

# VERTICAL FARMING

A photograph showing a massive vertical farm system. Numerous white metal racks are stacked vertically, each densely packed with lush, green leafy vegetables, likely lettuce. The perspective is from a low angle looking up between the racks, emphasizing the height and scale of the operation.

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# In This Issue

4

Welcome from the Editor  
*Deborah S. Ray*

5

Vertical Farming: Engineering Solutions In Glass and Concrete  
*Grant Imahara*

6

Urban Farming: Where Technology Grows Along With Crops  
*Sylvie Barak*

12

Improving Energy Efficiency in Vertical Farms with Proper Electrical and Mechanical System Selection  
*Alex Misiti*

18

Controlled Environment Agriculture: Connectivity Boosts Crop Yields and Quality  
*Steven Keeping*

24

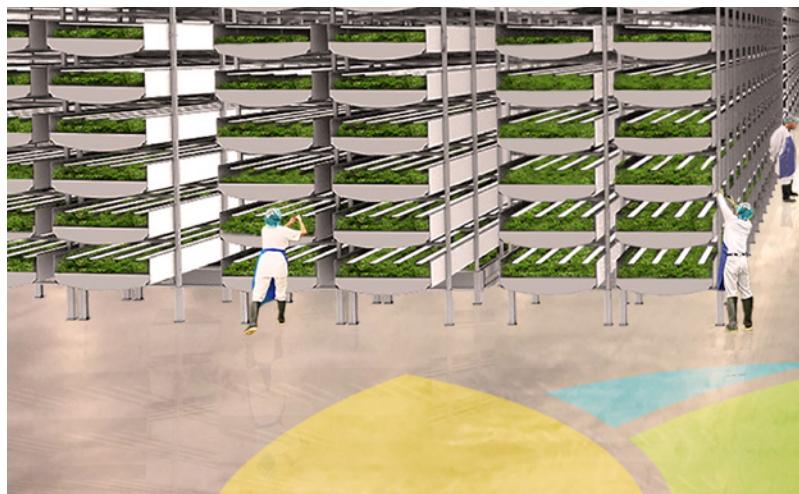
Smart Agriculture Sensors: Helping Small Farmers and Positively Impacting Global Issues, Too  
*Steven Schriber*

30

Harvesting New Ideas in Vertical Farming with Connected Intelligent LED Lighting Networks  
*Paul Golata*

35

Robotics Offer Boosts in Indoor Farm Efficiency  
*Rick DeMeis*



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# Welcome from the Editor

Imagine living in Babylonian times and being King Nebuchadnezzar's royal gardener tasked with building the hanging gardens of Babylon—if they did exist, that is—with their massive vaulted terraces raised one above another and with lush trees, plants, and vines spilling over its walls to create a green oasis in the middle of the desert. Transporting water from the Euphrates River up to the top of the gardens and watering the gardens in such a way that the water didn't damage the structure's mud-brick integrity probably seemed like a Herculean task, even with a chain-pump or screw-pump system that could have been devised at the time.

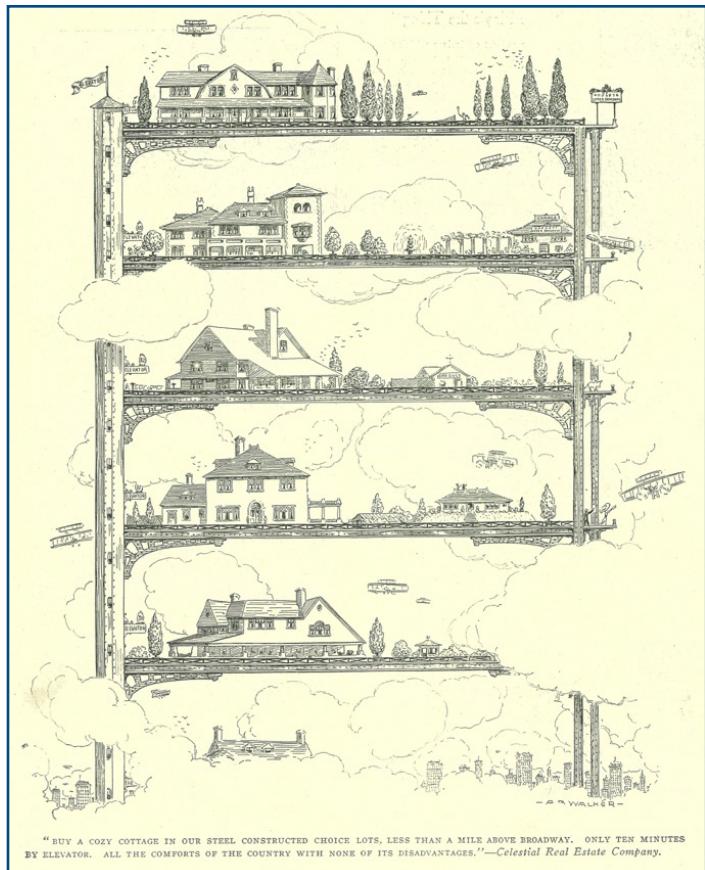
Vertical greenspaces like terraced gardens have persisted throughout history, with advances in engineering helping to solve problems and unearthing new challenges to explore. Indigenous farmers in South America, Asia, and other areas, for example, carved graduated terraces into hillsides, which used the land itself as part of the solution for managing runoff and erosion.

Fast-forward to the 20<sup>th</sup> Century, and the evolution of vertical farming accelerates, drawing on human need, land availability, and industrial advancements. By March 4, 1909, when *Life Magazine* published what is now known as the first vertical farm illustration, the concept included an open-air building with vertically stacked “vertical homesteads” that cultivated food for consumption.

Yet just six years after *Life Magazine* published the first-known illustration of vertical farming, Gilbert Ellis Baily described vertical farming in yet another light in his 1915 book, *Vertical Farming*. Until this time, vertical farming been defined as growing plants in layers above the ground or against vertical inclines. Baily’s idea of vertical farming referred to the plant root structure—specifically, preparing and maintaining the soil to maximize the vertical downward growth of plants’ root systems. He writes of engineering advances (pages 61-64 of *Vertical Farming*):

*If all this wealth of invention and labor is worthwhile bestowing upon the first few inches of the soil, why is it not worth following the roots down to their second foot of growth, their third, and even their eighth and tenth foot when they flourish at those depths.*

Today's vertical farms draw on their historical roots—with human need, population centers, and land availability at the center, and with industrial, scientific,



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*The first known illustration of vertical farming, as illustrated by A. B. Walker in 1909. (Source: architakes.com)*

and technological innovation bringing new solutions and challenges to the forefront. Today's vertical farms use interconnected smart technologies that provide light, monitor crop needs, deliver water and nutrients, adjust temperature and humidity, and harvest crops grown in ideal conditions that maximize growth and output.

Had King Nebuchadnezzar lived today, he might have envisioned gardens built with racks and racks stacked skyward with rows and rows of leafy greens spilling over the sides of containers...and defining yet a new era of vertical farming. In his absence, however, the continued evolution and advancement of vertical farming is up to us. What seeds from history and modern-times will you plant as you engineer the vertical farms of tomorrow? ●

**Deborah S. Ray**  
Editor, Mouser Electronics

# Vertical Farming: Engineering Solutions in Glass and Concrete

By Grant Imahara



While cities filled with flying cars and robot housekeepers (ala *The Jetsons*) may be a far cry from the present day, smart cities are not. You don't have to invent a time machine and travel into the distant future to see proof that smart cities exist. Many are presently being constructed in response to real-world issues like pollution and our quest for more sustainable energy sources.

Although a smart city can be defined in many ways, in general, a smart city uses IoT sensors, actuators, and technology to connect components throughout its borders. This impacts every layer of a city, from underneath the streets, to buildings and traffic, to the air its citizens are breathing.

In smart cities of the future, transportation systems will use sensors to detect congestion and bottlenecks in traffic patterns and rely on cameras to enforce speed and traffic infractions. Self-driving cars will shuttle people in and out of the city, giving rides and making deliveries, and apps will coordinate with smart parking meters to let drivers know where there's available parking. In fact, we just [visited one city that's transforming everyday traffic into a Wi-Fi mesh network](#) comprised of roving hotspots.

Sensors around town will detect the amount of garbage in cans to help sanitation workers maximize efficiency, while simultaneously monitoring devices to identify leaks or changes in water pressure in waterways. Solar panels will monitor how much energy they're providing and let workers know when they need maintenance.

Another idea currently being developed is having smart buildings that are capable of detecting fires in the areas around them and automatically placing a call to the fire department in the event of an emergency. Cameras and drones can monitor activity in remote areas not frequented by police or law enforcement, similar to the [Project First Responders](#) story we covered last year.

These are just a few examples of new ideas and products coming together, leading to inventive thinking and pioneering projects that solve real problems. As the world's population grows and urban centers become even more complex and congested, what new role will technology play in making cities of the future even smarter?

In this journey, we visit the engineers at Mirai in Tokyo, Japan and explore how urban farming could help smart cities meet the challenge of feeding their growing populations. Japan is 73 percent mountainous, with the remaining 27 percent of the land composed of scattered plains and basins, where the bulk of the country's population is concentrated. As the population expands, this puts a tremendous strain on its agricultural production. It's here that a former Sony semiconductor factory has been converted into the world's largest indoor farm—already shipping out 10,000 heads of lettuce per day.

Get ready to step inside and see how smart cities are farming right in the heart of the city. Join me on a quest for new knowledge and innovation. ●



# Urban Farming: Where Technology Grows Along With Crops

By Sylvie Barak for Mouser Electronics

While the term “vertical farming” is relatively new, its roots go back to one of the historical wonders of the world: The hanging gardens of Babylon in ancient Mesopotamia. A major city and commercial hub of antiquity, Babylon brings to mind the notion of urban greenery and is perhaps an important blueprint for humanity’s farming future. In more recent times, hydroponics, aeroponics, aquaponics, and other new technologies are beginning to take hold in areas one might never have imagined, turning food deserts in food oases, lending a new lease of life to crumbling real-estate assets in poor areas, and changing the face of the job market.

How will such climate-protected agriculture change our way of life? How will the localization of fresh produce at high-yield change our lifestyles, our eating habits, our job opportunities and our culture?

Will robot-intensive agriculture see itself polarized from individual food production and gardening? Will costs of vegetables decrease and our health see significant improvement? And what of cattle? The hypotheses are as rich and varied as the food we currently eat.

## Precision Agriculture is Taking Root in Modern Farming

An estimated 10 billion people will live on the planet by the year 2050. Resources from energy to water to space will be scarcer and more strained than ever, but humanity still needs to eat. Enter new farming methods like hydroponics, aeroponics, and aquaponics:

- **Aquaponics** is the process of growing plants in water teeming with fish to create a balanced ecosystem in which the fish and plants feed each other to the benefit of both.

- **Hydroponics** is a close cousin to aquaponics, where plants live and grow in nutrient-rich water (minus the fish).

- **Aeroponics** is soilless growing, where the roots live in misted air and receive drips of water filled with nutrients at regular intervals.

Each system has its pros and cons, though all can be used vertically as well as horizontally as needed. NASA, in particular, is interested in aeroponics with its own studies claiming aeroponic systems can reduce water usage by 98 percent, fertilizer usage by 60 percent, and pesticide usage by 100 percent, all while maximizing crop yields. Plants grown in aeroponic systems have also been shown to uptake more minerals and vitamins, making the plants healthier and potentially more nutritious.



