



THE FUTURE OF FARMING IS VERTICAL

A Guide to Developing Commercial Scale Production

Created and compiled by

GE Current, a Daintree company and Stockbridge Technology Centre

GE current
a Daintree company



The Future of Food

By 2050, the global population is expected to reach 9.8 billion¹ people.

Yet the amount of agricultural land has remained steady for the last 50 years (hovering around 37%² of total available land) with no dramatic changes in that figure anticipated over the coming period. Put like this, it's easy to see why governments are starting to make food security a high priority.

In 2013, when the 2050 population was projected to reach 9.6 billion, a UN report found that global food production would need to increase by approximately 70%³ just to keep pace with population growth. To significantly increase the pressure, others have highlighted that with economic development, global diets are also demanding more meat—an even less efficient use of available land.

The farming community has risen to the challenge by increasing production per hectare by leveraging technology innovation and advanced agronomic practices to boost yields and fight off pests (“intensification”). This approach has been successful in many ways, but it's not sustainable. And today's consumers have also become more conscious of the impact of pesticide use on health, as well as the environmental toll of plastic packaging, food miles and over-exploitation of the Earth's resources—including farmland.

The commercial farming industry is anything

but complacent. We know that food production of the future will look very different from that of today. We are entering a new era of technology-enabled growing, where indoor vertical farming, or Controlled Environment Production (CEP), is considered one of the best opportunities to boost the production of a range of crops whilst maximising quality, nutrition and visual appeal that will help maintain and, in many cases, improve living standards for global citizens.

We also see huge, relatively untapped potential in the pharmaceutical industry, with vertical farms offering controlled, cleanroom conditions in which to grow powerful, natural pharmaceutical ingredients.

Although the opportunity is significant, as an industry at its nascent stage, many indoor vertical farms fail due to poor planning, a lack of understanding of the complexity of controlled environment growing or an inability to scale to a level that ensures long-term commercial viability.

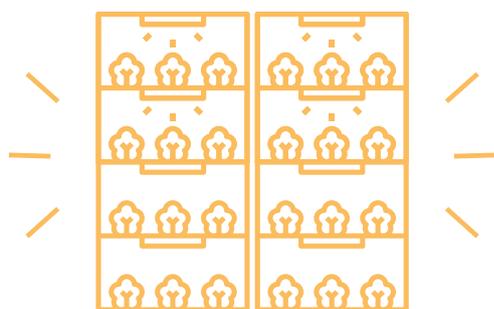
This guide is not intended to be a fully-fledged answer to all your questions about how, when or where to set up your own vertical farm installation, but it is intended to provide a foundational understanding of the elements at play, key considerations to explore, and some pitfalls to avoid and concrete next steps to take when planning your vertical farm.





What is Vertical Farming?

Farming on the vertical plane or using racks stacked vertically to grow low crops can apply to both indoor (where there is no natural light) and outdoor (where the sun's light is used solely or in combination with artificial lighting) scenarios. For the purposes of this guide, we will define vertical farming as indoor Controlled Environment Production (CEP), where the grower is able to tightly control every element: light, water, temperature, CO₂, nutrients, etc., to maximise the yield of their chosen crop.



In its 2017 report, Global Market Insights, Inc. predicted that the vertical farming industry (both indoor and outdoor applications) will grow from revenue of 2.5 billion USD in 2017 to 13.9 billion USD in 2024⁴. By adopting vertical farming techniques, we can significantly and materially increase available "farmable land" and situate these farms in brownfield and urban settings, regenerating industrial sites in decline and bringing fresh, nutritive produce from the farm to the fork in minimal time and with minimal transport costs. We can also reduce the

pressure on traditional farmland that has led to overuse of pesticides and issues of nutrient leaching, soil erosion and reduced biodiversity.

