Rensselaer Polytechnic Institute

A Guide for 21st century CEA

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Lighting Leadership Spring 2021

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01. Introduction to Greenhouse21 and 21st Century Technologies

Introduction

The last 20 years of this new century has brought an immeasurable amount of change to our workplaces, our society, and our daily lives. The invention of the Internet has connected us to each other in ways never thought possible, and has created technologies and processes that have changed the world forever. Greenhouses are no exception. Greenhouse21 is a student project aimed to provide growers and other Controlled Environment Agriculture (CEA) professionals with coping mechanisms to bring themselves and their organizations into the 21st century by utilizing all of the amazing technologies this new world has to offer. This document will walk you through some of these 21st century technologies that may be beneficial to your organization through a greenhouse use case, provide detailed information on new innovations in grow lights and sensor technology, and give you a crash course in community and ecosystem development to ensure your greenhouse(s) are built for sustainability.

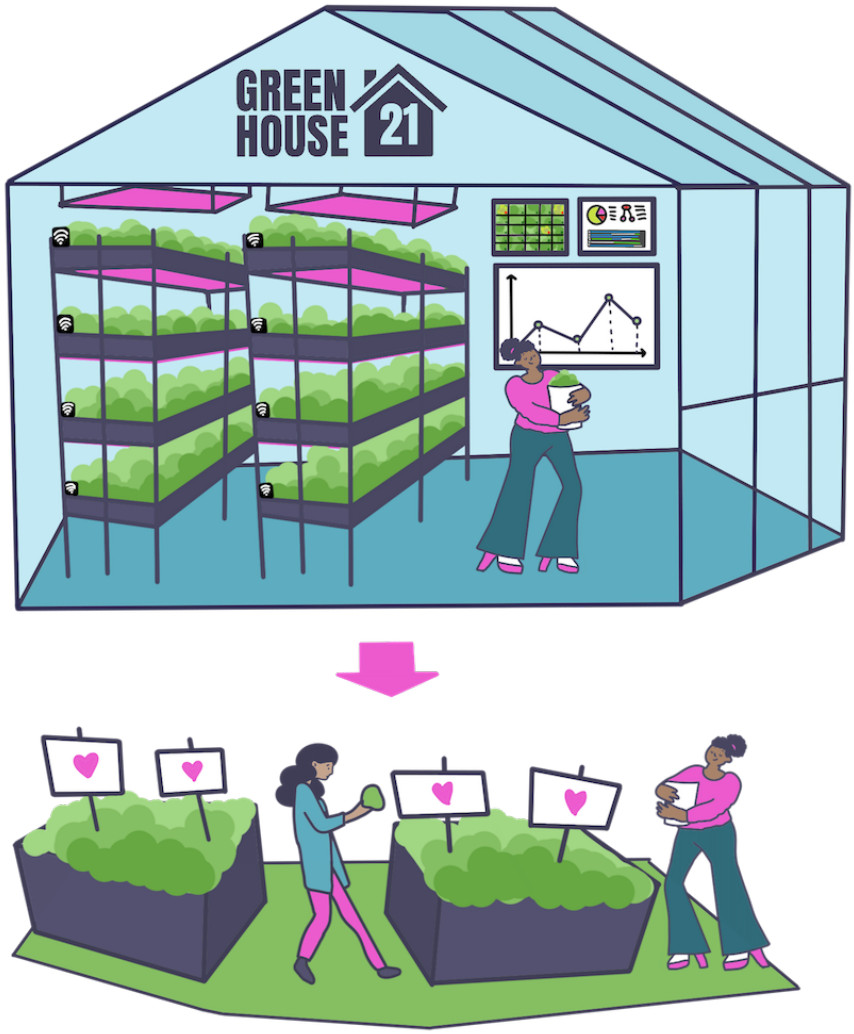
The 21st Century Greenhouse

Use our web tool to see the different components of a 21st century greenhouse, including advanced sensors, a data analytics dashboard, LED grow lights, and how the greenhouse fits into the community.

