Developing SME-Scale Controlled Environment Agriculture in the Highlands & Islands

Guide for Practitioners

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SUMMARY & CONTEXT

Introduction

The purpose of this guide is to outline options and considerations for businesses and organisations interested in developing controlled environment growing enterprises in the Highlands and Islands. It is intended for both existing growers looking to diversify their production systems and for businesses, community groups, SMEs, and enterprises with little or no background in horticulture.

Drawing on existing horticultural resources and controlled environment agriculture technologies, this guide interprets and tailors the information specifically for the Highlands and Islands context, while signposting readers to more detailed resources where appropriate. It also incorporates insights from expert interviews to inform recommendations on energy supply, site selection, and potential routes to market.

As such, this guide is designed to serve as a flexible reference, adaptable to the varying needs and knowledge levels of its readers.

Background

This research was commissioned by Highlands and Islands Enterprise (HIE) and Orkney Islands Council (OIC) in collaboration with SEFARI Gateway, Scotland's Centre of Expertise for knowledge exchange and innovation. The aim of the fellowship as a whole is to investigate business models for Controlled Environmental Agriculture (CEA) in rural and island communities (in the Highlands and Islands), with consideration to benefits to local food and wellbeing and low-carbon investment.

This 'how to' guide is one of the key outputs of the Fellowship and aims to provide practical information to organisations for exploring commercial opportunities for controlled environment agriculture. Additional to this guide, recommendations have been provided to Highlands and Islands Enterprise and Orkney Islands Council around provision of further technical, business, planning, regulatory and policy support that could be provided to assist the development of SME-scale CEA operations in the Highlands and Islands.

Context

Previous reports by SAOS in 2022 for Scotland Food & Drink[1] provide detail into benefits of CEA systems, practical considerations for their development, available technologies and systems, as well as comments on skills and market development, and links to suppliers, support and examples of companies operating in the CEA space. A series of feasibility studies were conducted across Orkney in 2021 to explore business models for CEA operations, although to-date, none have been commercialised.

At the time of writing two of the four known vertical farms in Scotland are operating as research units – namely Intelligent Growth Solutions' vertical farm at the James Hutton Institute (opened in 2018), SRUC's vertical farm (est. 2025), and two other recently established commercial operations in the northeast of mainland Scotland. Only one commercially heated glasshouse was identified in the research (Standhill Farm in the Borders), and while a much larger number of businesses are operating commercial-scale polytunnels across Scotland, the exact number that would classify as controlled environment agricultural systems is likely to be very small.

National and Global Trends

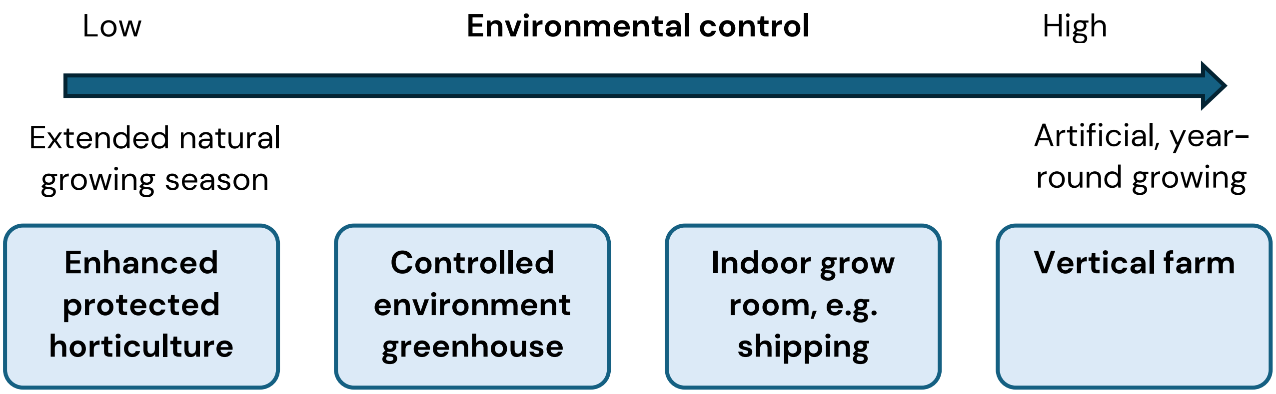
Controlled Environment Agriculture can be defined as "*the growing of crops while controlling certain aspects of the environment including lighting, temperature, humidity, irrigation, fertigation and other factors that influence plant physiological responses*.[2]" This includes a spectrum of operations, from marginal enhancement of protected growing systems (e.g. polytunnels), up to highly specialised and controlled systems (e.g. vertical farms).

The indoor farming market is estimated at a value of £9.6 billion annually and predicted to increase in value to £29 billion by 2033, with an annual growth rate of around 13%[3]. This growing interest stems from drivers in sustainable production, provision of local food (especially near urban centres), as well as

[1] SAOS Ltd. (2022) *Controlled Environment Agriculture Feasibility Study for Highland Good Food Partnership*. Edinburgh: SAOS Ltd. Available from: Highland Good Food Partnership.
[2] Agritecture & CEAg World. (2024). *2024 Global CEA Census Report*.
[3] Market Data Forecast. (2025). *Europe indoor farming market size, share & growth, 2033*. Retrieved June 16, 2025, from https://www.marketdataforecast.com/market-reports/europe-indoor-farming-market.

adding value to natural resources (e.g. surplus renewable energy), and providing low food-mile, fresh produce year-round.

***Figure 1**: spectrum of CEA systems based on complexity of environmental control.*



In the latest Global CEA Census Report (2024), over 40% of responding businesses were founded since 2020, showing the huge increase in interest for commercial CEA production. The annual report is well worth a read, providing detailed insights into trends and innovations in the sector. Interestingly, and unlike in the wider agriculture sector, an earlier census report (2021) indicated that 41% of respondents had no experience in agriculture prior to setting up the business[4].

With energy costs around 30% of operational costs for controlled environment agriculture, to-date, controlled environment systems have typically only been seen as commercially viable where there is an abundance of low-cost energy. Examples include geothermal (e.g. Iceland, New Zealand), solar (e.g. the Middle East), or, as renewable technologies and storage advances, hydro-, wind, heat pumps, biomass and anaerobic digestion. As such, in the UK, the majority of operational vertical farms operate within research institutes, rather than commercial operations, and commercial greenhouses are typically large-scale units on the periphery of major cities.

However, evolving technologies helping CEA systems to minimise energy usage, maximise and add value to production, as well as increasing consumer interest in provenance and sustainability of crops, shed new light on potential viability of commercial CEA operations.

[4] Agritecture & WayBeyond. (2021). *2021 Global CEA Census Report*.

Opportunities and challenges in the Highlands and Islands

In remote and island Scotland, the use of controlled environment agriculture for food production offers specific opportunities and challenges:

- **Geography and climate**: Short growing seasons, typically poorer soils (for horticultural growing), and variable daylight remain challenges, but CEA's ability to extend production year-round and provide stable conditions presents a strong opportunity to overcome these natural limitations. Managing wind exposure and leveraging supplemental lighting can improve crop quality and consistency.
- **Infrastructure**: Limited transport options and intermittent grid reliability may be a challenge for the application of typical commercial CEA models. Systems based on decentralised energy and supplying local markets may offer greater potential, as well as opportunities to maximise local resources. Economic feasibility, however, is crucial.
- **Workforce and skills**: CEA can offer opportunity for the development of digital and technical skills, as well as potential for the establishment of additional enterprises - increasing local employment and income generation alongside other employment activities.
- **Community and heritage**: Interest in supporting local enterprises and self-sufficiency through crofting heritage provide a strong foundation for community-supported and cooperative CEA ventures, and community engagement can help secure support and shared benefits.
- **Policy and funding landscape:** CEA may offer potential for initiatives to align with, and access funding streams, linked to various policies and public programmes, such as Just Transition, Community Wealth Building, and Regional Growth Deals. Aligning proposals with net-zero goals and rural development priorities would be key to unlocking this support.

This guide will run through options and considerations for businesses and organisations looking to explore commercial operation of controlled environment agriculture in the Highlands and Islands, enabling you to assess viability and begin developing a business model.

TECHNOLOGIES & SYSTEMS

By definition, controlled environment agriculture requires the ability to control the growing environment for crops, and therefore some means of containing this environment. There are several ways of doing this, requiring different levels of infrastructure and investment. This section will briefly cover the types of structures, growing systems and environmental controls available in CEA, although existing and fuller technology reviews are linked at the end of this section.

Structures

There are a variety of different structures available for controlled environment growing. The table below lists the pros and cons of these physical structures, without yet getting into the growing systems within them.

Table 1: *different structures available for CEA.*

System Type	Pros	Cons
Polytunnel Semi-cylindrical plastic-covered structure providing passive solar heating and wind/rain protection	Low to medium cost Extends growing season Easy to build and scale	Limited insulation and temperature control Vulnerable to wind damage Passive system largely dependent on local climate
Polycrub A reinforced, highly durable tunnel structure using recycled plastic with better insulation than standard polytunnels	Good for harsher/windier climates Longer lifespan than standard tunnels Moderate insulation and weather proofing	More expensive than polytunnels Still limited climate control Labour-intensive to construct
Unheated greenhouse Glazed or polycarbonate structure that traps solar energy but lacks active climate system like heating or cooling	Greater protection than tunnels Supports basic environmental control (e.g. ventilation, shade) Versatile with multiple growing systems	Limited use in winter without added heat Can overheat in summer More expensive than tunnels
Heated greenhouse Fully enclosed greenhouse with heating, ventilation, and sometimes supplemented lighting for extended year-round use	Good control over temperature and humidity Potential for year-round growing Supports hydroponics, aquaponics, and aeroponics	Higher capital and operating costs Significant energy use Requires climate and system monitoring Can increase yield compared to open field farming with less water and land
Geothermal greenhouse Uses underground thermal mass	Low ongoing energy costs Thermal stability	Higher construction complexity and cost

to regulate temperature without active heating	Ideal for cold, off-grid locations	Limited cooling capacity Suited to specific site conditions
Container farm/indoor grow room Shipping container retrofitted with indoor farm infrastructure – hydroponic or aeroponic, LED lighting, HVAC, climate sensors	Plug and play systems Fully controlled environment Minimal land footprint	High capital and energy costs Limited growing space Technical skill required
Vertical farm Multi-layer indoor farm using artificial lighting in a tightly controlled environment. Aims to optimise plant growth, and soilless farming techniques such as hydroponics, aquaponics, and aeroponics.	Maximal space efficiency Year-round production High automation potential	High capital and energy requirements Best suited to high value, fast-growing crops Requires technical expertise and monitoring

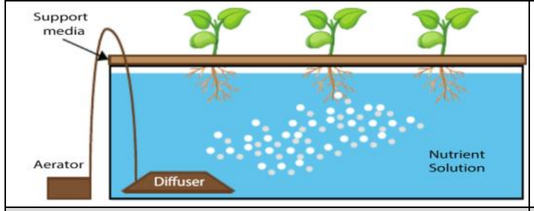
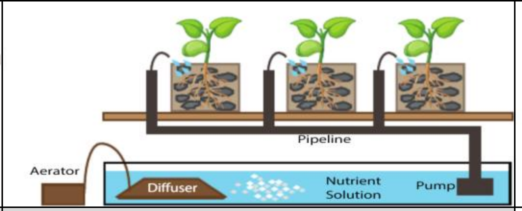
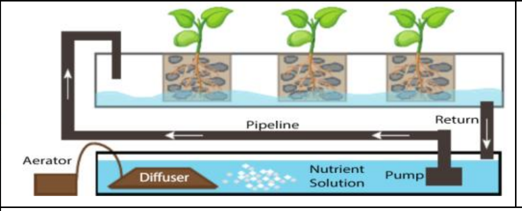
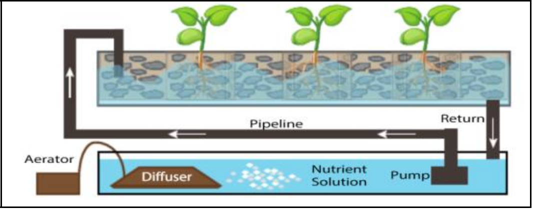
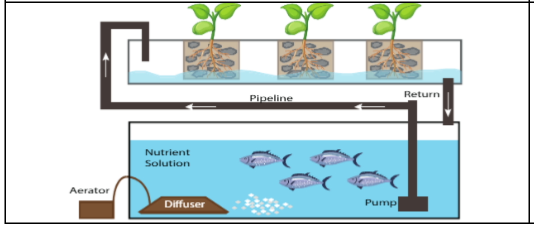
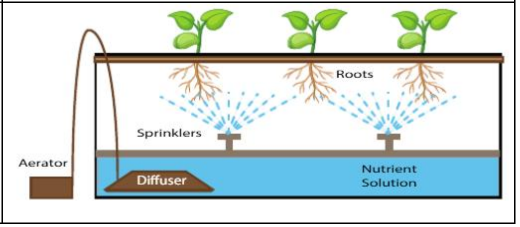
Systems

These structures support a variety of growing systems, with their suitability and effectiveness depending on the specific structure, crop selection, available investment, maintenance capacity, water and energy resources, technical expertise, and nutrient management strategies.