The main advantages of vertical farming are:

- The ability to produce crops 24/7, 365 days a year irrespective of climate, weather, season and geography
- The ability to enhance the natural output of every harvest (size, weight, nutritional value, appearance, taste, etc.) by combining intelligent technology with years of research by plant scientists and acquired knowledge from growers
- The removal of barriers to new growers – you don't need a significant acreage to develop a commercially successful farm
- You can produce more food locally – a trend that is attracting increasing attention and investment in many markets⁵

At a higher level, vertical farming helps to:

- Reduce the environmental impact of the food supply chain through the removal of pesticides during production and lower food mileage
- Ensure food security and sovereignty
- Enhance the variety and quality of available food and improve the health of citizens

The Science of Indoor Growing

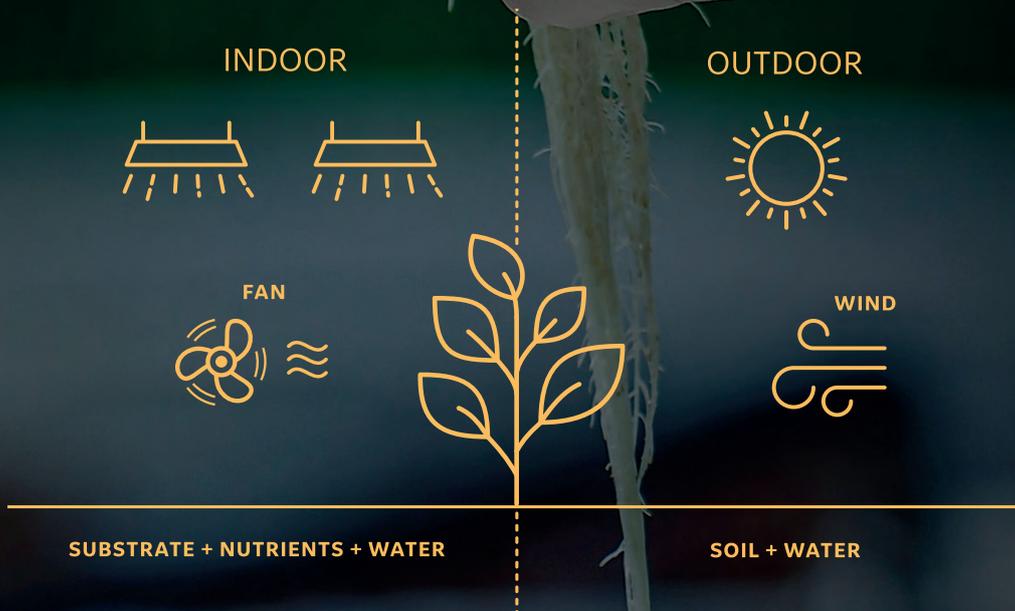
Every plant requires the same core essentials: light, CO₂, water and nutrients.

That's the simple part.

However, these core essentials combine with a multitude of additional factors depending not only on what crop you are looking to grow, but also what you want in terms of nutritional value, visual appearance and taste. When out of balance, these factors can also have a catastrophic effect

on the plant, potentially causing death at the extreme or a lower yield in a best-case scenario. Such factors include temperature and humidity, airflow, length of growing day and more.

The ability of growers to control just about every element of the recipe for growth means that we can truly ensure that every plant reaches its maximum potential. However, each element must be carefully monitored in order to optimise its impact on plant morphology.



Fluorescent lights were previously used for indoor farming, but advances in LED technology, including their processing ability when it comes to light generation, light extraction and re-absorbance, have made LED grow lights the most efficient product available on the market. As well as having the potential to run 24/7, LEDs offer a greater level of control as specific light recipes can be designed within the three main growth spectrum categories to maximise the results for individual crops. LEDs also offer a much longer lifespan than previous lighting technologies and can be manufactured in a way that makes them easy to clean and cheap to maintain.

Different light recipes can also be employed at the end stage of growth to increase anthocyanin synthesis and pigmentation in produce like red lettuce, where a green plant would be less appealing to the end customer.

However, light isn't just critical to maximising growth, manipulating colour and shortening the cycle from sowing to harvest. Light also governs the circadian rhythms of pests, bacteria and fungal pathogens, which may be found in growing rooms. Light can therefore be used to design traps to limit the movement of stray insects or to prevent fungal spores from spreading through the crop.