21st Century Technologies for Your Greenhouse

ADVANCED SENSORS

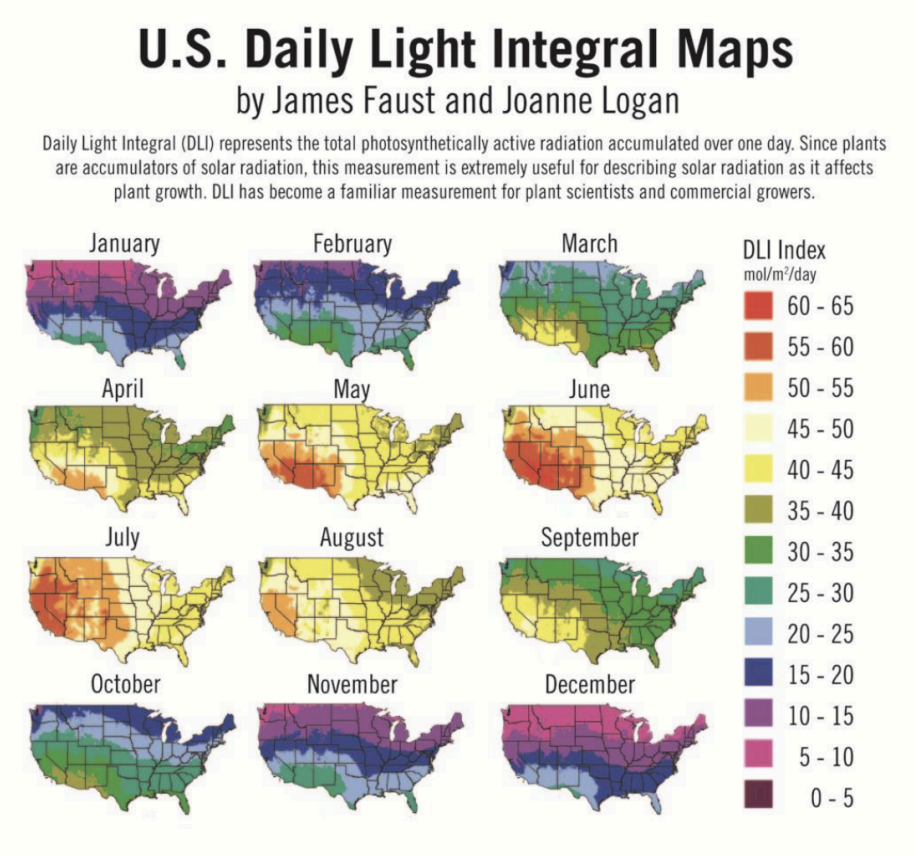
The Internet has become so prolific, and computer chips have become so inexpensive, it seems like everything nowadays is an internet-enabled device! What do you think of when you think about internet-enabled devices? Traditionally, you might first think of your computer and your phone, but with the rise of the 'Internet of Things' (IoT), it's not just our personal devices that are connected to the internet, but also our 'things,' like our thermostats, our doorbells, our lightbulbs, and sometimes even our refrigerators. In the greenhouse, it pays to be connected.



Having humidity, temperature, camera, and other advanced sensors can help you monitor your greenhouse in a more effective manner. Sensors are explored more in detail in the next section, “Horticultural Lighting for Controlled Environment Agriculture."

DATA DASHBOARD

Once you set up sensors in your greenhouse, those sensors are going to start generating data. This data is valuable, and can help monitor your greenhouse in real time, and spot trends over time that you can then use to make your business better, but your data can only work for you if you know how to work with it. When data becomes too large for you to handle using traditional data analytics (like spreadsheets), we call that ‘Big Data.’ Big Data needs special analytics to be



processed. One common big data analytic is 'Artificial Intelligence.' Artificial Intelligence, or AI, uses advanced computing to accomplish tasks that might be too time-consuming or arduous for a human to do. When handling your data, especially if you're using artificial intelligence, you'll need a lot of computing power. If you need big, powerful computers but don't want to manage them onsite, you can use 'Cloud Computing.' In Cloud Computing centers, engineers manage tons of computers that you can pay to connect to and use, so that you don't have to manage the maintenance of those computers yourself. The information and algorithms you store with Cloud Computing platforms, like Amazon Web Services (AWS) or Microsoft Azure, is often said to be in 'The Cloud.'

LED GROW LIGHTS

New innovations in lighting technology have made LEDs (Light Emitting Diodes) customizable, affordable, and energy-efficient. LED grow lights can be customized to provide certain types of light that can provide different outcomes for crops. For instance, changing the color used by the grow light can create crops that are shorter or taller, have smaller or larger leaves, have different fruiting outcomes, and more. LED grow lights are explored more in detail in the next section, "Horticultural Lighting for Controlled Environment Agriculture."

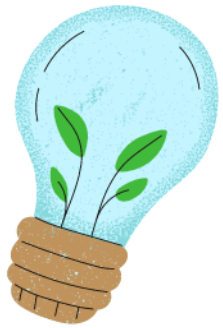
Conclusion

Tackling this brave new world of 21st century technologies is a big task for all industries, but with some dedication to learning and open-mindedness, you can use these technologies to create a more sustainable, cost-effective, and better greenhouse for your business and your community.

MORE RESOURCES FOR 21ST CENTURY TECHNOLOGIES

- Video: "Explained: How the Internet Works"
- Video: "Big Data In 5 Minutes"
- Article: "What Is Cloud Computing?"
- Article: "Using AI to Maximize Yield and Efficiency"
- Article: "Connected greenhouses: how the Internet of things can feed the planet"
- Article: "The internet of greenhouse things"
- Article: "Artificial intelligence: A digital brain for your greenhouse"