Helping these newer methods evolve is a variety of technologies. For example, **sensors** in fields allow farmers to make real time measurements of variables like soil temperature and acidity, which in turn enable farmers to adjust chemical treatments to optimize crop yields. Similarly, water sensors allow farmers to apply just the right amount of water to crops, a less wasteful practice.

Self-driving tractors equipped with GPS systems increase the uniformity and accuracy of the application of fertilizer, herbicides, and pesticides, as well as enhance crop harvesting efficiency. As self-driving tractors get smaller, they might even be able to work single crop rows at a time, and when combined with drones, the potential for customizing water and chemical treatment could be narrowed to individual plant needs. With precision planting afforded by self-driving tractors, seeds can be planted at precisely the correct

depth to take full advantage of fertilizer. Of course, the major advantage of self-driving farming machines is that they can work longer hours and drive more rapidly.

Technology in agriculture doesn't stop there: Satellites, drones, probes, and data crunching systems with front end apps are the modern-day farmer's new friends. There are even companies delving into farming techniques that allow us to venture beyond our earth's biosphere. "We're developing an operating system for plants and have started working on an initiative to bring plants we grow together from Earth to Mars," said Dave Howard, who works with companies developing sustainable food sources for space travel.

### The Trend Toward Indoor Farms

Many current advances relate to food being grown in fields on existing farms, but there's a

burgeoning movement to bring farming directly into cities by growing plants in abandoned warehouses using artificial lighting and either hydro, aqua, or aeroponics vertically. With advances in big data and analytics, it's possible for farmers to customize conditions (light, temperature, nutrients, etc.) inside buildings to the exact specifications of the type of plant being grown, which increases yield compared to that of either conventional farming or greenhouses.

According to studies featured in *The Vertical Farm: Feeding the World in the 21<sup>st</sup> Century*, indoor farming could increase crop yields 10 to 100 times over what could be successfully harvested in a similar footprint outdoors. Likewise, transportation of warehouse-grown crops would be negligible since they would mostly be consumed within a short distance of where they are grown.



The sociological implications of advancing agricultural technology are manifold, according to Steven J. Hausman, a 31-year veteran of the National Institute of Health, research scientist, senior executive, and recognized futurist. “For example, if farmers can once again make a profit from their rural farms, then there is no need for them to sell them to conglomerates. Food can also become fresher since it would be transported over shorter distances. This could mean that foods can once again be grown for flavor and not for the need to survive being packaged and transported for a week or more at a time.”

Working conditions and job satisfaction for farm workers would also improve, said Hausman, as farmers could now live within cities if they wanted to, and they’d be less exposed to pesticides and herbicides as farming became more efficient. Also, with higher farm revenues, there’d be higher wages to go around.

Not to mention that advances in precision agriculture and data science would mean the production of less surplus food, cutting down on waste and allowing more people to be fed at the same or lower cost, which is bound to have an impact on people’s diets, hopefully for the better.

## What Grows in Vegas stays in Vegas

The USDA defines food deserts as “parts of the country vapid of

**“Only about two percent of the U.S. population is involved in agriculture directly, and most of those jobs rely on immigrants. Robotics isn’t taking jobs; it’s substituting for ones that aren’t possible to fill!”**

fresh fruit, vegetables, and other healthful whole foods, usually found in impoverished areas.” These areas are typically devoid of grocery stores, farmers’ markets, and healthy food providers. “In some parts of the country, it’s not uncommon for people to ask what gas station you get your food from,” said Fred Haberman, a cultural anthropologist, noting that these areas also typically see far higher rates of obesity and diabetes than the national average.

“Food deserts are also job deserts and business deserts. We talk about the developing world abroad, but we have emerging markets right here in the U.S. And most of those are food deserts,” said Haberman. According to the U.S. Department of Agriculture Economic Research Service, about 23.5 million Americans live in food deserts. Nearly half of them are also low-income. Approximately 2.3 million people (2.2 percent of all U.S. households) live in low-income, rural areas that are more than 10 miles from a supermarket.

With those kinds of limited options, many people living in food deserts get meals from fast-food restaurants, and that type of food

insecurity has a high correlation with increased diabetes rates. In Chicago, for example, the death rate from diabetes in a food desert is twice that of areas with access to grocery stores.

In places like Las Vegas where 40 million tourists flock to the strip in the middle of the Nevada desert expecting luxury and fine dining, restaurants currently go to amazing lengths to source the freshest, highest-quality produce, mostly from California. That could all change with vertical greening projects, and indeed, local greenhouses using climate controlled, farm-forward techniques are already springing up just miles from the strip, using solar power, desalinated seawater, hydroponics, aeroponics, aquaponics, and sensors. Not only will producing food in Vegas cut down on the massive transport costs of trucking in produce daily, but items will be fresher and probably tastier too. It would usher in a whole new class of jobs in the city too. A real win for the house.

## From Supermarkets to Super Farmers Markets?

New farming methods and a push toward locally grown food could

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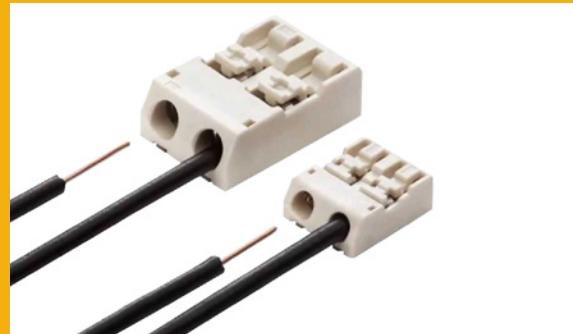
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have a profound effect, too, on where produce is sold. With farms potentially springing up all over cities, inside high rises or distressed real-estate assets, would moving them from one building where they're grown to another where they are sold make sense? Maybe not. Perhaps urban farmers would be able to cut out the middleman and sell their produce directly, in a sort of "farmers market on steroids" model.

That, or supermarkets themselves will adapt. "Intermediaries with the space to do so will become growers, leveraging growing technology and local market insights to contribute to the local food supply," said Stanley Cheng, an agri-tech startup founder. "Supermarkets are already conveniently located; it is simply a matter of how they themselves are supplied and how or whether they change their methods of getting their products to their consumers," he noted.

## Robo-Crop? Robotics, Jobs, and the New Agriculture

"I think that a majority of food in the future is going to be produced primarily using **robotics**," said John Kempf, thought leader in regenerative agriculture, crop scientist, and agronomist. "People are going to become less and less engaged with the production of food crops."

Pablo Solomon, an internationally recognized Green designer with advanced degrees in social psychology agrees with him: "The demand for higher wages, healthcare, and benefits will mean that more and more crops that require little attention will be attended to by fewer people and more robots. You already see this in the massive fields of wheat and corn. The soil can be prepared, seeds planted, and crops harvested by robotic tractors/harvesters directed by GPS."

While that may sound dire for humans—and not particularly optimistic in terms of the employment rate—it's important to remember a couple of things: Only about 2 percent of the U.S. population is involved in agriculture directly, and most of those jobs rely on immigrants. "Robotics isn't taking jobs; it's substituting



## **“Indoor farming could increase crop yields 10 to 100 times over what could be successfully harvested in a similar footprint outdoors.”**

for ones that aren’t possible to fill!” said agricultural consultant Niall Mottram, who argues that the larger effects would actually be felt in developing nations. “Millions of people who currently work the land will suddenly have the opportunity to pursue new careers, rapidly improving national productivity in the process,” he said.

“If you look at all of the technology and all of the innovations that have occurred during just the past five years, we are just barely scratching the surface,” added Haberman, who thinks agriculture is a job to bet on in the near future. “I believe that agriculture is going to be one of the top careers over the next 50 years. It’s going to be like the automotive industry and the internet but lasting longer. So much innovation is happening in the food space right now.”

“What’s going to be interesting is that companies like Google are

going to get into the food system. You’re going to see more local food production facilities powered by people who you never thought would be powering them. [Google has] all the data on you so why wouldn’t they offer you the food and the health tasks?” Indeed, with farming becoming increasingly technological, we may soon find computer scientists increasingly employed in agriculture, and even the emergence of “farm-trepreneurs.”

While **robo-farming** may be on the rise, many agricultural analysts are also seeing the pendulum swing in the other direction, too, with more humans taking an interest in growing their own food. “It is my observation that there is some inherent attraction in the human psyche of wanting to be connected to growing food and actually having your hands in the dirt. Gardening is the single most popular hobby around the world,

and as people find themselves with more free time because of the rise of automation, many will turn back to gardening and growing their own food,” said Kempf, noting that the opposite polarities of increased automation and humans growing their own food are probable in the future.

## **Local Growing for Better Food Awareness, Improved Health**

“From the grassroots level, I think we’ll start to see food sourcing and production be a bottom-up thing and much more commonplace,” said Dawn Casey Rowe, a teacher who years ago decided to grow her own food. “I teach at a school where I see pop tarts on a daily basis,” she lamented, though she’s confident the tide is turning. “I am starting to see more interest in hydroponics, sensors, and agricultural productivity tools make their way from the startup zone to the shelves of Home Depot where home users and small collectives can access them.”

Rowe hopes food education, urban gardening, self-reliance, and sustainability will help the younger generation get a better



understanding of the value of clean eating, leading to improved health. Currently, fast food is often the cheapest food in cities or food deserts. “I hope that [urban growing] will create a healthy-food market and drive down prices,” she said.

“We are going to be that much smarter about food, and by combining all our data with powerful algorithms, we’re going to be able to get food from close by that is customized especially for us. For our body types. For our specific metabolism,” said Haberman, who also believes insurance companies may move to make healthy eating a requirement for lower premiums.

### Urban Rurality and Rural Urbanity

Will we then be going back to having cities like Babylon, replete with hanging gardens? Perhaps not on a very large scale, but in some places it will make a lot of sense. “More and more cities and urbanites are recognizing that vertical greening is not only great for the environment and makes for beautiful landscaping, but it can also offer a way to maximize space

for food production,” said Solomon. Locally where population density is high and appetite for high value crops is strong, we will probably see increasing use of vertical farms. “Tokyo strikes me as a good potential site for this, possibly Manhattan too, but on a smaller scale. This will be very crop-specific—not growing corn using hydroponics, but growing produce like tomatoes and lettuce will definitely start switching to urban environments. The savings on transportation cost and the demand for ever fresher produce will drive this,” said Mottram. “With an increasing population, we definitely have to make the most efficient use of every piece of land. This means becoming better at predicting yields and harvesting at the right time. This means all agriculture, traditional or vertical, will see an increase in the use of technology to assist the grower.”

In terms of migration, all trends point to increased urbanization, but with several more billion people on the planet, there will be more population in rural areas, too, just because of sheer numbers. That said, new urban farming means farmers no

longer have to reside in rural areas, and autonomous vehicles mean city workers no longer need live inside cities. By 2050, said Haberman, “We have a world where organic agriculture is the norm because we have realized that organic farming and regenerative agriculture is the best way to save our planet, feed ourselves healthy food, and be friendly to the planet. We also have a world where every city is food secure because it has a localized food economy with multiple locations that help protect against climate change as well as various diseases.”

