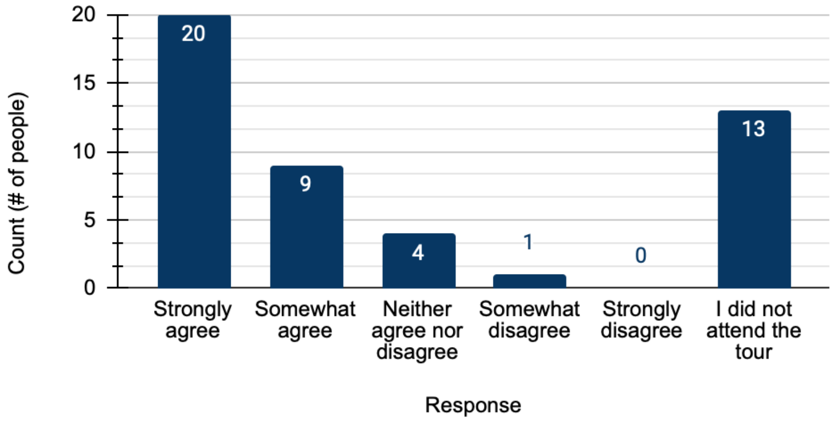
There was adequate time allocated for CEA in each thematic area



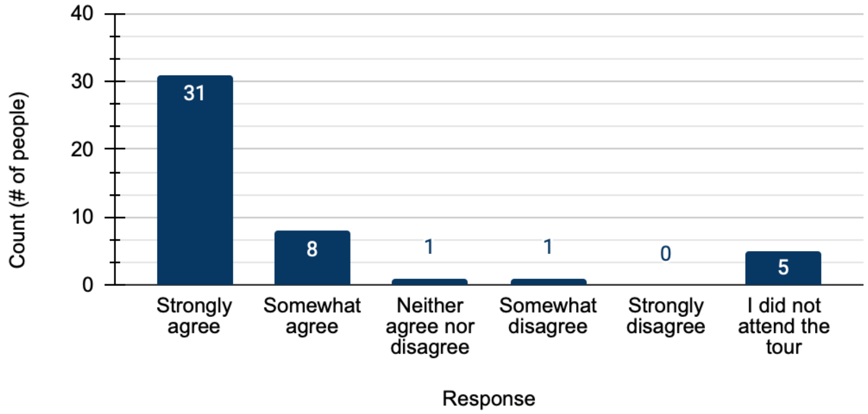
The afternoon breakout sessions for discussions within the themes were of value, allowing me to provide my input and t…



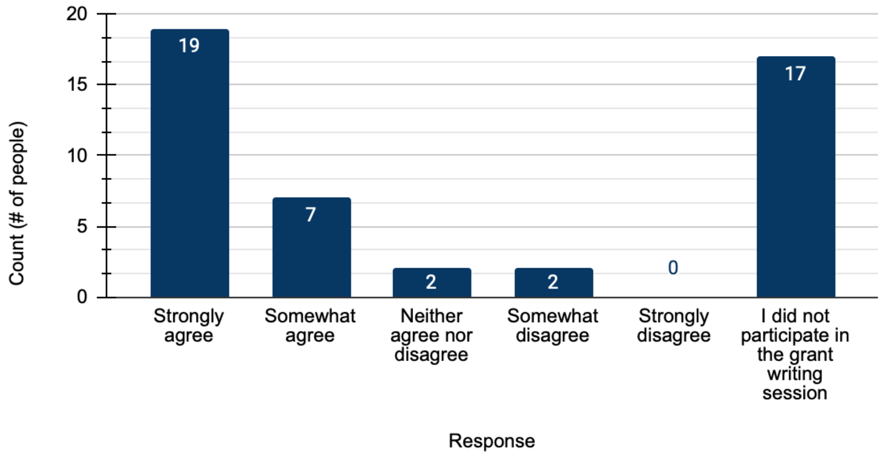
The pre-conference tour of the Bayer greenhouses was an important part of this conference