02. Horticultural Lighting for Controlled Environment Agriculture



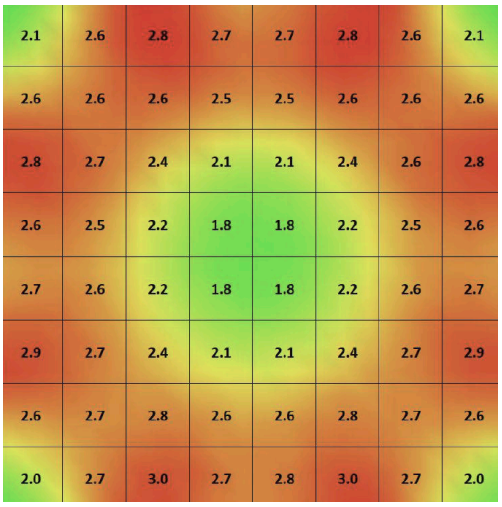
Controlled Environment Agriculture

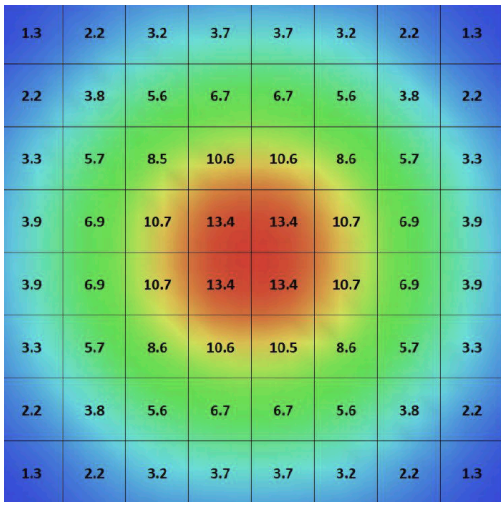
Why Controlled Environment Agriculture

The global population is expected to reach 9.7 billion by 2050, and to feed everyone, it is estimated that agricultural production will need to increase by 70%. There are several reasons why people may look more and more to controlled environment agriculture to meet these needs.

CLIMATE CHANGE

Rising temperatures and unpredictable weather - from floods to droughts - makes growing food using traditional outdoor methods increasingly unpredictable. Some crops will no longer be able to grow in areas where they traditionally have been cultivated as this gets worse. Controlled environment agriculture (CEA) provides a more reliable and predictable setting that will be less affected by the changes of a





warming planet.

INTEREST IN LOCALLY GROWN FOOD AND CONCERNS ABOUT PESTICIDES

Consumers have demonstrated increased interest in both locally grown and organic food. CEA provides a method to grow food locally that could not grow locally in an unprotected environment. With CEA, a consumer could buy a locally grown tomato in the middle of winter in New York City.

In traditional agriculture, the overuse of pesticides and fertilizers can build up and contaminate the groundwater. CEA offers more controlled conditions free of environmental contaminants. It also offers increased opportunities for novel approaches to pest management that do not rely on pesticides or herbicides.

BENEFITS OF ADVANCED CONTROLS

CEA offers the opportunity to fine-tune factors for plant growth to optimize yield. Temperature, humidity, CO2, and light can all be tracked and optimized to increase yield in different crops

Different Types of Controlled Environment Agriculture

Controlled environment agriculture can take many forms: rooftop greenhouses, vertical farming, interior growth environments, low-tech high tunnels, and variations of these connected to retail environments.

Current Players in the Field

- Gotham Greens in New York City started with the first commercial-scale rooftop greenhouse in the US with a facility in the Greenpoint neighborhood of Brooklyn in 2011. They have since expanded to nine farms across the United States. They grow salad greens and herbs.

- Plenty is a start-up that wants to build a vertical farm next to every major city. Plenty claims to be able to fit the equivalent of 1,500 acre farm in the size of a local grocery store, and grow up to 350 times more.
- AeroFarms is a vertical farm in Newark that currently harvests up to 2 million pounds of food each year. The farm was recently profiled in The New Yorker magazine. They claim to use less than 1% of the land used by conventional farms for the same harvest. They hope to expand their model to vertical farms around the world.

What is "light" for plants?

PAR vs "Light"

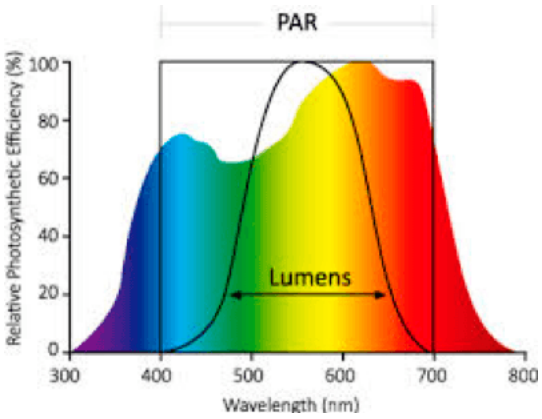
Light is defined explicitly based on the human's eye sensitivity to a certain band of electromagnetic radiation that produces a visual response. Plants, of course, do not have the exact same sensitivity as the human eye. "Light" for plants is defined as photosynthetically active radiation (PAR): in other words, radiation that plants are capable of using for photosynthesis.
While light for humans is weighted by spectrum, based on experiments on the eye's sensitivity to light of different wavelengths. PAR covers a similar area of the spectrum (400-700 nm) but is not weighted by wavelength.