What’s certainly true is that new technologies will allow farming to efficiently scale inside big cities, food culture will change as a result of which crops are easiest to grow in climate protected environments, and changes in the human diet may lead to better health and cheaper healthcare. Similarly, if we continue to focus in and innovate in the agricultural space, we can improve yields, reduce waste, and grow locally, we may finally be on the cusp of eliminating starvation, reducing damage to the environment, and decreasing our vast water usage. ●

# Improving Energy Efficiency in Vertical Farms with Proper Electrical and Mechanical System Selection

By Alex Misiti for Mouser Electronics

Vertical farming is a form of controlled environment agriculture (CEA) that consists of growing crops in an indoor environment, often in vertically-stacked layers or on inclined surfaces. In recent years, as the demand for fresh, locally grown produce from urban areas has risen, the number of vertical farms being built in warehouses, skyscrapers, and shipping containers has increased dramatically. This trend is expected to continue in the coming years, with many researchers forecasting the global vertical farming market to reach over \$9 billion by 2025, up from \$1.15 billion in 2015, according to Grandview Research.

Among the factors that play a role in determining whether a vertical farm will be financially viable or not, one of the most important is the energy input required to operate the farm versus the amount of produce it grows. While certain variables in that equation are relatively fixed and out of the control of operators and engineers—such as power source, utility rates, and similar—design decisions regarding power-consuming systems, such as lighting and heating, ventilation, and air conditioning (HVAC) are not. This article explores the impact that lighting and HVAC systems have on overall energy consumption in vertical farm environments.

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## Lighting Considerations

One of the primary advantages of farming in a controlled environment is that it enables growers to manipulate **lighting** to maximize crop yields. When designing a vertical farm, engineers have a variety of light sources to choose from, each with unique advantages and drawbacks with regard to cost, efficiency, and photosynthetically active radiation (PAR, which is the spectrum of light that plants can use to perform photosynthesis).

The primary lighting options for indoor farms include:

- High Intensity Discharge lighting
- Fluorescent lighting
- LEF lighting

### High Intensity Discharge (HID) Lighting

The primary advantages of HID lighting are that it requires little up-front cost and provides a good spectrum of light for crops. The two most widely used types of HID lighting include:

#### *High-Pressure Sodium (HPS) Lighting*

In the past, HPS lamps have been one of the most popular types of lighting used in vertical farms. They produce ample red and orange spectrum light, which is beneficial to crop growth; however, they also emit significant heat, making them relatively inefficient. Excessive heat from HPS lights can force cooling systems to work harder to maintain a particular temperature, which further increases energy consumption.



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**“Although energy consumption from HVAC systems in a facility is largely dictated by location and climate, these systems usually represent one of the largest operational expenses for vertical farms.”**

#### **Metal Halide Lighting**

Metal halides are a less widely used type of HID technology that produces abundant blue light. These types of lights often exhibit a short lifespan and present a number of handling challenges because bulbs have to be protected from contact with oil and water.

#### **Fluorescent Lighting**

Although fluorescent lights have been used in the past because of their low up-front cost, they typically lack the intensity offered by HIDs. Disposal of fluorescents can also increase operational complexity. For these reasons, their use in commercial indoor farming operations has decreased in recent years in favor of other lighting solutions.

#### **LED Lighting**

The use of LED lighting in vertical farms is growing rapidly. LEDs produce very little heat and represent a much more energy-efficient way of optimizing climatic conditions than HIDs. They can be placed in close proximity to plants, allowing for even light distribution and more uniform plant growth. LEDs also allow growers to experiment with bands of wavelengths corresponding to different colors.

The primary drawback of LEDs is capital cost; however, the monetary gains in terms of reduced energy consumption and increased crop yields often result in a short payback period. Overall, the use of LEDs in vertical farms is expected to see significant growth in the coming years, eventually becoming the light of choice for indoor farming operations.

See also “*Harvesting New Ideas in Vertical Farming with Connected Intelligent LED Lighting Networks*” in this eBook.

#### **HVAC Considerations**

Although energy consumption from HVAC systems in a facility is largely dictated by location and climate, these systems usually represent one of the largest operational expenses for vertical farms. Some general HVAC system considerations to keep in mind when designing a vertical farm are outlined next.

#### **Ventilation / Air Circulation**

In indoor farming operations, air exchange is necessary to replenish carbon dioxide and control relative humidity. Generally speaking, there are two types of ventilation that can be used:

##### **Natural Ventilation**

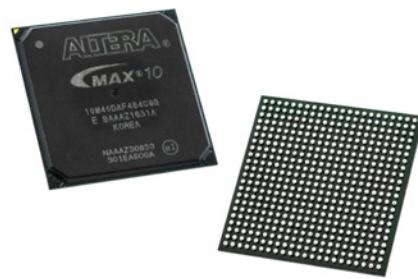
Because its effectiveness is largely dependent on outside conditions, natural ventilation alone is not always practical in vertical farms. While it does represent a low-cost solution, ensuring effective natural air circulation often requires strategic placement of vent louvers. Even then, it offers very limited air circulation predictability.

##### **Mechanical Ventilation**

Mechanical ventilation offers much more precise control of an indoor climate. Variable speed circulation fans (VSFs) are often the units of choice in indoor applications because their speed can be adjusted to produce optimal growing conditions. VSFs also limit on/off cycling, which results in increased efficiency and causes less wear and tear



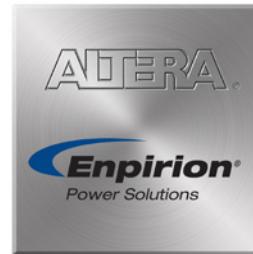
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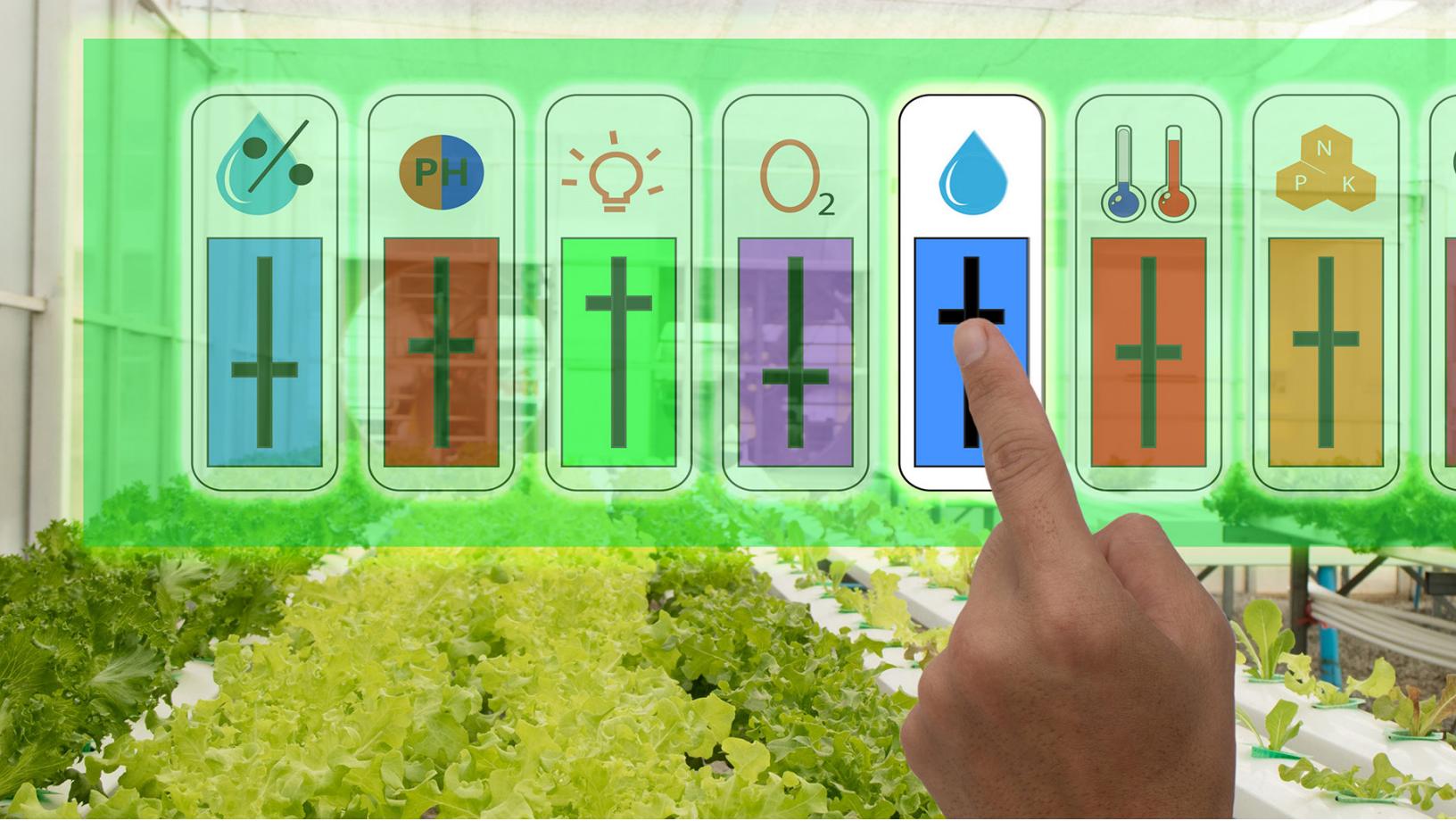


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- **Split systems**, which can also be used for heating, are more complex but allow for flexible ventilation control, resulting in increased energy efficiency. Depending on individual vertical farm design and needs, split systems may also require special contractors to install refrigerant piping.

## Heating

With the majority of vertical farms located in cities where temperatures can drop well below optimal growing temperatures, heating can represent a large portion of energy costs. Hot air, hot water, and radiant heating systems can be used:

### Hot Air

Hot air systems are often powered by natural gas or propane. They consist of large unit heaters and can be ducted or non-ducted depending on facility needs. One unique advantage of these systems is that off-gas from burning hydrocarbon fuels can be used for carbon dioxide enrichment.

### Hot Water

Hot water systems are desirable because they can be powered by renewable sources of energy, such as solar or geothermal. Generally speaking, they are more energy efficient than hot air systems; however,

the extent of that benefit largely hinges on proper selection and sizing of water pumps.

### Radiant

Radiant heating consists of either applying heat directly to plant surfaces or using heat emanating from systems within the subfloor. It typically requires many radiators to achieve uniform heat distribution. Additionally, because hot air and water systems can be integrated with ventilation systems, which are necessary in most vertical farms, radiant heating is not always a cost-effective option.

### Humidification

Controlling humidity in vertical farms is necessary not only to ensure plant growth, but also to reduce the need to irrigate (in non-hydroponic applications). Humidification can be achieved in a number of ways, including through misting, fogging, or steam generation. Misting and fogging are ideal in vertical farms located in hot, dry climates. However, they do not always allow for precise control over humidity, which may be problematic for some growers.

Using steam to humidify air is often used in farms where a boiler is present. These systems sometimes require the design and installation of complex piping and delivery networks, which is not always



**Figure 1:** In recent years, an increasing number of CEA operators have begun to leverage the capabilities offered by big data and IIoT.  
(Source: iStock Photo)

practical, especially in facilities where space is limited, such as shipping containers and high-rise buildings. Steam delivery networks can also be very maintenance-intensive.