Current Colour Spectrum Charts



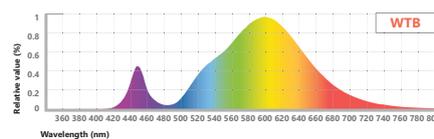
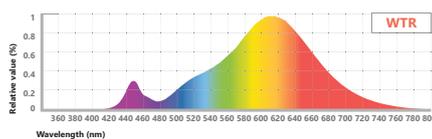
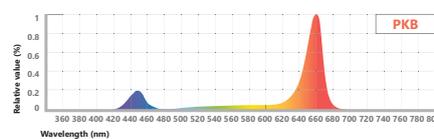
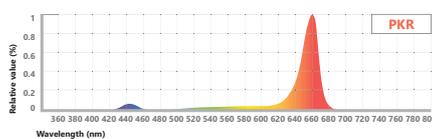
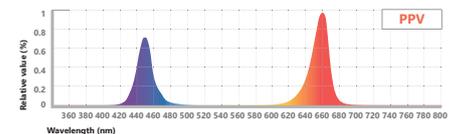
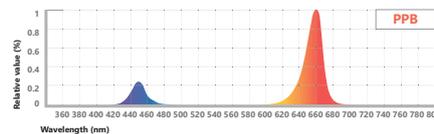
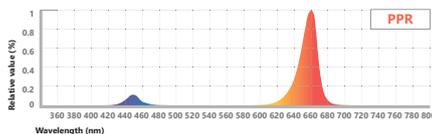
TYPE R



TYPE B



TYPE V



Heat and Humidity Control

Temperature and humidity both have the potential to accelerate growth or ruin a crop and are possibly the two most challenging elements of managing your vertical farm.

Temperature has a significant impact on the speed of growth, alongside the physiology of plants. The ideal temperature for a plant depends on a number of factors, and the correct balance between air temperature, relative humidity and light must be achieved. The growth habit of the plant also impacts this process.

Additionally, as you increase temperature within a defined range, you get an increase in gas and water exchange between the plant and the environment. When the temperature rises, you increase the loss of water, which is why you need to worry about the humidity of the environment even though warmer air can hold more water.



Humidity impacts photosynthesis. This is due to the need for water from plants, which is used to keep them cool and retain their cell flexibility⁶. The ability to retain water is determined, in part, by the humidity of the air which can increase levels of evapotranspiration.

Humidity also impacts the ability of the stomata to draw in carbon dioxide and release oxygen and water. Too much humidity can effectively stop the plant from functioning on a basic level⁷.

As the racks of lights filling the growing floor are the major source of heat in the facility, airflow and HVAC systems are crucial to reducing cases of tipburn and wilt.

Plant Nutrition

Plants require a range of nutrients to grow properly, but you will need to tailor your nutrient mix specifically to the crop, as well as your planned growth cycle, root mass and other variables. The three main types of nutrients are nitrogen, phosphorous and potassium, but calcium, sulphur and magnesium are also important⁸. A deficiency in key nutrients can result in everything from death of the tissue and discolouration to abnormal growth⁹ so it's crucial that you deliver the right nutrients at the right level of concentration to the roots at the right moment of the growth cycle.

When it comes to supplying plants with nutrients, there are several methods and substrates that you can use. These can be living substrates (soil, peat) or inert (non-biological). For the foreseeable future, irrigation and delivery of nutrients via hydroponics is considered the most viable and widespread method for indoor vertical farming. Aeroponics and aquaponics are expected to remain fairly niche, holding only 27.1% and 16.7% of the market in 2017 and 28.7% and 17.6% of the market in 2024, respectively¹⁰.

The advantage of a recirculating hydroponic system is that we can potentially cut the use of water by 90% versus traditional farming methods if you re-condense and re-use the humidity from the growing environment. This makes vertical farming an ideal option for regions where water is scarce or expensive and helps vertical farms to do their bit for environmental sustainability by reducing waste of inputs without compromising on output.



How Can You Ensure Success?

1 Avoid a Trial and Error Approach to Design

There are multitudes of factors that are naturally managed and balanced when farming outdoors. The sun cannot be changed, irrigation to every plant is different as weather patterns can change from moment to moment and even the nutrition in the soil can vary across the area of the field. Planning your farm therefore gives you the ultimate control but also dramatically increases the variables that you can and must consider.

These variables start with the facility's very layout, such as the size of growing space, plant distribution, airflow and more. Additionally, without having the right models in place to determine the exact light recipe and combination of CO₂, nutrients and water required to grow a successful crop, growers can find themselves wasting time and money on testing phases to try to maximise yield and revenue. Once you have developed a model for your vertical farm, you should then put it through a testing phase on a smaller scale to ensure it is viable.

