2021 Global CEA Census Report

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In 2020, the Global CEA Census was focused on COVID-19 and the impact on our industry. This year, the 2021 Census focuses on sustainability and how farms are addressing factors such as water and energy consumption and general sustainable practices.

Sustainability is not a new discussion. However, it is gaining importance with governments and consumers around the world demanding more transparency and accountability.

In 2015, the United Nations launched the 2030 Agenda for Sustainable Development. The agenda was adopted by all United Nations Member States and provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. Central to this are the 17 Sustainable Development Goals (SDGs) that call for urgent action by all countries.

Programs and other actions like this are here to stay. The question for this Census was 'how ready are CEA producers for a sustainable future?'

SUSTAINABLE DEVELOPMENT GOALS

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Disclaimer

The 2021 Global CEA Census is a joint project of Agritecture LLC and WayBeyond Ltd. Both parties have done their best effort to encourage participation in the Census among CEA farm operators globally. That said, all participation in the Census was voluntary and none of the information submitted by Census respondents has been verified by any independent sources.

We (WayBeyond & Agritecture) are not responsible for the accuracy of the data in the report since it has not been independently verified. We encourage any organization to conduct proper due diligence before making any critical decisions for you or your business.

Contents

The Definitions

The Controlled Environment Agriculture (CEA) industry is still refining its own identity. For the purposes of this report we are using the following definitions:

CEA is the growing of crops while controlling certain aspects of the environment including lighting, temperature, CO_2, humidity, irrigation, fertigation and other factors that influence plant physiological responses.

GREENHOUSE refers to a climate-regulated structure with walls and roof made out of a transparent material in which crops are grown.

SHIPPING CONTAINER refers to a climate-regulated shipping container using only artifical lighting (no sunlight) for crop production.

HIGH TUNNEL refers to crops covered with a canopy for protection against the elements and sometimes referred to as hoop houses or tunnel houses (not small backyard hobby tunnels).

INDOOR FARM refers to crop production that utilizes artificial lighting instead of sunlight. This can include rooms, warehouses, factories and other converted indoor spaces.

VERTICAL FARMING is crop production that uses the vertical space. Plants can be stacked horizontally or in tall towers.

The Report

For this report we have chosen to incorporate other research undertaken by external sources that can give further context to what is a complex industry.

Thoughts from the co-author

Kylie Horomia
WayBeyond
Head of Industry Transformation

“Every year 1.3 billion tonnes of food is wasted with 75 million tonnes of that in the production of fruit and vegetables. This is quite astounding when you consider 2.37 billion people are without food or unable to eat a healthy balanced diet on a regular basis. And if you reflect that 45 million children under 5 years of age suffer from wasting; these aren’t numbers we should be ignoring.

Sustainability is not just about the use of natural resources but also business practices and behavioural change that can make positive improvements. Addressing the issue of food waste and hunger can be done if we grow smarter, address the distribution challenges and make food affordable and accessible for everyone.

Not an easy challenge but one worth solving. The Global CEA Census helps us play a part in understanding how we as an industry impact the planet, and thereby the people.”

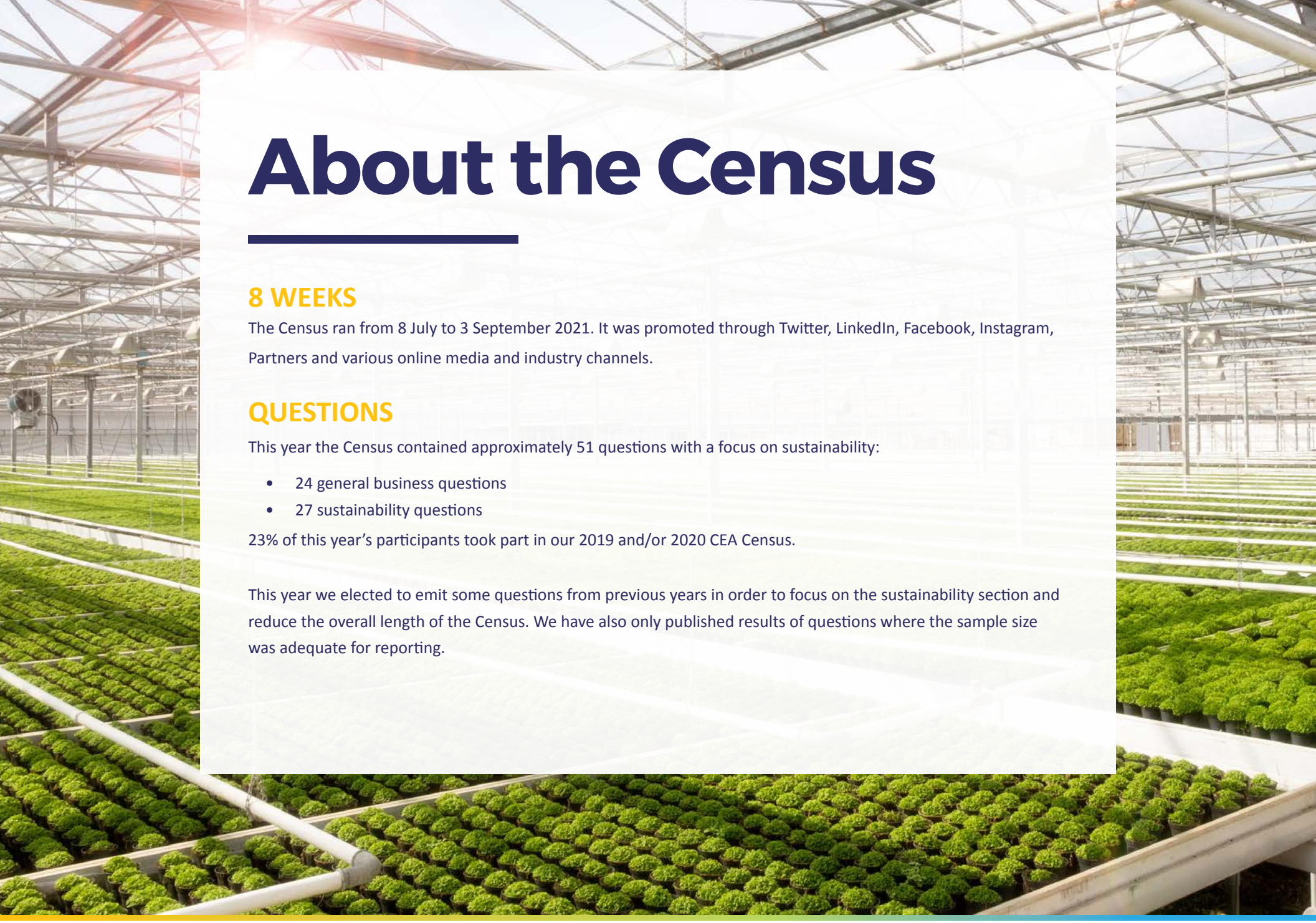
Thoughts from the co-author

Henry Gordon-Smith
Agritecture Founder & CEO

“2021 marks my 10th year in the CEA industry. Many things have changed since I first started visiting farms and interviewing founders ten years ago - most notably, advanced technology solutions and private investment have poured into the market in recent years. But surprisingly, the conversation around sustainability in CEA has not progressed much further.

Too frequently we see farms relying on vague and outdated claims when it comes to the true environmental impact of their operations. While there are many positive outcomes of controlled environment agriculture, our belief at Agritecture is that glossing over the drawbacks - or worse, purposefully trying to deceive others about the existence of any drawbacks - is a risk for the future viability of the entire industry.

We believe this year’s Global CEA Census Report will shine a bright light on many of the deeper nuances behind CEA as an inherently ‘sustainable’ farming model. Furthermore, we hope this report will contribute to the establishment of more industry baselines for specific sustainability metrics.”



About the Census

8 WEEKS

The Census ran from 8 July to 3 September 2021. It was promoted through Twitter, LinkedIn, Facebook, Instagram, Partners and various online media and industry channels.

QUESTIONS

This year the Census contained approximately 51 questions with a focus on sustainability:

- 24 general business questions
- 27 sustainability questions

23% of this year's participants took part in our 2019 and/or 2020 CEA Census.

This year we elected to emit some questions from previous years in order to focus on the sustainability section and reduce the overall length of the Census. We have also only published results of questions where the sample size was adequate for reporting.

The Respondents

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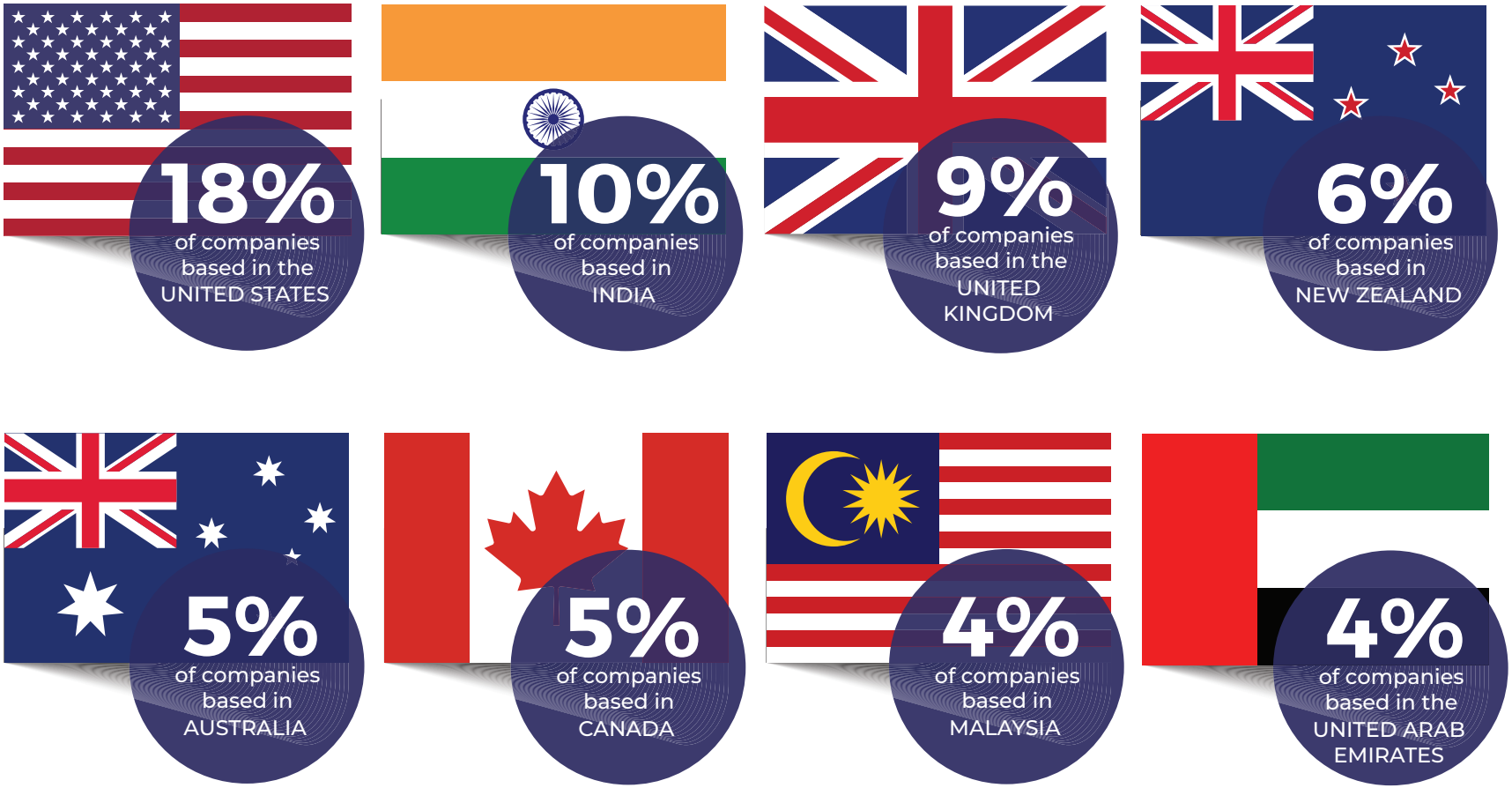
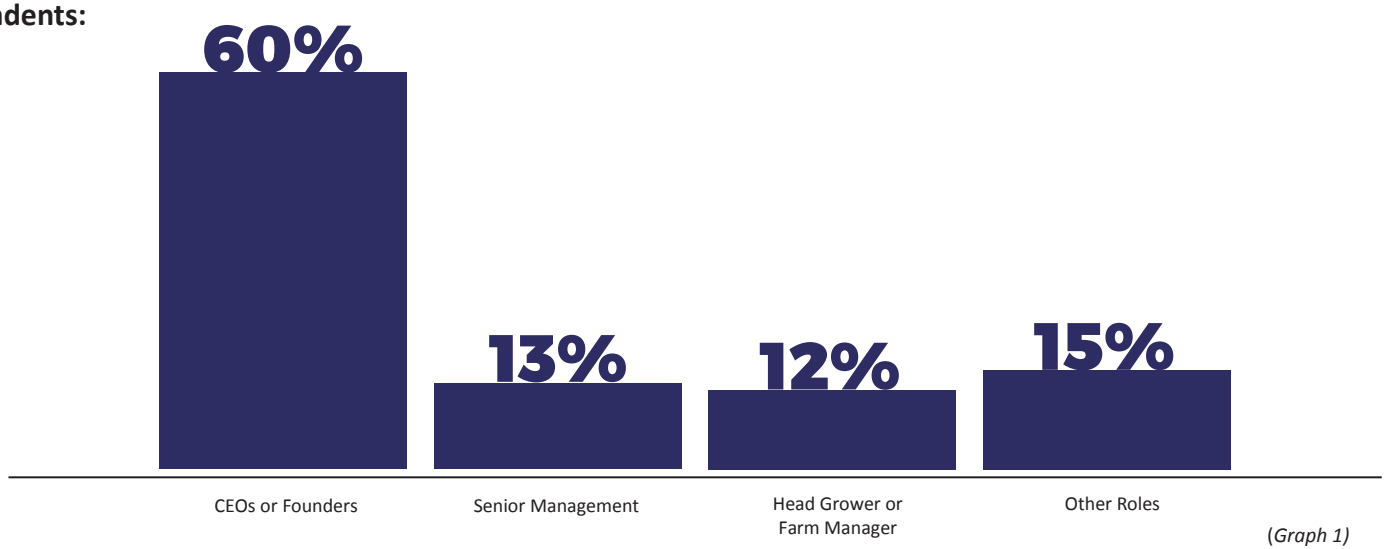
This year we received 336 overall respondents.

Even with the focus on growers, every year the Census gets feedback from others including suppliers, consultants, researchers etc. For this report we filtered out responses to only include those that were submitted by growers to ensure the legitimacy of the results.

This year respondents from 51 countries took part including:



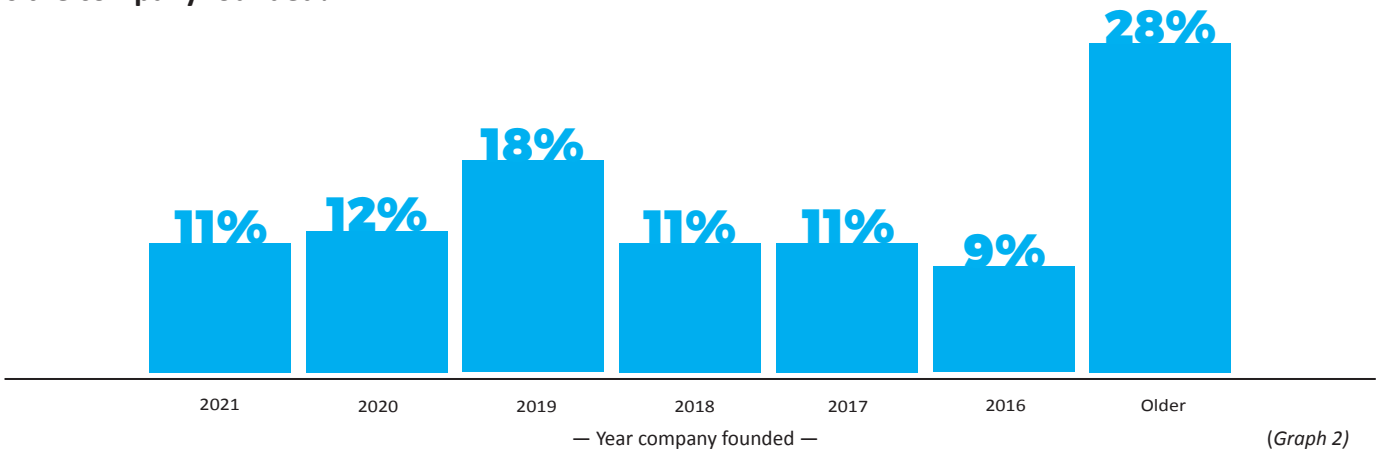
Of the respondents:



(*Graph 1)*

We asked the following questions related to their operations:

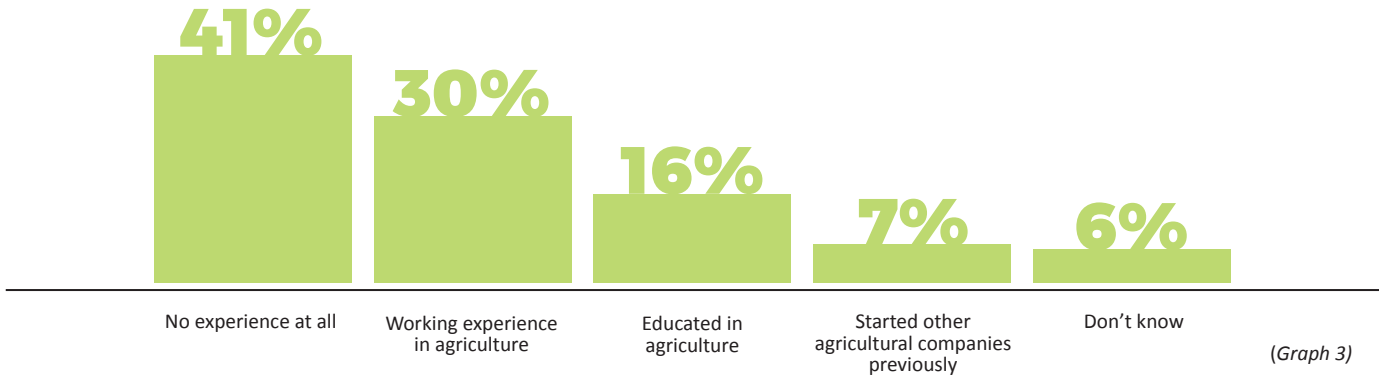
What year was the company founded?