## Climate Control Architectures

Vertical farms consist of plants stacked in layers or on inclined surfaces. This presents unique challenges because indoor spaces are often subject to stratification, which is the formation of distinct layers of air with varying temperature and humidity. In some instances, variations can be as high as 1°F per vertical foot. Proper selection of climate control technologies and placement of sensors is necessary to monitor and mitigate stratification issues.

In general, designers have three types of control architectures to choose from:

- **Manual control systems**, which consist of switches controlled by an operator.
- **Programmable logic controllers (PLCs)**, which allow operators to maintain optimal growing conditions based on predetermined set-points.
- **Automated building management systems**

**(BMSs)**, which have become more prevalent in recent years with the emergence of the Industrial Internet of Things (IIoT). This is particularly the case in commercial-scale operations, where vertical farmers have looked to leverage the power offered by big data and predictive analytics to maximize yields and reduce energy costs (**Figure 1**).

All control system options require sensors to measure variables such as temperature, humidity, soil and water pH, moisture content, and other possible variables. Choosing the right combination of sensors and control infrastructure will ultimately be dictated by the tolerances and precision required by the operator to produce optimal growing conditions.

## Conclusion

Electrical and mechanical system design and selection is critical to optimizing energy consumption, lowering operating costs, and ensuring profitability in vertical farms. When making decisions regarding these systems, designers should understand that no two vertical farms are the same and that equipment selection will largely be dictated by factors such as location, ambient conditions, electricity price, and crop type. In all cases, engaging early and collaborating with contractors and equipment suppliers is necessary to ensure cost and energy efficiency are maximized. ●



# Controlled Environment Agriculture: Connectivity Boosts Crop Yields and Quality

By Steven Keeping for Mouser Electronics

Although traditional farms embrace technology to boost yields, controlling other factors such as weather, pests, and disease remains difficult or even impossible and can compromise food production. Controlled Environment Agriculture (CEA) (sometimes called “indoor farming” or “vertical farming”) not only eliminates these factors, but also promises precise supervision of the key parameters that influence plant yield and profitability, such as light, temperature, humidity, CO<sub>2</sub> concentration, irrigation, and fertilization.

However, an indoor farming facility requires much higher initial investment than a similar-sized traditional farm. Until now, the monitoring, feedback, and control required to meet the plant yields to justify the high expense of CEA was very difficult to implement. The Industrial Internet of Things (IIoT) enables farmers to overcome those crippling technical and financial challenges—by inexpensively automating environmental control—dramatically improving profitability and making indoor farms practical.

**Wireless sensors** connected to the IIoT that constantly monitor the health and growing conditions of crops can be employed to control closed-loop systems for agribusinesses. Nonetheless, although a wide range of sensors is commercially available, the design of monitoring and control networks is not trivial. This article describes the engineering challenges presented by CEA and describes how new technology can overcome them.

## CEA: Potential Advantages for Farmers

CEA employs fully-enclosed and climate-controlled facilities that eliminate external environment factors such as disease, pests, or poor weather. The technology is not dependent on expensive, fertile land and can be established anywhere regardless of daylight hours, temperature extremes, and water resources.

Moreover, CEA lowers the barrier of entry into agribusiness; while establishing an indoor farm is expensive, unlike traditional framing where there's no substitute for experience, entrepreneurs don't need to



**Figure 1:** AeroFarms of NJ has opened the world's largest indoor vertical farm featuring a total of 7,000m<sup>2</sup> of floor space and employing LED lighting and wireless sensor networks. (Source: AeroFarms)

spend years learning how to contend with the vagaries of the sun, seasons, and crop damage.

CEA also brings other advantages, including:

- **Lower transportation costs:** Located in urban centers, facilities are close to the consumer. Moving food from traditional farms to city dwellers consumes up 10 percent of the total U.S. energy budget, according to a 2012 study.
- **Use of otherwise redundant space:** Disused factory and warehouse space is repurposed, and the multi-level design of indoor farms multiplies the growing area compared to a traditional field of the same footprint.
- **Higher quality products:** Profitable but fragile produce can be produced to a high standard. “Seasonal” crops can be grown year round.
- **Higher yields:** Fruit and vegetables that are prone to disease and weather harm on a traditional farm can be cultivated damage-free, eliminating losses.
- **Close control over input costs:** Optimized lighting and thermally efficient buildings reduce energy use. Moreover, CEA uses around 10 percent of the water required for traditional open field farming.

- **Pest and disease control:** Produce is protected from outdoor blights.
- **No unproductive fallow land:** CEA provides more crop rotations per year than traditional farming practices because cycles are accelerated due to optimized growth conditions and growing areas need no time to recover. CEA can produce market grade produce within 21 days of the start of the growth cycle.

Despite these advantages, CEA adoption has been slow because operating a profitable enterprise while bearing the overheads of the technology is tough. However, the situation is improving; for example, in 2010, it cost 64 times as much to illuminate a given area with **LED lighting** as it does today. (The energy costs—and environmental impact—when using conventional lighting almost always undermined the economic viability of CEA.)

Today, LEDs, wireless sensors, the IIoT, and the computing and memory resource needed to run CEA are plentiful, accessible, and available at a cost that makes economic sense to an indoor farmer. And yet, despite some notable examples like AeroFarms NJ facility ([see sidebar](#)) shown in **Figure 1**, projects that demonstrate CEA at scale are thin on the ground. Most exist as concepts or, at best, as small research initiatives because, despite the availability of suitable and relatively inexpensive technology, CEA systems are still challenging to design and implement.

# THE GROWTH CONTROLLED ENVIRONMENT AGRICULTURE

Early adoption of technology has enabled the agricultural sector to dramatically boost yields. According to the USDA, for example, the introduction of technology improved corn yields between 1950 and 2000 from 39 bushels (1062kg) to 153 bushels (4165kg) per acre, an increase of nearly 300 percent. At the end of the period, farmers produced 12 times as much per person-hour as a farmer did in 1950.

However, while sunlight, water, and CO<sub>2</sub> are free, high levels of agricultural productivity are reliant on skilled labor, consistently favorable weather, high soil fertility, and irrigation—all of which are either becoming increasingly difficult to source, more expensive, or less reliable. Indoor farming using CEA eliminates the demand for skilled labor by replacing it with electronic control systems augmented by a basic level of artificial intelligence. Moreover, the environment can be closely monitored and precisely controlled, optimizing the use of fertilizer and limiting water usage.

While indoor farming is unlikely to replace giant farms growing commodity crops such as wheat or common root vegetables, nor is it suitable for livestock, the method is ideal for high turnover plants that offer decent margin. Examples include leafy greens, herbs, and even edible flowers.

According to a 2011 article in *Science Illustrated*, replicating a conventional farm with computers and LEDs was expensive but proved cost-efficient in the long-run by producing up to 20 times as much high-end, pesticide-free produce as a similar-size plot of soil. Since the article was published, costs have continued to plummet.

Improved economics has encouraged an increase in CEA. Innovatus' Fuji Farm in Shizuoka Prefecture, Japan, is an almost 2,000m<sup>2</sup> facility where farmers have spent the past two years growing five different varieties of lettuce. In Narashino City in Chiba Prefecture, farmers have been experimenting with less common varieties of herbs, including edible chrysanthemums and coriander in an 80m<sup>2</sup> facility. South Korea boasts several practical vertical farms and NJ firm AeroFarms has opened what's claimed to be the world's largest indoor vertical farm featuring a total of 7,000m<sup>2</sup> floor space.

## CEA: Potential Challenges for Engineers

CEA presents several engineering challenges. Compared with conventional farming, which primarily demands natural facilities such as fertile land, benign weather, and plentiful water, supplemented by proven farming technology, CEA is almost completely reliant on leading-edge technology. That makes it difficult to implement.

Designing the technological framework to monitor and control CEAs poses several challenges:

- Developing systems that monitor and control multiple aspects, including heat, light, atmosphere, and water
- Designing complex wireless sensor networks for monitoring and actuation
- Designing secure Cloud connectivity solutions
- Affording rapid local and remote analysis of real-time data
- Developing low latency closed feedback loops
- Working with evolving technology regulations

## CEA and IIoT

The engineering challenges introduced by CEA mirror those of other process-oriented problems. CEA requires farmers to determine an initial set of conditions—for example, luminosity, wavelength of light, temperature, humidity, CO<sub>2</sub> concentration, and volume of water and nutrients—that need to be monitored and controlled by automated systems. Deviations from the initial conditions are rapidly corrected through a closed feedback loop.

IIoT allows CEA applications to take advantage of advanced process control without the overhead typically associated with industrial control systems because much of the platform (the Internet and third-party Cloud services) is already in place. Better yet, the IIoT adds a layer of intelligence enabling a control system to retain and “learn” from collected data. The result is a system that addresses the engineering challenges of CEA and runs, for the most part, autonomously, allowing farmers to concentrate of growing, marketing, and selling food rather than dealing with technology.

An IIoT application for CEA combines the following elements:

## LED Lighting

LED-based smart lights suit the precise illumination demands of CEA. The lights typically come equipped with built-in wireless Systems-on-Chip (SOCs) that allow rapid control of luminosity and color. The wireless connectivity is also useful for monitoring the energy usage of LED lights and determining when failure is likely to occur.

LED lighting not only brings the advantages of low energy usage, longevity, and precise control to CEA but also allows for fine-tuning of the wavelengths of emitted light. The emitted wavelengths can have a significant effect on plant growth; for example, according to a University of California report, plants grow more quickly when exposed to LED light richer in red and blue wavelengths. Red light increased the rate of growth of peppers and edible flowers, while blue light boosted tomatoes and basil yields. **Figure 2** shows a CEA installation using LED lights.

## Wireless Sensors and Actuators

Compact, battery-powered (or energy-harvesting) wireless sensors can be easily deployed, moved, and maintained far more easily than when using a wired network. Such sensors send data to a central hub (or “gateway”) where for aggregation and forwarding to Cloud-based servers via Internet or cellular networks. Wireless sensors allow constant, precise monitoring of all the parameters that are important for high yield indoor farming. In turn, using the bidirectional communication facilitated by the wireless connectivity, signals are sent to actuators controlling growth parameters to ensure the optimum environment is maintained.

## Sensor Networks

Combining **wireless sensors into a mesh network** enables all nodes to communicate with other nodes in addition to the central hub. The resulting network extends range, improves reliability, and builds in redundancy.



**Figure 2:** LED lighting enables precise control over luminosity and color to match a plant's specific requirements.  
(Source: AeroFarms)

to design practical wireless networks. 6loWPAN, IEEE 802.11ah, and ZigBee support mesh networking.

While the CEA sector is still in its infancy, Mouser Electronics already stocks specialized solutions to meet the monitoring and evaluation requirements of the technology. Such solutions save you designing systems and sensors from scratch:

### CO<sub>2</sub> Monitoring

The [Microchip Technology RE46C800](#) module is for pairing with a carbon monoxide CMOS sensor and an MCU. The analog, interface, and power management functions as a microcontroller-based CO or toxic gas detector. It is intended for use in both 3V and 9V battery or battery-backed applications. It features a boost regulator and horn driver circuit suitable for driving a piezoelectric horn, a 3.3V regulator for microcontroller voltage regulation, an LED driver, an operational amplifier, and an IO for communication with interconnected units.