Important Terminology for Quantifying Light for Plants

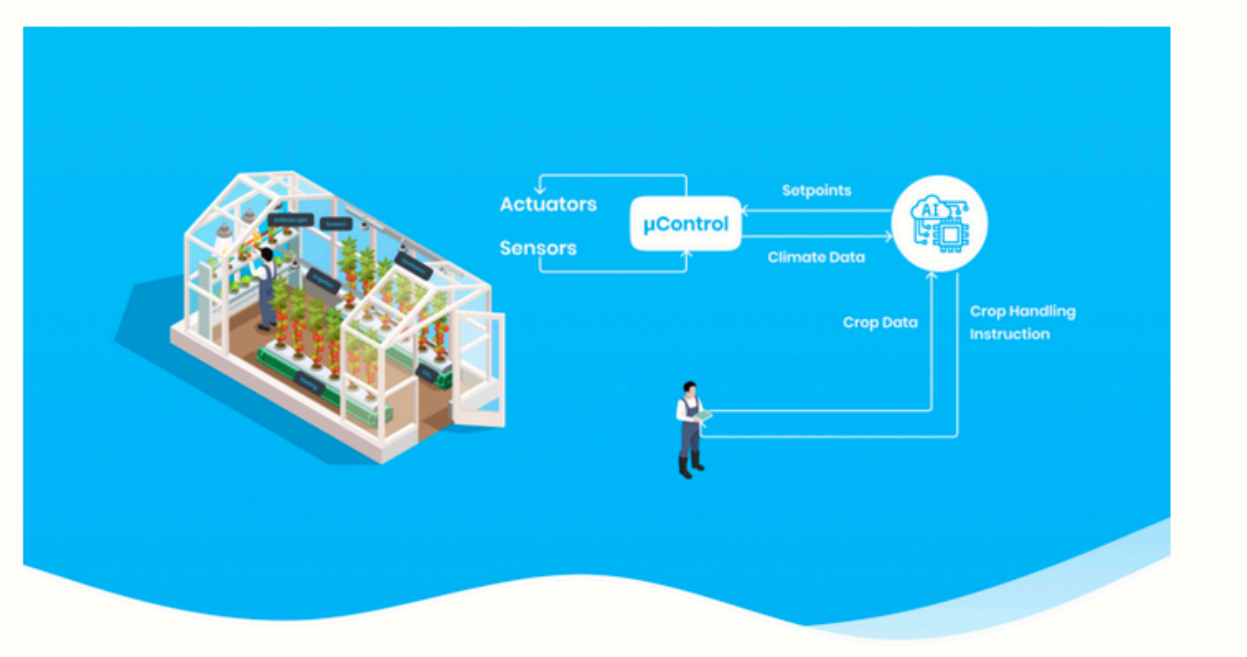
Photosynthetic photon flux (PPF) describes the light output of a fixture in the PAR region. It allows one to compare the overall output in the PAR region of one fixture to another.

Photosynthetic photon flux density (PPFD) describes the PPF incident in a one-meter square area. The units are micromoles per meters square per second (µmol/m2/s). It is analogous to illuminance measured in lux for humans.

Daily light integral (DLI) describes the amount of PAR received during a day. While PPFD is an instantaneous measurement, DLI is a measurement over time. A higher PPFD over a shorter duration and a lower PPFD over a longer duration could have equivalent DLIs. However, growers can manipulate PPFD and duration to achieve different effects even while the DLI remains constant. For example, in "Promotion of lettuce growth under an increasing daily light integral depends on the combination of the photosynthetic photon flux density and photoperiod," researchers found that a DLI of 15.6 mol/m^2*d, plant mass was increased with lower PPFD and longer duration compared to higher PPFD and shorter duration.



However, this may change from plant to plant and the desired plant feature. Lettuce, for example, is grown for its leaves and discouraged from flowering when it



is grown for food.

Distribution and Uniformity

Distribution and uniformity is also very important for fixtures for plants. Two fixtures may have the same PPF output, but if one is more uniform it could be more effective. The less uniform version will give some plants too much light and other plants not enough. The system with the less uniform light might then need to be over-designed to compensate.

Photomorphogenesis

While PAR weights all wavelengths equally, different wavelengths can be used to control the shape and other characteristics of a plant. Manipulating the ratio of red to far red light can change plant shape. With a lower ratio of red light:far red light, stems elongate and leaves get bigger to try to capture more light. With a higher ratio of red light:far red light, plants are more small and thick, with compact growth.

CEA and Daylight

Supplementing Electric Light with Daylight

In greenhouses and high tunnels, daylight can supplement electric lighting.
Maps have been developed to show typical daily light integrals (DLIs) across regions of the United States at different times of year.

However, the light transmission of the greenhouse must be factored in (typically 35-70%). In addition, electrical lights that are hung above plants can physically block sunlight. Depending on the size and density of these lights, this can be a significant factor, and all these need to be considered when using daylight and deciding how much electric light must be used to supplement it.

During the summer months, one may need to apply shades if the DLI supplied by the sun is more than what would be healthy for the plant.