2 Pick the Right Crop

It's far easier to develop a profitable and scalable facility if you know the needs of your crop inside and out. That ideally means specialising in one type of crop that you can design your facility around, selecting the right growth spectrum and studying that particular plant's biology to better understand how to optimise irrigation, nutrition, air flow, CO₂ concentration and propagation in order to maximise elements

such as taste, nutritional content, visual appeal, potency or shelf life.

Too many growers have tried to hedge against perceived risk by trying to grow multiple crops. By default, it is extremely difficult to have one installation that is optimised for a wide variety of plants, and therefore the returns from each crop are lower than they could have been. The facility then may have to suffer through downtime as the technology is tweaked and optimised for the next crop—eating into profitability and adding unnecessary costs.

3 Location, Location, Location

The old adage that location is half the battle has never been more relevant than in vertical farming today. Vertical farms have a key advantage in their ability to be located close to their customer, whether they are selling to food processors, supermarkets or local shops. Removing the vast transport logistics associated with today's food supply chain slashes costs and helps appeal to an increasingly conscientious customer. The lack of transport costs also helps counter the higher production costs resulting from higher energy and labour inputs.

At city planning level, there are also many advantages of co-locating a vertical farm with other facilities such as office buildings, shops or residences—which could draw the vertical farm's excess heat to reduce demands on other sources of energy.

Any business can fail for any number of reasons, but a vertical farm is an incredibly delicate organism that depends on many disparate factors being perfectly aligned and in balance. This increases the risk of failure for those unaware of the number of plates that need to be kept spinning in perfect time. This list is not definitive but gives you a good idea of the most common mistakes to avoid.

4 Simplify Your Business Model

Proximity to customers and the ability to produce crops year-round at a sustainable rate is a strong advantage in the market, whether you're growing for the food or pharmaceutical sectors. Therefore, consider the opportunities available through establishing exclusive contracts with customers at a fixed rate that will offer more financial security as you build your business.

5 Be Realistic About Operational Cost

Setup and fit-out costs represent a high initial outlay for any vertical farming entrepreneur, but the ongoing operational costs (energy, labour, inputs, maintenance, etc.) are also significant. Businesses not only need to find creative ways to mitigate these risks (e.g. growing through the night when energy tariffs are lower and the outdoor climate is cooler to assist HVAC systems' efficiency), but also consider the cost-benefits of different configurations and process flow.

6 Set Prices Based on What Consumers Will Pay

At the 2017 inaugural AgLanta Conference¹¹, PodPonics' CEO admitted that the company missed out on higher potential margins as it priced its crops to compete with conventional growers, ignoring the price premium that food traceability, pesticide-free growing and local production can increasingly attract from consumers in some markets.

7 The Skills Gap

In many cases, those who have embraced the promise of vertical farming have not been traditional growers but rather tech entrepreneurs, engineers or hobbyists. Vertical farming requires a unique mix of skills to be successful: big data scientists, systems integrators, project managers, engineers, growers and plant scientists all have a role to play in addition to the core functions that any business needs to be successful (financial strategists, marketing and business development, etc.). From the leadership perspective, experience at replicating and scaling a business is critical. Ignoring any one of these functions leaves a serious gap in business capability that could undermine the overall success of the operation.

8 Remember What You're Selling

In a bid to capitalise on the new technology and growth models offered by vertical farming, some growers have forgotten that their primary focus should be on growing and selling the highest quality food. Instead, they have tried to recoup their investment by trying to commercialise their vertical farm's technology, process and methodology. Unfortunately, as we have seen, every vertical farm is different with potentially very different needs. The trick is to not to try and do many different things at once, but instead keep a clear focus on doing one thing as well as possible.

What to do? Plan, Plan, Then Plan Some More

As vertical farming is still at the earliest stages of development, many of the early movers in this space have used an “informed trial-and-error” approach, investing huge sums of money into building and outfitting vertical farm facilities only to find that they don’t have the right lighting, inputs, growing area or plant distribution to produce the yield needed to start recouping their capital expenditure and making a profit.