(*Graph 2)*

It's interesting to note that, while the pandemic has substantially altered business practices in the CEA industry over the past two years, there is still optimism and new business growth. It was also pleasing to see older companies sharing their insight into this year's Census with 14% of companies founded at least 10 years ago.

What was the founder's experience in agriculture before starting the company?

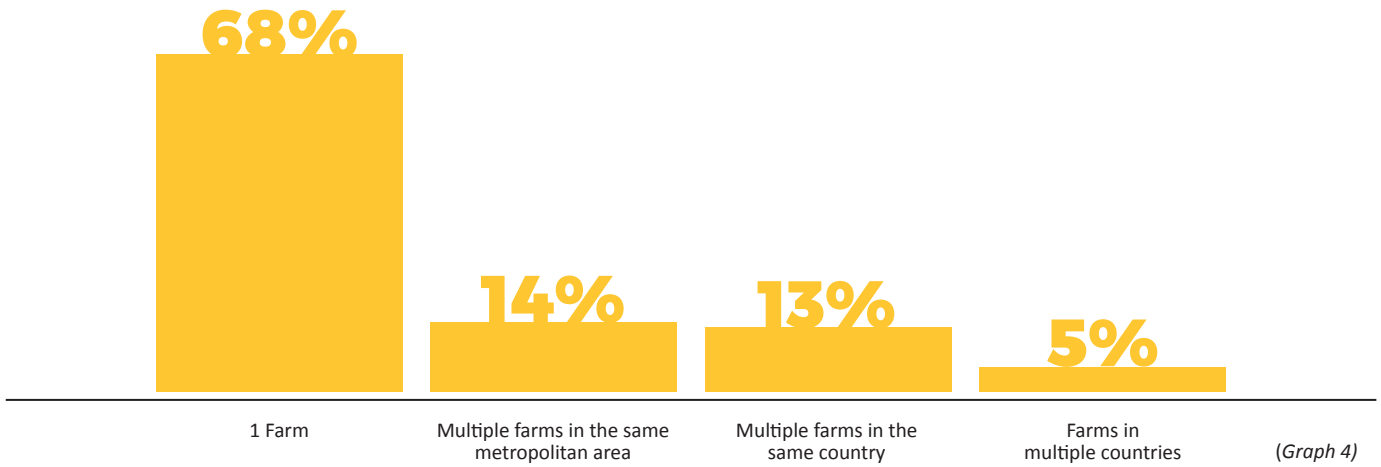


(Graph 3)

This question has consistently shown a high percentage of founders with no prior agricultural experience. In 2019 we found 41% of founders had no experience, in 2020 it was 49% and in 2021 the result was 41%.

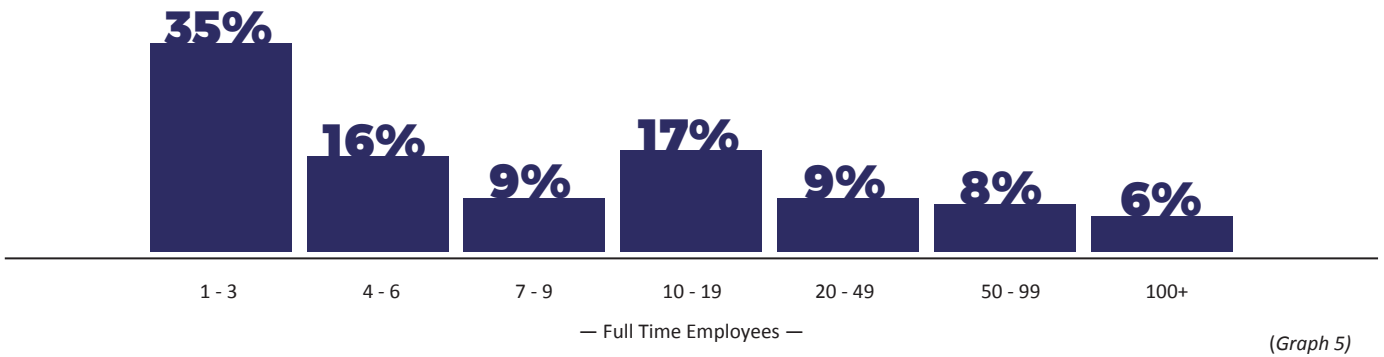
When you consider that 77% of respondents this year are doing the Census for the first time, this is a considerable amount of new entrants into the industry.

Does the company operate multiple farms?



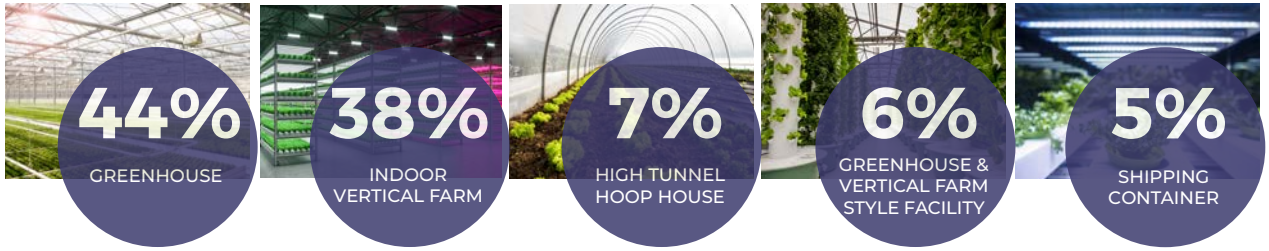
(Graph 4)

How many total full-time employees, including owners, does your company have?



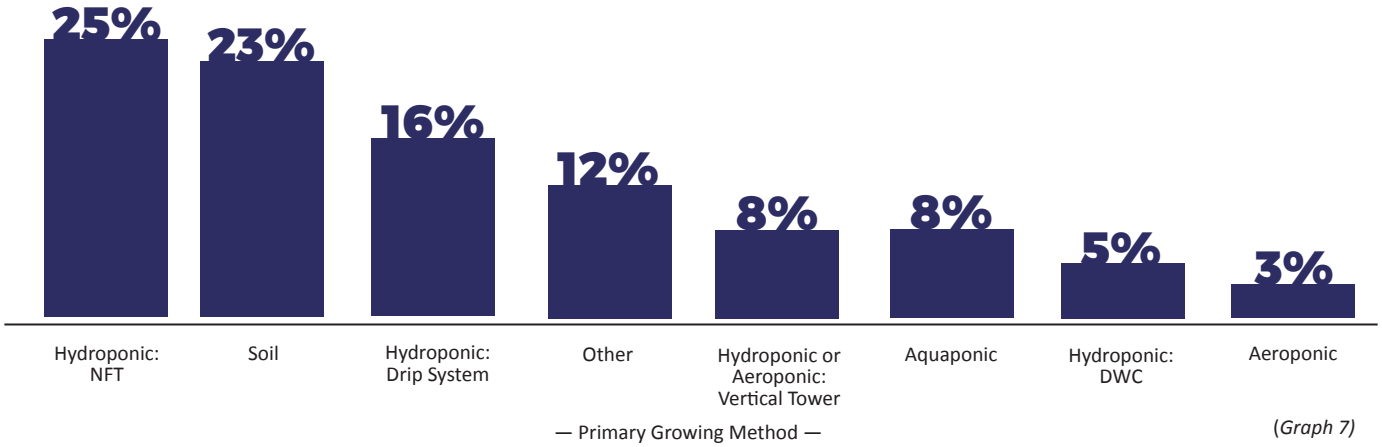
(Graph 5)

What type of CEA facility do you use for cultivation?



(Graph 6)

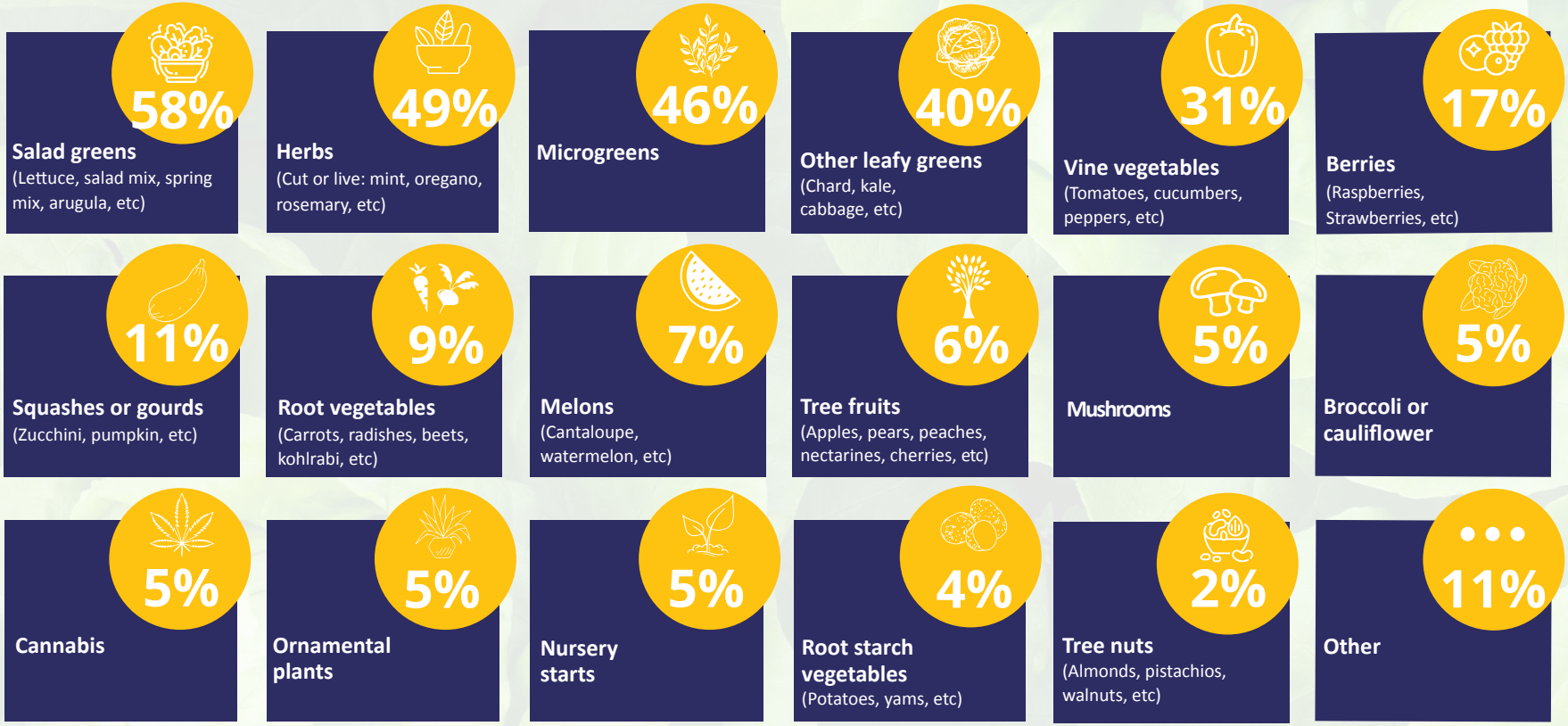
What is your PRIMARY growing method?



(Graph 7)

What crops are being grown.

The respondents from the Census produce a range of crops including:

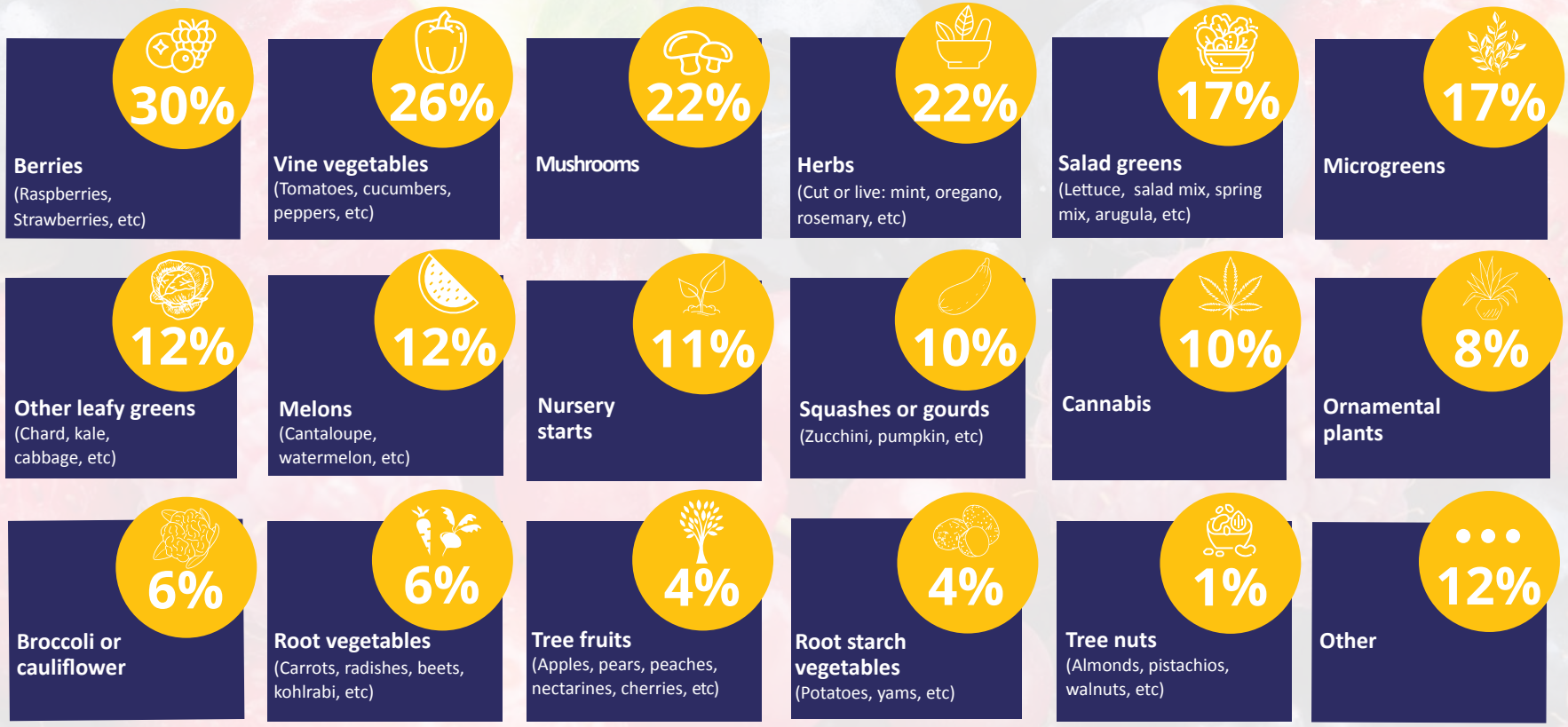


(Graph 8)

What crops are being considered

The respondents from the Census are considering growing these crops in the next 12 months:

With 30% of growers considering berries as a new crop in the next 12 months, the impact on the market would be something that all current berry growers would need to consider. Another crop that stands out for its popularity is mushrooms, with 22% of growers considering it.