Table 2: *different systems available for CEA.*

System Type	Pros	Cons
Soil- or substrate- based traditional agriculture using soil as the growing medium	Low cost Low tech Familiar to growers	Vulnerable to pests, weeds, and soil-borne disease Less precise control of nutrients and water Seasonally limited in colder climates
Hydroponic plants grow in nutrient-rich water solution, usually inert media or flowing water.	Precise control over nutrients and pH High yields in small spaces Reduced water use compared to soil	Requires water quality monitoring and pumps High upfront cost Susceptible to systems failures
Aquaponic Closed-loop system combining aquaculture with hydroponics. Fish waste provides nutrients for plants, and plants help clean the water.	Synergistic system Produces plant and fish crops Reduced nutrient input costs	High complexity – management of two systems Narrow margin of error for balancing pH, temperature, and waste levels Requires fish health management
Aeroponic Plants are suspended in the air and sprayed with a fine mist of nutrient solution directly onto the roots	Maximum oxygenation of roots Extremely high yields in a small space Idea for vertical farming	Technically complex and expensive Vulnerable to pump or misting failures Strict environmental control required

__Table 3:__ Diagrams and descriptions of CEA systems.[5]

Hydroponic Systems			
Floating Root System or Deep Water Culture	Drip irrigation	Nutrient film technique	Ebb and Flow
The root of the plant is immersed in nutrient solution, while the body is supported used materials such as polystyrene, cork bark or wood	The nutrient solution is pumped directly to the roots of the plants with regulated flow. The solution is administered at predetermined time intervals and, for closed, circular systems, the leftover solution is returned to the storage tank.	The plant roots are not completely submerged in the nourishing solution, but in a liquid stream flowing through a piping system. Although NFT requires smaller amounts of nutrient solution than the floating root system, it requires additional energy and components to operate. The excess solution returns to the storage tank by gravity and the flow of nutrient solution can be continuous or periodic.	Plants are placed in a tray, which is periodically filled with nutrient-rich water pumped from a reservoir below. The system uses gravity to return the water to the reservoir and reuse it.
			
Aquaponic system	**Aeroponic systems**		
This technique exploits the symbiosis of flora and fauna to achieve an efficient system in which fish feces afford the nutritional requirements of the plants. The absorption of nutrients by plants, combined with the microbial process of nitrification and denitrification, allows the recycling of water from the fish tank, forming a balanced micro-ecosystem.	In this configuration, the plants, with their roots hanging down in the air, get their nutrients from periodic spraying by a system of sprinkles. The main advantage of this technique is that it does not require an airing system as oxygen is carried along with the sprayed nutrient solution.		
			

[5] Velazquez-Gonzalez et al. (2022) *A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations*. Querétaro: Instituto Politécnico Nacional. Available from: ResearchGate.

CEA systems use a range of growing media, each with distinct physical and chemical properties. Options like peat and coco coir retain moisture well, while rockwool and perlite provide good aeration. Alternatives such as Biostrate (a biodegradable felt), expanded clay pellets, vermiculite, and wood fibre vary in sustainability, pH stability, and nutrient-holding capacity. The choice of medium depends on factors such as crop type, irrigation method, nutrient delivery system, suitability with growing equipment, environmental goals, and cost.

Table 4 summarises factors that are important to consider when selecting a growing system. Choice will involve trade-offs between cost, complexity, efficiency, and crop suitability — with soil-based systems offering low upfront costs but lower control, while hydroponics, aquaponics, and aeroponics provide greater precision and resource efficiency at higher capital and operational costs.

***Table 4**: factors to consider when selecting a CEA system.*

	Soil-based	Hydroponics	Aquaponics	Aeroponics
CapEx	Low	Medium-High	High	Very High
OpEx	Medium (labour-intensive)	Medium (electricity, nutrients)	High (fish care, energy)	High (tech maintenance, energy)
Water Use Efficiency	Low	High	High	Very High
Nutrient Control	Low	High	Medium	Very High
Technical Complexity	Low	Medium	High	Very High
Suitability for Leafy Greens	Good	Excellent	Good	Excellent
Suitability for Fruiting Crops	Excellent	Good	Moderate	Fair
Space Efficiency	Low	High (vertical farms)	Medium	High
Environmental Impact	Medium (runoff risk)	Low	Very Low	Low

Further and more detailed sources of information on this can be found here:

- Revolutionizing Agriculture: Sustainable Solutions for High-Yield Farming Using Vertical Hydroponics: https://gmsarnjournal.com/home/wp-content/uploads/2024/05/vol19no1-11.pdf
- Recent developments and inventive approaches in vertical farming: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1400787/full
- Harper Adams: CEA – a review of technology utilisation: Microsoft Word - CEA review 2023 Final No Comments.docx

Environmental Controls

CEA systems are designed to optimise plant growth by managing key environmental variables. The ability to precisely regulate conditions allows for increased productivity, resource efficiency, and year-round cultivation. The main areas of environmental enhancement and control include:

1. **Temperature Control:** Maintaining optimal temperatures is critical for plant development, metabolic function, and yield. Heating, ventilation, and air conditioning (HVAC) systems, along with thermal screens and insulated structures, are used to manage internal temperatures. Technologies such as ground-source heat pumps and waste-heat recovery systems are increasingly adopted to improve energy efficiency.
2. **Humidity Regulation:** Relative humidity affects transpiration, nutrient uptake, and disease pressure. Dehumidifiers, fogging systems, and ventilation can be used to control moisture levels in the air. Advanced systems integrate humidity control with temperature management to maintain ideal vapour pressure deficit (VPD) levels, optimising plant health and water use efficiency.
3. **Light Quality and Intensity:** Supplemental lighting can assist plant growth in low light areas and during darker seasons, particularly for high-value crops requiring consistent photoperiods. LED lighting systems are widely used due to their energy efficiency and tunability—allowing specific light spectra to be delivered for various plant stages (e.g., blue light for vegetative growth, red light for flowering). Automated lighting schedules can also be programmed to mimic natural day–night cycles or induce desired phenological responses.
4. **CO_2 Enrichment:** Carbon dioxide enrichment can significantly boost photosynthetic rates and yields, especially in enclosed systems. CO_2 levels are often increased to 800–1,200 ppm, compared to ambient levels of around 400 ppm. Delivery methods include bottled gas, CO_2 generators, or industrial capture systems, with careful monitoring required to avoid excess levels that may be harmful.
5. **Nutrient and Water Management:** Hydroponic, aeroponic, and aquaponic systems allow precise delivery of water and nutrients to plant roots. Recirculating nutrient systems minimise waste and improve input efficiency. Sensors and fertigation systems are used to adjust nutrient composition and irrigation timing in real-time based on plant demand, conductivity, and pH levels.

6. **Airflow and Ventilation:** Adequate airflow reduces disease risk, strengthens plant structure, and supports uniform temperature and humidity distribution. Fans, louvers, and ducted systems are employed to enhance circulation. Advanced control systems integrate airflow with temperature and humidity sensors to automate ventilation.
7. **Disease and Pest Control:** CEA environments reduce exposure to outdoor pathogens and pests, but integrated pest management (IPM) strategies are still essential. This includes physical barriers, biological control agents, and environmental adjustments (e.g., reducing humidity to suppress fungal outbreaks). UV sterilization, ozone treatment, and air filtration systems are also used to limit airborne pathogens.
8. **Automation and Data Monitoring:** Sensors and control systems allow real-time monitoring and adjustment of environmental parameters. Internet of Things (IoT) platforms, machine learning, and AI are increasingly applied to optimize conditions, predict plant needs, and enhance decision-making. Automation reduces labour and improves consistency, particularly in large-scale vertical farms and greenhouse systems.

By integrating these environmental controls, CEA systems can achieve higher yields, reduced resource inputs, and more predictable production cycles. However, balancing cost, crop requirements, and sustainability goals remains key to effective system design. The table below broadly summarises how decision factors positively or negatively influences uptake, with those scored 1 (green) supporting uptake of technologies, and -1 (red) disincentivising.

Table 5: *overview of implications of environmental controls in CEA.*

Technology Type	Cost Barrier	Energy Demand	Scale Dependence	Skill Requirement	Sustainability Impact	Integration Ease	Evidence of yield improvement
HVAC (Heating/Cooling)	-1	-1	1	0	1	-1	1
Dehumidification/Fogging	0	0	0	0	0	1	0
Supplemental Lighting (LEDs)	-1	-1	1	0	1	1	1
CO_2 Enrichment	0	-1	1	1	-1	0	1
Nutrient/Fertigation Systems	0	0	1	1	1	1	1
Airflow/Ventilation Fans	0	0	0	0	1	1	0
IPM/Biological Controls	1	1	0	1	1	1	0
Automation & Sensors	-1	0	1	-1	1	-1	1

Key takeaways from this are:

- **LED lighting, automation, and HVAC** face higher cost and energy barriers but offer high returns for large-scale, high-value crops.

- **IPM and fertigation systems** are relatively more scalable and sustainability-aligned, with broader policy support.
- **Airflow, ventilation, and basic environmental controls** are low-cost, easier to integrate, and adaptable to different scales and climates.
- Technologies with **high skill requirements** and **integration complexity** (e.g. automation, CO_2 dosing) may deter uptake in smaller or less technically equipped operations.

Innovations

The following tables summarise the current level of uptake of technologies, drawing from data published in the 2024 Global CEA report[6], based on surveying of CEA businesses globally.

***Table 6:** summary of CEA technology uptake in enhanced protected growing.*

Technology	Manual	Mechanical equip.	Software	Sensors & IoT	AI	Robotics
Climate control	Medium	High	Medium	Medium	Low	Low
Lighting control	Medium	Medium	Medium	Medium	Low	Low
Pest & disease management	High	Medium	Low	Low	Low	Low
Seeding/planting	High	Medium	Low	Low	Low	Low
Fertigation	Medium	Medium	Medium	High	Low	Low
Crop monitoring	High	Medium	Low	Low	Low	Low
Harvesting	High	Low	Low	Low	Low	Low
Packaging & post-harvest	Medium	Medium	Low	Low	Low	Low

***Table 7**: summary of CEA technology uptake in indoor / container / vertical farming.*

Technology	Manual	Mechanical equip.	Software	Sensors & IoT	AI	Robotics
Climate control	Medium	High	High	High	Low	Low
Lighting control	Low	High	High	High	Low	Low
Pest & disease management	High	Medium	Low	Low	Low	Low
Seeding/planting	High	Medium	Low	Low	Low	Low
Fertigation	Medium	Medium	Medium	Medium	Low	Low
Crop monitoring	High	Low	Medium	Medium	Low	Low
Harvesting	High	Low	Low	Low	Low	Low
Packaging & post-harvest	High	Medium	Low	Low	Low	Low

[6] Agritecture & CEAg World. (2024). *2024 Global CEA Census Report*.