A lack of data in this regard has been a major barrier to the vertical farming industry making the leap from “interesting concept” to scalable, commercial viability. One important point to remember is that running a successful vertical farm at commercial scale requires it to be run more like a factory, rather than a conventional farm.



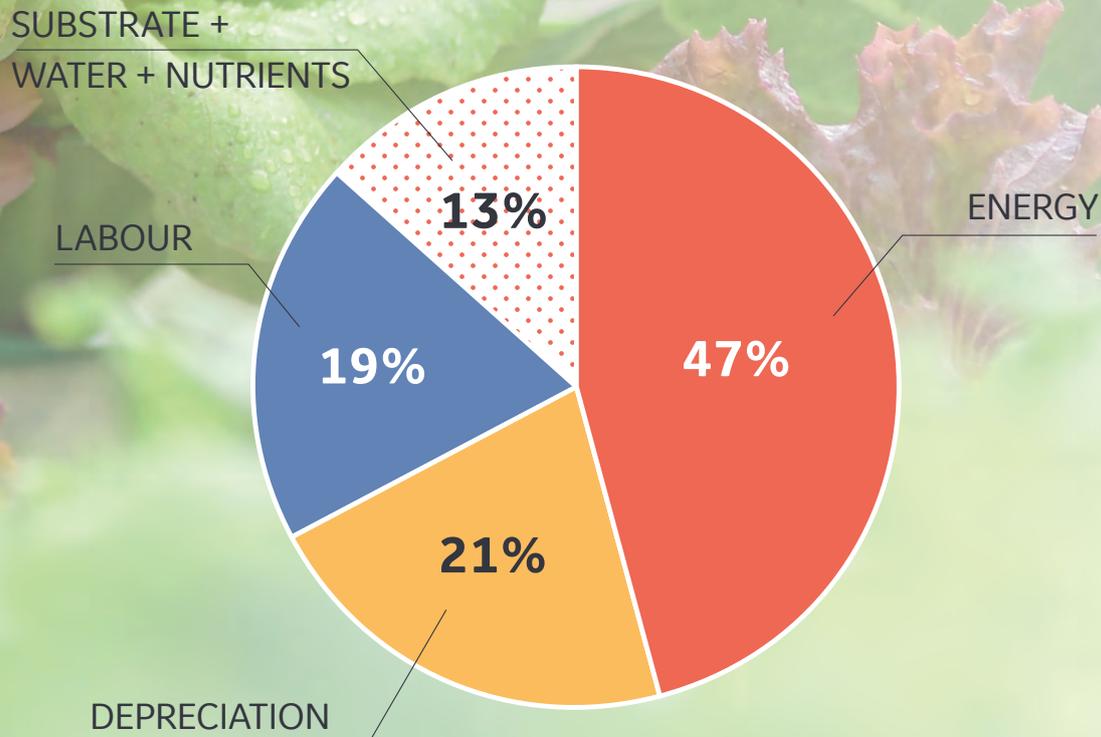
Planning your Vertical Farm

If this guide has convinced you of anything, it should be that there is no “one-size-fits-all” when it comes to vertical farming. Everything from the type of crop to the growing area, levels of automation and location can have a significant impact on the setup of the facility, as well as its commercial opportunity. This is why it’s so crucial to remove as much of the guesswork from the equation as possible with accurate modelling to find the optimal balance of inputs that will maximise the potential yield and earnings per harvest.

Such modelling should also include operational costs such as estimated energy usage, labour, input costs and the logistics required to bring the harvest to market, whether direct to consumers or to food processing customers nearby.

Example Operational Cost Breakdown*

Provided by Stockbridge Technology Centre



*The following chart represents a system with a minimal level of automation, with an estimate for depreciation, based on a large facility with £1000 per square metre of growing space.

Minimising Costs and Looking to the Future

The two highest costs in vertical farming are energy, which can typically vary between 20-50% of the total cost, and labour, which can account for 10-40% per kilogram of plants grown. Therefore, getting the right balance between initial investment in equipment and reduction in input costs per unit output is of prime importance.

To minimise costs, growers need to look to current and emerging technology and systems planning to improve operational efficiency. Compared with older sodium bulbs, LED lights offer a high level of control over energy usage, as they use comparatively less power. However, they will still draw significant power and generate heat that must be managed, potentially creating new opportunities to reduce the overall energy burden through co-location and heat reclamation for other purposes.