(Graph 9)

What the Experts Say

"Mushrooms have been traditionally grown in CEA systems for decades and a forecasted increased demand for specialty mushrooms have seemed to catch the interest of many CEA operators. The main drivers for the uptick in demand are customers' increasing awareness of the health benefits of mushrooms (specifically around protein as a meat-alternative), the unique medicinal benefits provided by fungi, and a desire to try different types of mushrooms other than mass-produced button (Agaricus bisporus) mushrooms.

From the CEA operator side, the increased online resources available to new growers and the ease of access of acquiring mushroom cultivation equipment, such as laminar flow hoods and sterilization equipment, contribute to the overall growth of specialty mushrooms grown in CEA systems. For better resource use efficiency, there could be synergies within the system where the CO_2 generated from the colonization process could be used to enrich plants instead of resorting to traditional methods of CO_2 enrichment such as burning natural gas."

Justin Hyunjae Chung
Agritecture Technologist Fellow

What the Experts Say

"We believe that CEA berries are the next wave to take off in the North American and Asian markets. We see enough working CEA operations in the UK and in Northern Europe to know that both the genetics and indoor/greenhouse growing techniques and tools work. The human expertise is still scarce, but it is there. In some ways, California provided the 'spark' for this inflection: with increasing pressures of labor availability, restrictions on chemicals, water availability and climate shifts.

Lastly, the industry is maturing to understand that CEA berries will not be solved and scaled by throwing technology and CapEx at it, e.g. the use of high-tech glasshouse and indoor vertical will not be the only solution. Like all crops, we will learn to select 'appropriate-tech' to match the climate, culture, and market"

Dave Chen

Equilibrium Capital CEO

Funding & Financials

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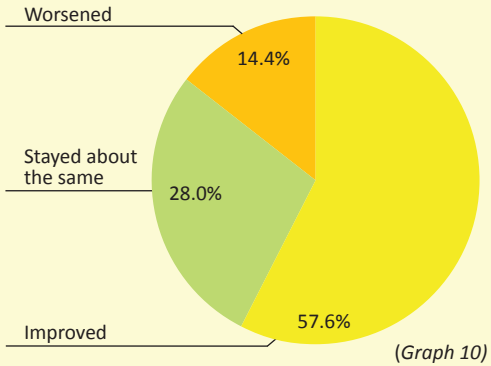
Respondents represented operations ranging from small businesses with revenue under USD$25,000 to large ones with more than 100 employees and annual revenues exceeding USD$10,000,000.

Comparing 2021 to 2020, how has the financial health of the business been?

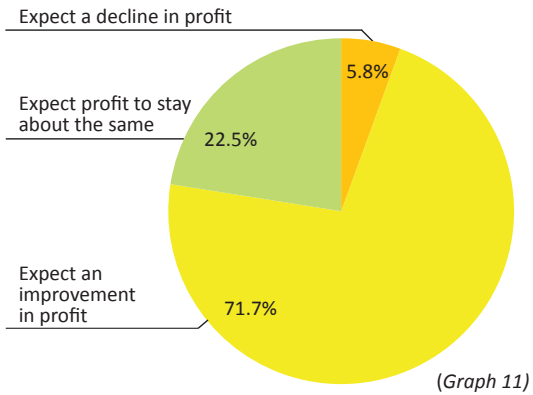


(*Graph 10)*

In a good overall sign for the industry, about 58% are seeing financial improvement from 2020, and only 14% are seeing a decline in financial health. In last year's Census, since it was still early in the COVID-19 timeline, we asked explicitly about the pandemic's impact on crop sales assuming that it might be too early for many farms to fully gauge the impact on overall financial performance. What we discovered was that while performance varied drastically, more farms had experienced a significant decline in sales (43%) than those that had seen a substantial increase in sales (26%).

Financial expectations for the next year

Similar to last year's Census, respondents are showing clear signs of optimism about the immediate future. In fact, nearly 72% of farms indicate that they expect improved net margins, whereas last year 52% answered similarly. Only 6% of farms this year expect a decline in net margin over the next 12 months; last year, 5% responded similarly.



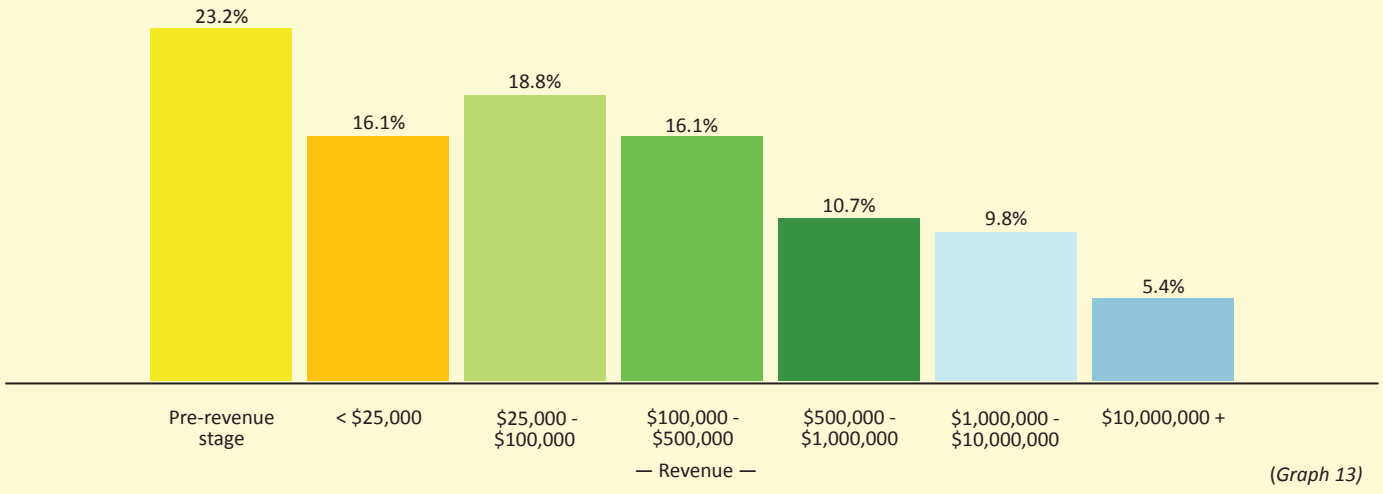
(*Graph 11)*

Financial expectations for the next year — crop type: leafy greens

One trend that stands out this year is the optimism specifically amongst leafy greens and microgreens growers, relative to other respondents.

(*Graph 12)*

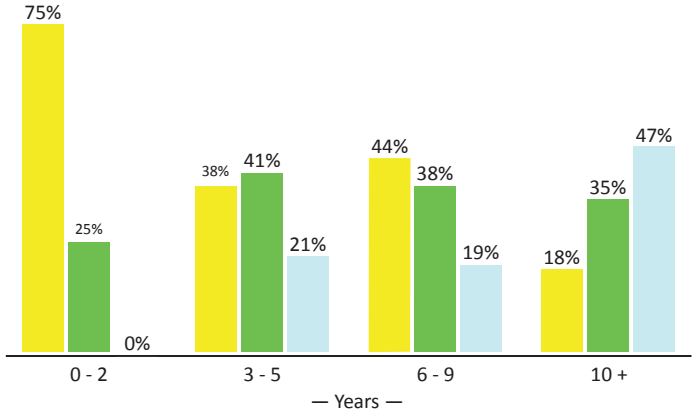
Sales revenue in the past 12 months



(Graph 13)

Sales revenue in the past 12 months — age of business

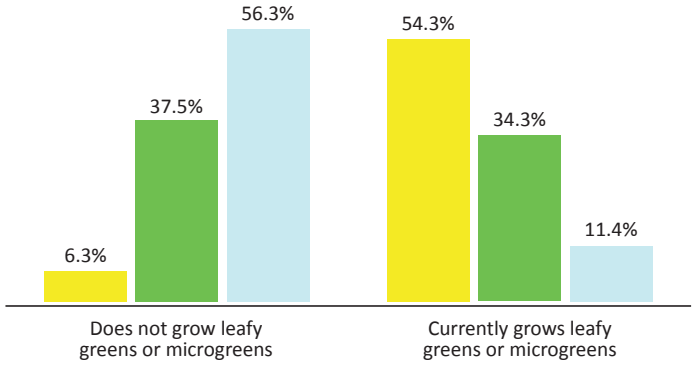
Unsurprisingly, there is a correlation between age of the business and revenue. Last year's Census also established the correlation between age of the business and overall profitability.



(Graph 14)

Sales revenue in the past 12 months — crop type: leafy greens

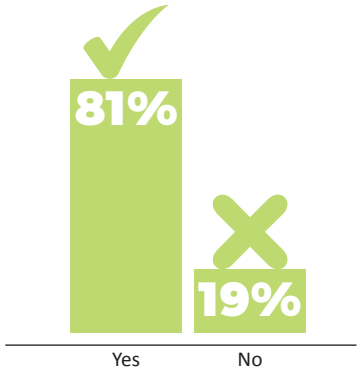
One observation from this year is that our leafy greens and microgreens growers are much more likely to be small revenue businesses when compared to all other crops (vining, berries, etc.). Given that microgreens and lettuce varieties tend to be the most popular 'beginner' crop types, this certainly makes sense.



(Graph 15)

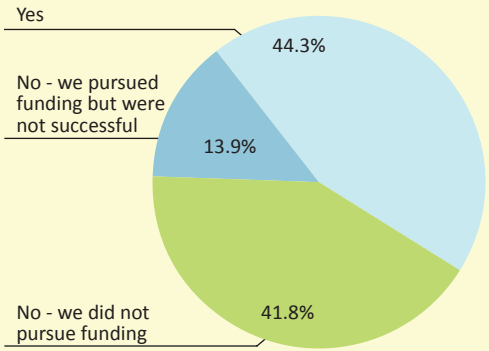
< $100,000 $100,000 - $1,000,000 $1,000,000 +

Do you plan to increase your production area in the next 12 months?



(*Graph 16)*

Has your operation received investments / funding in the last year?



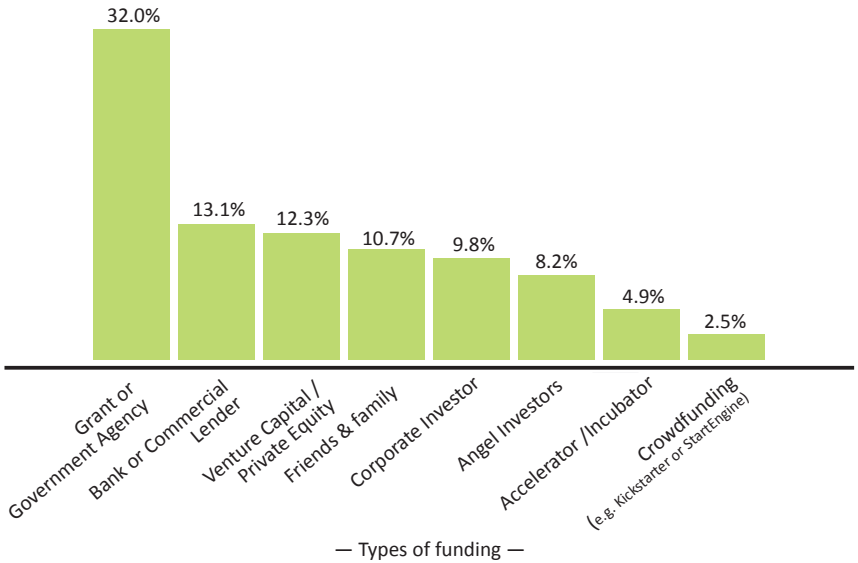
(*Graph 17)*

A higher percentage of respondents pursued funding (58%) relative to last year (40%). This could potentially be driven by the negative effects of the pandemic or the increasingly bullish market for private investment into CEA.

Two points stick out:

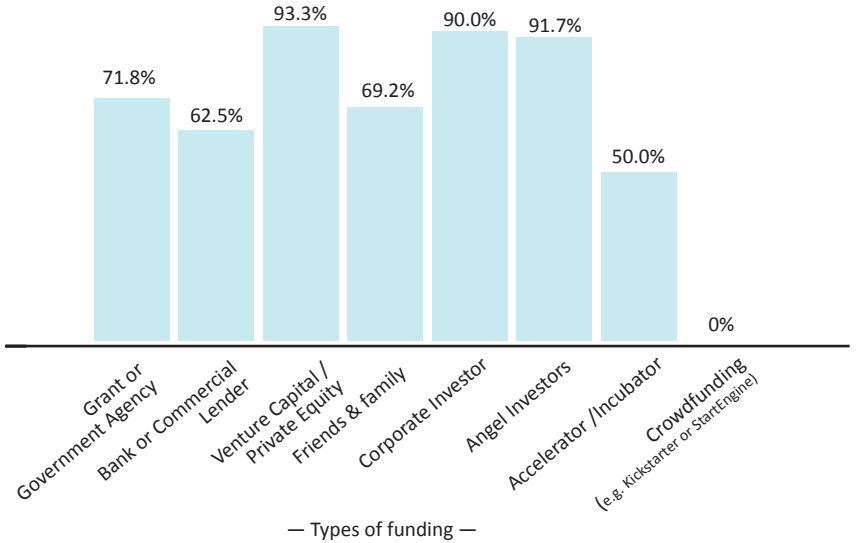
1. 'Grants or government agency' was the most popular route pursued by a wide margin (32% of all respondents).
2. The success rate of CEA businesses who pursued funding through angel investors, venture capital/private equity, and corporate investors was staggeringly high: a combined 92%.

Type of Funding Pursued



(*Graph 18)*

Success Rate of Funding Pursued



(*Graph 19)*

Sustainability: General

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This is the 3rd year that Agritecture and WayBeyond have conducted a CEA Census. Each year, we've aimed to collect data that would shed light on what this industry truly looks like, major challenges for operators, and opportunities on the horizon. Our motivation with this data has been to move the industry narrative beyond the media headlines, half-truths, and generalizations that are so frequently reiterated publicly about controlled environment agriculture. At the same time, we must balance how much data we want to collect with how long of an attention span it is fair to expect of survey participants.

With all this in mind, we decided to focus much of this year's Census on questions related to sustainability: how businesses think about the topic, specific practices they employ, and actual performance metrics - such as water use, energy use, waste generation, product shelf life, and more.

In an attempt to filter out businesses that do not track these sustainability-related metrics and avoid any feelings of pressure to report numbers that these farms do not have, we first asked respondents to indicate whether or not they track numbers related to each category. For example, for metrics related to water use, we first asked: "Does your business track data related to water use?" Only those who answered "yes" were then able to answer specific questions about their water usage. We did the same for energy use and shelf life.

Here's what surprised us

Regarding water use, 70% of respondents indicated that they track this metric. Yet only 40% actually provided a credible number on water usage. The numbers were more bleak when it came to energy: 62% indicated that they track energy consumption, but only 28% provided a credible number. (By credible, we mean a number with units, in the format we requested - kWh per kg or kWh per lb of produce.) From there, only about half of this 28% were able to give us a breakdown of energy consumption by use case on the farm.

This resulted in relatively thin data for us to work with for most quantitative measurements of sustainability. While we would have liked to segment the numbers many different ways (for example, looking at differences in energy use between large-scale vs. small-scale greenhouse vine crop growers), it was challenging to do this with any meaningful statistical significance. For this reason, we are only reporting on results with a reliable sample size.

CEA is often cited as a more resilient way of protecting produce against the negative impacts of climate change - such as extreme temperatures, higher incidence of droughts and floods, and increasing pressure from pests and disease. Some also point to increased shelf life - and thus lower food waste - that is obtainable with CEA facilities producing food much closer to consumers. Others highlight the significantly higher water efficiency in recirculating systems employed within CEA facilities. Furthermore, with much higher yields per acre, CEA is often cited as a solution to rising global populations and decreasing amount of arable land per person. Finally, we often hear of CEA as a way of attracting younger generations to farming.