### Ambient Light Monitoring

The [Microchip Technology DM160214-x series](#) is a lighting communication platform that provides all of the components to create an intelligent, network controlled DMX512A or DALI lighting network. These kits include two main boards, two communications-interface adapters (DALI or DMX512A), one prototype board, and the required cables and power supplies. The platforms use a single, low-cost 8-bit PIC MCU for the user interface, LED control, and communications. Software development is based on the free Microchip DALI and DMX512A libraries, which are written in C and can be ported to any PIC microcontroller. Additionally, the kit includes a color LED, enabling high-lumen output in a small form factor, along with a collimator optic and holder for high quality color mixing and tight beam control. The network can then control the luminance and color of LED smart lights to ensure ambient light is optimized for plant growth.

### Cloud Connection

Wireless sensor and actuator networks use short-range, low power wireless technology that is not interoperable with Internet communication protocols such as IPv6. Today, Internet connectivity for wireless sensor networks is realized via relatively expensive and resource-intensive gateways that receive data from the sensors and “translate” the information into IPv6 for relay across the Internet or cellular network. In an agribusiness application, these gateways would typically take the form of proprietary routers. While each router could support hundreds of sensors, in a large facility, the range limitations of low power wireless technology might demand the services of multiple routers—strategically

Mesh networks also make it easy to add nodes and rapidly scale the system as the indoor farm grows.

### Cloud Resources

Connectivity to the IIoT enables wireless networks to leverage Cloud resources that would otherwise be too expensive to employ for process control of CEA. Several third-party companies offer “If This Then That” (IFTTT) platforms that simplify process control by implementing automated routines. For example, a routine could trigger water misting every time the relative humidity in the indoor farm drops below 60 percent. The IFTTT platform could also trigger a notification to the farmer’s smartphone to inform him or her that water consumption has increased by four percent this month compared to last and is worthy of further investigation.

Perhaps more important for the future expansion of CEA, Cloud resources could be used to run algorithms that analyze the constant stream of data from the indoor farms to continually refine the growth process. This artificial intelligence would allow the Cloud servers to recognize, for example, that a 0.25°C increase in temperature accelerates the speed of lettuce growth such that the plants can reach market in 19 days instead of 21, but the same increase in temperature lowers humidity, stunting the growth of herbs. Such information would allow the farmer to separate lettuce and herb plants and set conditions that ideally match conditions for each plant. Over time, information would build into a database to provide instant answers as to what effect a minor change in a growth parameter will have on input costs, plant quality, and, ultimately, indoor farm profitability.

### Designing CEA Systems

Designing a CEA system is not a trivial process, but has been made easier through availability of wireless sensors. These sensors employ proven [low power](#) RF protocols such as 6loWPAN, Bluetooth low energy, IEEE 802.11ah, and ZigBee. All these protocols comply with open standards and are supported by a multi-vendor supply chain, technical support, and development tools that permit engineers with little or no RF experience

positioned to ensure all nodes are within range of at least one—increasing costs.

Low power wireless suppliers of all the popular protocols are working on solutions to lower the cost of Internet connectivity by including provision within their software stacks for an IPv6 transport layer. The transport layer would enable the node itself to transmit data compatible with other IPv6 devices, including Cloud servers. Such technology allows complex gateways to be replaced with simple and inexpensive bridges relaying short-range wireless signals to remote Cloud-based servers without translation.

### Moisture Monitoring

The [Analog Devices EVAL-CN0398-ARDZ](#) evaluation board is used in conjunction with the CN0398 pH and soil moisture measurement system to monitor the soil and determine when to water plants and when nutrients should be added to balance the pH for optimal plant growth. The evaluation board matches the form factor for Arduino shields which makes it easy to mechanically connect to [Arduino](#) computers, many of which include built in Bluetooth low energy, Wi-Fi, and ZigBee wireless connectivity.

### Conclusion

CEA is a relatively new sector of agribusiness that aims to take advantage of enclosed spaces in cities to reduce the environmental impact of food production by cutting the distance between farm and consumer.

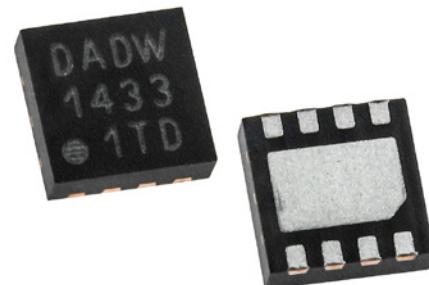
However, CEA requires a significantly higher investment compared with conventional farming. To justify higher investment, indoor farms must produce high yields of quality products that will reap good margins for farmers. Precise monitoring and control of a wider range of growth factors such as light, temperature, humidity, and irrigation meets the demand for higher yields but requires engineering solutions unfamiliar to agribusiness suppliers. The IIoT can address the engineering challenges that previously slowed adoption of CEA.

By constantly monitoring the health and growing conditions of crops, and feeding Cloud databases with huge volumes of data that can be used to enhance plant yield, the IIoT continually improves the practicality of CEA for agribusinesses and ensures its growth.

Contemporary smart lighting, wireless sensor and actuator network, Internet gateway, and Cloud technologies can be combined to implement a system that reliably and automatically controls a CEA installation freeing the farmer to concentrate on his or her core objective of growing and selling food. ●

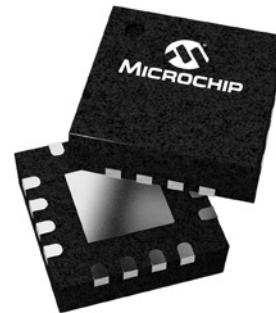


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# Smart Agriculture Sensors: Helping Small Farmers and Positively Impacting Global Issues, Too

By Steven Schriber for Mouser Electronics

**S**mart agriculture, also known as *precision agriculture*, allows farmers to maximize their yields while using the smallest amount of input: Water, fertilizer, and seeds, for instance. By deploying sensors and mapping fields, farmers can begin to understand their crops at a micro scale, conserve resources, and reduce impacts on the environment. Smart agriculture has roots going back to the 1980s when Global Positioning System (GPS) capability became accessible for civilian use. Once farmers were able to accurately map their crop fields, they could monitor and apply fertilizer and weed treatments only to areas that required it. During the 1990s, early precision agriculture users adopted crop yield monitoring to generate fertilizer and pH correction recommendations. As more variables could be measured and entered into a crop model, more accurate recommendations for fertilizer application, watering, and even peak yield harvesting could be made.

In this article, we will explore how these sensing technologies have been woven into modern large agribusiness and discuss progression of the technology both to small farms at home as well as globally to increase our capacity to feed the world.

## Agricultural Sensors

A number of sensing technologies are used in precision agriculture, providing data that helps farmers monitor and optimize crops, as well as adapt to changing environmental factors:

**Location sensors** use signals from GPS satellites to determine latitude, longitude, and altitude to within feet. Three satellites minimum are required to triangulate a position. Precise positioning is the cornerstone of precision agriculture.

**Optical sensors** use light to measure soil properties. The sensors measure different frequencies of light reflectance



in near-infrared, mid-infrared, and visible light spectrums. Sensors can be placed on ground vehicles or aerial platforms such as drones or even satellites. Soil reflectance and plant color data are just two variables from optical sensors that can be aggregated and processed. [Analog Devices](#) has developed [CN0397](#), a reference design that can measure received light spectrum and intensity. Other optical sensors have been developed to determine clay, organic matter, and moisture content of the soil.

**Dielectric soil moisture sensors** measure moisture by measuring the dielectric constant in the soil, which is an electrical property that changes depending on the amount of moisture.

**Electrochemical sensors** provide key information required in precision agriculture: pH and soil nutrient levels. Sensor electrodes work by detecting specific ions in the soil. Currently, sensors mounted to specially designed “sleds” help gather, process, and map soil chemical data. [Analog Devices](#) [CN0398](#) reference design enables resistive pH and capacitive (dielectric constant) soil moisture measurement.

**Mechanical sensors** measure soil compaction or “mechanical resistance.” The sensors use a probe

that penetrates the soil and records resistive forces through use of load cells or strain gauges. A similar form of this technology is used on large tractors to predict pulling requirements for ground engaging equipment. Tensiometers, detect the force used by the roots in water absorption and are very useful for irrigation interventions.

**Airflow sensors** measure soil air permeability. Measurements can be made at singular locations or dynamically while in motion. The desired output is the pressure required to push a predetermined amount of air into the ground at a prescribed depth. Various types of soil properties, including compaction, structure, soil type, and moisture level, produce unique identifying signatures.

**Agricultural weather stations** are self-contained units that are placed at various locations throughout growing fields. These stations have a combination of sensors appropriate for the local crops and climate. Information such as air temperature, soil temperature at a various depths, rainfall, leaf wetness, chlorophyll, wind speed, dew point temperature, wind direction, relative humidity, solar radiation, and atmospheric pressure are measured and recorded at predetermined intervals. This data is recorded, compiled, and sent wirelessly

to a central data logger at programmed intervals. Plug and play designs with code exist for under \$30, making smart agriculture weather stations attractive for all sized farms.

## Sensor Output Applied

**Sensing technologies** provide actionable data to be processed and implemented as seen fit to optimize crop yield while also minimizing environmental effects. Here are a few of the ways that precision farming takes advantage of this data:

**Yield monitoring** systems are placed on crop harvesting vehicles such as combines and corn harvesters. They provide a crop (in weight) yield by time or distance or GPS location measured and recorded to within 30cm.

**Yield mapping** uses spatial coordinate data from GPS sensors mounted on harvesting equipment. Yield monitoring data is combined with the coordinates to create yield maps.

**Variable rate fertilizer** application tools use yield maps and perhaps optical surveys of plant health determined by coloration to control granular, liquid, and gaseous fertilizer materials. Variable rate controllers can either be manually controlled or automatically controlled using an on-board computer guided by real GPS location.

**Weed mapping** currently uses operator interpretation and input to generate maps by quickly marking the location with a GPS receiver and datalogger. The weed occurrences can then be overlapped with yield maps, fertilizer maps, and spray maps. As visual recognition systems improve, the manual entry will soon be replaced by automated, visual systems mounted to working equipment.

**Variable spraying** controllers turn herbicide spray booms on and off, and customize the amount (and

blend) of the spray applied. Once weed locations are identified and mapped, the volume and mix of the spray can be determined.

**Topography and boundaries** can be recorded using high-precision GPS, which allows for a very precise topographic representation to be made of any field. These precision maps are useful when interpreting yield maps and weed maps. Field boundaries, existing roads, and wetlands can be accurately located to aid in farm planning.

**Salinity mapping** is done with a salinity meter on a sled towed across fields affected by salinity. Salinity mapping interprets emergent issues as well as change in salinity over time.

**Guidance systems** can accurately position a moving vehicle within 30cm or less using GPS. Guidance systems replace conventional equipment for spraying or seeding. Autonomous vehicles are currently under development and will likely be put into use in the very near future.

Large-scale farming has had an early foothold in the practice of precision farming. Expensive sensors, infrastructure, and processing equipment could only be realistically put to work by agribusiness that had sufficient capital available to invest. Those that did make that investment saw handsome paybacks in terms of crop yields.

## Scaling to “Small” Agriculture

Large-scale agribusiness has primarily been the early adopters of precision agriculture technology and techniques. In the United States, small farms—including organic and traditional—make up 91 percent of nearly 2 million farms. With a potential market of 1.8 million small farms in the United States alone, developers and designers have taken notice of the opportunities presented by integrating precision farming techniques on a smaller scale. Using smartphone sensors and apps, as well as

small-scale machinery, smaller farms to take advantage of precision agriculture technologies.