In the future, growing indoors with LEDs combined with solar panels could use solar energy more effectively than outdoor growing, as photovoltaic solar panels can capture and convert more of the sun's energy to electricity and the LED luminaires convert

this to the most efficient wavelengths to spur plant development. Some futurists, like Swedish company Plantagon¹², are designing vertical farms in office buildings, using the heat generated in the farm to heat the workspace and CO₂ generated by the workforce to feed the growing spaces in return. The goal is to create a sustainable facility with a lower carbon footprint that can fit into modern city planning.

Additional ways to maximise your energy efficiency include:

- Strategies for optimal cooling (e.g. growing at night when the surrounding air is cooler) and dehumidification
- CO₂ supplementation and recycling from other sources
- Water recycling and drawing excess nutrients from the mist in the air¹³

By planning carefully and being exact in your modelling, you will have a much better idea of day-to-day operational costs. Intelligent management systems can then help you monitor and adapt your settings to maintain the delicate balance of maximum yield set against minimal costs and track your performance against benchmark estimates.

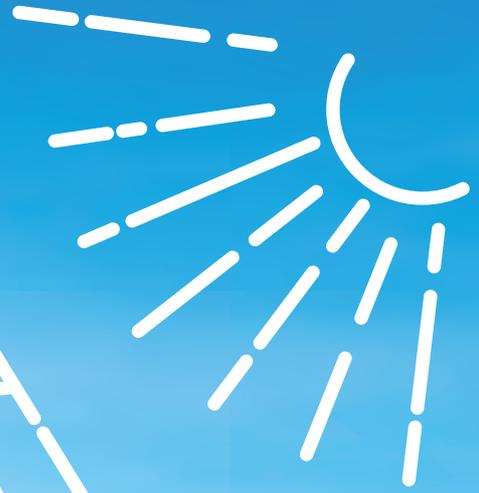
Funding and Investment

With vertical farming set to have positive effects for not only agriculture, but the wider environment and eco-system, many local governments and non-departmental public bodies are helping with a range of subsidies and incentives to help promote the growth of the industry.

These incentives can take the form of initial

set-up subsidies that can help keep costs down when building vertical farms, alongside additional rebates on everything from energy bills to labour costs.

Every country is different so take time to research the resources available to you.



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Additional Resources

Deciding to embark on your journey is only the first step. Although the vertical farming movement is still in its early stages, there are many resources that will help you find more information for designing and building the vertical farm that's right for you.

Relevant Associations and Organisations

GE Current, a Daintree company

www.gecurrent.com

Current enhances commercial, industrial, city and specialty applications with advanced lighting and intelligent controls. Working with our partners, we deliver the best possible outcomes for our customers. See why Current is always on at www.gecurrent.com

Stockbridge Technology Centre

www.stockbridgetechnology.co.uk

The Stockbridge Technology Centre (STC) was launched in April 2001 to ensure continued technological developments for the horticultural industry. This grower-led initiative has created an independent horticultural centre of excellence supported by both the production and supply sectors of the industry.

The Association for Vertical Farming

www.vertical-farming.net

The Association for Vertical Farming is an internationally active non-profit organisation of individuals, companies, research institutions and universities focusing on leading and advancing the sustainable growth and development of the vertical farming movement.

European Association of Agricultural Economists

www.eaae.org

The European Association of Agricultural Economists (EAAE) brings together agricultural economists and others interested in the problems of the agricultural and food industries and rural development in Europe.

AmericanHort

www.americanhort.org

AmericanHort is the leading national association for the green industry, built to promote and advance horticulture across states and segments. Members span the entire industry market chain, including breeders, greenhouse and nursery growers, retailers, distributors, educators, researchers and manufacturers.

American Society for Horticultural Science

www.ashs.org

ASHS was established over 100 years ago and serves to promote and encourage national and international interest in scientific research and education in all branches of horticulture. Members are focused on research and education about how to improve food security, develop urban farms and address major issues facing the nation when it comes to crop sustainability.

PennWell LED & Lighting Network

www.pennwell.com/industries/leds-lighting

PennWell is a network of information sources including LEDs Magazine and Strategies Unlimited that regularly hosts events in the lighting and horticultural space, with a goal of providing a 360 view of the trends within the global market.