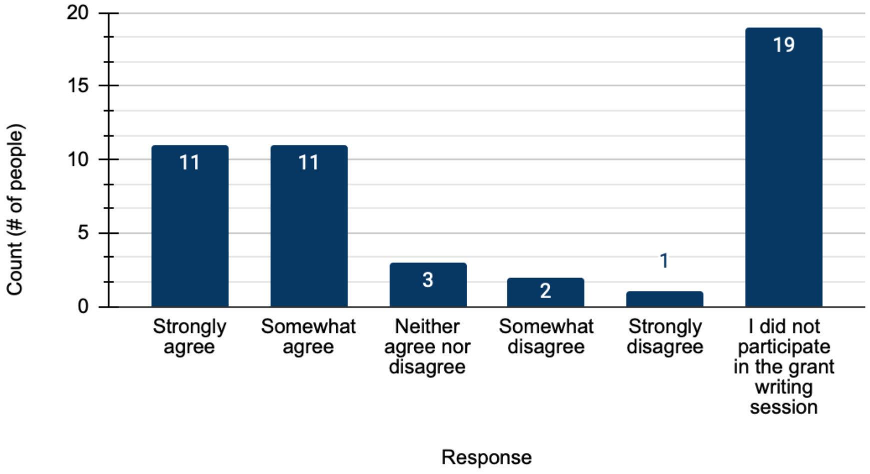
The tour and BBQ at the Controlled Environment Agriculture Center (CEAC) at the University of Arizona was an important part of this conference



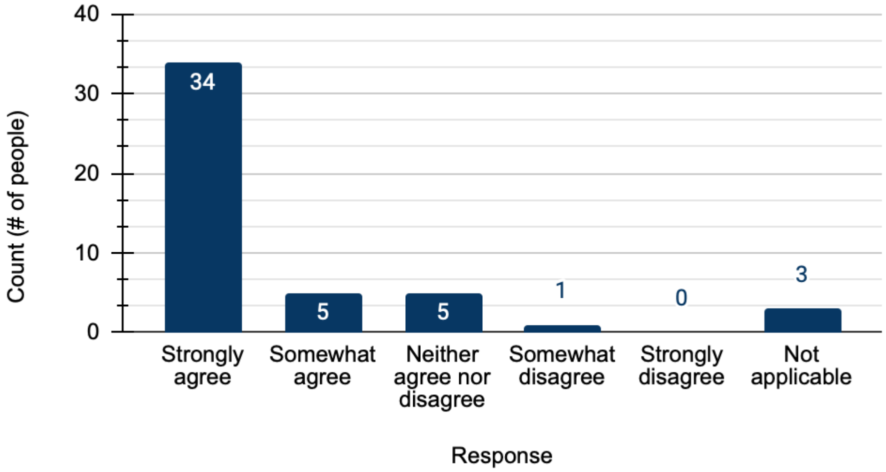
The post-conference grant writing session was an important part of this conference



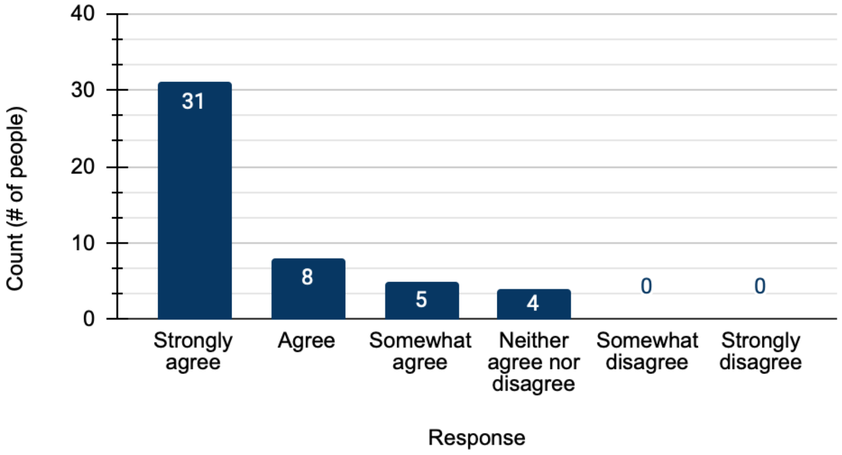
The format of the grant writing session was effective