### Smartphone Tools

The smartphone alone has several tools that can be adapted to farming applications. For instance, crop and soil observations can be logged in the form of snapped pictures, pinpoint locations, colors of soil, water, plant leaves, and light properties.

**Table 1** lists some in-phone tools that are useful for gathering data:

**Table 1: Agricultural uses of existing smartphone tools.**

Smartphone Tool	Smart Farming Applications
Camera	Provides pictures of leaf health, lighting brightness, chlorophyll measurement, and ripeness level. Also used for measuring Leaf Area Index (LAI) and measuring soil organic and carbon makeup.
GPS	Provides location for crop mapping, disease/pest location alerts, solar radiation predictions, and fertilizing.
Microphone	Helps with predictive maintenance of machinery.
Accelerometer	Helps determine Leaf Angle Index. Also used as an equipment rollover alarm.
Gyroscope	Detects equipment rollover.

### Smartphone Apps

Typical smartphone applications are beginning to use [Internet of Things](#) (IoT) ideals, data aggregation, and speedy processing to bring up-to-date actionable information to small farmers regarding seeding, weeding, fertilizing, and watering. Gathering data from handheld sensors, remote sensors, and weather stations, in-depth analysis with valuable recommendations can be made. Several applications have been developed that specifically target the small farmer:

- **Disease Detection and Diagnosis:** Photos taken of suspect plants can be forwarded to experts for analysis.
- **Fertilizer Calculator:** Soil sensors and leaf color can determine what nutrients are needed.



**Figure 1:** Rowbot is a small, self-driving, multi-use platform that travels between rows to apply fertilizer, among other potential uses. (Source: Rowbot)

- **Soil Study:** Capturing soil images, as well as pH and chemical data from sensors, allows farmers to monitor and adjust to changing soil conditions.
- **Water Study:** Determining Leaf Area Index from photos and brightness logging can help farmers determine water needs.
- **Crop Harvest Readiness:** Camera photos with UV and white lights accurately predict ripeness.

The targeted users of these applications are farmers who—by necessity—spend hours daily on farming activities. When specialized applications improve farm productivity by analyzing soil, crop, weed, and pest variables, as well as offer valuable feedback for agricultural decisions, the small farmer's quality of life can noticeably improve.

### Small-Scale Machinery

Manufacturers are also looking at developing solutions specifically for small farms, such as the “Rowbot,” which can fertilize, mulch weeds, and sow seeds for cover crops. Much smaller and more nimble than traditional cultivating equipment, the Rowbot can fit between crop rows, does not compact soil, and can distribute micro-doses of fertilizer (**Figure 1**). Scaling up operations can be achieved by networking the machines into “flocks.”

### Global Implications

In the developing world, roughly 500 million small farms produce more than 80 percent of the food consumed. Precision agriculture technology is becoming more widely accessible around the globe. New handheld devices are available that can be used to measure the health of plants and soil, giving farmers the information to accurately calculate fertilizer requirements. Given that the United Nations projects that worldwide demand for food will increase by 50 percent by 2050, precision agriculture technologies for farms of all sizes will be in demand.

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Solving problems for farms of all sizes and helping farmers meet ever-increasing food demands, however, aren't the only problems that smart precision agriculture address. Smart farming offers a number of other benefits, including

- Lowering fuel and energy consumption and, thereby, reducing carbon dioxide emissions
- Reducing nitrous oxide released from soil by optimizing nitrogen fertilizer use
- Reducing chemical use by pinpointing fertilizer and pest control needs
- Eliminating nutrient depletion by monitoring and managing soil health
- Controlling soil compaction by minimizing equipment traffic
- Maximizing water use efficiency

## Conclusion

Precision agriculture has grown to meet increasing worldwide demand for food using technologies that make it simpler and cheaper to collect and apply data, adapt to changing environmental conditions, and use resources most efficiently. Although large farms have been the first to adopt these technologies, smaller farms are now able to benefit as well, using tools built into smart phones, relevant applications, and smaller-sized machinery. What's more, these technologies are contributing to solutions that extend beyond farms, including pollution, global warming, and conservation.

Future developments in precision agriculture include expansion of **autonomous farm vehicle** use, as well as smarter and smaller UAV and UGV telemetry will gain higher capacity for wirelessly transmitted crop and soil data. The same goes for status of farm machines, allowing farmers to improve equipment servicing and maintenance. In general, process improvement learned in the **industrial manufacturing** arena will continue to find its way into agriculture. ●



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# Harvesting New Ideas in Vertical Farming with Connected Intelligent LED Lighting Networks

By Paul Golata, Mouser Electronics

Connected intelligent LED lighting is a key technological component in vertical farming. Vertical farming is an indoor farming technique that employs space in three plains (length x width x height) rather than simply in the two traditional planes (length x width). The advantage is that a much lower real estate footprint is required. Additionally, because vertical farming happens in an indoor environment, all of the conditions can be controlled. However, the indoor environment presents some unique challenges—one of which is how to ensure that all the crops receive enough proper lighting in order to perform photosynthesis to convert carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ) into chemical energy (carbohydrates,  $\text{C}_x\text{H}_x\text{O}_x$ ) that the plant uses for fuel and oxygen ( $\text{O}_2$ ). LED lighting networks and Power-over-Internet (PoE) provide the technological backbone of indoor farm solutions.

## LED Lighting Networks

Imagine an indoor farm where

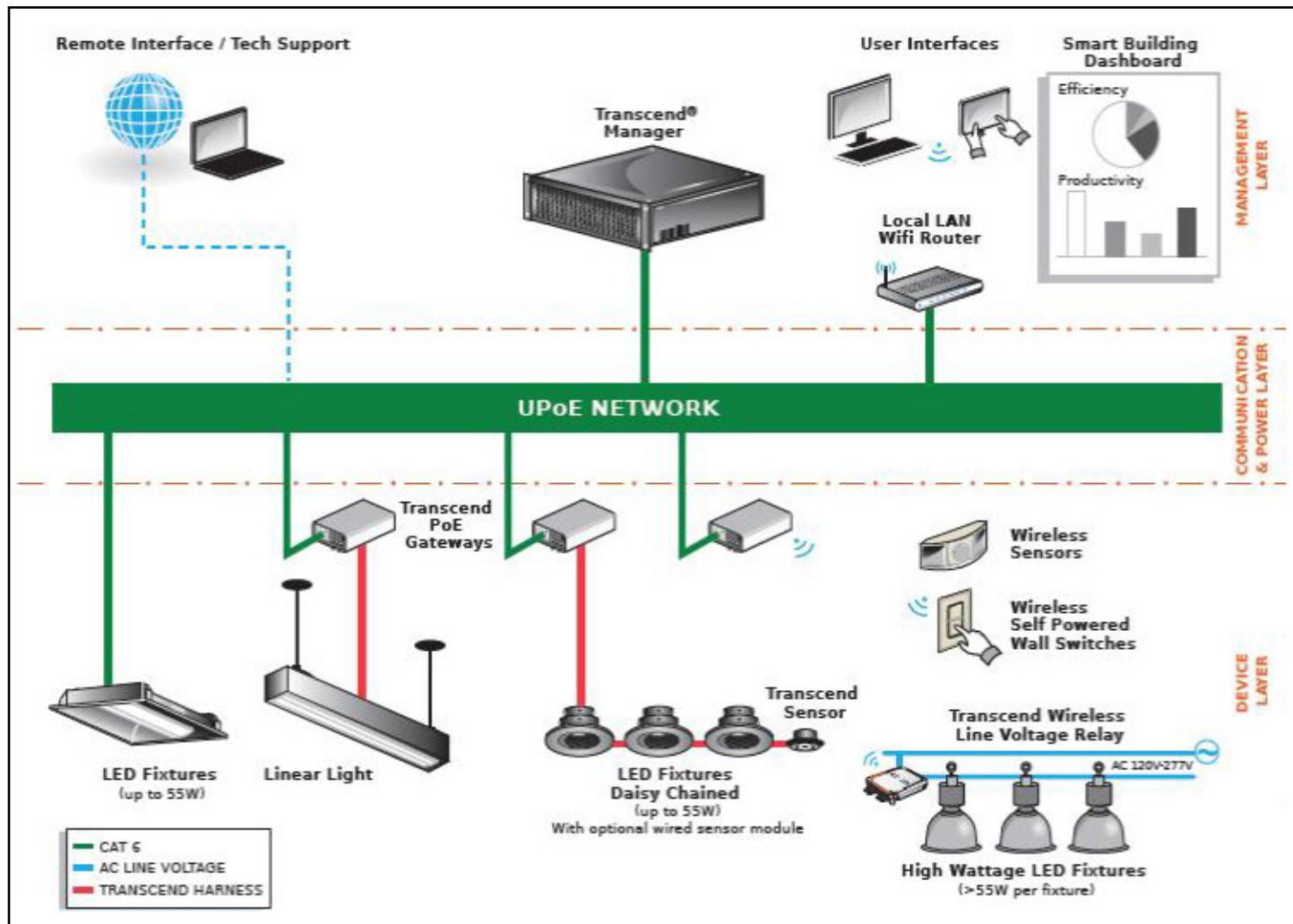
the entire left side of the facility houses tomato plants and the entire right side houses potatoes. In general, tomatoes thrive in abundant light and warm temperatures compared to potatoes that thrive in cooler and darker environments. LED lighting networks offer unique advantages to indoor farms in that they make artificial lighting easy to monitor and control. Additionally, such lighting networks can be connected to irrigation and HVAC systems to support appropriate localized watering, temperature, and light exposure requirements.

A key technology behind intelligent LED lighting networks is Power-over-Internet (PoE). PoE enables the low-voltage cabling and equipment that connect assets to LED fixtures. In addition to the benefits of providing power and data over a single-layer infrastructure, PoE is also less expensive than copper cable. As **Figure 1** shows, PoE system architecture includes the following devices, discussed in the next sections:

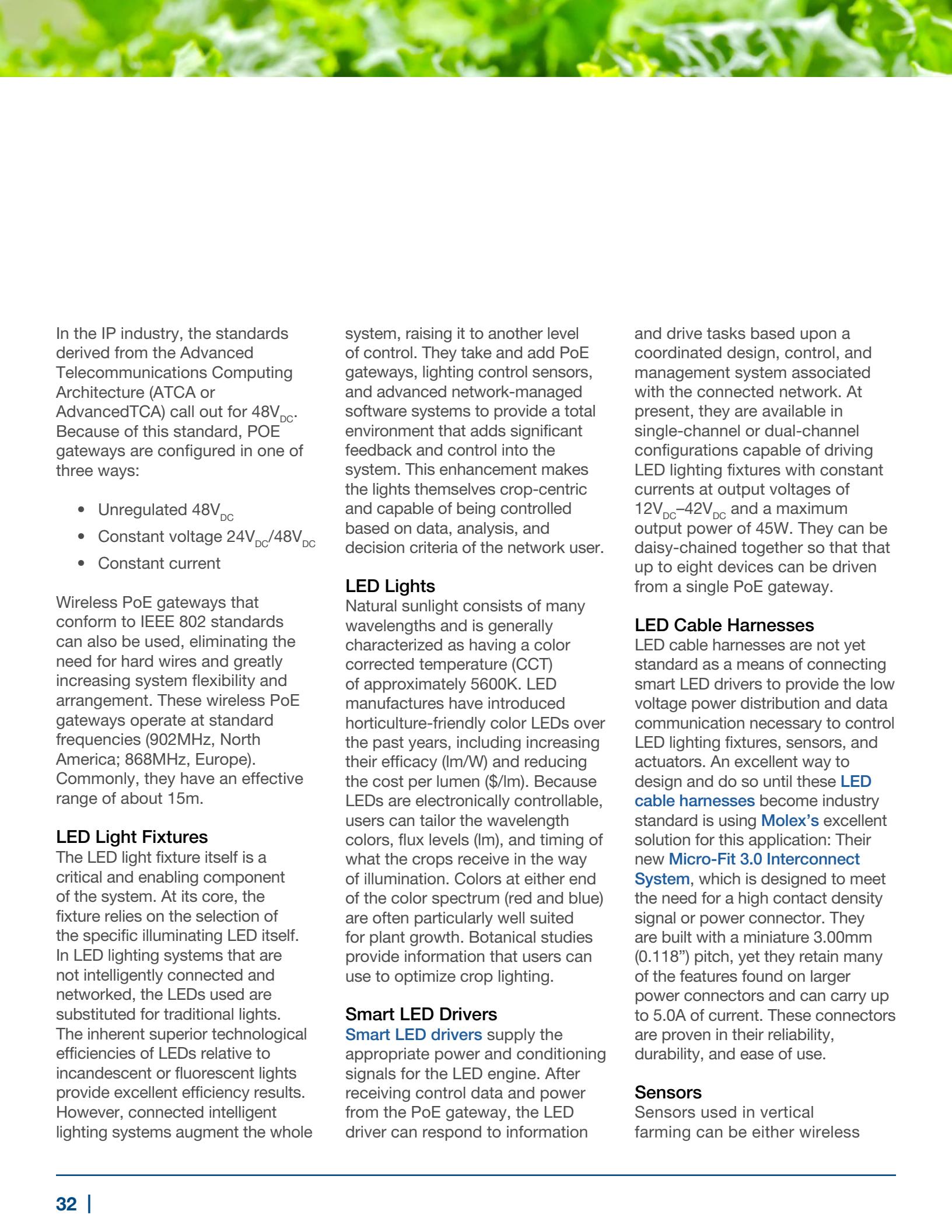
- PoE gateways
- LED light fixtures
- LED lights
- LED smart drivers
- LED cable harnesses
- Sensors
- Wireless switches and dimmers

## PoE Gateways

PoE gateways enable secure two-way communication between devices. In vertical farming, PoE gateways connect to, control, and power the light fixture luminaires that operate the LEDs, and they control LED lighting functions, including dimming, color tuning, and sensor reporting. PoE gateways applied in vertical farms are capable of delivering up to 60W. In cases where more wattage is needed, such as in high-bay lighting, AC line voltage ( $120\text{V}_{\text{AC}}\text{--}277\text{V}_{\text{AC}}$ ) is still required, wherein the devices can be controlled by a wireless line voltage relay.



**Figure 1:** PoE system architecture includes gateways, fixtures, lights, drivers, cable harnesses, sensors, and wireless switches and dimmers. (Source: Molex)



In the IP industry, the standards derived from the Advanced Telecommunications Computing Architecture (ATCA or AdvancedTCA) call out for 48V<sub>DC</sub>. Because of this standard, POE gateways are configured in one of three ways:

- Unregulated 48V<sub>DC</sub>
- Constant voltage 24V<sub>DC</sub>/48V<sub>DC</sub>
- Constant current

Wireless PoE gateways that conform to IEEE 802 standards can also be used, eliminating the need for hard wires and greatly increasing system flexibility and arrangement. These wireless PoE gateways operate at standard frequencies (902MHz, North America; 868MHz, Europe). Commonly, they have an effective range of about 15m.

## LED Light Fixtures

The LED light fixture itself is a critical and enabling component of the system. At its core, the fixture relies on the selection of the specific illuminating LED itself. In LED lighting systems that are not intelligently connected and networked, the LEDs used are substituted for traditional lights. The inherent superior technological efficiencies of LEDs relative to incandescent or fluorescent lights provide excellent efficiency results. However, connected intelligent lighting systems augment the whole

system, raising it to another level of control. They take and add PoE gateways, lighting control sensors, and advanced network-managed software systems to provide a total environment that adds significant feedback and control into the system. This enhancement makes the lights themselves crop-centric and capable of being controlled based on data, analysis, and decision criteria of the network user.

## LED Lights

Natural sunlight consists of many wavelengths and is generally characterized as having a color corrected temperature (CCT) of approximately 5600K. LED manufacturers have introduced horticulture-friendly color LEDs over the past years, including increasing their efficacy (lm/W) and reducing the cost per lumen (\$/lm). Because LEDs are electronically controllable, users can tailor the wavelength colors, flux levels (lm), and timing of what the crops receive in the way of illumination. Colors at either end of the color spectrum (red and blue) are often particularly well suited for plant growth. Botanical studies provide information that users can use to optimize crop lighting.

## Smart LED Drivers

**Smart LED drivers** supply the appropriate power and conditioning signals for the LED engine. After receiving control data and power from the PoE gateway, the LED driver can respond to information

and drive tasks based upon a coordinated design, control, and management system associated with the connected network. At present, they are available in single-channel or dual-channel configurations capable of driving LED lighting fixtures with constant currents at output voltages of 12V<sub>DC</sub>–42V<sub>DC</sub> and a maximum output power of 45W. They can be daisy-chained together so that up to eight devices can be driven from a single PoE gateway.

## LED Cable Harnesses

LED cable harnesses are not yet standard as a means of connecting smart LED drivers to provide the low voltage power distribution and data communication necessary to control LED lighting fixtures, sensors, and actuators. An excellent way to design and do so until these **LED cable harnesses** become industry standard is using **Molex's** excellent solution for this application: Their new **Micro-Fit 3.0 Interconnect System**, which is designed to meet the need for a high contact density signal or power connector. They are built with a miniature 3.00mm (0.118") pitch, yet they retain many of the features found on larger power connectors and can carry up to 5.0A of current. These connectors are proven in their reliability, durability, and ease of use.

## Sensors

Sensors used in vertical farming can be either wireless



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or wired, and they can be deployed and powered through the PoE gateway or integrated into the LED lighting fixture. Wireless ambient light sensors are a commonly deployed device in this application, however, because they are self-powered through collecting light and **harvesting energy**, which makes them economical and reliable.

Other common types of sensors used in LED lighting networks include those that monitor air quality, plant color, temperature, humidity, and passive infrared (PIR) motion/presence, among other possibilities.

### Wireless Switches and Dimmers

Self-powered wireless wall switches and dimmers use energy harvesting technology to communicate wirelessly with the PoE gateway, providing convenient control of lighting, temperature, and miscellaneous electric loads. The local switch/dimmer pads are self-powered and never require batteries because the simple act of pressing the rocker generates enough energy to send a wireless signal to gateway devices.

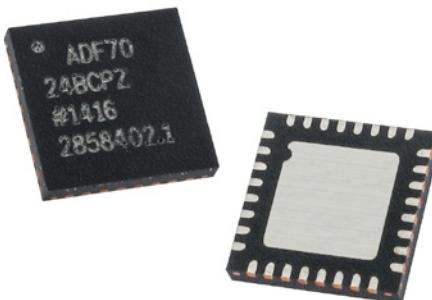
### Conclusion

Connected intelligent LED lighting is a key technological component in vertical farming. Indoor growing environments present unique challenges—one of which is how to ensure that all the crops receive enough proper lighting in order to perform photosynthesis to convert carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ) into chemical energy (carbohydrates,  $\text{C}_x\text{H}_{x_2}\text{O}_{x_2}$ ) that the plant uses for fuel and oxygen ( $\text{O}_2$ ). LED lighting networks and Power-over-Internet (PoE) provide the technological backbone of indoor farm solutions and include PoE gateways, LED light fixtures, LED lights, LED smart drivers, LED cable harnesses, sensors, and wireless switches and dimmers. Connected intelligent LED lighting solutions enable real-time autonomous decision making, greater efficiencies, and simplified operations that aim to help reap and sow a bountiful harvest. ●



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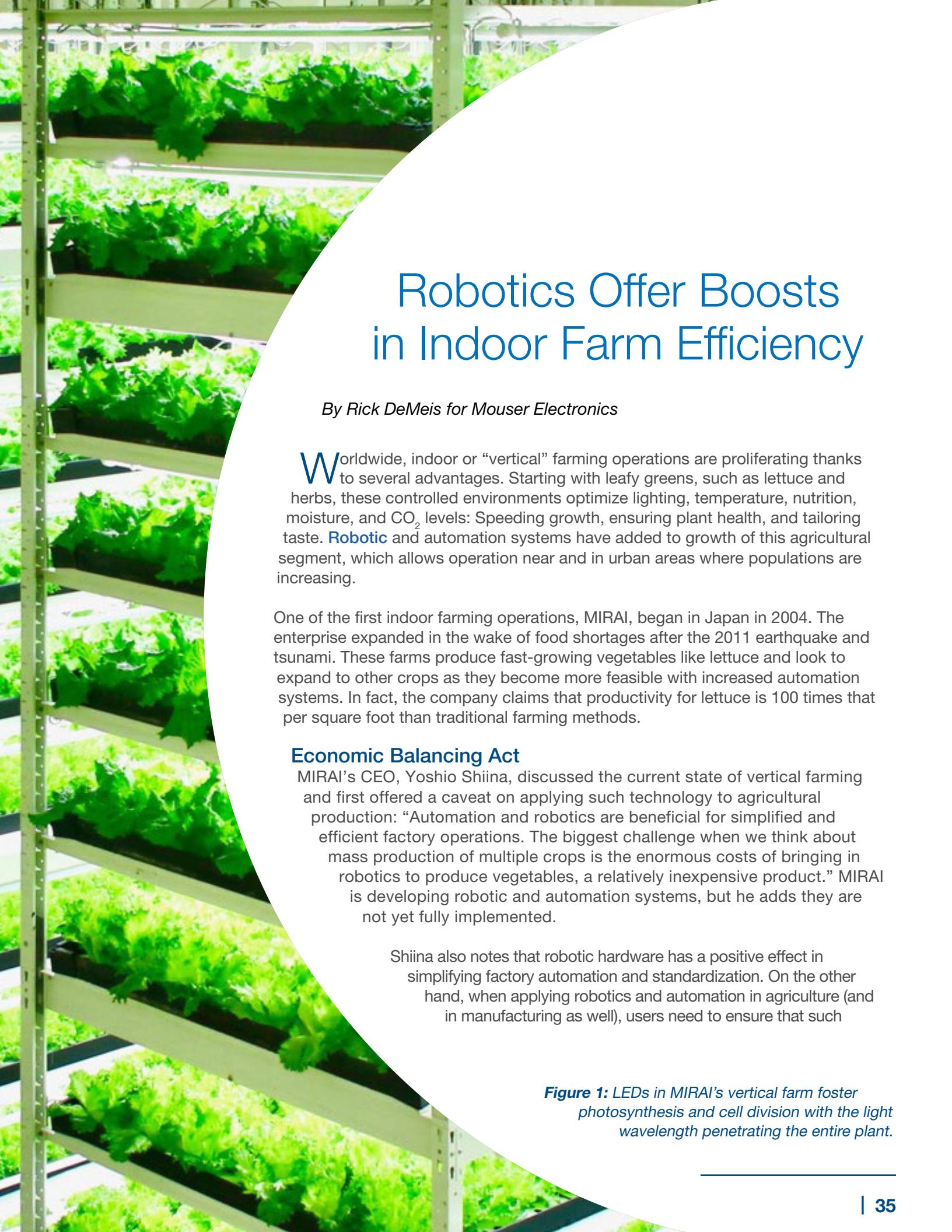


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# Robotics Offer Boosts in Indoor Farm Efficiency

By Rick DeMeis for Mouser Electronics

Worldwide, indoor or “vertical” farming operations are proliferating thanks to several advantages. Starting with leafy greens, such as lettuce and herbs, these controlled environments optimize lighting, temperature, nutrition, moisture, and CO<sub>2</sub> levels: Speeding growth, ensuring plant health, and tailoring taste. **Robotic** and automation systems have added to growth of this agricultural segment, which allows operation near and in urban areas where populations are increasing.