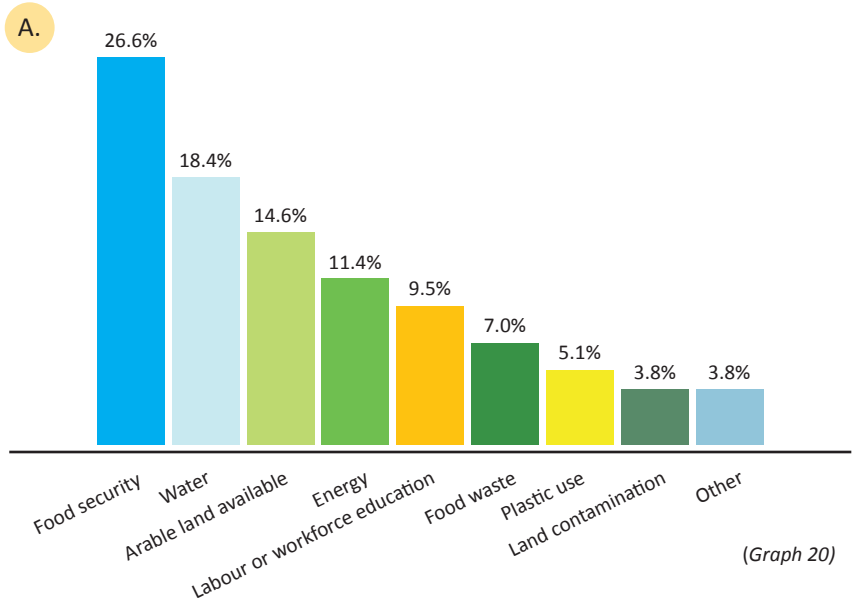
With that being said, skeptics of CEA often point to high on-farm energy usage, high capital costs, and the reliance on non-renewable materials (including but not limited to plastics) as challenges to CEA being considered inherently "sustainable."

So we were curious to hear from respondents:

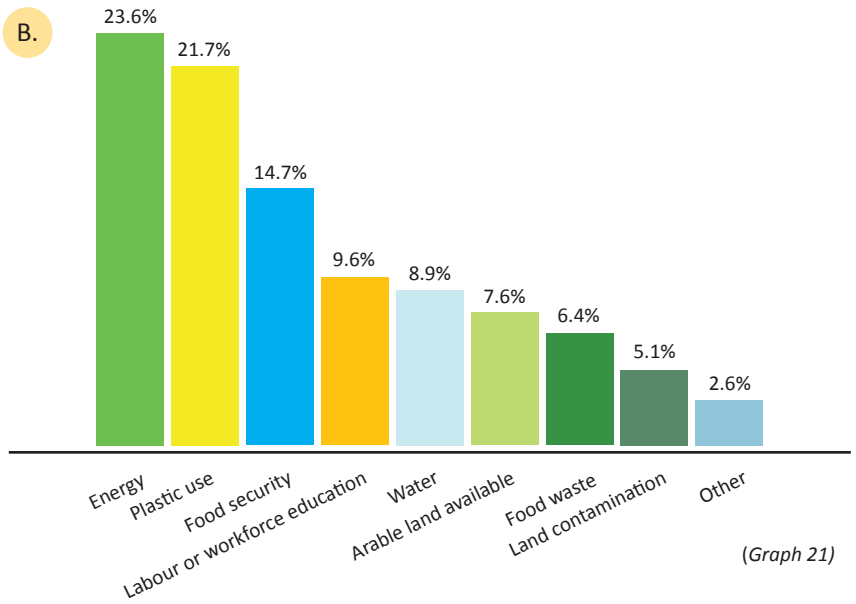
A. What do they believe are the greatest sustainability challenges addressed by their business?

B. What do they as individuals believe their businesses can do a better job of when it comes to sustainability?

Perhaps unsurprisingly, the answers to these two questions differed. While respondents elevated Food Security and Water as the top sustainability challenges being directly addressed by their businesses, they highlighted Energy and Plastic Use as areas for improvement.



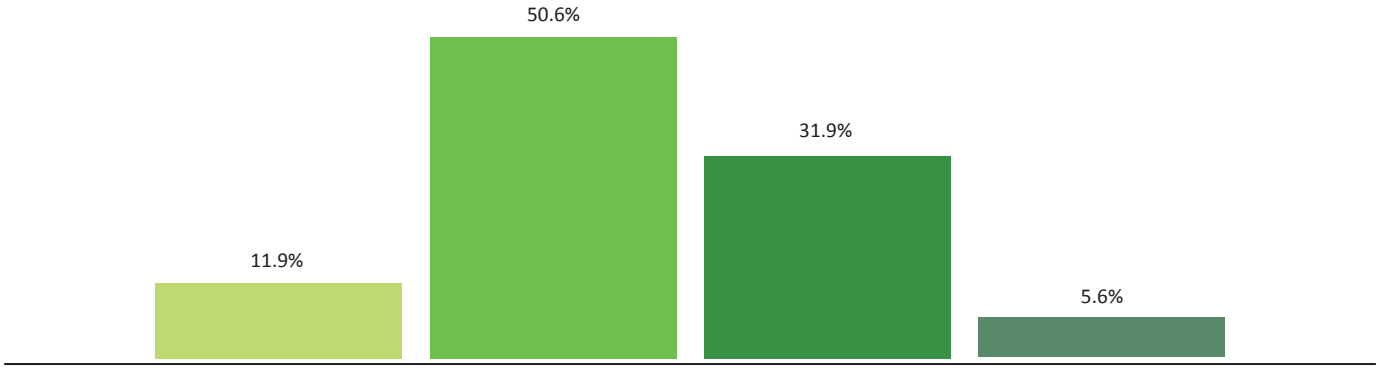
(Graph 20)



(Graph 21)

While more follow-up questions are warranted, these responses led us to conclude that CEA businesses are aware of the tradeoffs they are making when it comes to sustainability outcomes, whether or not they are publicly acknowledged.

How often do your customers inquire about your practices related to sustainability?



(*Graph 22)*

The Economist Intelligence Unit sponsored by the World Wildlife Fund reported that online searches related to sustainability have increased by 71% globally, and public demand for action has also been growing through protests and increased press coverage.[1] The study shows that society's general understanding of biodiversity and nature loss has increased.

In Twitter's 2019 Trends Report, the company noted a 53% increase in conversations about food production increase, zero-waste, energy, plastic, and pollution. They also pointed out that people are demanding more from those with power, and businesses are being held accountable for their environmental impacts through these conversations.[2]

Other companies report similar findings. An Impossible Foods' 2019 survey found that 62% of Gen Zers were willing to spend more money on sustainable food options. Additionally, according to the 2019 Deloitte Global Millennial Survey, "42% of millennials said they have begun or deepened a business relationship because they perceive a company's products or services to have a positive impact on society and/or the environment."[3]

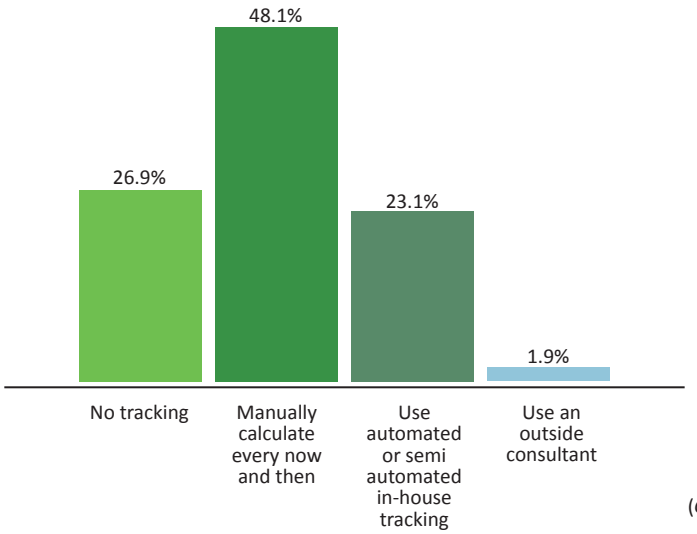
Our respondents indicated that their consumers do not inquire about sustainability practices as often as we may have expected, with the majority either "occasionally" or "never" inquiring. One pattern that stood out: European respondents indicated that their consumers were more than twice as likely to inquire about sustainability practices "all the time" than the global average.

In discussing these results, we recognized that the question could have been improved, as businesses that sell through distributors, supermarkets, or to restaurants, are likely not interacting with the end consumer very frequently, and therefore may not have a clear read on this. Next time, we would also ask how often the business has polled their end consumers, what their methodology is for doing this, and how easy it is for customers to read or ask about the grower's sustainability practices (i.e. is there a page on their website dedicated to sustainability? How often is that page viewed relative to other pages?)

1 The Economist Intelligence Unit (source dated 2021)
2 The Conversation: Twitter Trends (source dated 2019)
3 Equitable Food Initiative (source dated March 4, 2020)

How does your business track sustainability metrics?

We were surprised to see that 48% of respondents are tracking sustainability metrics by “manually calculating every now and then” and that still another 27% do not track at all. Looking across typical operation segments (small vs. large facilities; greenhouse vs. vertical farms; new vs. existing businesses) resulted in very little variability in the data.

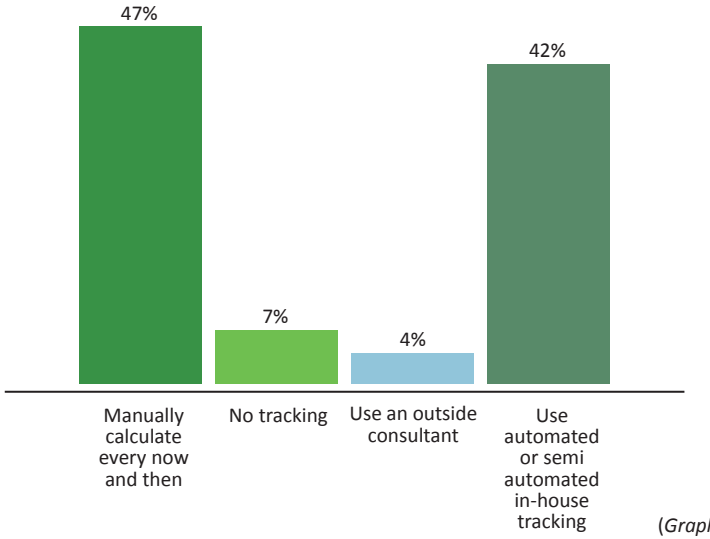


(*Graph 23)*

One positive takeaway was that a slight majority of businesses (57%) reported this being their first year tracking sustainability metrics. What this means is that many farms are still learning the ropes.

For businesses that currently do not track sustainability metrics, some simple metrics to start tracking would be energy consumption, water consumption, and wastage, all of which have an important impact on the operation’s profitability as well.

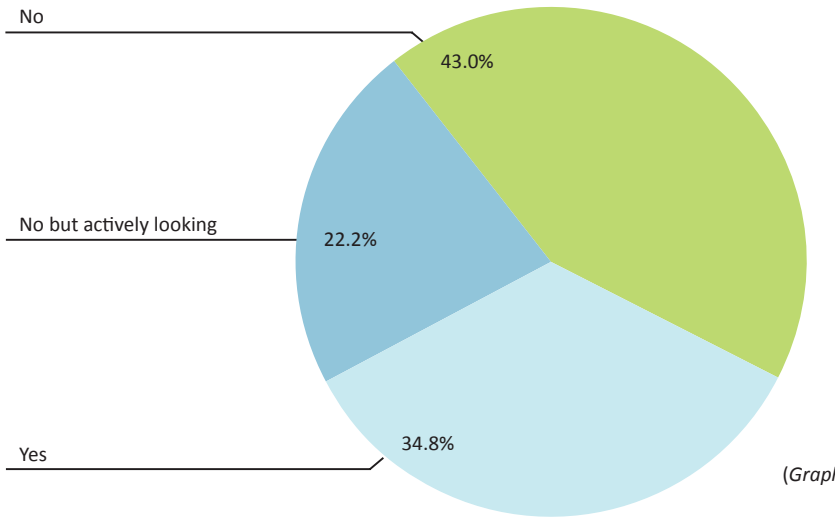
How does your business track sustainability metrics (For those businesses that currently have a specific role in charge of improving upon sustainability outcomes)



(*Graph 24)*

Do you currently have a specific role within your business whose day-to-day responsibilities include tracking and improving upon sustainability outcomes?

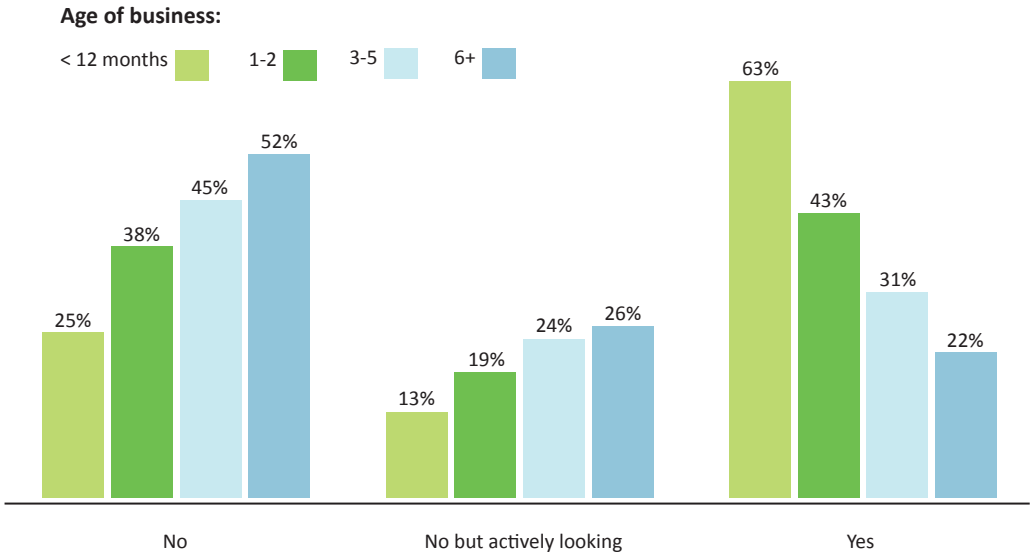
Currently, only about 35% of businesses have a specific sustainability-focused role appointed. But we were again encouraged that another 22% answered that they were actively looking for someone, despite not having that role filled today.



(Graph 25)

Do you currently have a specific role within your business whose day-to-day responsibilities include tracking and improving upon sustainability outcomes? — Age of business

Interestingly, as Graph 26 illustrates, the newer the business, the more likely it is that they have a specific role focused on tracking sustainability outcomes. One would think that more experienced operations would have more financial leeway to hire for this role given the positive correlation between the age of a CEA business and overall profitability (see: 2020 CEA Census Report).



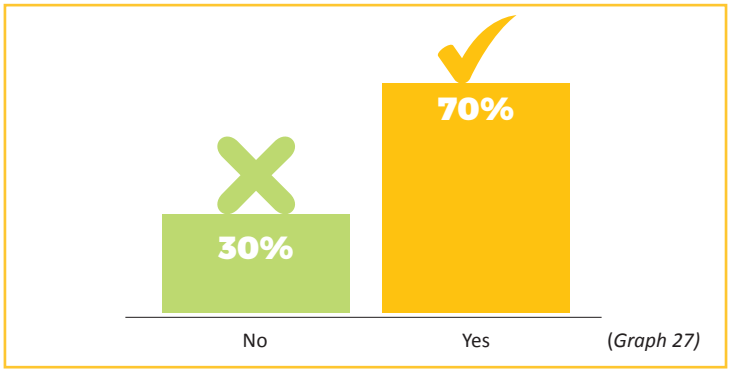
(Graph 26)

Do you think the CEA industry has been susceptible to excessive "greenwashing"?

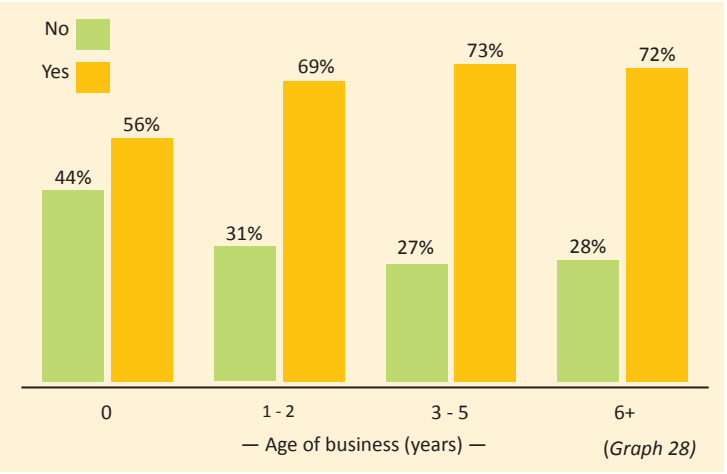
Greenwashing refers to providing misleading information so as to create the impression that a company or product is more sustainable than it actually is.

According to The World Economic Forum, greenwashing can occur through both selective disclosure and through symbolic actions.[4] While some companies may be aware that they are making misleading claims, others may simply lack the proper data or the method to collect data, and instead rely on general averages or anecdotes. Whether the greenwashing is intentional or not, the danger is in its ability to slow progress toward true sustainability.