Natural Photoperiods

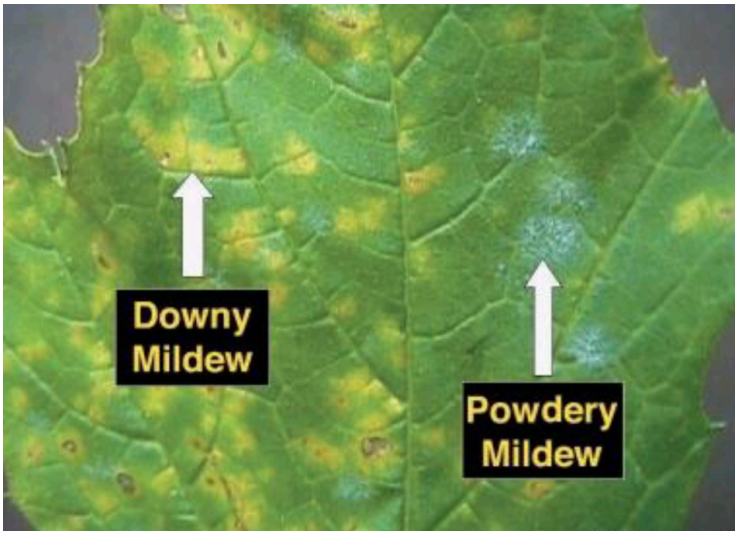
Plants have circadian rhythms also. These rhythms change throughout the year as the length of day and night changes, especially as one gets farther from the equator and these changes are more pronounced. There are both short-day plants, which flower when the day is short and night is long, and long-day plants, which flower when days are long and night is short. Cannabis is an example of a commercially important short-day plant. Spinach and lettuce are long-day plants, but for food growing purposes, these plants are not allowed to flower. Tomatoes and strawberries are examples of day-neutral plants, which can flower regardless of day length.

Pest Management

CEA does not eliminate plant pests and pathogens, it merely selects for what pathogens are adapted for the specific CEA environment (greenhouse, etc.). However, CEA does offer the opportunity to more easily implement pest management alternatives to traditional pesticides and herbicides. Ultraviolet radiation--usually referred to as ultraviolet light in the world of agriculture--can be used in CEA. There can be a 24-hour cycle, with PAR during the day, and UV treatment at night.

Common Plant Diseases and Pests

Powdery mildew and downy mildew are widespread plant diseases that are a concern in CEA. Powdery mildew thrives in moist, hot environments, so is particularly well adapted for greenhouse environments.



Powdery mildew is a fungus and is of particular concern in cucurbits, including squash, cucumbers, melons, and pumpkins. Downy mildew is of particular concern in grapes and other vegetables or fruit that grow on vines (including cucurbits). It can also be a problem for basil.

Treatment with UV Radiation

UV-B and UV-C radiation both damage DNA. UV-C is the most commonly used radiation in plant pest management. Damage done by UV is reversed by blue light and UV-A, which is why the UV-B present in sunlight does have the same effect. This repair system is not present in darkness, or in red light. Thus, UV pest management is generally performed at night.

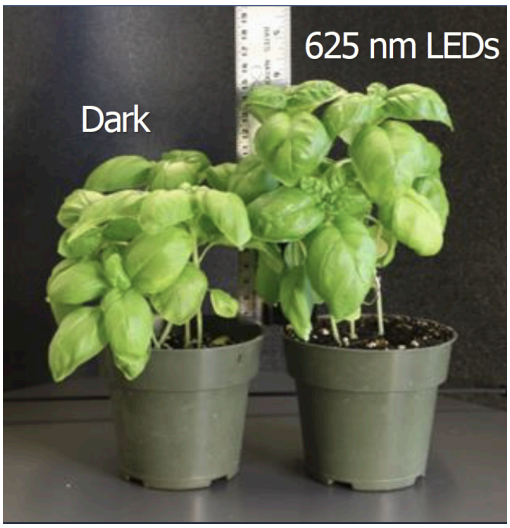
One of the major advantages of pest management with UV radiation is that while pathogens have quickly developed resistance to pesticides, they do not seem to develop resistance to UV, or at least not at the same quick rate. Another major advantage is that while pesticides leave undesirable residue on food, UV treatment does not.

UV dose is the product of irradiance (W/m^2) and time which is expressed as Joules per meter square (J/m^2). UV dose must be carefully calibrated for pest management in plants: too much can harm the plant, and not enough will not be effective.

A Lighting Research Center study "Nighttime Application of UV-C to Control Cucumber Powdery Mildew" found that application of either a lower dose (7.2 J/m^2) every night or a higher dose (7.2 J/m^2) every fourth night could both be effective without damaging the plant.