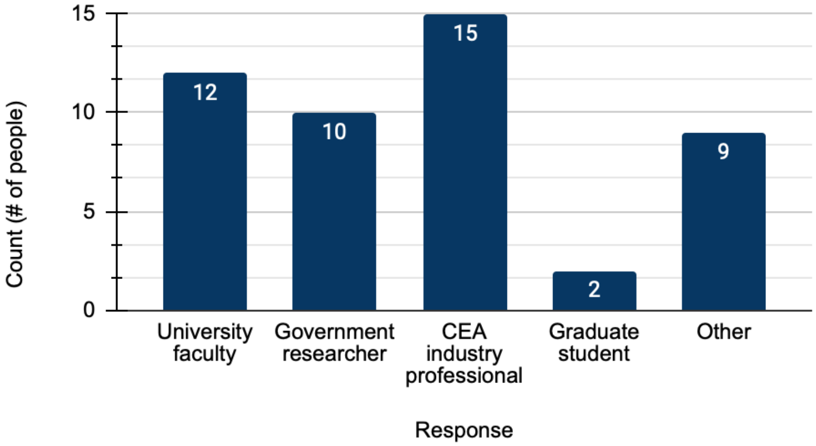
The registration cost to attend the conference was appropriate



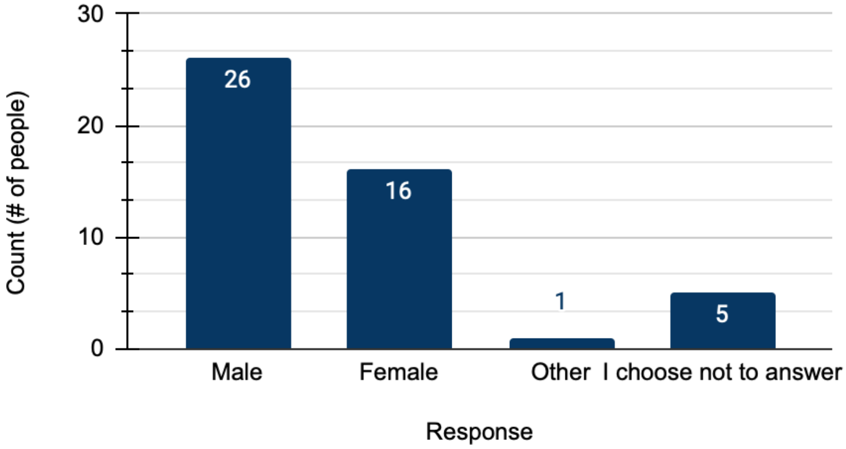
The local arrangements were sufficient for my needs



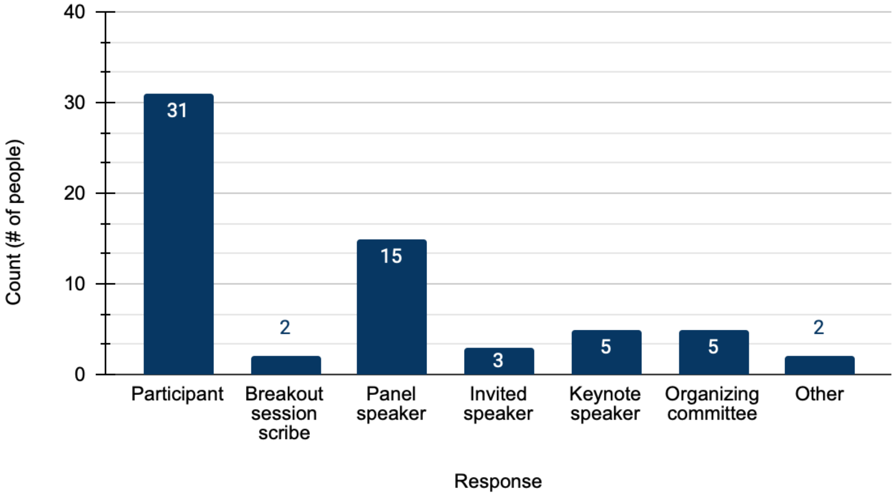
What is your role or position?



Gender



What was your role at the conference?



A-4. Controlled Environment Agriculture Design Standards (CEADS) informational documents

A-4-1. CEADS One-Pager

CEADS

CONTROLLED ENVIRONMENT AGRICULTURE DESIGN STANDARDS

WHAT IS CONTROLLED ENVIRONMENT AGRICULTURE?