Interestingly, respondents who agreed that the CEA industry has been susceptible to excessive greenwashing also reported lower average use of water, energy, and less wastage. This could be a general indication that those who are more efficient with their use of resources tend to be more conscious of greenwashing.



(Graph 27)



(Graph 28)

For those CEA businesses using terminology around the "sustainability" of their methods without currently tracking or reporting on specific outcomes, we believe greenwashing can be mitigated by transparently tracking energy use, water use, and waste on a per pound or kilogram of yield. And we hope the numbers that follow can serve as a starting point for establishing baselines - though in the future, more data is needed to further segment this data.

To go even further, we believe transparency will also be important in regards to the following topics (though we agree that determining how best to measure and report on these categories can be tricky and more conversation is needed):

- Sourcing of CEA "consumables" - specifically fertilizers/nutrients and growing media
- Biodiversity effects of the CEA facility on the surrounding ecosystem of living organisms
- Production and end-of-life disposability of key capital expenditures such as LED lights
- Human capital - investing in farmworkers and meeting their needs of safe working conditions and living wages

4 WE forum (source dated May 20, 2021)

Insights From A Grower

"There is a TON of greenwashing in the industry. Not to throw the vertical indoor guys under the bus, but it is crazy how indoor farms (and greenhouses) will say less food miles (e.g. lower carbon footprint) but then use an unbelievable amount of energy (lights/HVAC) per lb/lettuce. If consumers knew how much energy went into their "indoor" food, they would be shocked!"

Greenhouse grower, United States

"If you look at the communication of CEA actors and especially indoor/vertical farming companies, sustainability claims are widespread in public statements but almost never backed with factual and comprehensive data (e.g. Life Cycle Assessment based).
As most data is kept secret (yields, energy consumption per kg, actual water footprint, source of electricity, raw material usage...) those claims are quite hard to be challenged, and thus it is quite easy for companies to cherry-pick the environmental benefits and not talk about the issues.
I believe this is fostered by the dependence on fundraising, as most actors have not yet proven the viability of their business models, and need arguments to keep attracting investors to back their projects, which will remain the case in the next few years at least."

Container Grower, France

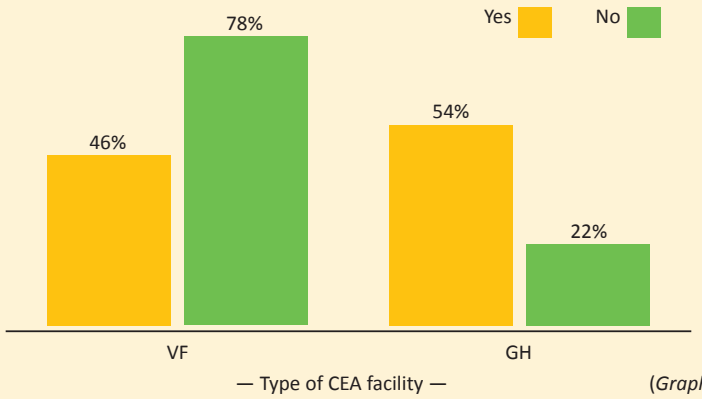
Does your business use integrated pest management (IPM) practices?

As defined by the University of California Statewide IPM Program, integrated pest management (IPM) is "an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism."[5]

When compared to conventional pest management, IPM only uses chemicals when absolutely necessary and is often combined with other methods to ensure that the method is more effective and long-term. With pesticide residue polluting local water bodies and leading to higher cancer rates amongst communities of farmworkers,[6] avoiding its application as much as possible is a positive sustainability outcome.

As shown in Graph 29, there is a clear gap in IPM adoption between greenhouses (GH) and vertical farms (VF), with 78% of GH respondents utilizing IPM techniques compared to only 46% of VF respondents" to "54%" for GH, based on the graph.

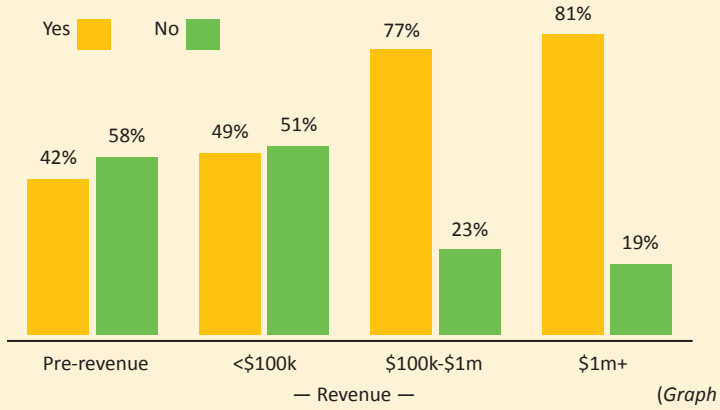
Does your business use integrated pest management (IPM) practices?



(Graph 29)

Our hypothesis is that vertical farms tend to see IPM as less necessary since they are growing in a more controlled environment. Additionally, crops more typically grown in vertical farms will have less pest pressure due solely to the shorter grow cycles. Greenhouse operations are more likely to be growing vining crops which have longer grow cycles and thus are more susceptible to pest pressure.

Does your business use integrated pest management (IPM) practices?

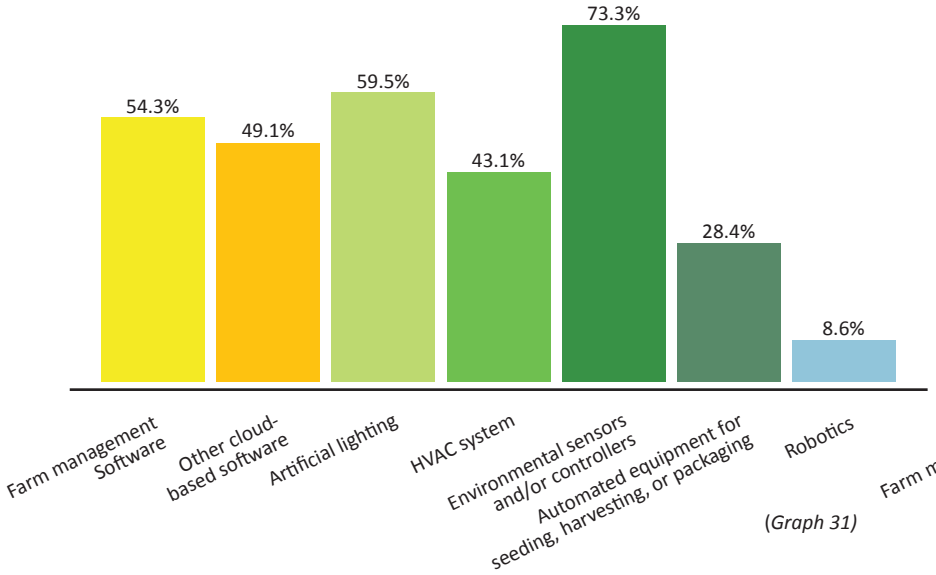


(Graph 30)

One other pattern emerges with IPM, which is that there is a correlation between revenue of the business and adoption rate of integrated pest management practices. This may be an indication that farms are generally choosing to implement IPM practices once revenue or profit allows for it, or perhaps after experiencing an actual pest issue. It is in the best interest of producers to implement IPM practices in the initial stages of setting up their farm to prevent more severe and costly issues later.

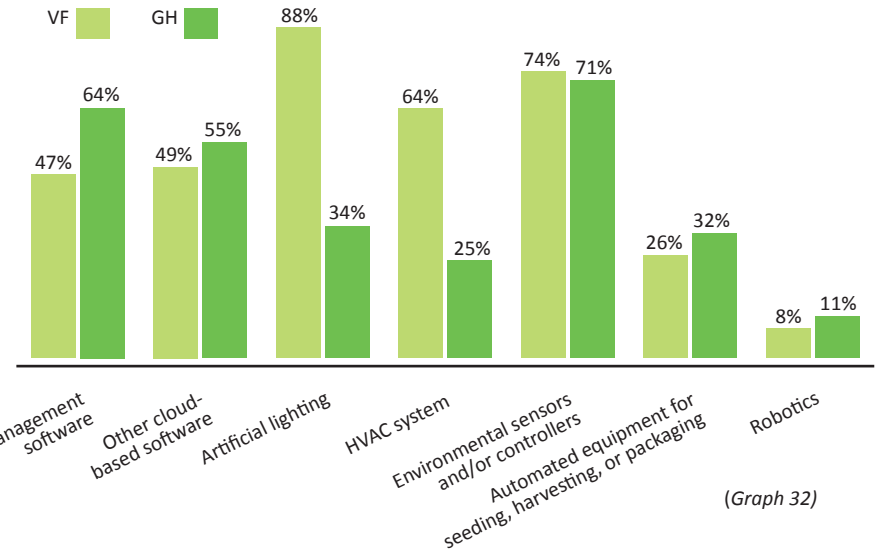
5 UC IPM (site accessed October 26, 2021)
6 Cancer in Migrant and Seasonal Hired Farm Workers (source dated Feb 2009)

Technology solutions currently used



(Graph 31)

Technology solutions currently used - VF vs GH

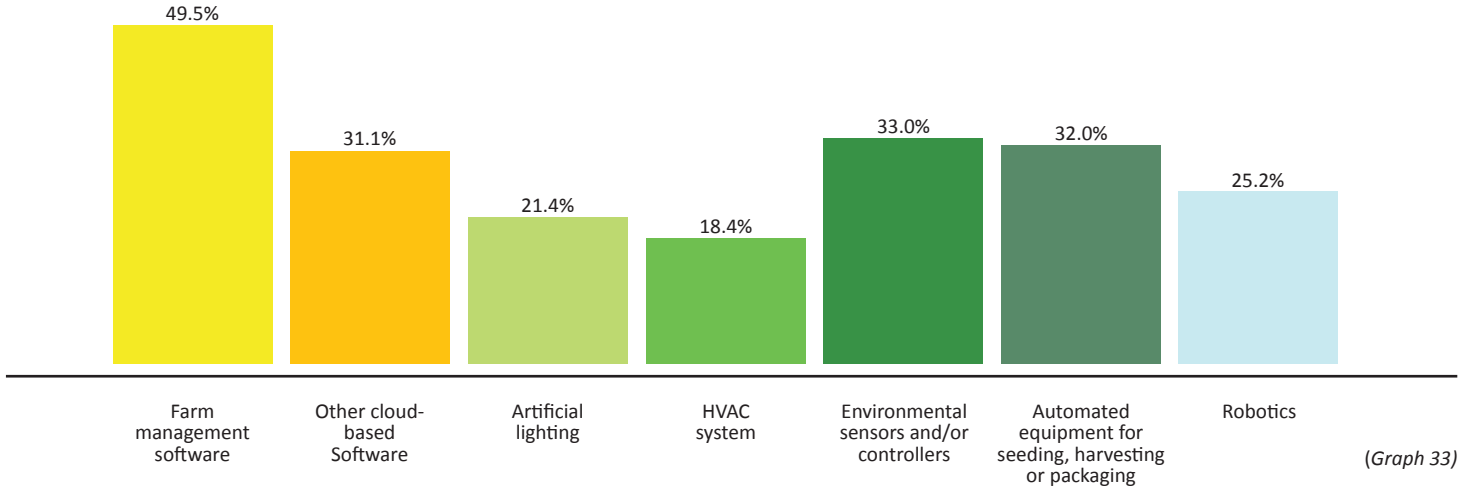


(Graph 32)

While 73.3% of respondents are using environmental sensors and/or controllers, more advanced solutions such as automated equipment for seeding, harvesting, or packaging (28.4%) and robotics (8.6%) were further behind for the majority of operations.

However, nearly half (32%) of those surveyed indicated that they will consider implementing automated equipment in the next 12 months.

Technology solutions being considered in the next 12 months



(Graph 33)

Insights From A Grower

"We have developed all our own systems and in some cases components. Our climate control system is a cascade setup of units, our lights are developed by us, using the most technologically advanced diodes available. All motors are high efficiency (VSD driven), with EC fans where available. The actual system is contained in a sealed room with air-locks at each entrance. We introduce the minimum amount of outside air at present for CO_2 and will be employing CO_2 injectors into the air filtration system which is using HEPA's. We use proprietary growing media that allows water to flow away from the crops, this allows us to recapture as much of the irrigated water as possible."

Tyrone Dickson
Co-Founder & Chief Technical Officer
DT Australasia Pty Ltd.

Sustainability: Waste

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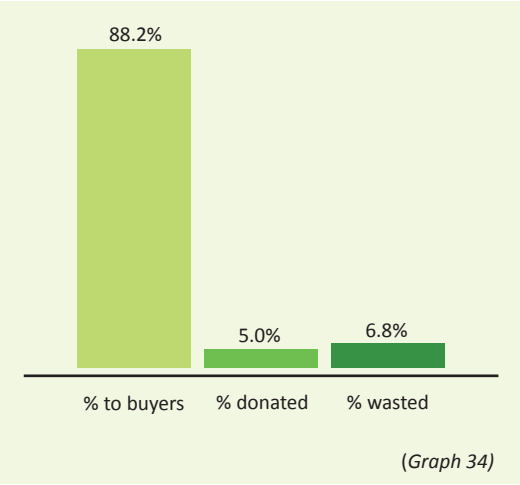
Percentage of crops grown that are wasted

Food waste is a huge contributor to climate change. According to Project Drawdown, food waste accounts for 8% of global greenhouse gas emissions.[7] Food waste can happen at essentially every level of the supply chain. The Natural Resources Defense Council (NRDC) reports that food wastage can happen at production, post-harvest (handling, storage), packaging, distribution & retail losses, and at the consumer level. The highest percentage of fruit and vegetable loss comes at the production phase (20%) and consumer phase (28%).[8]

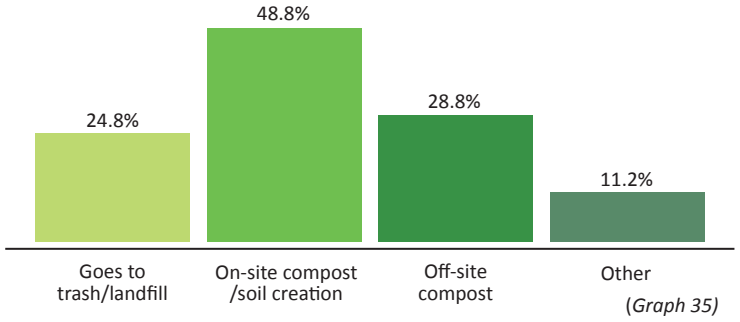
Meanwhile, according to our Census respondents, the average CEA farm wastes only 6.8% of its harvested crop; 88.2% makes it to buyers and 5% is donated. A waste figure of 6.8% would represent a drastic improvement over conventional fruit and vegetable production and supply chains. One note is that our question does not account for additional crops that are not harvested but still wasted, which can vary substantially depending on growing conditions and pest management practices.



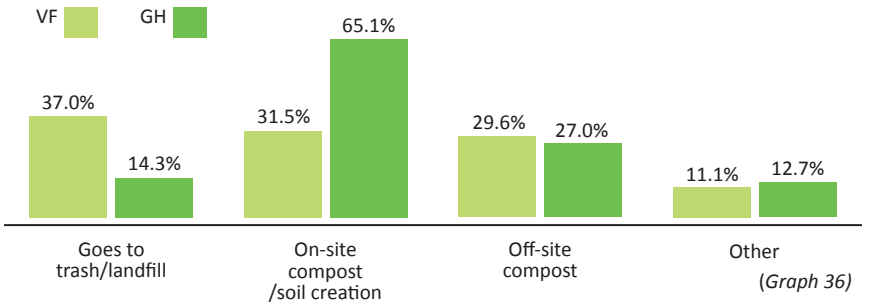
(*Graph 34*)

Usage of inedible harvested biomass

Inedible harvested biomass can include roots, stems, inedible leaves of the crop being grown and harvested. It is not uncommon for CEA facilities to simply toss their inedible biomass in the trash. This is an issue because organics that make their way into landfills emit methane as they decompose in an anaerobic environment. According to our respondents, about 1 in 4 currently contribute to this problem.