Real-time monitoring and **sensing technologies** enable precision control of environmental factors by continuously tracking conditions such as humidity, light, pH, and nutrient levels, often integrating with actuators for automated responses. **Automation** and **AI-driven systems** build on this by using predictive models to dynamically manage irrigation, climate, and nutrition, reducing water and energy use while improving yields. **Robotic systems** are increasingly deployed to handle labour-intensive tasks like seeding and harvesting, enhancing accuracy and lowering operational costs. Innovations in physical infrastructure and **ergonomics**, such as scalable bench systems, streamline workflow and support commercial-scale growth. Advances in **nutrient formulations** and biodegradable growing media reduce waste and align with circular economy goals. **Modular system designs** allow phased investment and flexibility for small-scale and urban producers, while genomic innovations are beginning to tailor crop traits for controlled environments. Finally, the integration of **renewable energy and storage technologies**—including solar, wind, and waste heat recovery—enhances energy efficiency and supports the decarbonisation of CEA, particularly in regions like Scotland where grid constraints are a consideration.

While the technological landscape of CEA is rapidly advancing, its feasibility at the SME scale in Scotland requires careful consideration. Adoption is often constrained by high upfront costs, limited technical capacity, and the need for reliable labour, challenges that are particularly acute for small-scale growers. Insights from community-led initiatives highlight the potential of hydroponic systems, especially closed-loop designs that minimise water use and support off-grid operation. These systems not only enhance yield and quality but also offer ergonomic advantages, making them accessible to growers with mobility needs. Yet, scaling such models beyond volunteer-led contexts demands robust support structures.

In terms of supply chains, financial viability at the SME level often hinges on alternative models such as CSA schemes or social enterprise frameworks, rather than conventional wholesale routes, which favour scale and consistency. For CEA to thrive at this level, innovation must be paired with tailored business models, localised infrastructure, and policy mechanisms that reflect the realities of small-scale production in Scotland's diverse rural and urban settings.

MARKET RESEARCH & DEVELOPMENT

One of the first stages to establishing viability of a CEA business is to assess the potential market. Once you know what could sell to your chosen market(s), you can then assess suitable structures, technologies and financials. These steps will give you a guide as to what to consider in this process:

Routes to Market, Market Demand, and Customer Analysis

Horticultural businesses typically sell via various of the following routes:

Table 8: *pros and cons of different routes to market for horticultural businesses.*

Market	Pros	Cons
Direct sales to customers (e.g. farm shop, veg boxes)	Higher profit margins Strong customer relationships Flexible pricing and product range Builds local brand loyalty	Labour-intensive Requires marketing and logistics Seasonal demand Limited scale
Direct sales via farmers markets	Immediate customer feedback Low entry barriers Community engagement Cash-based sales	Time and labour-intensive Weather-dependent Limited sales volume Competitor presence
Supply to local restaurants or food service	Regular repeat orders Higher prices for premium produce Local brand recognition Collaboration potential	Need for consistency in quality/volume Logistics coordination Tight margins in hospitality Seasonal variability
Public procurement (e.g. schools, hospitals)	Stable, long-term contracts Supports community and local food agendas Policy alignment with local sourcing Scalable potential	Complex tendering process Lower margins Certification/compliance needed Slow payment terms
Supply to local independent retailers	Supports local economy Flexible terms Higher prices than wholesale Smaller delivery radius	Small order sizes Regular deliveries needed Retailers vary in professionalism Payment delays possible
Supply to local franchise branches (e.g. Scotmid)	Wider market access More consistent demand Formalised contracts Greater visibility	Strict quality and packaging standards Tighter pricing margins Limited flexibility Longer payment cycles
Supply to wholesale buyers	Large, simple orders Less time spent on marketing Predictable logistics	Lowest price margins No control over branding Market price volatility Risk of rejection on quality
Supply to food/drink manufacturers (e.g. breweries, bakeries)	Stable volume sales Product development collaboration Diversified income Value-add potential	Requires consistent quality May need custom standards Lower pricing power Less brand visibility

Unless an operation is highly specialised and growing on contract for a particular market, it is not recommended to rely on only one route for sales. While more complex to manage production for multiple channels, doing so balances both risk in sale price and quantity (e.g. cancellation of orders), but also being able to monetise on the diversity of crop characteristics.

For example, restaurants may have requirements of shape, size and colour, so that produce can look a certain way on a plate. Selling on a farmers' market inevitably will see the least aesthetically pleasing produce left until last. Where vegetable boxes serve customers directly, they may be more willing to accept produce that is non-standard shapes and sizes.

Previous studies have indicated challenges for local producers selling into local supermarkets and wholesalers, such as case studies on local food in Orkney.[7] Understanding the retailer's requirements, such as price point, as well as consistency of quality and supply (particularly in remote and island locations), is likely important in negotiating with these types of buyers.

Particularly in a remote area, understanding the cost, feasibility and practicalities of getting produce to end markets should also be a factor. The greater number of smaller sales, the greater the cost and labour requirement for deliveries. Given sufficient renewable energy production, the use of electric vehicles could also help manage energy supply and use on site.

Porter's Five Forces model[8] can help in analysing the potential competitiveness of a business, and the potential for profitability:

[7] Rural Exchange. (2024). *Island Agriculture*. SRUC. Retrieved June 16, 2025, from https://www.ruralexchange.scot/projects/island-agriculture/.
[8] HRC Online. (2023). *Porter's Five Forces Model*. Retrieved June 16, 2025, from https://hrcoursesonline.com/porters-five-forces-model/.

Price and Willingness to Pay

Labelling of organic and local can attract an additional premium, although certification of organic within CEA system is limited; contact an organic certifier for more information on this. Enhanced shelf life of local produce due may also enable a premium (see Quality Marketing Standards for further information[9]). While fresh produce from centralised supply chains has the additional cost of haulage to remote and island areas, they still have the advantage of scale. These should all be factored into assessing economic feasibility of crop choices and market demand. Storage may help to balance supply and demand, to some extent, but must be done within food safety regulations. Guidance on storage conditions and storage life for common fruits and vegetables can be found here[10].

Willingness to pay will also vary across seasons, relative to prices of fresh produce via wholesalers, as well as the prevalence of different routes to market

[9] Department for Environment, Food & Rural Affairs. (2024). *Comply with marketing standards for fresh fruit and vegetables*. GOV.UK. Retrieved June 16, 2025, from https://www.gov.uk/guidance/comply-with-marketing-standards-for-fresh-fruit-and-vegetables.

[10] CRS Cold Storage. (2022). *Cold storage for fruits and vegetables*. Retrieved June 16, 2025, from https://www.crscoldstorage.co.uk/news/cold-storage-fruit-and-veg.html.

seasonally. A high tourism area, for example, may have high opportunity for sales of high value crops in the tourist season through markets, direct sales, food service and local shops.

Product Selection

Choice of crop varieties, quantities produced and growing systems strategically throughout the year may assist in capturing the highest value in certain markets (e.g. food service, direct sales), while balancing a need for consistent, year-round supply for other markets (e.g. local supermarkets). Defra regularly publish horticultural statistics on average wholesale prices of fruits and vegetables[11], as well as import and export statistics for the UK. A digest of 2024 average, minimum and maximum prices is provided in the appendix, and showcases the wide variety of price per kilogram as well as throughout the year. Targeting a variety of higher-value crops that are not typically grown by household growers is recommended.

Degree of processing and packaging of products may also be a factor in determining both crop choice and economic feasibility of end markets.

Box 1. Considerations for crop selection

Speaking to local buyers and understanding their specific needs of all potential markets is fundamental, including:

- Quality characteristics of produce, including colour, shape and size
- Quantity, timing and consistency of supply
- Crop and variety preferences
- Seasonality preferences
- Competition with other suppliers, whether local, national or international

It is also key to consider adaptability of the system to changing market preferences.

Typical Crops

The most common food crops grown in CEA systems are salad greens, herbs, microgreens, other leafy greens, vine vegetables (tomatoes, cucumbers, peppers), and soft fruits. As systems advance, however, crops that previously

[11] Department for Environment, Food & Rural Affairs. (2025). *Wholesale fruit and vegetable prices: Weekly average*. GOV.UK. Retrieved June 16, 2025, from https://www.gov.uk/government/statistical-data-sets/wholesale-fruit-and-vegetable-prices-weekly-average.

were unsuitable for growing in such systems are becoming more feasible, and the design of some units (e.g. tray-based indoor growing) facilitating greater diversity of crops within systems, if desired.

Many commercial operations specialise in one or a small number of crops, given the scale of production for wholesale markets. Smaller-scale operations producing for local markets may wish, or require, a much greater diversity of crop production to meet the needs of potential markets. This should be reflected in system choice, as well as the adaptability of the system for different crops. The taller and leafier the crop, for example, the more light is required. However, high value crops such as microgreens are likely to have a ceiling market volume, especially in more remote locations, and certain crops such as fruits are notably harder to grow economically in controlled environment systems.

The table on the next page summarises typical crop choices for controlled environment systems. It draws on data from the 2021 Global CEA Census Report[12] to provide an indication of popularity by growers, as well as scoring low-to-high for various factors influencing production viability (including heat, light, water and space requirement, value, complexity, market demand etc.), and suitability for enhanced protected growing versus vertical farming/indoor growing.

[12] Agritecture & WayBeyond. (2021). *2021 Global CEA Census Report*.

Table 9: *indication of crop viability depending on market and crop factors. NB: Unknown indicates where data was not available to make an assessment, e.g. wholesale crop data, or where crops are novel*

Crop	% of respondents growing[13]	Heat	Light	Water	Size/space required	Value	Growing complexity	Market demand	Storage capability	Enhanced protected growing	Vertical farming
Salad greens	58	Medium	Medium	Medium	Low	High	Low	High	Low	x	x
Herbs	49	Medium	High	Medium	Low	High	Low	High	Low	x	x
Microgreens	46	Low	Medium	Medium	Low	High	Low	High	Low	x	x
Other leavy greens (e.g. chard, kale, cabbage, etc.)	40	Medium	Medium	Medium	Low	Medium	Low	High	Low	x	x
Vine veg (toms, cucumbers, peppers etc.)	31	High	High	High	Medium	Medium	Medium	High	Medium	x	x
Berries	17	Medium	High	High	Medium	High	Medium	High	Low	x	x
Squashes/gourds	11	High	High	Medium	Medium	*Unknown*	Medium	Medium	High	x	x
Root vegetables	9	Medium	Medium	Medium	Medium	Low	Medium	Low	High	x	x
Melons	7	High	High	High	Medium	Medium	Medium	Medium	High	x	x
Tree fruits	6	High	High	Medium	High	*Unknown*	High	Low	Medium	x	
Mushrooms	5	Low	Low	High	Low	Medium	High	Medium	Low	x	x
Broccoli/cauliflower	5	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	x	x
Cannabis	5	High	High	Medium	High	High	High	Low	NA	x	x
Ornamental plants	5	Medium	Medium	Medium	Medium	*Unknown*	Medium	Low	?	x	x
Nursery starts	5	Medium	High	Medium	Low	*Unknown*	Medium	Low	Medium	x	x
Root starch vegetables (potatoes, yams)	4	Medium	Medium	Medium	Medium	Low	Medium	Low	Medium	x	x
Tree nuts (almonds, pistachios, walnuts)	2	Very High	High	Low	High	*Unknown*	High	Low	High	x	
Microalgae	NA	Medium	High	High	Low	*Unknown*	High	*Unknown*	*Unknown*		
Hops	NA	Medium	High	High	Medium	High	High	*Unknown*	Medium	x	x
Mini-tubers	NA	Medium	Medium	Medium	Low	High	High	High	High	x	
Fodder trays	NA	Low	Medium	High	Low	Low	Low	Low	Low	x	x

[13] Data drawn from Agritecture & WayBeyond. (2021). 2021 Global CEA Census Report.