Treatment with Visible Light

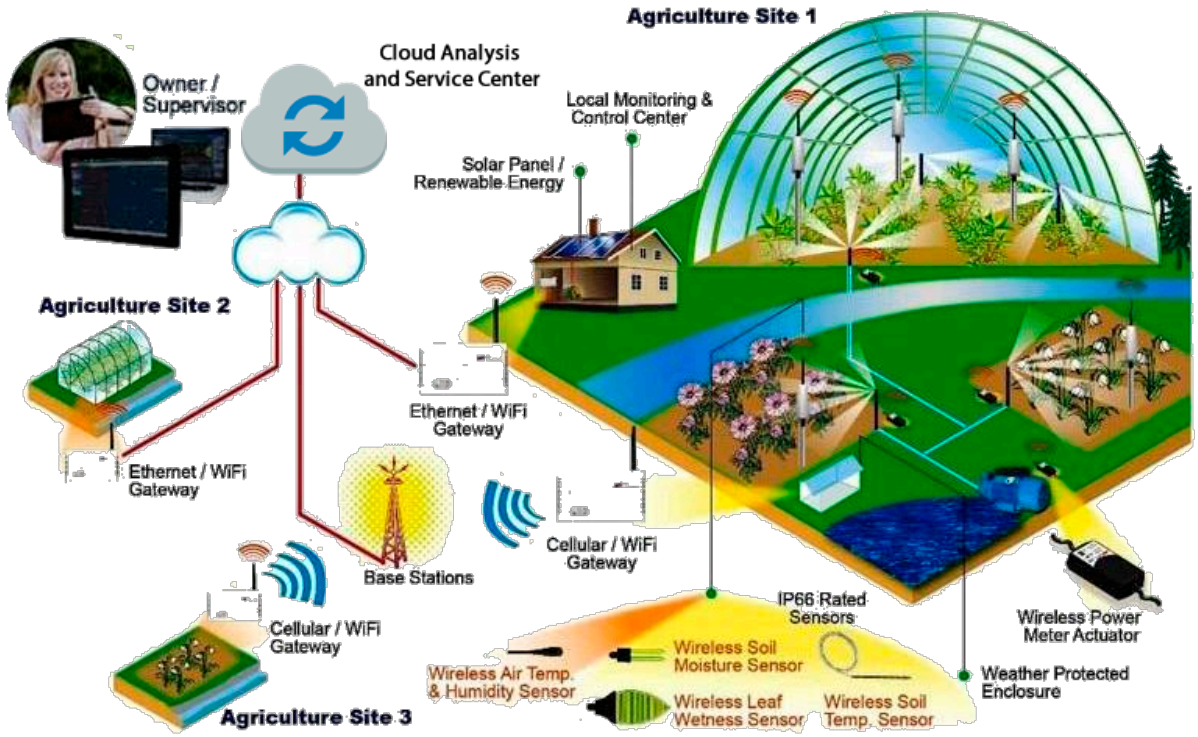
Another LRC study, "The value of red light at night for increasing basil yield" showed that red light alone at night could suppress downy mildew in basil and at the same time, increase yield.



Another area of developing research is the application of nano titanium dioxide (TiO_2) activated by visible light as a strategy for plant pest management.

Safety

UV radiation can damage human skin and eyes, so it is very important to take safety measure while working with it. Because it is not visible to the human eye, it can be



particularly dangerous if people do not realize they are being exposed to it. Thus, controls should be very clearly labeled and occupancy sensors should be used to ensure that it cannot operate when humans are present. When UV exposure is possible, all skin should be covered and safety glasses should be worn to protect the eyes.

Sensors

Controlled-environment agriculture can be optimized with advanced sensors to optimize plant growing conditions. A University of Georgia project on Smart Cyber-Physical Systems for Controlled-Environment Agriculture illustrates how all these technologies might come together.

Sensors can monitor environmental conditions (temperature, soil moisture, air humidity, carbon dioxide, and light) and make automatic adjustments to those

systems or send data to the supervisor for analysis. Monitoring and optimizing these conditions can help achieve food security by minimizing problems that cause fluctuations in supply.

In CEA systems where electric light is used in combination with solar light, photosensors can be used so that electric lights are automatically dimmed or shut-off at given levels to ensure that the desired daily light integral (DLI) is reached but that no energy beyond that is wasted every day. Cornell University developed Light And Shade System Implementation (LASSI) software controls to control both electric light and shade systems so that DLI is reached each day while maximizing energy efficiency.

Multiple parameters can have complex interactions. Researchers at Cornell studied the interaction between light and CO_2 levels. At a PPFD of 50 µmol/m2/s, there was little benefit to increasing CO_2 levels. At a PPFD of 50 µmol/m2/s, the net photosynthesis significantly increased when raising CO_2 levels from 400 to 675 ppm. There is little additional benefit when increasing to 950 ppm, and almost no additional benefit for increasing to 1225 ppm. As the PPFD increases, the CO_2 levels separate further but the overall benefit flattens out at higher PPFDs.

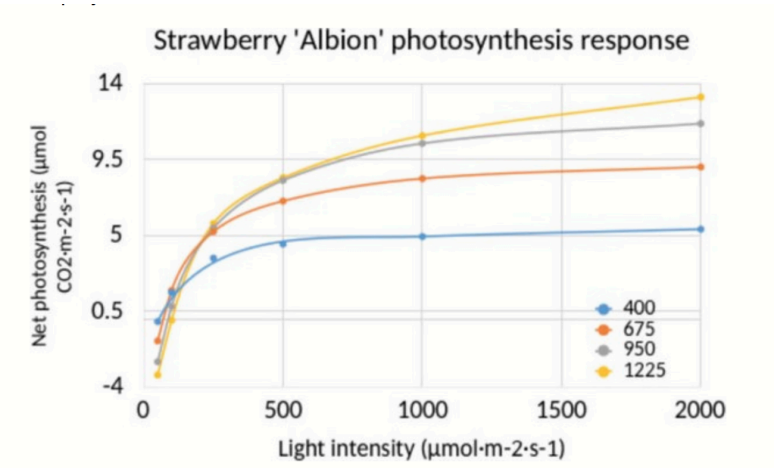


Figure 1: Photosynthesis of a single recently expanded leaf of strawberry 'Albion' in response to light and CO2. (Graph prepared by Jonathan Allred, Cornell University.)