(*Graph 35)*



(*Graph 36)*

7 Washington Post (source dated February 21, 2021)
8 NRDC (source dated August 2012)

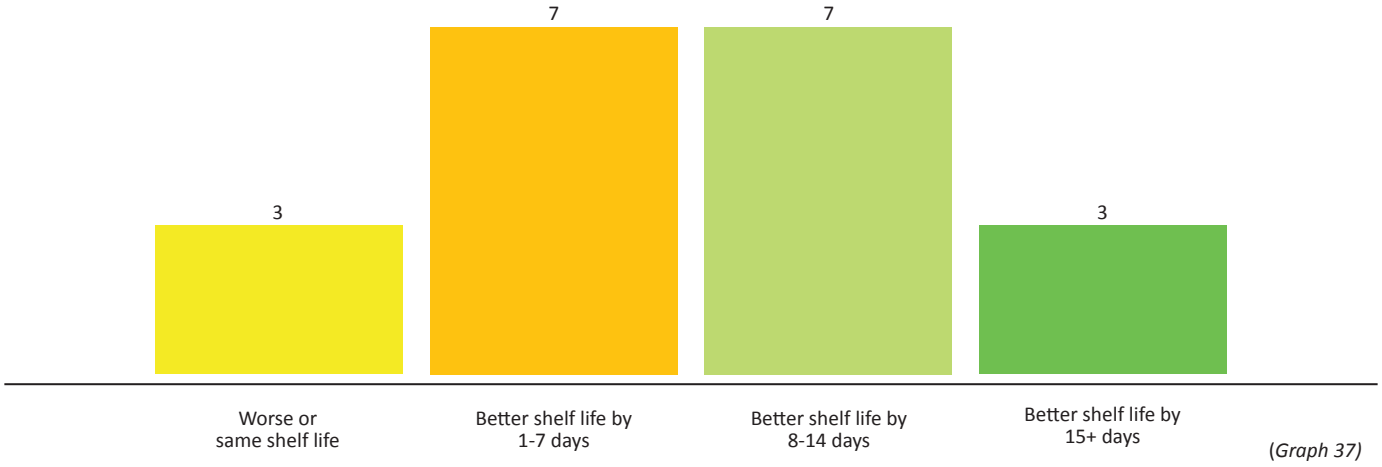
On the positive side, more businesses compost this surplus biomass, with 48.8% composting on-site, and 28.8% composting off-site. Upon segmenting the data, a substantially higher percentage of greenhouses are conducting on-site compost/soil creation with their inedible biomass, and only about 1 in 7 greenhouses send this surplus to landfills as opposed to more than 1 in 3 vertical farms.

One consideration that could affect the ability to compost excess plant biomass is growing media. If operations find it inconvenient to separate roots and stems from a growing medium such as rockwool, which is non-biodegradable, it is less likely that they will take the time to dispose of this biomass in an environmentally-friendly way.

Shelf life compared to field-grown produce

Shelf life of produce is impacted by various factors during the processing and handling phase. For example, when processing romaine lettuce, it is beneficial to use sharpened knives to reduce the amount of decay, discolouration or wilted leaves. Upon harvesting, some produce will go through a rinsing phase and may also go through a hydro cooling step to slow down the ripening process.[9]

According to a U.C. Davis study on lettuce, ideal temperatures are essential for optimizing shelf life and can impact the amount of days by ±7 days.[10] In this sense, CEA facilities may benefit from being able to control the temperature of their system and keep it consistent.



(Graph 37)

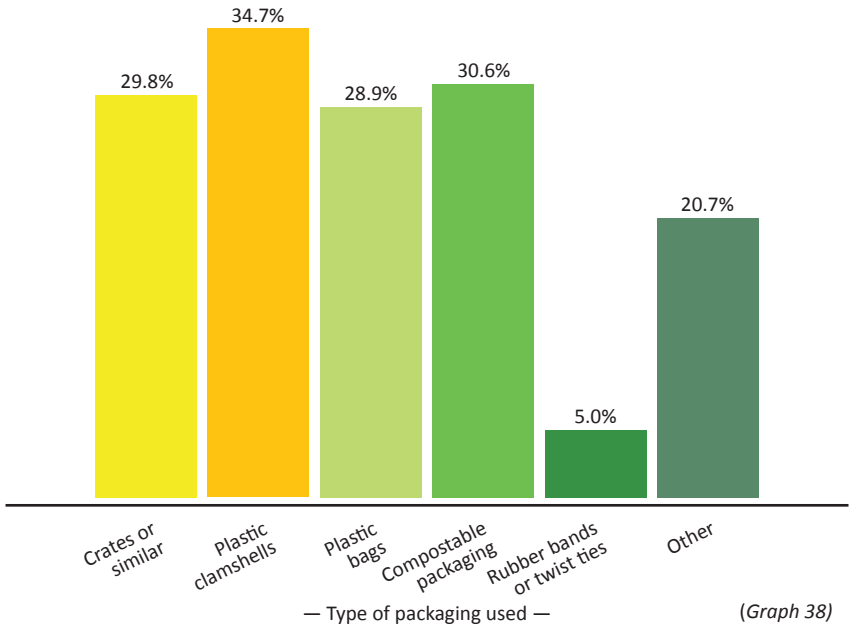
9 Reda et.al Reaching the highest shelf: A review of organic production, nutritional quality, and shelf life of kale (Brassica oleracea var. acephala) (source dated February 15, 2021)
10 Post Harvest Center (site accessed October 29, 2021)

We asked respondents if they had ever measured shelf life and shrinkage of their products relative to that of field-grown products. For shrinkage, we did not receive enough data to formulate any meaningful conclusions. For shelf life, we had 20 responses, and, while the data is thin, there was a clear trend that emerged as 17 of the 20 reported a better shelf life than their field-grown counterparts, and another two saw no difference. Nearly all of these respondents grew either microgreens or leafy greens. Furthermore, several other respondents simply answered that their shelf life was "better". Of those reporting a specific number of days, the average was 8.5 days of extended shelf life. Only a few of these respondents included reasons why they believed their shelf life to be longer - these included shorter logistics and the fact that some of them sell a living product with roots attached.

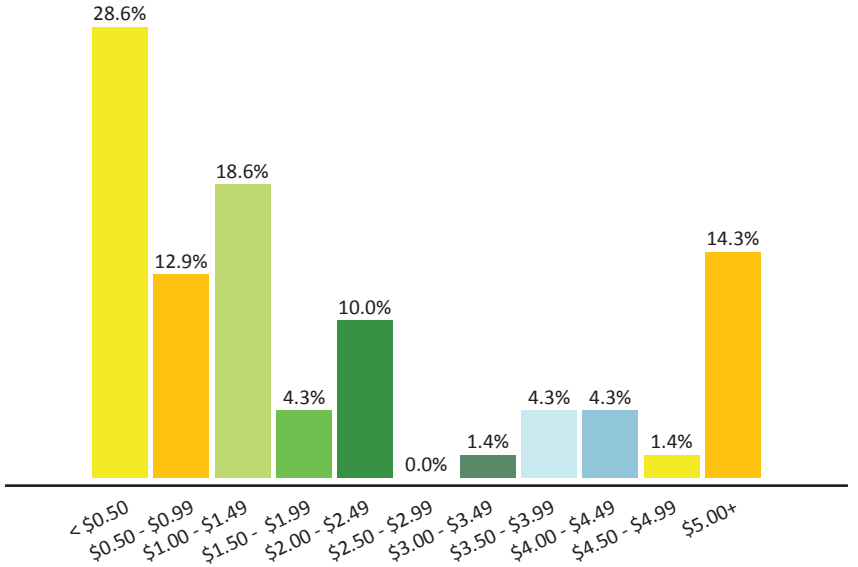
Types and costs of packaging options

Single-use plastic packaging is a clear environmental concern that both consumers and producers are aware of. The biggest problem with single-use plastic packaging is the fact that it is designed to be used once and usually ends up in landfills or as litter.[11] As illustrated in Graph 38, there is a wide variety of packaging options used by CEA businesses, with plastic clamshells being the most popular by a narrow margin.

We found a wide range in the cost of packaging. While 60% of respondents pay between $0.01 and $1.49, there was a "long tail" of responses including several outliers. Even after removing some of the larger outliers, we were still left with an average of $1.67 per kg of product, substantially higher than the median of $1.00 per kg.



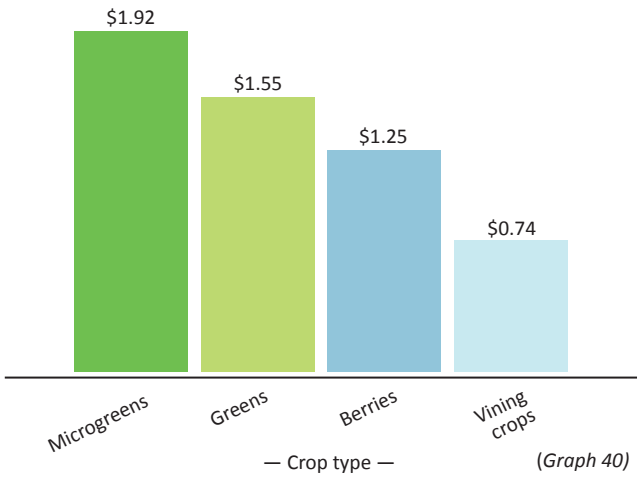
(Graph 38)



(Graph 39)

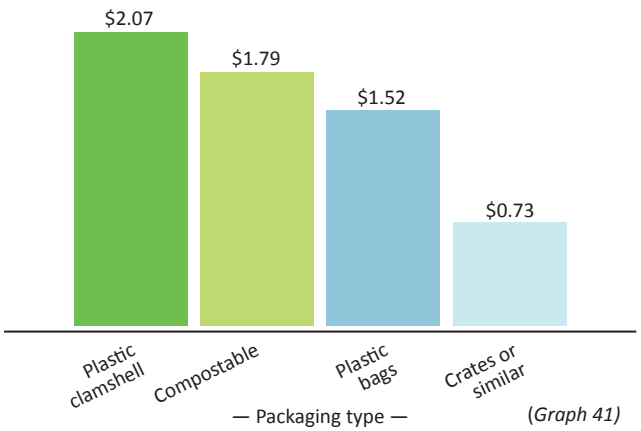
11 Footprint (site accessed October 28, 2001)

Packaging cost per kg of product — crop type



(Graph 40)

Packaging cost per kg of product — packaging type



(Graph 41)

There were two primary factors that influenced the cost of packaging: crop type and package type.

There was only a minor difference in cost between small farms (under $100,000 in revenue) and medium-to-large farms ($100,000+ in revenue) with small farms paying $1.88 per kg and medium-to-large farms paying $1.49 per kg.

Single-Use Plastic vs. Bioplastics vs. Compostable vs. Reusable

An important factor to consider when exploring packaging solutions is not just the package's end life, but also the emissions generated to create that package, as well as the implications of food waste.

Bioplastics - which can be biodegradable or compostable - are often marketed as a better alternative to plastic packaging with reportedly reduced amounts of fossil fuels, smaller carbon footprint, and faster decomposition to name a few benefits.[12] However, a study conducted by the University of Pittsburgh determined that production of bioplastics actually produced a higher amount of pollutants. This was due to the amount of fertilizers and pesticides necessary to grow the crops used in the production of these bioplastics and also a result of the chemical processing used in production.[13]

If packaging can influence the shelf life of a product, and thus impact the amount of food waste, businesses should consider the tradeoffs between shelf life and packaging type.[14] If considering a compostable option, two questions emerge: (1) will the shelf life of the product hold up?; and (2) will the end consumer truly be able to compost that package? For instance, does the package break down in residential/community composts, or only at commercial compost sites? Israeli-based TIPA® is one company that claims to have achieved the same or better shelf life for certain fresh fruits and vegetables with their compostable packaging solution.[15]

One alternative route that we found a handful of farms employing is reusable plastic containers. Earlier in 2021, Agritecture highlighted two farms that have adopted this strategy. Farm.One, based in New York City, found that this model "saved 156 plastic clamshell containers per customer every year" whereas Dream Harvest, based in Houston, found that their reusable containers actually increased the shelf life of their leafy greens by at least three days. Both farms use these solutions in selling direct to consumers. Reusable packaging may be more complicated if selling through other intermediaries such as distributors or supermarkets, who then must market and sell the product themselves to the end consumer.

12 Columbia Climate School (source dated December 13, 2017)
13 Sustainability Metrics: Life Cycle Assessment and Green Design in Polymers (source dated May 13, 2010)
14 Table Debates (source dated April 23, 2018
15 Packaging News (source dated July 19, 2021)

Sustainability: Water

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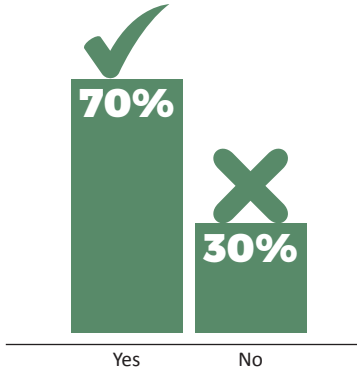
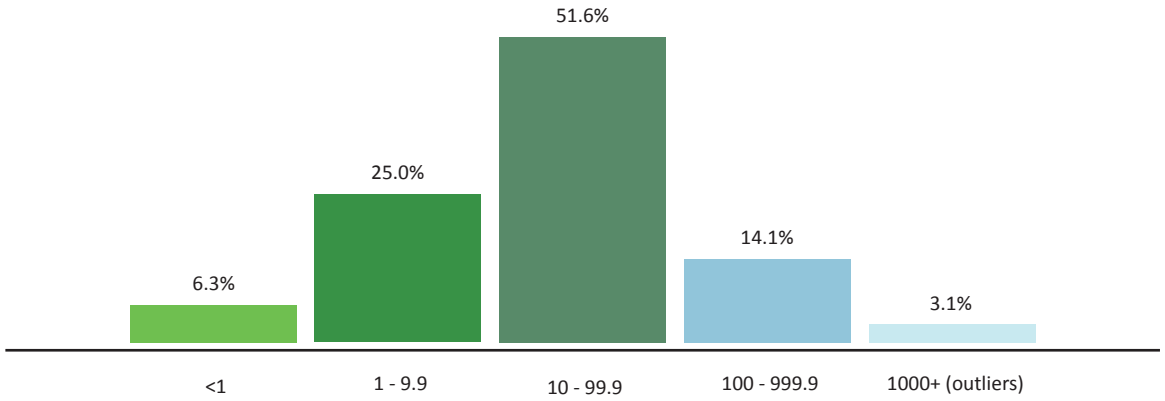
Does your business track data related to water use?



(Graph 42)

Amount of water used?

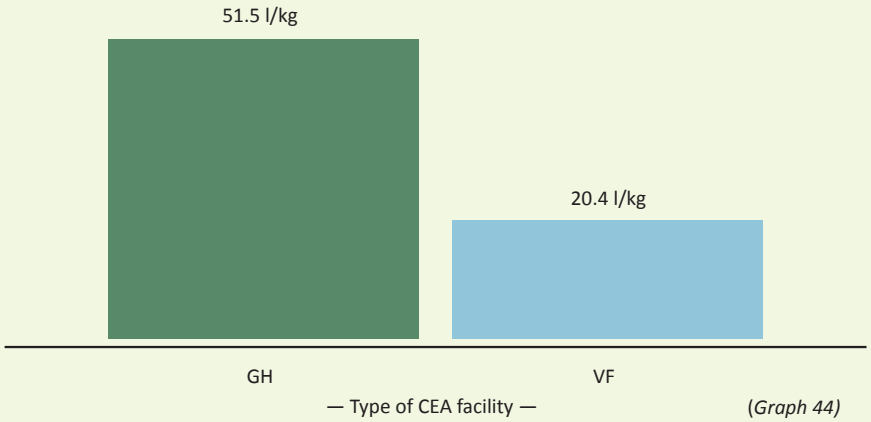


(Graph 43)

Similar to the data we received in other categories such as packaging costs and energy use, we found that many farms use minimal water, but that there was a "long tail" of respondents that use much more. This resulted in a median water use (20 liters per kg of product) that was substantially lower than the average water user (39.9 l/kg).

The vast majority of respondents (76.6%) used between 1 l/kg - 99.9 l/kg of water.

Amount of water that is used - average water use by CEA facility (l/kg)



(Graph 44)

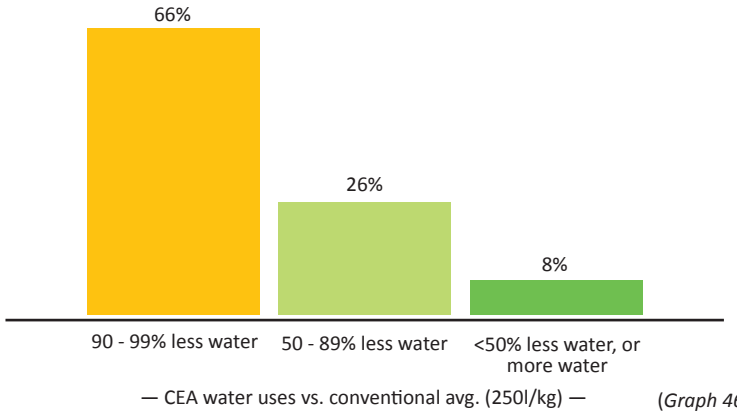
The amount of water being used varies depending on the type of CEA facility. We can see in Graph 44 that greenhouses had an average water use of 51.5 l/kg whereas vertical farms had an average water use of 20.4 l/kg. This is not surprising given that vertical farms are more often recapturing transpired water through their HVAC systems and that a higher percentage of vertical farms grow leafy greens, which are a less water-intensive crop. Some greenhouses also use water to cool their facilities in dry climates through evaporative cooling.