Alternative Crops

While the focus of this work has primarily been on opportunities for CEA to support local food production, other crops are worth noting for their economic potential, whether as an alternative or complementary enterprise alongside food production. Given the speciality of crop requirements for many of these crops, these typically require higher technological capability, investment and training for successful production.

Medicinal cannabis

Medicinal cannabis is a high-value crop increasingly grown in controlled environments due to its need for precise control of light, humidity, nutrients, and biosecurity. In Scotland, there are already licensed commercial producers, and at least one vertical farming operation has transitioned exclusively to medicinal cannabis production, reflecting its potential to support the economic viability of intensive CEA investments.

While the crop requires significant upfront capital, compliance with strict licensing, and ongoing security and quality controls, its market value can far exceed that of conventional horticultural products. For the Highlands and Islands, the economic opportunity lies in combining clean energy potential, secure remote sites, and high health status to attract or develop specialised production facilities. However, access to Home Office licensing and the need for specialist expertise remain major entry barriers. As regulatory conditions evolve and demand grows, this could become a strategic sector for rural innovation and investment.

Mini-tuber production

Mini tubers are the essential foundation of the Scottish and UK seed potato industry, supplying the first generation of high-health seed from which all further field-grown seed and ware potatoes are produced. With over 4.6 million mini tubers grown in Scotland in 2024 by just five main producers, there is growing pressure on production capacity to meet demand — particularly as certification requirements tighten and EU import routes remain restricted post-Brexit.

Controlled environment systems offer a strategic opportunity to expand mini tuber output in the Highlands and Islands, leveraging the region’s remote location and high-health status for phytosanitary advantage. While specialist infrastructure is required, including clean lab space, propagation tunnels, grading, and cold storage, CEA systems could enable smaller-scale or modular production closer to existing seed-growing areas, especially where availability of growing medium (e.g. peat, coir, hydroponic or aeroponic systems) and skilled labour can be secured.

Key advantages include improved biosecurity, environmental control (for temperature, water, and disease), and potential year-round production cycles. However, high start-up costs, certification demands, and specialist knowledge requirements remain significant barriers. The sector's need for greater volumes per variety and the retreat of producers elsewhere in the UK indicate market headroom for well-equipped new entrants, particularly if integrated into the existing seed potato supply chain.

Nursery stock

Similar to mini-tuber production, since EU-Exit, nursery stock production has become more of a domestic market opportunity, as import restrictions, plant health checks, and increased biosecurity requirements have made sourcing stock from the EU more complex and costly. This shift has increased demand for UK-grown plants, particularly high-health, traceable stock. Nursery stock in the Highlands and Islands presents both opportunities and challenges.

Remoteness can be a phytosanitary advantage, helping reduce disease transmission and supporting high-health plant production — a growing priority in UK horticulture. However, distance from major markets adds logistical complexity, particularly for bulky, perishable plants requiring careful handling and prompt delivery. Routes to market may favour direct-to-consumer sales, regional contracts (e.g. local authorities, estates), or supplying centralised distributors with existing cold chain infrastructure. Strategic partnerships and investment in packing and storage facilities can help overcome transport barriers, making remote production more viable for high-value or niche stock.

Hops

Hop production in CEA systems is an emerging opportunity for the Highlands and Islands, particularly to supply the growing craft brewing sector with locally grown, specialty hops. Controlled environments can overcome challenges of latitude, poor soils, and short outdoor growing seasons, allowing multiple harvests per year and consistent quality. However, production is complex —

requiring significant infrastructure, precise climate and light control, and labour-intensive harvesting and drying processes. While UK demand for home-grown hops is rising, especially among brewers seeking provenance and sustainability, competition with established low-cost outdoor producers (e.g. in England and Europe) means premium or niche varieties may offer the best route to market. For remote producers, proximity to local breweries and a focus on fresh or unique hop products could offer a competitive edge.

Microalgae

Microalgae cultivation offers a high-value, low-footprint opportunity for the Highlands and Islands, particularly in areas like Orkney where previous feasibility studies have explored its viability. Microalgae can be grown in bioreactors or photobioreactors using controlled environment systems, producing biomass for markets ranging from nutraceuticals and animal feed to cosmetics and biofuels. The region's clean environment, available space, and renewable energy potential support low-carbon, high-integrity production. However, systems are technically complex and capital-intensive, requiring specialist expertise, biosecurity measures, and access to downstream processing and markets. While local demand is limited, partnerships with research institutions or niche product developers can help build a value chain. Success is most likely where production can be integrated with circular economy models (e.g. using waste heat or CO_2 from other processes) or where infrastructure and grid access challenges can be offset by on-site renewables.

Mushrooms

Mushroom cultivation in controlled environments offers potential for utilisation of local by-products, such as coffee grounds (such as Rhyze Mushrooms in Edinburgh), and enabling year-round food production. While large firms like Monaghan Mushrooms dominate the standard button mushroom market, can be demand for specialty varieties such as oyster, shiitake, and lion's mane, especially in gourmet and health-focused markets. Though infrastructure and labour requirements are significant, smaller-scale operations focused on niche products can compete on quality, provenance, and sustainability. Local supply chains and direct sales can help overcome logistical challenges, while the region's isolation supports strong biosecurity.

Fodder trays

Growing fodder in CEA systems using hydroponic trays — typically sprouting barley or wheat over 6–8 days — offers a way to produce fresh, high-moisture livestock feed with minimal land use. These systems require controlled temperature, humidity, and lighting, but avoid soil, pesticides, and fertilisers. While used internationally in arid regions and by niche livestock operations, they have yet to gain commercial traction in Scotland, largely due to high costs of production and lack of competitiveness versus traditional grazing and other supplemented feeds.

Costing, Business Models, and Investment

Gross margins & breaking even

Gross margins are a critical financial metric for CEA systems, particularly in rural and remote regions such as the Scottish Highlands and Islands. These areas often face unique challenges, including higher transportation costs, limited access to skilled labour, and increased energy expenses due to colder climates and grid constraints. As such, understanding and optimising gross margins becomes essential for ensuring the economic sustainability of CEA ventures in these locations.

Gross margins are the difference between revenue and the cost of goods sold (COGS) divided by revenue, provides a clear picture of how efficiently a CEA operation converts inputs—such as seeds, nutrients, energy, and labour—into marketable produce. For rural and island-based businesses, where operational costs can be disproportionately high, maintaining a healthy gross margin is vital to cover fixed costs, reinvest in technology, and remain competitive in broader markets.

Gross margins help inform strategic decisions about crop selection, pricing, and technology investments. For example, crops with shorter growth cycles and higher market value may yield better margins, making them more suitable for remote operations where maximising output per unit of input is crucial. Additionally, gross margin analysis supports funding applications and investor confidence, both of which are essential for scaling up or integrating renewable energy solutions in off-grid or weak-grid areas. While gross margins measure operational efficiency, they do not on their own determine the commercial viability of a horticultural enterprise.

Table 10 below provides indicative gross margin data for tunnel-grown strawberries, reflecting inflation in key input costs. Labour is a major cost component, with the following breakdown:

- **Total labour cost**: £48,305 per hectare
- **Labour requirement**: 4 people per hectare
- **Yield assumption**: 30 tonnes per hectare
- **Labour efficiency**: 1 person per 7.5 tonnes of crop
- **Labour cost per person**: £12,076
- **Labour cost per tonne of crop**: £1,610

This estimate is based on a relatively labour-intensive and lower-yield production model. However, the figure of **£1,610 per tonne of crop** may serve as a useful benchmark for estimating labour costs in other enhanced environment horticultural operations.

By contrast, **highly automated vertical farms**—which can produce thousands of kilograms per square metre—typically operate with significantly fewer staff, resulting in much lower labour costs per unit of output.

***Table 10**: indicative gross margins for growing strawberries, figures taken from ABC handbook and key inputs adjusted for inflation based on Defra data.*

Category	Details	£/ha
Yield	30 t/ha @ £4560/t	**£139,500.00**
Planting	Plants plus substrate	£16,725.82
Structures	Polytunnels, tables, irrigation equipment	£9,317.00
Fertiliser & Crop Protection		£2,995.02
Husbandry Labour		£8,222.22
Harvest Labour	Includes supervision costs	£26,722.22
Other Crop Costs		£1,500.00
Transport		£7,362.49
Packing Labour	Grading, packing, handling	£13,361.11
Packaging		£10,500.00
Marketing	@ 10% of output	£15,000.00
Total Variable Costs		**£111,705.88**
Gross Margin		**24.88%**

Breakeven analysis determines the volume of production or sales required for total revenues to cover total costs (both fixed and variable), answering the essential question: *can the business survive, and at what scale must it operate to do so?*

In remote areas, CEA ventures must also factor in the **'remoteness premium':** the extra cost incurred when transporting fresh produce from central distribution depots to rural retailers. This premium arises from higher per-unit logistics costs over long distances and can significantly inflate the price of food in remote shops. Local CEA production, if properly established, can potentially avoid these haulage costs, and if local consumers are willing to pay slightly more for fresher or locally grown produce, this creates a double economic advantage. Comparing these two factors—the cost savings from reduced distribution and the additional income from local price premiums—can help determine the breakeven point for producers and assess whether small-scale horticulture is commercially viable. However, for these benefits to be realised, local producers must also have the capacity to process, package, and store produce on-site, in compliance with food safety and quality standards. Without that infrastructure, the savings and premium value are unlikely to be captured in practice.

There are some useful sources to support the analysis of haulage costs and remoteness premium for local CEA producers:

- Research from **SRUC** and Kantar Worldpanel shows consumers in Scotland's remote rural areas pay a small but statistically significant premium—around **0.2%**, rising possibly to **10–40%** depending on location, goods, and shopping behaviour.[14] Elevated prices arise from a mix of **higher transport costs** and lower retail competition.
- A **Scottish Parliament report** confirms that remote communities face higher costs for food, energy, and transport compared to urban areas—key components of the overall "rural premium."[15]
- **Survey data from RHA/Haulage Cost Movement reports** provide averages and trends across the transport industry—including fuel, labour, and per-mile operating costs.[16]

[14] Revoredo-Giha, C. & Russo, C. (2021) *Food prices in Scottish remote rural areas: Measuring and explaining the 'remoteness premium'*. Prague: 16th Congress of the European Association of Agricultural Economists. Available from: SRUC. https://pure.sruc.ac.uk/files/42222244/EAAE_paper_Remote_rural_27_01_20.pdf

[15] Scottish Affairs Committee. (2024) *Remote Scottish communities worse off due to 'rural premium' despite cost-of-living support, MPs find*. London: UK Parliament. Available from: UK Parliament Committees.

[16] Road Haulage Association. (2024) *Annual Cost Movement and Pay Surveys*. London: RHA. Available from: Road Haulage Association.

- **Food Cost of Remoteness** data from gov.scot quantifies higher living costs and fuel poverty uplifts in island and mainland remote areas—underscoring systemic cost differentials.[17] [18] [19]

Additionally, local producers may consider the value of *avoided marketing costs*—not just haulage, but also packaging, losses during transport, and handling—which could enhance competitiveness even if unit production costs are higher.

Ultimately, integrating both **gross margin analysis** and **breakeven modelling** enables a fuller picture of viability. Gross margins tell us how efficiently a business operates once running, while breakeven analysis reveals whether the business is structurally viable at all. For CEA operations in the Highlands and Islands, combining these tools will be crucial to navigate higher costs, access funding, and build models that can be both economically and environmentally resilient.

The economic viability of CEA businesses also has broader implications for local food resilience and self-sufficiency. By enabling year-round production of fresh produce close to the point of consumption, CEA systems can reduce reliance on imports, lower food miles, and enhance food security for remote communities. However, this potential can only be realised if such operations are financially sustainable. When CEA ventures can operate profitably, they contribute to a more robust local economy, create skilled jobs, and support community well-being. Conversely, if margins are too thin to sustain operations, the promise of local food independence may remain out of reach. Thus, understanding and optimising both gross margins and breakeven thresholds is essential not only for individual business success but also for building a more self-reliant and sustainable rural food system.