In "Crop Management in Controlled Environment Agriculture (CEA) Systems Using Predictive Mathematical Models," researchers at the University of Naples suggest that data from sensors monitoring parameters such as plant yield and water use can be used to predict responses to environmental changes.

Koidra's mission is to use artificial intelligence, machine learning, and the internet of things to improve industrial automation, particularly in the world of CEA.

In 2018, they won first place in the Autonomous Greenhouse Challenge international competition. Five teams were competing to grow cucumbers: one consisted of experienced human growers and the other four teams consisted of AI specialists that managed their crops remotely and autonomously. (After Koidra, the experienced human growers came in second.)

While researchers believe that machine learning and artificial intelligence could be used to further optimize plant growth and increase yield, development suffers from a lack of centralized data. The Controlled Environment Agriculture Open Data project was developed to promote data sharing and advance research. The project is a collaboration between researchers from Ohio State University, Cornell's GLASE (Greenhouse Lighting and Systems Engineering), Koidra, Purdue University, and Plenty.

03. Community and Ecosystem Development

So, you want to help your community and combat food deserts? Great, we do too! You already read how technology and lighting can play a role in taking your garden or greenhouse to the next level, but before you can build the best, most advanced agricultural urban farm, it is just as important to consider how to develop the strongest community organization to help you accomplish your goals. This chapter guides you through how to effectively develop a successful urban farm organization by first laying some background knowledge of how food deserts are a public health problem and how to harness the effectiveness of co-opting some proven public health strategies when trying to launch your organization. This chapter will also go more in-depth for how to get started in building your successful organization, how to create a coalition, identifying partners and building relationships, and how to engage your local community and government, recruit members, and promote your organization through media partnerships.

The importance of using public health practices when organizing a community intervention

Where people live, work, and play affects their health

The environment where a person lives impacts their health. This notion not only includes the environmental pollution of the soil, water, and air that is located within a community, but also that the physical environment and layout. The physical environment influences a person's daily choices and those choices in turn affect the way that we live and behave and consequently impact our mental health, physical health, and weight. For example, persons who live in areas with inefficient public transportation, unsafe infrastructure, lack the means of being able to drive, and live in a location that is unsafe for pedestrians or cyclists are limited in their ability to purchase affordable and healthy groceries for their family. Furthermore, families

living in neighborhoods that are zoned exclusively for residential use must drive to work, school, and stores, because it is too far to walk or unsafe to walk. Communities that lack full-service grocery stores and neighborhood food markets have less access to fresh fruits and vegetables. These are just a few examples of how policies and the environment can affect what we eat and how we move, which in turn affects our health.

Framework for improving health and investing in your community

Consider the "what, where, who, and how" to help achieve the greatest impact for improving your community's health and well-being. WHAT: Know what affects health. Health is complex, influenced by the health care we receive, our own choices, and our communities. Some modifiable factors impact health more than others. Clinical care alone is not enough to improve community health. For example, socioeconomic status is the largest factor that impacts a person's health; followed by individual health behaviors, clinical care, and lastly physical environment. WHERE: Identify where there are vulnerable populations at greatest risk. Our health and well-being are products of not only the health care we receive, but also the places where we live, learn, work, and play. Our zip code can be more important than our genetic code. Ensure your efforts include programs to address vulnerable populations, as such programs and populations have the potential for the greatest gains. WHO: collaborate with others to create a collective vision and maximize efforts. The community health improvement process brings together health care, public health, and other stakeholders to identify and address the health needs of their community. Working together has a greater impact on health and economic vitality than working alone. Each sector in the community, including community members, has a unique role. It is vitally important to involve the community, represented by the "People" at the top of the circle above, as they bring critical strengths and insights to the collaboration. HOW: Implement interventions or initiatives that work across all 4 action areas for the greatest impact on the health and well-being for all. Choose an evidence-based, balanced approach to community health improvement that is based on shared priorities. Start by using interventions that work across all 4 action areas. Note that action in one area may

produce positive outcomes in another. Over time, increase investment in socioeconomic factors for the greatest impact on health and well-being for all.

Creating successful coalitions

A coalition is a group of people that has a shared purpose or affiliation. They are most likely all working together towards a common goal. Other coalition-like terminologies include advisory committees, useful for organizational assistance and technical support; alliances and consortia, groups/organizations with a common goal spread across a large geographical area; commissions, generally appointed for a specific goal or task; networks, which are loose-knit groups for sharing resources and information ; task forces, deployed for specific series of activities; and associations, defined as having formal structure, professional or common interest. Benefits of forming a coalition include, they are taken more seriously, makes your organization viewed as more creditable, particularly helpful for disenfranchised, especially when members of the coalition are members of the community,

encourages community participation, and valuable to agencies, because they decrease duplication of other local organization and decreases the likelihood of diversion of resources towards the same goal.

In order to form a collation, the Prevention Institute lays out an 8-step process for identifying effective coalitions: Analyze the program's objectives and determine whether there is a need to form a coalition; recruit the right people, devise preliminary objectives and activities, convene the coalition, anticipate necessary resources, develop a successful structure, maintain coalition vitality, and improve the coalition through internal and external evaluations.