Controlled Environment Agriculture (CEA) is a technology-based approach to farming that aims to create ideal conditions for plant growth while optimizing the use of resources such as space, water, and nutrients within controlled environments. Advances in cultivation, climate control, and lighting technologies, combined with the need to reduce resource consumption in agriculture, are making CEA an increasingly critical component of our global food system.

WHY CEA STANDARDS?

Despite the advantages of CEA compared to conventional field-based farming, CEA enterprises face a number of obstacles to maintaining both profits and consistent, high-quality yields. The CEA industry is still young, which means there is ample opportunity to influence the design and operation of CEA systems to be more efficient and profitable, as well as environmentally and socially responsible. These criteria are not tradeoffs - all can be accomplished simultaneously through good design, operation, and management strategies.

ABOUT CEADS

Objective

The Controlled Environment Agriculture Design Standards (CEADS) set industry benchmarks and guide CEA enterprises in improving the design and performance of their operations, considering economic, environmental and social dimensions.

Mission

CEADS enable growers to become leaders in the CEA industry through recommending standard best practices for the design and operation of CEA enterprises.

WHO IS BEHIND CEADS?

CEADS was initiated in September 2019 at the USDA/ NIFA Az-CEA Conference, where CEA professionals from the private sector, government, and academia recognized the need to define goals for the advancement of the CEA industry. CEADS members contribute their knowledge, expertise, and networks toward the development and implementation of CEADS.

PROFITABLE
SUSTAINABLE
RESILIENT

CEA DESIGNED TO LAST

THE CEADS FRAMEWORK

CEADS encompass the management of energy, water, materials, byproducts, pests, safety, and finances. Growers can obtain recommendations in the following seven CEADS Domains:

- Utilities
- Materials & Waste
- Crop Quality
- Integrated Pest Management
- Automation & Labor
- Equity & Localness
- Profitability

HOW DOES CEADS CERTIFICATION WORK?

CEADS are voluntarily adopted benchmarks and practices. The application process for CEADS certification involves self-reporting by the CEA enterprise of the facility's fulfillment and commitment to CEADS requirements. Based on the number of points achieved, CEA facilities can be certified at one of four levels: *Certified*, *Seeded*, *Rooted*, and *Cultivated*.

BENEFITS OF CEADS CERTIFICATION

- Industry-vetted, peer-reviewed design standards
- Validations for the enterprise market
- Positioning of sustainability that improves reputation with consumers, retailers, and business partners

For more information on the CEADS project, our members, and how you can get involved, please visit our website: **https://ceads.ag**

PAST, PRESENT, AND FUTURE OF CEADS

SEPTEMBER 2019
CEADS formation

OCTOBER 2020
https://ceads.ag
launch

JANUARY 2021
CEADS v0.9
internal review

FEBRUARY 2021
CEADS v0.9
external review

MARCH 2021
CEADS v1.0
beta launch +
pilot program

MAY 2021
CEADS v1.0
publication

A-4-2. Reference Guide for CEADS standards

CEADS REFERENCE GUIDE

This document provides summary information on the scope and topics covered in the Controlled Environment Agriculture Design Standards (CEADS), specifically for the CEADS v0.9 completed for external peer-review prior to publication.

PROJECT OVERVIEW

CEADS establish a comprehensive framework of best practices and industry benchmarks for the design and operation of CEA facilities, aligned with the economic, environmental, and social dimensions of sustainability. CEA enterprises can utilize CEADS to guide the entire planning, design, construction, and expansion phases of their growing facilities, enabling long-term business success and a more resilient CEA industry overall.

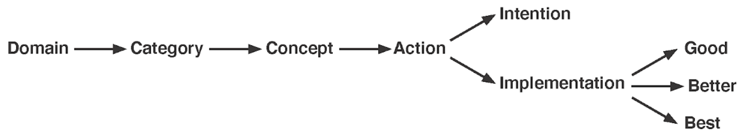
SEVEN CEADS DOMAINS

The standards include seven CEADS Domains that encompass the management of energy, water, materials, byproducts, pests, safety, and finances. While the goals of each Domain are distinct, in concert these categories represent a complete picture of sustainability for CEA enterprises:

- **Automation and Labor (A+L)**
  The balance of the effective use of automated technologies with human labor in CEA facilities in order to increase crop productivity sustainably and ensure worker safety and wellbeing.
- **Materials and Waste (M+W)**
  The reduction, reusage, and recycling of resources used in CEA facilities in order to maximize output per input and minimize the negative environmental impacts of CEA.
- **Utilities (U)**
  The effective and efficient use of electrical, water, and energy resources in order to achieve energy and cost savings in a sustainable manner.
- **Crop Quality (CQ)**
  The knowledge and management of crop health and safety in the growing environment in order to produce CEA products that exceed consumer and retailer expectations on a consistent basis with traceability.
- **Integrated Pest Management (IPM)**
  The incorporation of prevention and mitigation measures to control the presence of plant and human pests in CEA facilities while fostering environmental stewardship and sustainability.
- **Profitability (P)**
  The development of holistic business models for CEA enterprises that can serve both the short-term and long-term financial goals of the company.
- **Equity and Localness (E+L)**
  The mutualistic relationships between CEA enterprises and their employees, other businesses, and the communities in which the facilities operate.

CEADS FORMAT

Each CEADS Domain contains recommended actions and strategies for implementation. The recommended actions are thematically organized, and the strategies for implementation are ordinally ranked as *Good*, *Better*, or *Best* to indicate the relative effectiveness of each strategy in meeting the goal of the recommended action. All Domains utilize the following format to organize content:



OVERVIEW OF CEADS DOMAINS

Domain	Topics Covered	Number of Actions
Automation and Labor	control of rootzone and aerial environment conditions; production processes; system maintenance; worker health and safety	40
Materials and Waste	infrastructural materials; growing operation materials; product packaging and transport; runoff management; organic/inorganic waste management	18
Utilities	energy sources; energy storage; water sources and storage systems; electrical lighting systems; CO_2 sources; HVAC systems	17
Crop Quality	crop safety requirements; crop nutritional/chemical quality; plant health management; post-harvest product quality; traceability	16
Integrated Pest Management	pest identification; outbreak prevention; pest mitigation; outbreak management; pest data recording and sharing; system safety	15
Profitability	site selection; crop type selection; supply chain and distribution channels; labor; business structure; financial practices; economic tradeoffs	24
Equity and Localness	siting decisions; stakeholder engagement; employment; economic development; community and business relationships	14

A-5. Input From No-Profits, Private Industry and Stakeholder Groups

There were 41 non-profit, private industry, academic and stakeholder group members involved in meeting coordination and planning, who provided letters of support.

- Aerofarms, Ed Harwood
- Aerofarms, David Rosenberg
- Plenty Unlimited, Nate Storey
- Green Sense Farms, Robert Colangelo
- Sananbio-UA-Oasis Biotech, Jim Pantaleo
- Merchant’s Garden, Chaz Shelton
- Gotham Greens, Jennifer Frymark
- AVC, Myles Lewis
- WGVa, Robert Brot
- HortAmericas, Chris Higgins
- GRODAN, Austin Smith
- Signify (Philips), Ron DeKok
- GVC, Ken Gerhart
- GVC, Karen Tifft
- AmHydro, Jenny Harris
- FarmTec (Engineering Services and Products Co), Mike Briotta
- Premier Tech Horticulture, Remi Naasz
- Ridder-Hortimax, Wil Lammers

- Argus Control, John Provens
- Fluence, Dung Duong,
- CEA Cornell, Neil Mattson
- Tech News Frontiers Arizona, Michael Munday
- Coalition for Sustainable Organics, Lee Frankel
- Newbean Capital, Nicola Kerslake
- NCERA-101 – Executive leadership and membership (R. Kanwar - Advisor, M. Lefsrud - Chair, N. Yorio, R. Morrow, M. Romer, E. Runkle)
- NE-1335 – membership (R. Dickson - Chair, UNH, R. Brumfield, Rutgers University, C. Kubota, Ohio State University, R. Gates, UIUC, A.J. Both, Rutgers University, P. Ling, Ohio State University, C. Gomez, University Florida, R. Rhodales, University Connecticut, S. Burnett, University Maine, H-J. Kim, Purdue University, Ellen Paparazzi, University Nebraska-Lincoln, Ricardo Hernandez, North Carolina State University)