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[17] Revoredo-Giha, C. & Russo, C. (2022) *Food Expensiveness in Scotland's Remote Areas: An Analysis of Household Food Purchases*. Rural Sociology, 88(1), 32–70. Edinburgh: Scotland's Rural College. Available from: Scotland's Rural College (SRUC).

[18] Russo, C. & Revoredo-Giha, C. (2024) *Food Expensiveness in Remote Areas of Scotland: A Natural Experiment Measuring the Out-Shopping Effect*. Food Security, 16(4), 1019–1029. Dordrecht: Springer. Available from: SpringerLink.

[19] Scottish Government. (2024) *The Cost of Remoteness: Reflecting Higher Living Costs in Remote Rural Scotland When Measuring Fuel Poverty*. Edinburgh: Scottish Government. Available from: gov.scot.

Box 2. Steps for a Practical Breakeven Analysis in Remote Horticulture

1. Estimate All Costs

- **Fixed Costs**:

Build/purchase of CEA infrastructure (greenhouse, vertical system).
Equipment: lighting, HVAC, irrigation
Salaries, wages, and NHI
Maintenance and depreciation.

- **Variable Costs per kg**:

Seeds / plants
Substrates / growing media
Energy (electricity/heating)
Packing, post-harvest handling
Labour (per unit)
Distribution

2. Estimate Potential Revenue

- Use a base selling price from comparable produce in the region.
- Apply **local food premium** based on willingness-to-pay studies.
  - Example: If consumers are willing to pay **20% more** for local lettuce than for imported lettuce, apply this uplift.

3. Factor in Avoided Costs (e.g., Haulage)

- If local production **avoids transport costs**, you can consider this as a **cost-saving advantage** that increases commercial viability.
  - E.g., if it costs £0.25/kg to ship lettuce from a central depot, this can be considered a margin the local producer doesn't have to compete on.

4. Run Scenarios

Create different pricing and cost scenarios to reflect:

- Energy price volatility.
- Yield variation.
- Uptake of willingness to pay (e.g., not all consumers will pay the premium).

Useful Add-ons

- Include **payback period** (how long until capex is recovered).
- Calculate **cost per kg vs. wholesale/retail benchmark prices**.
- Consider using tools like spreadsheets or basic farm business planning models (e.g., from the Farm Advisory Service in Scotland).

CapEx – setting up and building your operation

Your capital expenditure (CapEx) will depend on several key factors, including the size of your facility, the equipment required, and your desired output. How much produce you intend to grow, the facility's dimensions, the necessary equipment, and the level of automation you pursue all combine to determine your CapEx.

If you already have a service area for pre- and post-harvest activities, it may be suitable without further modification. Building costs will vary depending on whether you opt for new construction or retrofit an existing structure. Additional factors such as the cost of hiring local architects and site-specific geographical conditions can also influence overall expenditure.

Consider starting with a semi-automated system to gain a deep understanding of your operational processes. You can then increase automation as you scale. Full automation is typically only recommended if your business model justifies it—particularly in cases where high labour costs would otherwise render operations unfeasible.

Don't overlook the need for office and staff areas. These spaces support worker comfort and productivity by providing environments separate from the growing area.

Finally, plan for storage costs. These will depend on your production volume, supply chain logistics, and any requirements from offtakers.

***Table 11:** indicative CapEx costs for various CEA structures and systems.*

System Type	Description	Indicative Cost	Notes
Glasshouse (Basic)	Basic structure on level site	£1 million/ha	Assumes land ownership
Glasshouse (Commercial)	Well-equipped commercial unit	£2 million/ha	
Glasshouse (Advanced)	Sophisticated climate control	Up to £5 million/ha	
Glasshouse (Second-hand)	Used structures	~£600,000/ha	Market volatile; supply chain issues
Installation (General)	Varies by scale and automation	£1,000–£3,541/m²	
Fully Automated System	Glasshouse + automation + renewables	~£4 million	
Polycrub (Small)	4x12m climate-controlled unit	£25,000	Based on Orkney feasibility study
Polycrub (Larger)	Larger polycrub structure	£170/m²	
Vertical Farm (IGS)	Intelligent Growth Solutions module	£1.5–2 million	
Vertical Farm (Other)	CambridgeHOK, Urban Crop Solutions	£1,000–£3,000/m²	Complete module ~£275,000
GrowUp Farms (Pepperness)	Large-scale vertical farm	£100 million	Built next to bioenergy power station
Container (Used)	40-foot shipping container	\$3,000–\$6,000	Cost varies by condition and location
Container Retrofit	Conversion to controlled environment	\$50,000–\$100,000	Includes insulation, lighting, hydroponics, climate control
Polytunnels (Basic)	Empty tunnel structures	Varies	See Highland Polytunnels

OpEx – the monthly costs of running your operation

For most CEA operations, the largest ongoing operating expenses (OpEx) are typically power and labour. It's important to explore strategies to reduce these costs, such as adopting automation and implementing low-voltage power distribution systems.

Recurring inputs, such as propagation trays, seeds, growth media, and fertigation system, will also contribute to your operational expenditure. These costs vary depending on the growing system you adopt but typically make up a smaller share of total running costs compared to energy and labour. However, the exact proportion will be influenced by the scale and specifics of your operation.

CEA can serve as a complement to traditional agriculture, rather than a full replacement. Its real value is often in producing crops that are not easily achievable through conventional methods. In this way, CEA can help diversify, stabilize, and grow your agricultural business.

Finally, don't forget to account for ongoing maintenance and technical support—both of which are essential for ensuring reliable operation and minimizing downtime.

Table 12: *indicative OpEx costs and impacts in different CEA structures and systems.*

System/Factor	Description	Indicative Cost / Impact	Notes
General Energy Use	Energy accounts for a significant portion of OpEx	~1/3 of total costs	Low-cost heat and power sources are essential
Polytunnels (Double-skinned)	Energy efficiency improvement	Up to 30% reduction in energy costs	Compared to standard polytunnels
Polycrub (Shapinsay study)	Climate-controlled structure energy use	3,000 kWh/m²/year	At £0.18/kWh = **£5.30/m²/year**
Polycrub (Updated energy price)	Adjusted for 50% higher UK grid prices	£7.95/m²/year	Energy = ~3% of total OpEx in this case
Vertical Farming (General)	LED lighting + climate control	Up to 65% of OpEx	Energy is a major cost driver
Vertical Farm (1,000 m²)	Daily energy consumption	~1,705 kWh/day	Monthly cost: **£1,600–£6,800**, depending on local rates
Vertical Farm (Per kg)	Energy cost per kg of produce	2.3 kWh/kg → ~£0.51/kg	Based on UK energy prices
Container Farm (Economic mode)	Low-energy setting	168 kWh/day	Designed for efficiency
Container Farm (Standard mode)	Balanced yield and efficiency	191 kWh/day	
Container Farm (Performance mode)	High-yield setting	231 kWh/day	

Further Information

There are various organisations that can provide further support in the following areas:

Market research and business model development:

- Business Gateway – https://www.bgateway.com/
- Scottish Enterprise market research service – https://www.scottish-enterprise.com/support-for-businesses/grow-your-business/find-new-customers-and-suppliers/domestic-market-research
- Consumer trends and statistics – https://theknowledgebank.scot/

Integration of community benefits:

- ImpactHub Inverness – https://inverness.impacthub.net/business-support-services
- CEIS – https://ceis.org.uk/
- Community Enterprise Scotland – https://communityenterprise.co.uk/
- STAR Development Group – https://stardevelopmentgroup.org/about/senior-consultants/
- Highland Good Food Partnership – https://highlandgoodfood.scot/

Sources of funding and technical advice:

- Crofting Agricultural Grants Scheme – https://www.ruralpayments.org/topics/all-schemes/crofting-agricultural-grant-scheme-cags/
- HIE Food and Drink TechHub – https://www.hie.co.uk/support/browse-all-support-services/nih/techhub/
- Food Processing, Marketing and Cooperation (FPMC) Scheme – https://www.ruralpayments.org/

Horticultural advice and guides

- Propogate Growers Pack – https://www.propagate.org.uk/resilient-growers-pack
- British Growers Association – https://britishgrowers.org/
- The Market Gardener Guide to greenhouse farming – https://themarketgardener.com/farming-techniques/the-ultimate-guide-to-greenhouse-farming-for-market-gardeners/

SITING, INFRASTRUCTURE & SERVICES

For CEA in the Highlands and Islands, addressing availability of land and infrastructure involves navigating unique local factors, such as crofting laws, remote geography, and planning constraints. Local zoning rules and tax rates might either limit or encourage CEA activities.[20]

Land Availability and Suitability

Land ownership is the simplest route to developing CEA as it gives full rights to develop structures, but land can be scarce or tightly held, especially in crofting areas or island communities. Another option is community land ownership, which is common in parts of the Highlands and Islands area, but you may need to engage with community trusts. You also need to be aware of land use designations (agricultural, conservation, national park) that may restrict CEA projects, especially large-scale or industrial style greenhouses and vertical farms.

Tenant farmers or crofters need written landlord permission to erect structures or materially change land use. The type of structure will often determine the level of agreement needed. Temporary structures may only require informal consent, but this may be unlikely to be the case in CEA where technological enhancements are made to the growing structures. Temporary or mobile structures, like movable polytunnels, may be exempt from planning permissions, or quality under permitted development, but you must still notify the local planning authority. Rules on this vary by council. Permanent buildings likely need a formal lease amendment or a license. Planning permissions is almost always required, especially if the structure is over 280 m^2 or it is impacting public infrastructure like drainage, roads, or the visual landscape. For CEA with renewable energy components, check if the energy infrastructure is covered under tenancy agreements. Building warrants may be required in addition to planning permission if structure safety or services are involved.

Disused farm building, like barns or byres, may be ideal for retrofitting with enhanced growing systems and potentially present fewer planning hurdles depending on the degree of change of use. Old industrial or community buildings

[20] Coon, D., et al. (2024). Reporting and practices of sustainability in controlled environment agriculture: A scoping review. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10669-024-09964-z.

may be available through community asset transfer schemes or local development trusts. Repurposing these buildings may reduce costs and speed up approval, especially where the infrastructure for access to water and electricity is already in place. However, energy efficiency upgrades, insulation, and compliance with building codes must be factored into retrofit projects.

Proximity to Markets

The Highlands and Islands are geographically remote from Scotland's major population centres. Outside of Inverness and a few larger towns, such as Fort William, Stornoway, and Kirkwall, local market sizes are relatively small. Logistics costs for reaching urban centres like Aberdeen, Glasgow, or Edinburgh from more remote rural or island locations can be high. Transporting produce over long distances may also undermine the core value proposition of CEA as a local, sustainable food solution.

For high-value, perishable crops such as leafy greens, herbs, or mushrooms, proximity to local demand is often essential. These crops benefit from short, efficient, and low-waste supply chains. Developing a resilient local food supply chain can not only support community food security but also serve as a key marketing advantage—potentially justifying premium pricing.

This localised approach aligns closely with the ambitions of the Scottish Good Food Nation (GFN) policy, which aims to ensure that everyone in Scotland has access to healthy, sustainable, and locally produced food. The National Good Food Nation Plan[21], published in 2024, outlines six overarching outcomes, including:

- Improved health and wellbeing through better diets
- A flourishing food economy
- Reduced environmental impact from food systems
- Stronger local food supply chains
- Enhanced food education and culture
- Greater equity and fairness in food access

One of the key mechanisms for delivering these outcomes is through public procurement. Local authorities, schools, hospitals, and other public institutions are encouraged to source food locally where possible, supporting regional producers and reducing food miles. CEA operations that can demonstrate

[21] Scottish Government (2024) *National Good Food Nation Plan*.

sustainability, traceability, and community benefit may be well-positioned to access these contracts.

The Proposed National Plan currently under parliamentary scrutiny also highlights the role of local government in delivering GFN aims through procurement, community growing, and food education[22]. This presents a strategic opportunity for CEA ventures, particularly those in rural or island communities, to become embedded in local food systems and secure stable demand through public sector partnerships.