A coalition is a prevention tool, so groups must be specific about what needs to be accomplished. After the needs have been determined, the group must consider if a coalition is the best approach to meet the identified needs. The group's objectives will prescribe the type of coalition developed. Some groups may choose to start small to accomplish specific tasks and then strategically expand. Depending on the needs of the coalition, either program directors or front-line staff should be encouraged to attend. In addition, invite community members, youth leaders, and politicians. The size of the group matters. It takes large groups longer to define and agree on common objectives and activities. Yet large groups may have access to greater resources that may be required for accomplishing certain tasks. A key to a successful coalition is the early identification of common goals and benefits of working together. The coalition must avoid competing with its members for funding. An important consideration for adopting specific coalition activities is to identify some short-term outcomes. A coalition can be convened at a meeting, workshop, or conference. The lead agency should plan the first meeting using a time-specific prepared agenda, a comfortable and well-located meeting area, and adequate refreshments. It is appropriate to prepare a draft mission statement and proposal for coalition structure and membership. Lead agencies usually provide staff time to keep the coalition up and running and to handle detailed work. Structural issues of the coalition include: how long the coalition will exist, meeting locations, meeting frequency and length, decision-making processes, meeting agendas, membership rules, and participation between meetings by subcommittees or planning groups. Methods for noting and addressing problems, sharing leadership, recruiting new members, providing training on identified needs, and celebrating success can help ensure a coalition's viability and success. Finally, Each coalition activity and event should include evaluations.

Strategies for Community Organization and Improvement

- What is a community organizer? The process by which people get to know each other.
- Community organizing: identify common goals, mobilize resources, develop strategies, and accomplish goals
- Why organize: to bring about change, empower the local community, increase self-sufficiency, and increase social support.
- Strategies for organizing: locality development, social planning, policy change, systems advocacy, and coalitions.
- Techniques for how to create change include involving the community, identifying the problem, reframing the problem as an issue, developing a strategy, developing tactics, choosing action steps, creating short-end wins, and continue working!

Identifying Partners and Building Relationships

Community coalitions consist of public- and private-sector organizations working together with individual citizens to achieve a shared goal through the coordinated use of resources, leadership, and action. Local governments have critical perspectives and resources to share with community coalitions aiming to prevent obesity by improving the local food and physical activity environment. So partnering with local municipalities, NGOs, for-profit businesses and organizations, and the local media can help with the impact of your urban agriculture organization. City Agencies/Local Municipalities include the Mayor's office, economic development departments, redevelopment agencies, the planning department, and community development departments. Go on your towns website to find the name, email, and phone number of the civil servant that will help you and your organization. Outside of the local government, you might find a plethora of nongovernmental organizations (NGOs) that would be more than happy to assist you in your ambitious task to start your own organization. Some NGOs include, community development corporations (CDCs), economic development corporations (EDCs), business technical assistance organizations, community benefits districts and business improvement districts, neighborhood associations and community groups, workforce/employment development organizations, community development intermediaries, and private business organizations (ex. Chamber of Commerce).

To find partners in the local government, the first step is to go to your local government website and research the city's structure, key players, and economic

development strategy (or lack thereof) related to healthy food and urban agriculture. Some questions to help guide your search: Who is responsible for economic development and what types of projects are they funding and not funding? Is the city targeting any specific neighborhoods for resources or redevelopment activities? Is healthy food needed in those neighborhoods? What are the priorities of local elected officials (the Mayor, city council, and county supervisors)? Do they have any special initiatives related to urban agriculture? Do the redevelopment agency's implementation plans highlight healthy food attractions? What are the city's goals for CDBG funds What is the city spending CDBG money on? When are there opportunities for citizen input on major development projects or neighborhood plans? What other resources is the city using for economic development purposes?

To find community partners the approach is similar to that above. First, visit the websites of local foundations and the organizations they are supporting. Banks also give community and economic development grants to local organizations, so talk to your local community development intermediary. Examples of local initiatives and community development intermediaries include Habitat for Humanity, Enterprise Community Partners, Low-Income Investment Fund, and Nonprofit Finance Fund. Next find out who is receiving public funds (CDBG, redevelopment, etc.) for economic development or healthy food work. This information is publicly available through your city's economic development or planning agency. Furthermore, redevelopment project areas must have citizen oversight through either a project area committee (PAC) or a community advisory committee (CAC). If your target neighborhood is located in a redevelopment area, reach out to the committee. Finally, check networking and social media sites online.

Relationships with the Media

The goal for establishing a reliable relationship with the media is to become an authoritative and credible resource for media professionals. To do this is it important to know media relations, which is knowing who to contact in the media, how to contact them, maintain open lines of communication, successfully deliver messages to the intended audiences, translate media relations into media advocacy. Media Advocacy is the strategic use of media to advance an organizations objectives or goals. The way that the media presents the issue shapes how people will think about the issue. Imperative to frame the issue in a way that demonstrates its importance to the community. Some techniques for framing your message include: Change the way key decision makers and the general public look at the community issue. Create a reliable, consistent stream of publicity for your

program's key issues and activities. Explain how these problems could and should be solved. Motivate community members and policy makers to get involved. More information for successful media partnerships can be found at Media Access Guide (CDC Healthy Communities Program, 2009).