One of the first indoor farming operations, MIRAI, began in Japan in 2004. The enterprise expanded in the wake of food shortages after the 2011 earthquake and tsunami. These farms produce fast-growing vegetables like lettuce and look to expand to other crops as they become more feasible with increased automation systems. In fact, the company claims that productivity for lettuce is 100 times that per square foot than traditional farming methods.

## Economic Balancing Act

MIRAI’s CEO, Yoshio Shiina, discussed the current state of vertical farming and first offered a caveat on applying such technology to agricultural production: “Automation and robotics are beneficial for simplified and efficient factory operations. The biggest challenge when we think about mass production of multiple crops is the enormous costs of bringing in robotics to produce vegetables, a relatively inexpensive product.” MIRAI is developing robotic and automation systems, but he adds they are not yet fully implemented.

Shiina also notes that robotic hardware has a positive effect in simplifying factory automation and standardization. On the other hand, when applying robotics and automation in agriculture (and in manufacturing as well), users need to ensure that such

**Figure 1:** LEDs in MIRAI’s vertical farm foster photosynthesis and cell division with the light wavelength penetrating the entire plant.

**Figure 2:** With optimized LED lighting, and plants that do not shadow each other, growth takes place at twice the rate of outdoor farming.

improvements do not impose their own excessive limitations on what can be cultivated and how it is grown.

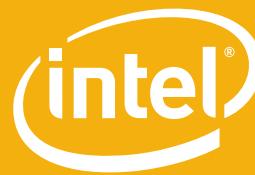
### Connectivity is Key

Interestingly, MIRAI's company philosophy places connectivity as more important than robotics. Handling data from a myriad of sensors via the IoT, connectivity is vital in controlling the cultivation and growing environment (**Figure 1**). Factors including temperature, humidity, photosynthesis, lighting, and more—upwards of 200 variables—affect the outcome of agricultural production. These must be continuously balanced for healthy crops and evaluated so that harvesting takes place at flavor and nutrition peaks. The indoor environment itself mitigates against pest infestation and allows optimal growing year-round.

MIRAI, in conjunction with nursery software firm PLANTX and Toyoki Kozai, a leading vertical farming scientist and professor emeritus at Chiba University, is developing the specialized SAIBAIX IoT system. Shiina says the first goal for the IoT system is to control the three main factors in cultivation: Light, water, and air (**Figure 2**). SAIBAIX is not currently controlling these factors. Instead, it is monitoring the inputs and outputs, learning, and getting smarter. "But eventually, it will be given control to change the various inputs to the optimal levels," he adds. "Already, the data from this system has helped increase production 25 percent from January to May of this year."

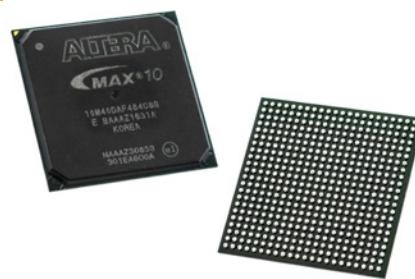
That improvement came from scientists looking at the data and analyzing it, so the recommendations were not made by the system. Shiina states, "Eventually the system can become smart enough to learn these





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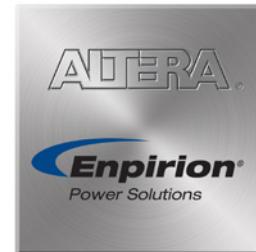
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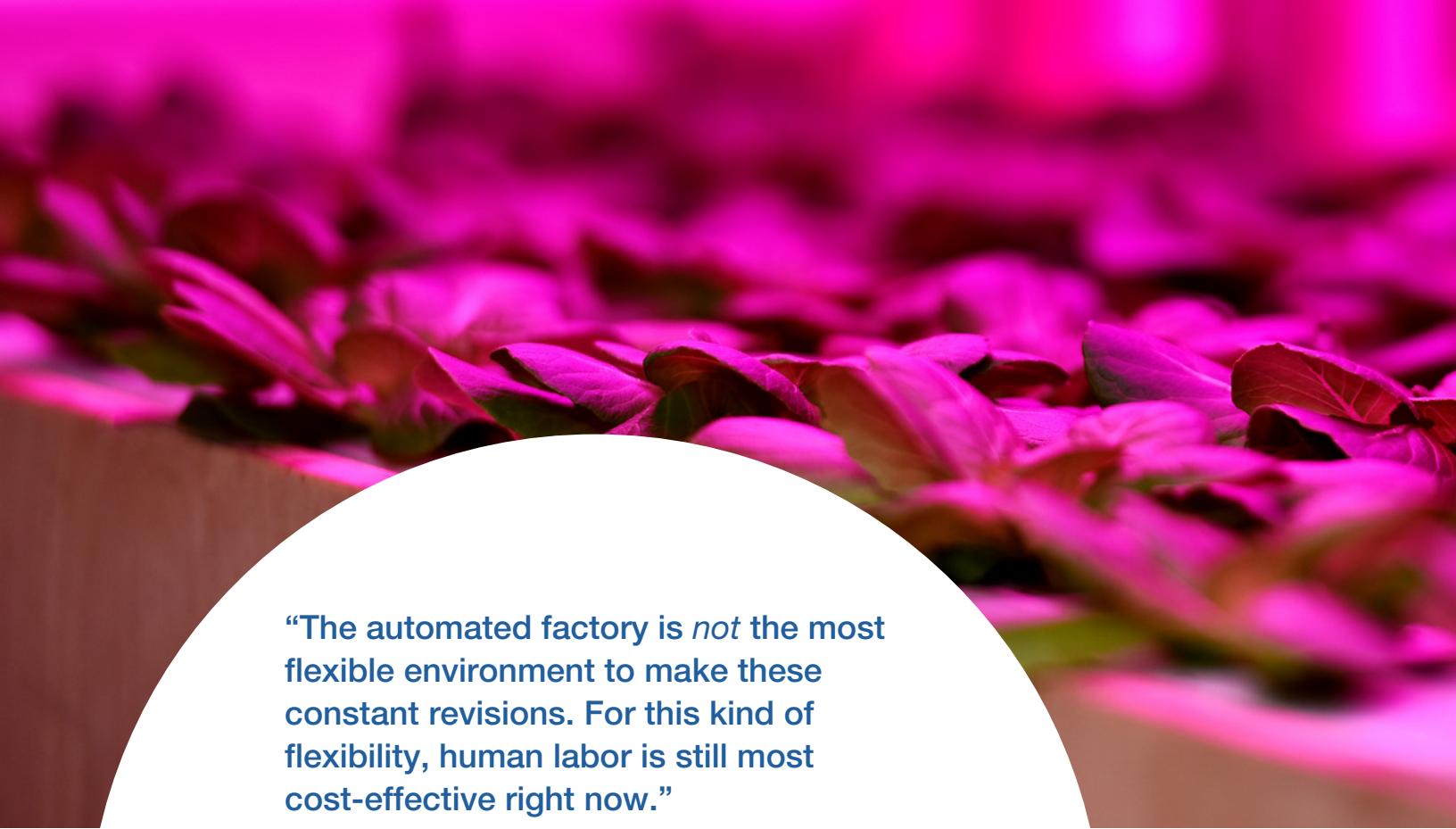
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**“The automated factory is *not* the most flexible environment to make these constant revisions. For this kind of flexibility, human labor is still most cost-effective right now.”**

relationships between the inputs and outputs, so that it can automatically adjust various settings for the optimum output.” The system will then be extended to govern variables including humidity, oxygen level in the water, and temperatures.

MIRAI is developing more efficient cultivation systems by connecting cultivation rooms and packaging rooms. By making the cultivation system more efficient, the company gained valuable space, which is then used for automation systems. For example, the company is developing a partially automated conveyor carrying system that will take the products from growing racks to the packaging room. But again, Shiina comes back to the economic conundrum of efficiency—cost versus outcome. “At the end of the day, we are just selling vegetables. It is harder to justify the big capital expense of robotics compared to its use in the production of expensive items like electronics or cars.”

### **Organic Variables, Human Labor**

Part of the legerdemain of balancing the organic, flexible variables that go into a robotic and automated agricultural production system is not only knowing what crops to produce, but how much to produce as well as who, and where, are the target customers.

“These must be clarified to know the cost and returns in order to justify such an investment,” Shiina emphasizes. “And since you are dealing with living organisms, you have to do a lot of trial and error. You have to keep revising and upgrading your systems and process. The automated factory is *not* the most flexible environment to make these constant revisions. For this kind of flexibility, human labor is still most cost-effective right now.”

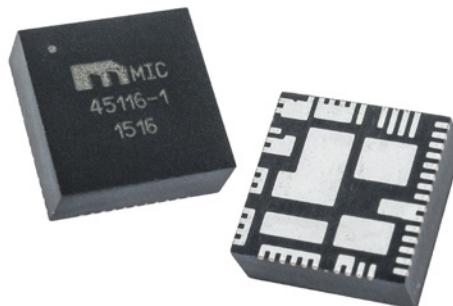
Shiina goes on to note the failure of several Japanese electronics giants that tried to enter this field. Some companies, including Toshiba, retreated or went bankrupt. Vegetables do not make much money!” To meet those challenges for a viable automated vertical indoor farm, Shiina highlights basic understanding and know-how of cultivation environment control—the best cultivation environment for each crop—so you can create it by robotics and the IoT.

“Customers won’t buy vegetables just because they were made by robots or the IoT. But if you can do consistent cultivation, you can establish a dependable supply to your customers. Food processing companies, delicatessens, and restaurants make up more than 90 percent of our clients, with individual



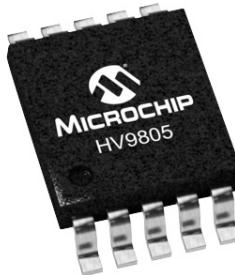
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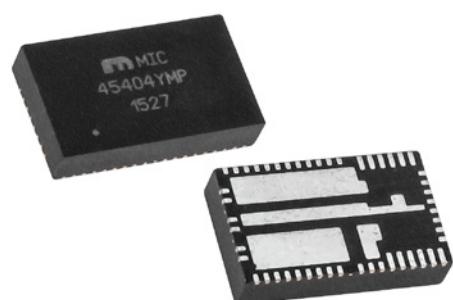
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