Proximity to Labour

Many rural areas and islands in Scotland face challenges related to population decline and ageing demographics, which can limit access to a local workforce. This is particularly acute for CEA, where skilled labour, such as technical operators, engineers, and data monitoring specialists, can be scarce.

Projects located near population centres like Inverness, Oban, or Stornoway tend to have better access to labour pools. However, in more remote areas, CEA operations may need to rely on automation and low-labour systems (e.g. hydroponic leafy greens or container farms) to remain viable.

To address workforce limitations, CEA can be **linked to rural skills development, apprenticeships, and training partnerships. The University of the Highlands and Islands (UHI)** plays a key role in this space, offering regionally accessible education and training. Additional providers include:

- **SRUC – Scotland's Rural College** offers a wide range of agriculture and horticulture programmes, including practical and research-based training relevant to CEA.
- **Lantra Scotland** supports land-based industries with accredited training and career development, including in horticulture, aquaculture, and machinery use.
- **Rural Services Scotland Ltd** provides LANTRA-accredited and NPORS-certified training across Scotland, which can support foundational skills for CEA operations.
- **Universities such as Aberdeen, Glasgow, and Edinburgh** offer advanced programmes in plant science, sustainability, and data analytics that may support technical roles in CEA.

[22] Scottish Parliament (2025) *Good Food Nation: Proposed National Plan – Consultation*.

In addition to formal education, there are several non-institutional opportunities for developing CEA-relevant skills:

- **Community-led initiatives** such as local food growing groups and cooperatives often run informal workshops on hydroponics, composting, and sustainable growing.
- **On-the-job training** through internships or placements within CEA projects can provide hands-on experience across multiple roles.
- **Online learning platforms** (e.g. FutureLearn, Coursera, OpenLearn) offer flexible courses in agritech, sustainability, and data monitoring.
- **Supplier-led training** is often available from equipment providers, covering system-specific maintenance and optimisation.
- **Innovation hubs and maker spaces** may support experimentation with DIY hydroponics, sensor integration, and automation.
- **Agricultural networks and events** (e.g. Soil Association Scotland, LEAF, Scotland Food & Drink) offer informal learning and networking opportunities.

By engaging with these institutions, CEA projects can contribute to local capacity-building and create pathways for employment and innovation in rural communities.

Requirement of External Inputs

CEA systems rely on a range of external inputs that can pose logistical and cost challenges due to the region's remoteness and limited infrastructure. These inputs typically include growing media (such as peat-free compost, coco coir, rockwool, or sterilised straw for mushrooms), seeds or plugs, nutrient solutions, climate control equipment, and technical components like sensors and lighting. Because many of these materials are not readily available locally, especially in more remote islands or upland areas, they often need to be shipped in, sometimes from long distances, which increases both cost and complexity.

Transporting these inputs to the Highlands and Islands comes with unique difficulties. Freight services are often limited in frequency, especially to the islands, and weather-related disruptions can complicate deliveries if reliant on ferries or aircraft. Bulky or sensitive materials, such as sterilised mushroom substrate or nutrient solutions, may require refrigerated or protected transport, further increasing logistical costs. This can significantly affect operational budgets and the consistency of supply chains, particularly for high-volume or time-sensitive growing cycles.

To mitigate these challenges, CEA operators can explore several strategies. One option is to develop local infrastructure to reduce dependency on imported materials. For example, building on-site sterilisation systems can allow mushroom growers to process their own substrate from locally sourced sawdust or straw. This not only reduces costs but also improves resilience and sustainability. Additionally, bulk ordering and seasonal stocking of key supplies during more accessible months can help overcome transport limitations during winter or adverse weather conditions.

Sourcing other inputs locally—such as using forestry by-products, agricultural waste, or spent grain from distilleries as growing media—can reduce dependence on external suppliers while supporting circular economy practices. While these solutions require up-front investment and coordination, they can significantly enhance the viability of CEA operations in remote parts of the Highlands and Islands.

However, there are important considerations regarding the volume compatibility between industrial by-products and the needs of CEA operations. For example, while a mushroom farm might use spent grain or woodchips as substrate, it is unlikely to absorb the full volume of waste produced by even a single distillery. According to the Scottish Government, Scotland's whisky industry produces approximately 500,000 tonnes of draff and 1.6 million tonnes of pot ale annually, volumes that far exceed the capacity of most small-scale food production systems.[23]

Moreover, these by-products are already widely used in livestock feed and bioenergy production, particularly through anaerobic digestion. These established uses are economically viable and well-integrated into existing supply chains, meaning that CEA projects would need to compete with or complement these markets. For instance, draff is often used wet or dried in feed mixes, while pot ale is increasingly used to generate biogas in distillery-linked energy systems.

[23] Scottish Government (2019) *Distillery Co-products for Livestock Feed and Bio-energy Use in Scotland.*

To compete effectively, CEA operators must demonstrate added value, such as environmental benefits, local economic impact, or co-location advantages. A mushroom farm situated near a distillery could, for example, use sterilised spent grain or woodchips as substrate and tap into the distillery's waste heat to maintain optimal growing temperatures. This not only reduces the need to import growing media and heating systems but also lowers the distillery's waste disposal costs. Similarly, co-locating with aquaculture operations could enable integrated aquaponic systems, where nutrient-rich water from fish tanks fertilises hydroponic crops.

Site Requirements

Water usage

Water plays a critical role in CEA systems, serving as the primary medium for delivering nutrients to plants, especially in hydroponic and aeroponic setups. Efficient water management is essential not only for plant health and productivity but also for sustainability. CEA systems can use up to 90% less water than traditional agriculture by recycling and precisely controlling water use.

Table 13: *water use implications in different growing systems.*

Growing System	Water Demand	Water Quality Requirements	Water Reuse Potential	Storage Needs	Typical Source	Notes
Soil-based	High	Moderate (can use non-potable with treatment)	Low (excess usually drains away)	Large volume or frequent supply needed	Rainwater, mains, or borehole	Evapotranspiration losses high; sensitive to over/under watering
Substrate-based (e.g., coco coir, rockwool)	Moderate to high	Moderate to high (clean to prevent clogging or salt build-up)	Moderate (can capture drain-off if designed for it)	Medium tanks for batch irrigation	Mains or treated rainwater	Water-holding capacity of substrate can buffer inconsistent supply
Drip irrigation	Moderate	Moderate (filtration needed to prevent clogging)	Moderate to high (depending on system design)	Small to medium (system dependent)	Borehole, rainwater, mains	Efficient for targeted watering; common in soil/substrate setups
Hydroponic	Moderate to low	High to very high (low salt,	High (80–90%+	Medium (nutrient	Mains, RO-	Sensitive to water quality fluctuations;

	(per kg yield)	pathogens, algae)	reuse with proper treatment)	tank + top-up reservoir)	filtered rainwater	constant monitoring and nutrient balancing required
Aeroponic	Low (highest efficiency)	Very high (ultra-clean; prone to clogging)	Very high (closed-loop misting)	Small (low volume needed, but stable flow critical)	Purified mains, rainwater with RO/UV	Most efficient system; vulnerable to water supply or pressure interruptions

Key Considerations:

- **Vertical farms** and **container farms** can typically be the most water-efficient due to recirculation systems.
- **Greenhouses** and **polytunnels** have higher water losses due to transpiration and evaporation, especially if ventilation is natural.
- Water storage and backup are crucial in the Highlands and Islands where supply disruptions or reliance on rainwater harvesting can affect consistency.
- For all systems, filtration and treatment may be necessary, especially if using rainwater or borehole sources.
- **Aeroponics and hydroponics** are the most water-efficient, but require consistent, high-quality water and technical expertise.
- **Soil and substrate systems** are more tolerant of variable water quality but require more water overall and can generate more waste.
- Rainwater harvesting can supply many systems, but for recirculating systems (hydroponic/aeroponic), filtration (e.g. UV, RO) is often required.
- In remote areas of the Highlands and Islands, boreholes or rainwater collection may be more sustainable long-term, but need upfront investment in storage and treatment**.**

In CEA energy and water are closely linked: energy is required to move, treat, and heat water, while water is often needed for cooling, humidification, or as part of energy generation systems.

Table 14: *the energy-water nexus in various interactions.*

Interaction	Description	Implications for CEA in Highlands & Islands
Water pumping and circulation	Energy is required to pump water for irrigation, nutrient delivery, and circulation in hydroponics or aeroponics.	More energy-intensive in hilly or off-grid locations; off-grid systems need storage + solar or battery backup.
Water treatment &	Treating water (e.g., RO filtration,	Clean water is essential for

purification	UV sterilisation) requires electricity.	hydro/aeroponics; treatment adds to energy demand.
Heating of irrigation water	In colder climates, water may need pre-heating to avoid shocking plants or destabilising root zone temperatures.	Especially important in winter or unheated greenhouses; can use waste heat or renewables.
Evapotranspiration control	Higher temperatures increase water demand; more energy needed for ventilation or cooling to prevent losses.	In heated systems, this can create a feedback loop of rising energy and water use.
Humidity regulation	Energy is used to control humidity (dehumidifiers, HVAC) which affects water retention and plant transpiration.	Critical for container and vertical farms; excessive humidity = disease risk.
Wastewater recycling	Treating and recirculating water (especially in hydroponics) can save water but requires energy for pumps and filtration.	Efficient but technically demanding; essential where water supply is limited.

Rainwater harvesting

The harvesting of rainwater can be seen as making use of a renewable resource. Capturing rainwater on farm can offset some or all of the mains water supply, which with increased metering and charge rates is becoming a more important cost. Because rainfall in the UK is relatively high, significant potential exists for the adoption of rainwater harvesting (RWH).

In CEA, RWH is typically used for irrigation, hydroponic systems, climate control like evaporative cooling, and cleaning and hygiene within the facility. RWH is easier to be included in the design of new buildings rather than being retrofitted into existing buildings, an opportunity for those looking to set up new CEA structures. RWH systems need to maintain adequate water quality for given use of water. It is important to have fitted filters to screen out debris (such as bird faeces and vegetation debris on the roof) from the water and ensure the stored water is clean. Water from RWH can be a sustainable option for CEA if treated properly, like being filtered and disinfected before use, its quality monitored regularly, and it treatment tailored to CEA system and crop type.

RWH costs and savings:

- Taking an agricultural building with a roof area of 600m^2 (i.e. 20m x 30m) and assuming average annual rainfall of 800mm per year as well as a rainfall yield of 90%, an estimated 432,000 litres of water could be harvested in a typical year

RWH is potentially useful for all types of CEA, but its effectiveness and practicality depends on the system design, water needs, and location.

***Table 15**: suitability to harvest rainwater in different CEA structures.*

Structure	**Suitability**	**Considerations**
Polytunnels / Polycrubs	Medium	Structures are light and less durable, but can still support gutters and downpipes. Filtration and sediment control is important due to high debris and less rigid structures.
Greenhouses	High (if large roof surface area)	Water can be used for soil-based or hydroponic irrigation, as well as fogging and evaporative cooling. Integration with fertigation can optimise resource use.
Container Farms	Low (unless large roof surface area)	Can be useful for humidification and irrigation, but the cost-benefit may not justify installation unless scaled.
Vertical Farms	Medium	Limited roof space compared to water demand. Can be used as a supplementary water source or part of a closed-loop system alongside condensate recovery and hydroponic recirculation.

When evaluating RWH for CEA:

- Match water supply potential with demand, through calculating the monthly need in litres for activities such as irrigation, cooling, and cleaning. Compare this with the RWH estimate, and what percentage of your needs you can and want your RWH to meet. If this percentage is insufficient, only consider it as a supplementary source.
- Factor in local rainfall patterns and roof catchment area. Multiply your approximate roof surface area by the annual rainfall at your location, using SEPA or Met Office data, to estimate the annual harvestable water at your site.
- Consider storage capacity for bridging dry periods through water tanks or underground storage. Budget for technical feasibility, like components such as tanks, filters, gutters and pumps, as well as staff time to maintain the system.
- Consider water quality and treatment needs, RWH can pick up contaminants from roofs, grow algae or bacteria in storage tanks, and lack

minerals and nutrients. Especially for closed and pest-free systems like vertical farms, water carrying contaminants or imbalances can harm crops or equipment. Pre-filtration screens at inlets can block leaves, insects and debris. Covered and opaque tanks prevent algae growth and should be sealed to prevent animal access. Sediment and carbon filters remove fine particles, odours, and chemicals. UV sterilisation can be used as a disinfection mechanism to destroy bacteria and viruses without using chemicals.