Relevant Events

Agriculture Technology

agriculturetechnology.conferenceseries.com

Held in Boston, MA, this event brings together experts, researchers and decision makers both from academia and industry to discuss different research innovations. Various tracks at the event highlight advancing agribusiness, including a dedicated section for Greenhouse and Horticulture developments and how technology can assist in yielding more crops, more sustainably.

China International Modern Agricultural Exhibition

www.cimae.com.cn

China International Modern Agricultural Exhibition is an international event that looks to trade and co-operation across the value chain, with a focus on the latest techniques, materials and innovations for the industry.

Cultivate19

www.cultivate19.org

Cultivate19 is run by AmericanHort and comprised of horticulture professionals from all segments of the industry, including retailers, producers and installers. The event is an opportunity for networking and education and is the largest all-industry trade show and conference for the horticulture industry.

GreenTech Amsterdam

www.greentech.nl

GreenTech is the global meeting place for all professionals involved in horticulture technology in RAI Amsterdam. GreenTech focuses on the early stages of the horticulture chain and production issues relevant to growers.

Growtech Eurasia

www.growtech.com

Growtech Eurasia takes place with participation of leading companies from the Greenhouse and Technologies, Agricultural Technologies and Equipment, Irrigation Systems, Seed Growing, Seedling Cultivation, Plant Nutrition and Protection, Biological Control, Agricultural Machinery and Livestock Equipment areas.

Horticulture Lighting Conference

www.horticulturallightingconference.com

The Horticulture Lighting Conference is dedicated to the impact of LEDs on the horticultural market, bringing growers and manufacturers together under one roof.

Indoor Ag-Con

www.indoor.ag

The event will include the best and the brightest of the Asian and Antipodean indoor agriculture scene, with a focus on a range of technologies including artificial intelligence, LED lights and control systems.

Rethink Agri-Food Innovation Week

www.agrifoodinnovation.com

Rethink Agri-Food Innovation Week is a three day event looking at the growing role of technology in building an efficient, resilient and sustainable agri-food supply chain that can deliver fresh, nutritious food to today's fast-changing consumer market.

The Association for Vertical Farming Summit

vertical-farming.net/events-page/avf-summit-2018

This event is the annual summit of the Association for Vertical Farming, a global not-for-profit organisation dedicated to advancing the vertical farming movement on the international stage.

Vertical Farming Conference

www.verticalfarmingconference.com

The Vertical Farming Conference is part of the two-day Agri-Food Innovation Event, which includes four dedicated conferences: the Healthy Nutrition Conference, Vertical Farming Conference, 3D Food Printing Conference and Smart Farming Conference.



References

1. <https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html>
2. <https://data.worldbank.org/indicator/ag.lnd.agri.zs?end=2015&start=1961&view=chart>
3. <https://news.un.org/en/story/2013/12/456912>
4. Global Market Insights, Inc. Insights Report 2017, "Vertical Farming Market Size by Product, Fruits, Vegetables & Herbs, Aquatic Species, By Technology, By Application, Industry Analysis Report, Regional Outlook, Growth Potential, Price Trends, Competitive Market Share & Forecast, 2018 – 2024"
5. <https://uk.businessinsider.com/the-demand-for-local-food-is-growing-2017-4>
6. <https://sciencing.com/high-humidity-effects-photosynthesis-12060330.html>
7. <https://www.maximumyield.com/how-plants-breathe-the-stimulating-story-of-stomata/2/3827>
8. <https://www.dpi.nsw.gov.au/agriculture/soils/improvement/plant-nutrients>
9. <https://www.nature.com/scitable/knowledge/library/plant-soil-interactions-nutrient-uptake-105289112>
10. Global Market Insights, Inc. Insights Report 2017, "Vertical Farming Market Size by Product, Fruits, Vegetables & Herbs, Aquatic Species, By Technology, By Application, Industry Analysis Report, Regional Outlook, Growth Potential, Price Trends, Competitive Market Share & Forecast, 2018 – 2024", p113
11. <https://university.upstartfarmers.com/blog/9-reasons-why-vertical-farms-fail>
12. <https://www.plantagon.com/>
13. <https://large.stanford.edu/courses/2016/ph240/swafford2/docs/banerjee.pdf>

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