Amount of water per crop (l/kg)

(*Graph 45)*

Claims are often made in this industry that CEA facilities use 90-95% less water than conventional outdoor farms.
We wanted to see if we can support this claim.

Comparing Water Use — All CEA Census Respondents vs. Field-Grown Avg. (250 l/kg)



(*Graph 46)*

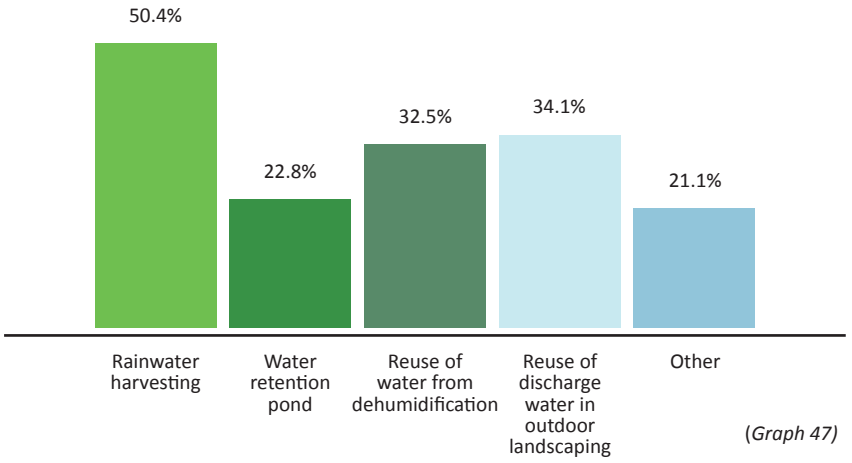
Water use varies greatly in outdoor production based on soil type and local climate. According to a 2008 study, the average water use globally for open field lettuce production was estimated at 130 ltrs of water per kg of final product.[16] A more recent study on lettuce grown in an open field in Arizona found a water use of 250 l/kg.[17]
For our analysis purposes, we used the latter number, 250 l/kg, and found that 66% of our respondents indeed used 90+% less water than this figure for conventional open field production. Yet a sizable enough percentage of respondents were lower than this figure, and some of which significantly lower, indicating that not every CEA facility should blindly make this claim without first measuring their own water use.

16 Hoekstra, AY. The water footprint for food (source dated September 15, 2020)
17 Barbosa, GL, Gadelha, FD, Kublik, N, et al. Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. (source dated June 15, 2015)

How often is water flushed or drained?

Flushing can be done in a system for several reasons with the most common being nutrient imbalance. Plants use nutrients and nutrients are replenished in different ratios. After a while, some nutrient levels can be out of balance and crop production can suffer. Another reason for flushing or draining is to clean the system to be proactive in preventing diseases like root rot, or to prevent excessive algae buildup which can affect dissolved oxygen levels.

Typically, growers with more advanced nutrient and disease management technology and skill can manage nutrient systems without requiring a system flush. An example of such technology is filtration and sterilization systems, which were used by 1 in 5 respondents.



(Graph 47)

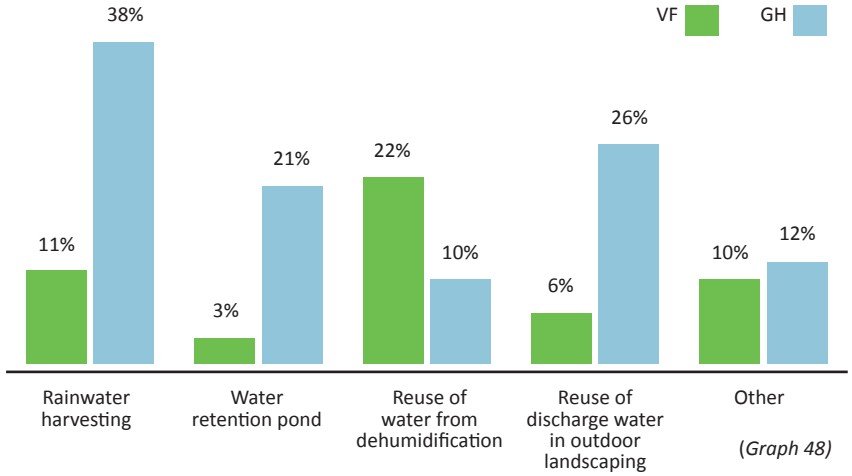
Does your farm do any of the following related to water sustainability?

Sustainable water practices are a practical way to keep systems running efficiently, to make good use of our natural resources, and to reduce the amount of stress being put back into the combined sewage systems that exist in many older cities.

For example, rainwater harvesting is used to capture stormwater and runoff for irrigation purposes. Implementation of such sustainability practices is not only beneficial to the environment by reducing the amount of overall water drained from aquifers, but also offers cost saving methods to the business itself.[18]

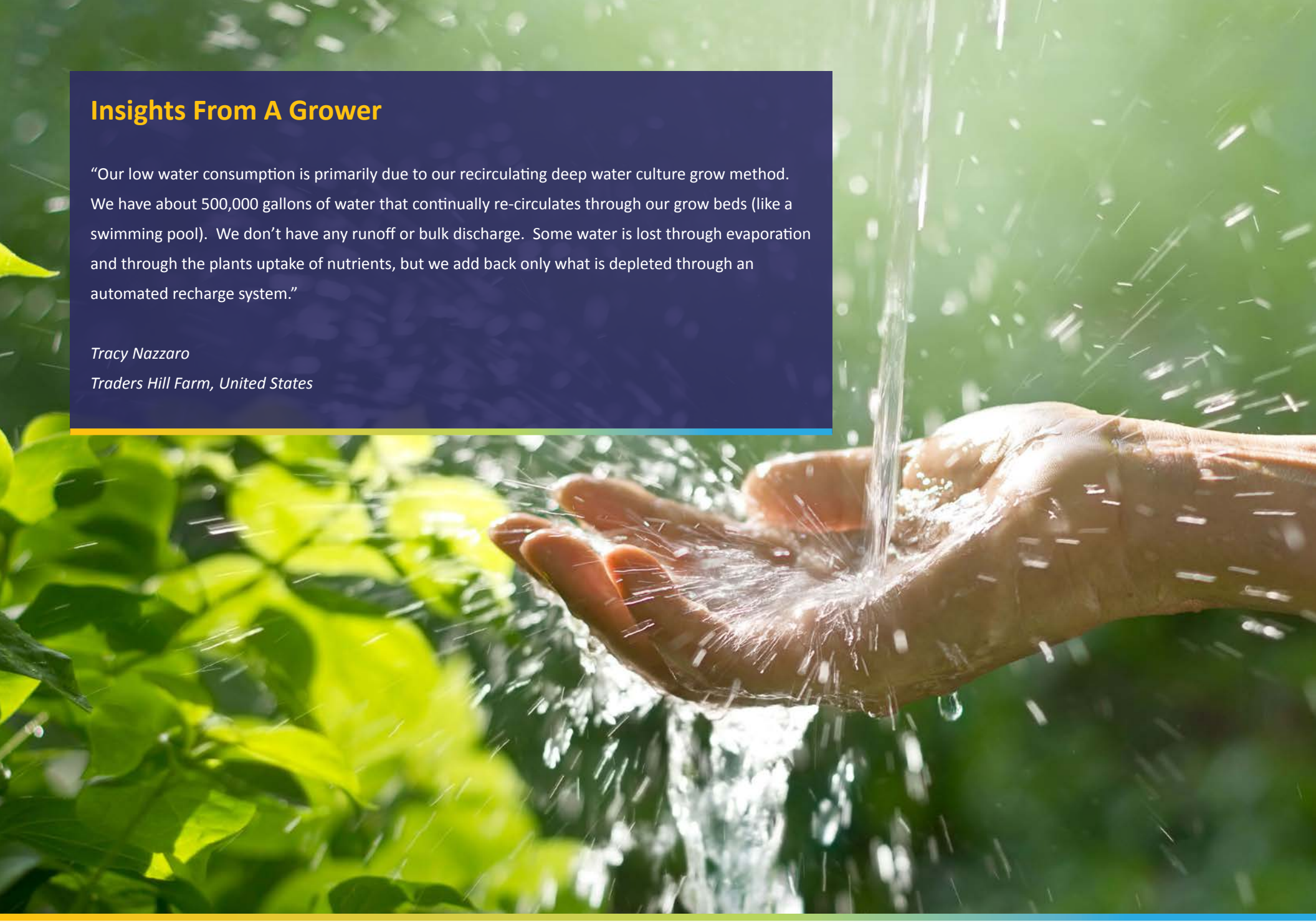
Respondents indicated that the highest percentage of water sustainability implementations in farms is through rainwater harvesting methods, which most commonly is carried out by greenhouses.

Overall, a higher percentage of greenhouses have implemented various water sustainability methods into their operations compared to vertical farms, with the exception of water reuse from dehumidification.



(Graph 48)

18 Pacific Institute: Sustainable Water Management for Urban Agriculture (source dated November 1, 2021)



Insights From A Grower

"Our low water consumption is primarily due to our recirculating deep water culture grow method. We have about 500,000 gallons of water that continually re-circulates through our grow beds (like a swimming pool). We don't have any runoff or bulk discharge. Some water is lost through evaporation and through the plants uptake of nutrients, but we add back only what is depleted through an automated recharge system."

Tracy Nazzaro

Traders Hill Farm, United States

Sustainability: Energy

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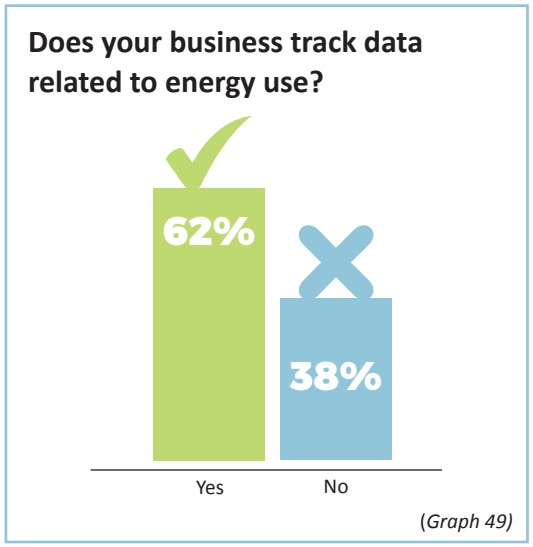
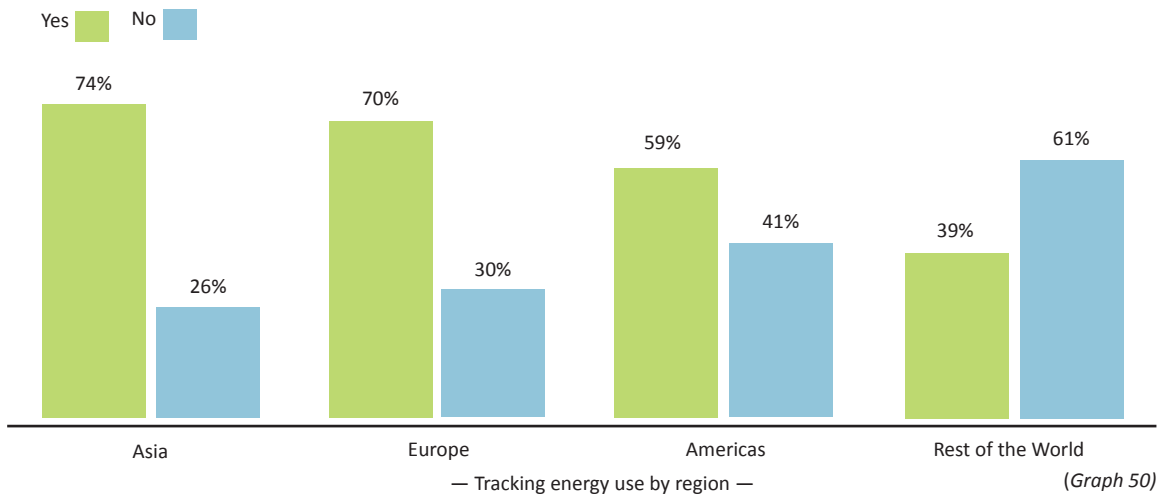


(*Graph 49)*



(*Graph 50)*

Often, the amount of energy it takes to power a CEA facility is not scrutinized as part of "sustainability" claims being made. But energy use and sources of energy are significant factors that must be taken into consideration with any sustainability assessment.

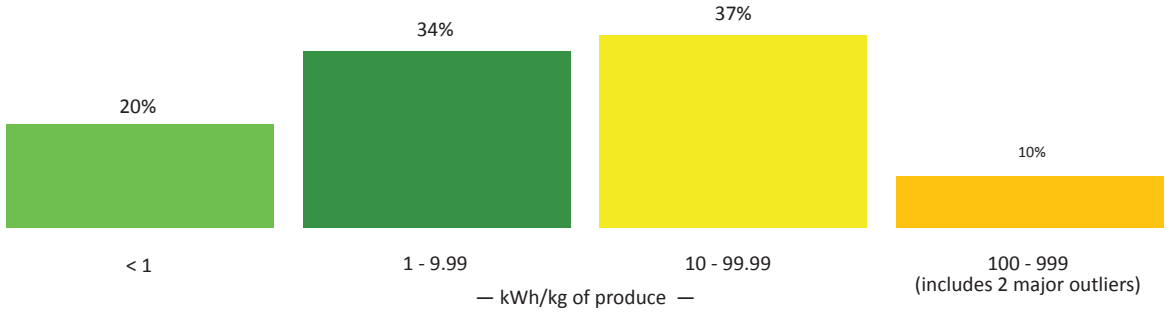
When looking at energy tracking globally, it seems apparent that certain regions (Asia and Europe) are emphasizing energy tracking at higher rates than others (rest of the world).

Direct energy use within conventional, open-field agriculture for a head of lettuce originates primarily from the use of fossil fuels during operational processes and from the electricity used for irrigation pumps. A life cycle analysis would also take into consideration energy used in the production of farm inputs including nitrogen fertilizer, which is significant, and the (generally) longer and less efficient supply chains for getting that produce to market.