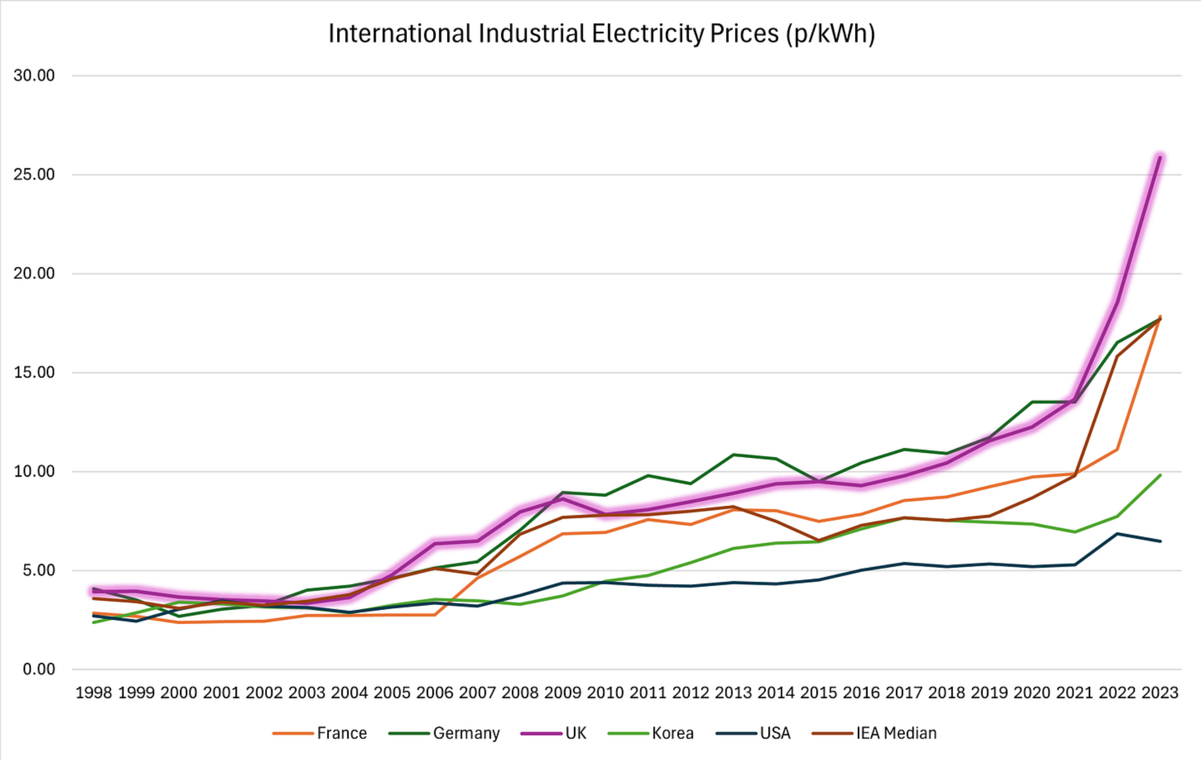
- Integrate with other water-saving systems (e.g. recirculating hydroponics, water meters, sensors).
- Check with the local authorities whether there are any legal or regulatory considerations for being on non-mains water for irrigation or food production purposes.

Energy

Arguably one of the most important elements of CEA is energy provision. As visualised in the chart below, the UK has some of the highest industrial energy costs in the world and the highest in Europe, which have driven up costs for energy intensive businesses.[24]

Energy costs typically account for around 30% of CEA operational expenses, making access to low-cost, renewable energy a critical factor in commercial viability. Globally, CEA has thrived in regions with abundant, affordable energy sources such as geothermal (Iceland, New Zealand), solar (Middle East), and increasingly, wind, hydro, biomass, anaerobic digestion, and heat pumps.

[24] Pinnington, M. (2024). *Industrial electricity: Why are costs so high?* Resolve Energy. Retrieved June 16, 2025, from https://www.resolveenergy.co.uk/blog/article/industrial-electricity-why-are-costs-so-high.



One of the most promising opportunities for synergy in the Highlands and Islands lies in aligning CEA with renewable energy infrastructure. This region generates substantial electricity from wind, hydro, and tidal sources. However, due to limited grid capacity, a significant portion of this energy is curtailed or wasted.

Locating CEA operations near community-owned renewable energy assets or guaranteeing your own source of energy provision for the CEA operation, can enable producers to harness local energy to power essential systems like lighting, heating, and water circulation. Specifically in Scotland, which grid access varies across the Highlands and Islands, off grid systems can thrive in areas with strong wind resources and be supported by Scottish Government policy through grants and innovation funding for rural renewables and low carbon agriculture.

Table 16: *considerations for on and off-grid energy operations.*

	Advantages	Disadvantages
On-Grid	Reliable power supply - access to consistent electricity for lighting, heating and automation.	High electricity costs – UK industrial energy prices are among the highest globally.
	Grid back up – renewable systems can be supplemented by grid power during low generation periods.	Grid constraints – in rural Scotland, grid capacity may be limited or require costly updates.
	Feed in tariffs or Contracts for Difference – excess renewable energy can sometimes be sold back to the grid.	Carbon intensity – grid electricity still includes fossil fuel sources, affecting sustainability goals.
Off-Grid	Energy independence – not affected by grid outages or price fluctuations.	High upfront costs – requires investment in generation, storage, and back-up systems.
	Sustainability – can achieve near-zero carbon operations with the right mix of renewables and carbon storage.	Energy balancing – must carefully balance supply and demand.
	Ideal for remote areas – useful in parts of Scotland where grid access is limited or non-existent.	Technical complexity – requires robust system design and maintenance.

For CEA in Scotland, the most beneficial renewable energy sources are those that align with the climate, energy infrastructure, and agricultural needs. There can be significant economies of scale associated with renewable energy systems, so most plants tend to be large as it makes most sense to spread fixed costs over more output. Costs vary significantly depending on local construction and labour costs, type and access to feedstock. Based on recent guidance and strategies, the top renewable energy sources for CEA in Scotland are:

Table 17: *considerations for the most prominent sources of renewable energy.*

Source	Strengths	Considerations	Costs	Returns
Wind	Scotland has some of the best wind resources in Europe, especially in coastal and upland areas	Best for agricultural operations with sufficient land and grid access or battery storage	Mainly capital, as well as associated finance / depreciation. Indicative costs for a variety of scales: -5kW (10-12m height): £25k -15kW turbine (15-20m height): £75k -75kW turbine (25-35m height): £250k -250kW turbine (40-45m height): £550-700k	For individual turbines, the value of electricity produced for installations under 5MW will be the prevailing price under the SEG – might be around 5.5p per kWh. Offsetting purchased electricity ~15p-17p per kWh. Output depends on avg. windspeed but a 15 kWh turbine can provide enough power for 2 – 3 dwellings.
Solar	Despite Scotland's cloudy climate, solar PV can still contribute significantly, especially during long summer days.	Works well when paired with battery storage to balance intermittent generation. Have a lower lifespan than other systems, and usefulness is weather-dependent	Typically a solar panel costs around £750 per kW of capacity, supplied and installed. Costs per kW (£1,250) are higher for installations up to 20kW. A typical household might use 2-3k kWh per year on water heating, which would be more in agricultural settings. For a thermal unit that meets 50% of household hot water needs, the cost is likely to be between £3-7k.	Approximately 6-6.5m^2 of PV panels is required to generate 1 kW of electricity. A 3-4kW installation would typically suffice domestically. Income from savings on purchased electricity (around 12-17ppkWh for daytime), sales of surplus (usually 5.5ppkWh), plus receipts from SEG. Depending o the type of water heating replaced, savings can be between £50-150 per year.
Biomass & AD	Converts organic waste (crop residues, manure) into heat and electricity.	Ideal for mix-used farms, or operations located close to farms, with livestock or crop waste streams. High capacity electricity connection should be close by – any distance over 700m could adversely affect the	OpEx: purchase or transport of organic waste / crops / manure, storage and handling, skilled operators and technicians, maintenance and repairs, utilities and consumables, digestate handling / treatment /	Typical AD plant is 450 kW.

		economics of the project.	disposal, insurance and compliance. CapEx: digester tanks, biomass boilers, CHP units, gas storage, piping, civil engineering and site preparation, feedstock pre-treatment systems, control and monitoring systems, grid connection, EIA's, planning applications and legal fees.	
Hydro	Reliable and consistent energy source in areas with flowing water. Generally considered the most efficient of all renewable technologies.	Is site specific and requires environmental assessments.	Estimates exclude the cost of grid connection. Low heads: -£4-6k per kW up to 10 kW. -£2-3k per kW for 50-100kW. Medium heads: -£10k plus £2.5k up to 10kW. -£10k plus £1-1.5k per kW for 50-100kW. OpEx is generally 1-2% of Capex.	Income is comprised to savings on purchased electricity, sales of surplus, and receipts from the SEG.

Anaerobic digestion

Anaerobic digestion (AD) is the natural breakdown of organic material by micro-organisms in an oxygen-free environment, typically using waste products as feedstock. The consistency and reliability of feedstock quality and quantity are critical to the success of an AD plant. Importing waste from off-farm sources can enhance economic viability by providing high-energy inputs and generating income through gate fees. Industrial and food manufacturing waste tends to be consistent, while catering and retail food waste may offer higher gate fees but with more variable composition.

An AD plant functions like a mechanical rumen, requiring skilled management to maintain optimal output. Slurry alone is insufficient due to its low energy content and biogas yield; instead, high-energy crops like maize silage are preferred, along with grass silage, wholecrop, and grains. The process produces biogas—typically 40% CO_2 and 60% CH_4—and digestate. Biogas is often used in combined heat and power (CHP) systems, with electricity exported and heat reused in the digestion process or sold locally. Alternatively, biogas can be upgraded to biomethane, a direct substitute for natural gas.

Typical biogas yields per tonne of feedstock are:

- Slurry: 20–50 m^3
- Silage: 150–200 m^3
- Food and industrial waste: 120–170 m^3
- High-energy feeds (e.g., oils, grains): 500+ m^3

Each cubic metre of biogas can generate approximately 1.9 kW of electricity and 2.2 kW of heat. For installations under 5 MW, electricity is typically sold under the Smart Export Guarantee (SEG) at around 5.5p/kWh, though on-site use can offset electricity costs of 15–17p/kWh.

Wind

Smaller wind turbines tend to have a higher cost per kilowatt than larger ones due to several factors: lower production volumes increase unit costs, fixed costs make up a larger share of total project expenses, and smaller systems often operate at lower capacity. Additionally, they may not qualify for the same subsidies or incentives available to large-scale projects. According to the *ABC Handbook*, a single turbine is unlikely to fully offset a farm's electricity use, though it may cover around one-third of domestic consumption.

Key considerations for small-scale wind installations include:

- Wind resource at hub height, ideally measured over several months for accuracy.
- Site exposure, which can boost energy capture but may raise construction costs.
- Minimum wind speed of 5 m/s is required, with higher and steadier winds significantly improving output.
- Grid connection costs, which are less economical for lower-output systems.
- Planning permission, which can be challenging, especially in designated landscapes.

Hydro

Small streams and brooks can be harnessed to generate electricity through micro-hydro systems, including both new installations and refurbished watermills. These systems are particularly valuable in remote areas where grid access is limited. Micro-hydro setups producing under 100 kW can be ideal for off-grid buildings located near reliable watercourses.

Key considerations include:

- Water flow and head height: Energy output depends on flow rate and elevation drop. Medium-head systems (10–50 m) are common, while "run-of-river" schemes typically have higher energy costs.
- Environmental flow: A portion of the natural water flow must be preserved to maintain ecological balance.
- Electrical connection: A nearby connection point is essential for energy use or export.
- Planning and engineering: Robust civil works are required to withstand flooding and meet environmental regulations.

Solar

Solar energy can be harnessed either to heat water using thermal systems or to generate electricity via photovoltaic (PV) panels. Both systems are most effective when installed on south-facing surfaces. Thermal systems typically use evacuated tubes or flat plate collectors mounted on roofs to preheat water, which is then brought to usable temperatures by a conventional or immersion heater. PV panels can also be effective on east- or west-facing roofs, especially where electricity demand peaks in the morning or evening. While panels still function on cloudy days, output is highest in sunny, unshaded locations.

Key considerations:

- Roof-mounted systems require a minimum pitch of 10° and structural strength to support panels weighing 10–15 kg/m^2.
- Ground-mounted systems on flat fields are fixed at a 35° angle facing south, allowing for tighter spacing.
- Grid connection is necessary for exporting electricity; up to 50 kW can typically be handled by a three-phase supply.

- Costs have decreased due to technological advances and economies of scale, with minimal ongoing maintenance—mainly inverter replacements and occasional cleaning.
- Lifespan: Panels can last up to 45 years, with typical warranties of 25 years for panels and 5 years for inverters (which often need replacing every 10–15 years).
- Productivity varies by location, reaching up to 800 kWh/m² annually in the Scottish Highlands.

Further guidance

- Scottish Government's Community and Renewable Energy Scheme: We are Local Energy Scotland · Local Energy Scotland. Part of CARES, the Community Energy Generation Growth Fund supports the development of renewable energy generation projects by community and rural organisations: Community Energy Generation Growth Fund · Local Energy Scotland

Planning Permission and Building Requirements

While some structures can be erected on agricultural or crofting land without planning permission (under Class 18 of Schedule 1 to the General Permitted Development Order (GPDO)[25], it is likely that erection of structures for commercial horticultural production will require planning permission, given size, permanence of purpose of the building, and it is advised to seek guidance from your local planning authority.

Planning permission may also be required for modification of an existing permanent building, or the change of use from a structure or land use. Documents typically required for an application will include:

- Planning application form (via ePlanning Scotland)
- Location plan and site plan
- Design and access statement (for larger or sensitive developments)
- Supporting statement (describing the business case or use)
- Environmental assessments (where required—see below)
- Drainage and surface water management plans

[25] Scottish Government. (2024). *Circular 2/2024: Non-domestic permitted development rights*. Retrieved June 16, 2025, from https://www.gov.scot/publications/circular-2-2024-non-domestic-permitted-development-rights/.

- Noise, odour, or traffic impact assessments (as applicable)
- Ecological or biodiversity surveys (e.g. protected species)
- Contamination survey (if on previously developed land)

Screening, Environmental Impact Assessment, SEPA licencing and environmental consents

Some developments must undergo EIA or at least a screening opinion from the planning authority. You must request an EIA screening from the local planning authority, who will decide if a full EIA is needed.

Table 18: *type of developments requiring permissions.*

Type of development	Permissions required
Enhanced growing systems	CAR licence, EIA screening
Renewable energy	EIA screening, flood risk assessment, grid connection discussions with DNO[26]
AD plant	EIA screening, CAR licence, waste management licence, possibly PPC permit
Aquaculture	EIA screening, CAR licence
On-site water abstraction or discharge	CAR licence

Any development on sensitive sites such as Natura sites, SSSIs, peatlands, etc. may also require EIA screening. Consultation with NatureScot may also be required regarding biodiversity and protected species.

Forestry consent would be required if woodlands is being cleared, and access agreements considered if public access is affected.

Developments on crofting land

Legal definitions of crofting may restrict use of crofting land for the development of commercial CEA activities.

According to the Crofting (Scotland) Act 1993 (Section 3), "*'Crofting purposes' means cultivation, including the use of land for horticulture, or the keeping or breeding of livestock (including poultry) or bees, or the growing of trees, and includes the use of land for any ancillary or incidental purpose connected with the croft or the crofter's residence on the croft*."

[26] DNO = Distribution Network Operator (e.g. SSE, SPEN)

Activities such as grazing animals, growing trees and horticultural crops, use of polycrubs and small polytunnels, and beekeeping are considered core crofting activities. Agricultural buildings often fall within permitted development on crofting land, within thresholds for use – consult your planning authority for more detail.

While processing of croft products for local food and small-scale renewable energy generation for croft use may qualify as ancillary activities, development of commercial, industrial or retail operation would not qualify as crofting or ancillary activities. Legally, if activities can be justified as providing benefit to the croft or crofting community, there may be scope for 'consent for purposeful use' (e.g. farm shop, workshop etc.), but this would require approval from the Crofting Commission. Otherwise, such development would require decrofting of the land involved, i.e. a permanent removal of that land for crofting use, again applied via the Crofting Commission.

Tenant crofters would also require landlord consent for any development. Crofting tenure imposes strict land-use rules:

- You must **apply to the Crofting Commission** to change the land use from agricultural to another (e.g., CEA using hydroponics or aquaponics).
- There is a **statutory duty to cultivate**, so "non-agricultural" structures (like sealed vertical farming units) may be challenged unless justified as cultivation.
- Some CEA may count as diversification under crofting law, but it requires **regulatory approval**.
- Sub-letting or assigning croft land for commercial CEA operations may require both landlord and Crofting Commission approval.

WORKFORCE & SKILLS

Controlled Environment Agriculture businesses in the Highlands and Islands face a complex labour landscape shaped by demographic, economic, and seasonal factors. While CEA systems typically require fewer employees than conventional horticulture, 59% of global CEA businesses employ fewer than nine people[27], they still depend on access to skilled and flexible labour, particularly for tasks such as environmental monitoring, system maintenance, and crop handling.

[27] Agritecture & WayBeyond. (2021). 2021 Global CEA Census Report.

A study by European Centre for Development of Vocational Training found that nearly 40% of agricultural businesses struggle to find people with expertise in precision agriculture & controlled-environment technology[28]. Alongside horticultural skills, which are already a minority within agriculture, CEA business may require skills in:

- Use of environmental control and monitoring technologies (often digital skills)
- Maintenance of growing and energy systems
- Business and operations management
- Marketing and sales management of produce within multiple sales channels

Availability of labour and skills, whether regular labour as part of core business operations, or occasional labour through contracting (e.g. energy system maintenance) must be considered when evaluating business options.

Where these skills are not readily available within the locality, the business may need to think about routes for training and skills development, such as vocational courses. Suggestions for horticulture-specific training is provided in the further information box below.

Box 3. Skills needed in different CEA growing systems.

Enhanced protected growing	Indoor/container/vertical growing
Use of more typical horticultural skills and knowledge Potentially higher staff requirement, due to more manual operations, e.g. plant maintenance, harvesting, processing & packaging Extended seasons of production, but still likely seasonal demand, coinciding with peak seasons in other industries e.g. hospitality	Greater training and skills required in use of technology, and phytosanitary measures Potential for lower staff requirement, partly due to size of production, partly due to greater automation potential Consistent production through year meaning consistent labour demands

National Insurance and Employment Costs

[28] Market Data Forecast. (2025, April). *Europe Indoor Farming Market Size, Share & Growth Forecast (2025–2033)*. Retrieved June 16, 2025, from https://www.marketdataforecast.com/market-reports/europe-indoor-farming-market.

As of April 2025, the UK government increased employer National Insurance contributions from 13.8% to 15% and lowered the earnings threshold to £5,000.[29] This change has raised employment costs for small businesses, including those in agriculture and horticulture. While the Employment Allowance was increased to £10,500 to offset this, the rise in NI contributions may still deter small CEA businesses from expanding their workforce, particularly in low-margin operations.

Various recent studies have shared experiences from rural businesses in retention of staff, particularly in minimum-wage work. A study for Scottish Government on the horticulture sector post-Brexit reported challenges in competing with sectors paying similar wages, but able to provide preferable working conditions, hours or remuneration (e.g. aquaculture, hospitality). A 2019 working paper estimated that labour costs now account for around 60% of input costs for horticultural businesses[30].

The Scottish Agricultural Wages Board produce annual guidance for workers and employers on pay and employment conditions. As of the 1st April 2025, the minimum hourly rate was £12.21 for all agricultural workers, in line with the National Living Wage, with entitlements to an uplift for employees with relevant qualifications.

Since Brexit, access to seasonal agricultural labour has become more challenging due to the end of EU free movement, creating labour shortages due to caps on the Seasonal Worker visa scheme and competition from employers within the EU. This has particularly been a challenge for soft fruit and open-field crop cultivation, which often require a high degree of manual harvesting.

Tourism Sector Labour Competition

Tourism is a major employer in the Highlands and Islands, accounting for approximately 245,000 jobs across Scotland in 2023—around 9.2% of total employment.[31] Much of this work is seasonal, peaking in the summer months. This

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[29] HM Revenue & Customs (2025) *Employer Bulletin: April 2025 Issue.*
[30] Cardiff University. (2019). *The state of horticulture in the UK* (Working Paper). Horticulture.org.uk. Retrieved June 16, 2025, from https://www.horticulture.org.uk/wp-content/uploads/2023/06/State-of-horticulture-in-the-Uk-Cardiff-uni-Working-Paper-2019.pdf.
[31] VisitScotland (2025) *Scottish Tourism Observatory.*

creates potential competition for labour with horticulture and CEA, especially when both sectors require manual labour during the same period.

For CEA systems, the relevance of seasonal workers depends on the degree of automation. Highly automated vertical farms, hydroponic systems, or climate-controlled greenhouses can reduce reliance on seasonal labour, instead requiring smaller, year-round workforces with more technical skills. However, CEA systems that include manual tasks like seeding, transplanting, pruning, or harvesting — especially for delicate crops like herbs or soft fruit — may still need seasonal or flexible labour during peak periods.

However, the relationship between tourism and CEA labour needs is not necessarily adversarial. Many rural residents engage in portfolio working—holding multiple part-time or seasonal jobs across sectors. CEA operations can complement this by offering flexible, off-season employment (e.g. propagation in spring, maintenance in autumn) or part-time roles that fit around tourism work. Additionally, the influx of visitors during the tourist season increases local demand for fresh produce, creating market opportunities for CEA businesses to supply restaurants, hotels, and food retailers. These strategies, as also discussed in the recent Regional Transformational Opportunities report commissioned by HIE highlights the importance of place-based, collaborative approaches to economic development, including strategies for population retention, skills development, and housing provision.[32]

Rural Proofing and Community Impact

CEA can also contribute to rural development goals through alignment with rural proofing principles. As highlighted by the Rural Exchange blog on rural health and poverty,[33] rural proofing is not only about avoiding harm to rural communities but about actively identifying opportunities to improve wellbeing, reduce poverty, and support inclusive growth.
CEA businesses can support these aims by:

- Creating year-round employment in areas with limited job opportunities
- Supporting flexible, portfolio livelihoods common in rural economies
- Enhancing local food security and reducing reliance on imports
- Embedding operations within community development trusts or social enterprises

[32] Highlands and Islands Enterprise (2025) *Regional Transformational Opportunities Research.*
[33] Atterton, J. (2025). *Reflections on rural proofing, rural health and rural poverty.* Rural Exchange.

- Contributing to circular economy initiatives through local sourcing and waste reuse

These contributions position CEA as a valuable tool for rural resilience and regeneration, particularly when designed in collaboration with local communities and aligned with broader economic development strategies.

Further guidance

- The Scotland Growers Training Network
- Farm Advisory Service – specialist advice on agricultural diversificaiton
- Skills Development Scotland - https://www.skillsdevelopmentscotland.co.uk/
- LANTRA – horticulture, aquaculture and more
- BASIS – IPM, FACTs, Agronomy
- Horticulture courses – offered by SRUC, UHI, Royal Botanic Gardens