Still, most life cycle analyses have shown that CEA facilities have significantly higher energy consumption than conventional agriculture, per kilogram of yield.[19]

19 World Wildlife Fund: Indoor Soilless Farming report (source dated May 14, 2020)

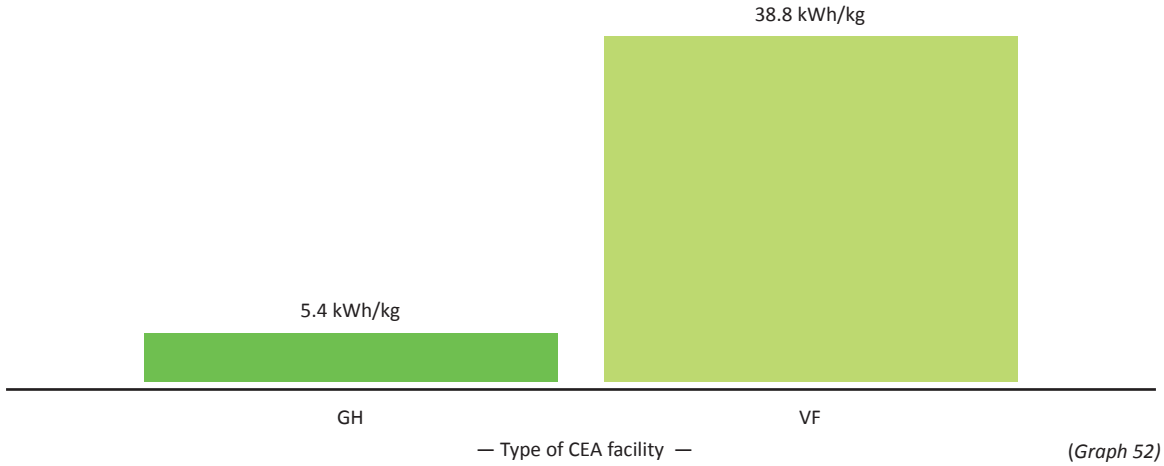
What is the amount of energy used (kWh/kg of produce)



(Graph 51)

Similar to water use, there was a wide variety in responses to energy use per kilogram of product, with more than 50% of farms having an energy use under 10 kWh/kg and 20% using under 1 kWh/kg, but a long tail of responses that had much higher consumption rates which dragged the average up. This resulted in a median of just 5.4 kWh/kg, but an average of 22.5 kWh/kg. Comparatively, data from a 2015 study noted earlier in this report estimates an on-farm energy use of approximately 0.3 kWh/kg for lettuce.[20]

Amount of Energy Used (kWh/kg) x CEA Facility Type



(Graph 52)

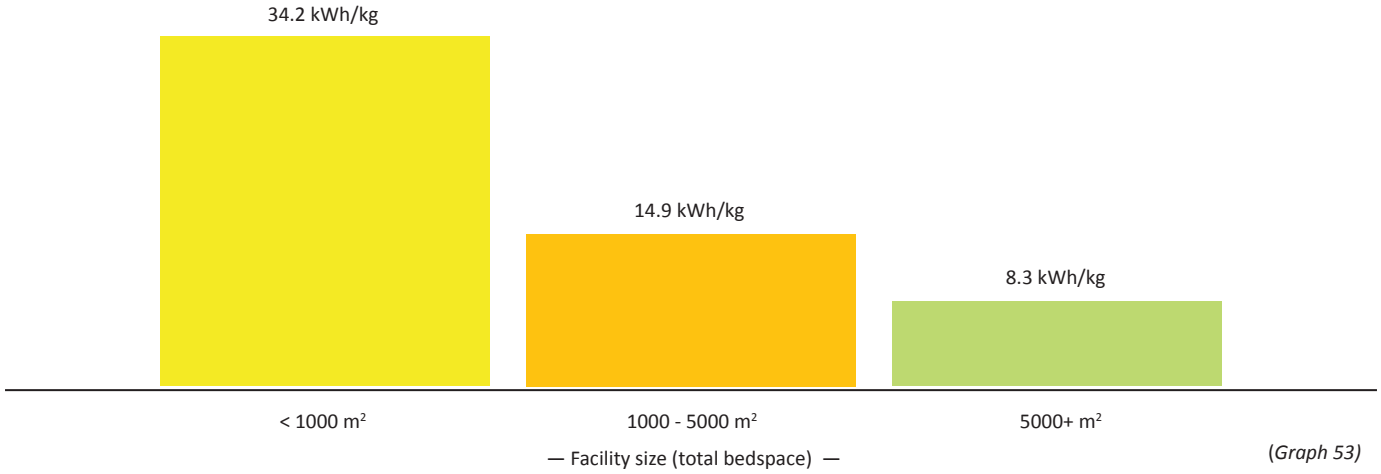
As expected, Graph 52 demonstrates that vertical farms have a significantly higher average energy use of 38.8 kWh per kg of produce as opposed to greenhouses that average 5.4 kWh per kg. Even when accounting for the same crop type (leafy greens), the differences were quite similar. When looking at the amount of energy used for vertical farm facility types, we also looked at warehouse-style indoor vertical farms versus shipping containers. While there was a higher average energy use among shipping containers compared to warehouse-style vertical farms, we did not feel there was sufficient data to publish these results.

20 Barbosa, et al. Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods (source dated June 15,, 2015)

Amount of Energy Used (kWh/kg) x Facility Size

Energy use by facility size was another factor that we were interested in exploring. Graph 53 shows that smaller facilities (under 1000 m^2) had significantly higher energy use per kilogram of product relative to their larger counterparts.

This would seem to indicate that, like many other financial benefits, there are also environmental benefits that come with scale.



(*Graph 53)*

Do you currently source energy from renewable sources?

Renewable energy sources range from solar, geothermal, wind, biomass from plants, and hydropower.

According to our respondents, 37% of CEA facilities currently get their energy from renewable sources. Of these, roughly 2/3 generate energy onsite, and another 1/3 pay their utility provider explicitly for renewable energy.

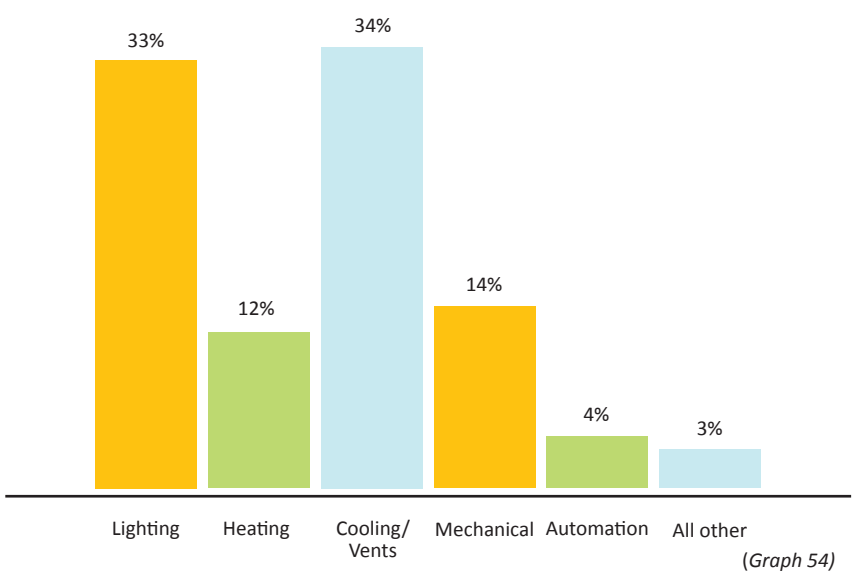
Anecdotally, Agritecture has heard of farms working with their utility provider to “shut down” by turning off their lights (and thus reducing much of their energy needs) during peak energy demand hours, since all plants need periods of rest anyway, in order to work out a deal on their energy rates. The argument is that this can “flatten” the energy demand curve for energy providers and create higher utilization for renewable energy.

Shockingly, 64% of respondents indicated that they do not employ any energy efficiency strategies to minimize their energy consumption. Given that energy is, on average, operations’ second highest operating expense behind only labor (per our 2019 Census Report), we were very surprised to see this.

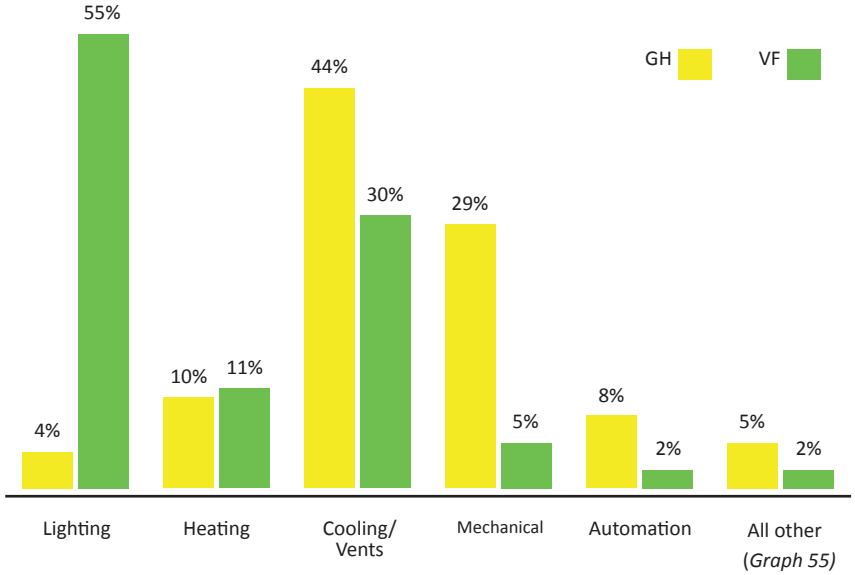
We were also curious about whether businesses that utilize automated in-house tracking systems consumed substantially less energy than those that did not. While we did see a reduction in energy use amongst these farms relative to those that do not track at all, the data was thin and lacked any statistical significance.

Breakdown of energy consumption

Investigating use cases for energy consumption, we used a weighted average of all farms that reported data, meaning that a farm using more energy will have a greater influence on the average than a farm using less energy. An important note is that our data was rather thin, and we believe there was likely some misinterpretation of the categories we used, which likely resulted in some respondents who use mechanical cooling classifying their "cooling" energy use under "mechanical". However, we hope by publishing this data, we can contribute to some general baseline figures - albeit with a grain of salt.



(*Graph 54*)



(*Graph 55)*

What The Experts Say

"Large-scale CEA facilities enjoy the benefits of larger, higher efficiency support systems such as HVAC, automation, and lighting systems that are able to produce higher volumes of product per unit of energy input. Additionally, larger greenhouses further benefit from the more favorable ratio of production bedspace to greenhouse surface area, leading to lower energy loss rates per unit of operable bedspace (especially in cooler regions). The combination of these benefits provide significant advantages to operators that have invested in scaled operations as opposed to their more distributed industry counterparts."

Djavid Amidi-Abraham
Agritecture Director of Consulting

General Conclusions

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Takeaways

Throughout this report we considered two questions (1) “Is CEA more sustainable than traditional field-grown operations?” and (2) “How ready are producers for a sustainable future?”.

Our opinion is that the first question you cannot simply answer with a ‘yes’ or ‘no’ - there is more nuance needed. But below is a summary of our main conclusions at the heart of this question:

- **Water use:** two-thirds of CEA leafy greens producers use at least 90% less water than their traditional outdoor counterparts, per a study on Arizona lettuce growers.
- **Energy use:** the vast majority of CEA growers use significantly more energy when looking at on-farm uses only. When comparing to this same study of outdoor lettuce growers in Arizona, greenhouse growers used 15-20x as much energy, on average, and vertical farms used a little over 100x as much energy.
- **Waste:** two-thirds less on-farm wastage, on average, relative to a global NRDC study of fruit and vegetable loss.
- **Shelf life:** CEA growers reported 8 days, on average, of additional shelf life relative to their traditional field-grown competitors; however this data was self-reported and no third-party group or peer-reviewed research paper was used in this assessment.

Regarding how ready producers are for a sustainable future - based on the data we would say there’s more work to be done around transparency, but we are encouraged to see the direction many producers are taking.

What The Experts Say

What is WayBeyond doing about these takeaways as leaders in the industry?

"Data is everything: capturing it, exploring it and using it to get the best out of your business. This in turn will ultimately lead to sustainable practices including less resource consumption and less food waste - while still attaining high yield and quality.

WayBeyond has been advocating for years that you can't manage what you don't measure, and this is even more important today with climate change, increased consumer demand for transparency and global challenges of labour and resource consumption.

Our goal is to continue innovating digital technology and advocating for more collaboration that empowers growers and pushes the industry forward towards greater sustainable crop production."

Kylie Horomia,
Head of Industry Transformation,
WayBeyond

What The Experts Say

What is Agritecture doing about these takeaways as leaders in the industry?

"While much of the food and beverage industry has been known to mislead consumers through their advertising efforts, CEA operators have the opportunity to provide real transparency about the benefits and areas for improvement related to their unique growing practices.

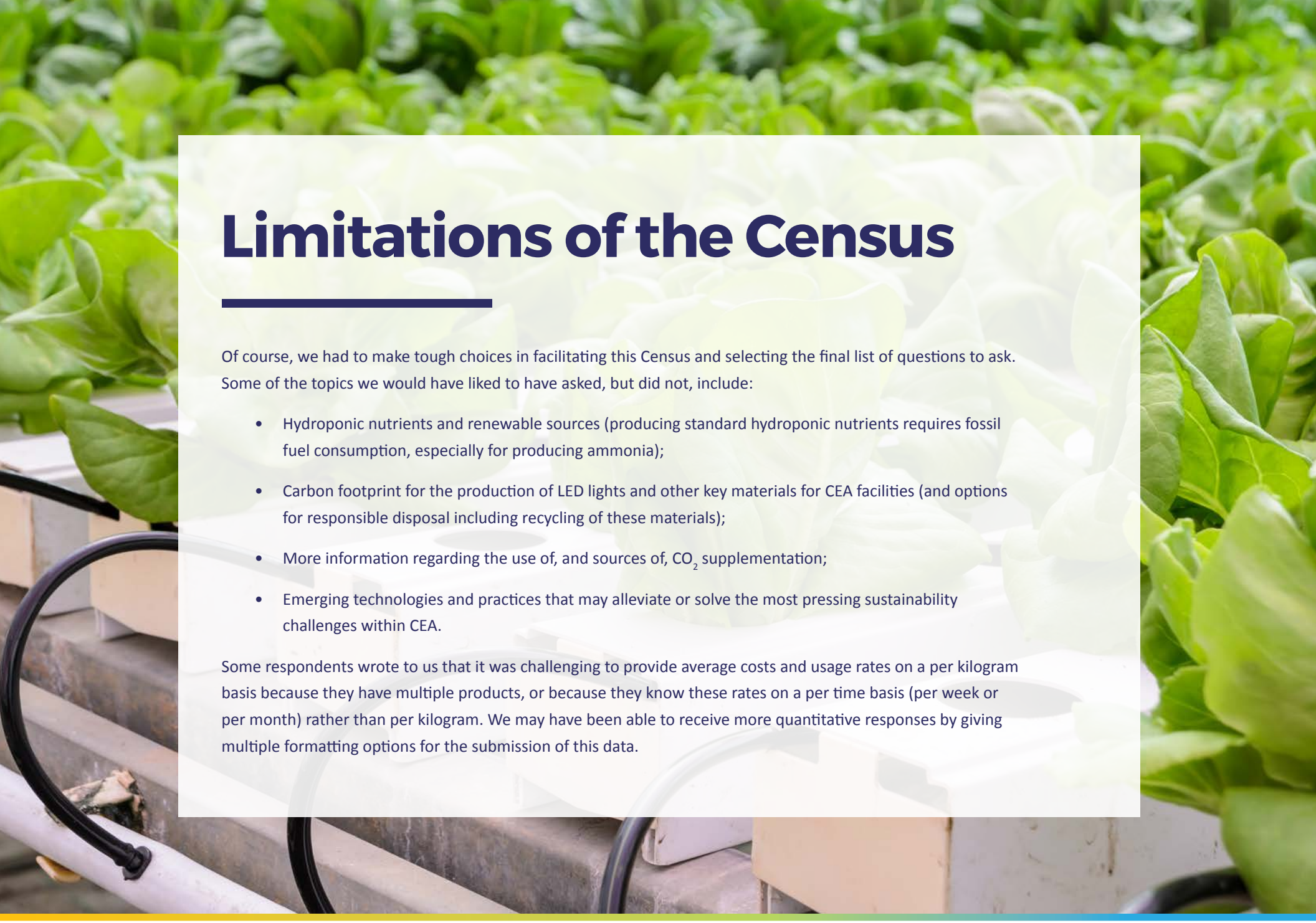
Agritecture is leading efforts to push the industry forward when it comes to sustainability and broader ESG efforts. Specifically, we have committed to the following:

- Adding sustainability-related estimates to every farm model built in our Agritecture Designer software platform;
- Recording and publicizing information related to sustainability and ESG efforts for every member of the Agritecture Partner Network;
- Holding CEA businesses accountable for their public messaging around sustainability by commenting directly on their posts where appropriate, and adding editor's notes to articles we publish on agritecture.com when we feel a sustainability claim is unsubstantiated;
- Continuously updating our company's broader ESG-related efforts at agritecture.com/sustainability

Ultimately, we're confident these efforts can help set a new bar for how CEA businesses track and communicate about sustainability."

Briana Zagami,

Marketing & Sustainability Lead, Agritecture



Limitations of the Census

Of course, we had to make tough choices in facilitating this Census and selecting the final list of questions to ask. Some of the topics we would have liked to have asked, but did not, include:

- Hydroponic nutrients and renewable sources (producing standard hydroponic nutrients requires fossil fuel consumption, especially for producing ammonia);
- Carbon footprint for the production of LED lights and other key materials for CEA facilities (and options for responsible disposal including recycling of these materials);
- More information regarding the use of, and sources of, CO_2 supplementation;
- Emerging technologies and practices that may alleviate or solve the most pressing sustainability challenges within CEA.

Some respondents wrote to us that it was challenging to provide average costs and usage rates on a per kilogram basis because they have multiple products, or because they know these rates on a per time basis (per week or per month) rather than per kilogram. We may have been able to receive more quantitative responses by giving multiple formatting options for the submission of this data.

Acknowledgements

We'd like to thank everyone who took part in the Census, particularly the producers who dedicated time to share their knowledge and expertise.

We'd also like to recognize the additional research that has added value to the report.

This report would not have been completed without the hard work of the WayBeyond team - Kylie Horomia and Debs Abraham and Agritecture team - Ricky Stephens, Briana Zagami, David Ceaser, Grace Lee, and Justin Chung.

Sustainability is an incredibly important topic in the industry and will continue to be vital to the production of food going forward. Anything we can learn from this process goes towards improving the industry for everyone.

Any queries or comments regarding the Census please contact Ricky at ricky@agritecture.com or Kylie at kylie.horomia@waybeyond.io

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