Hort Innovation

## Final Report

# Feasibility study into opportunities for high-technology horticulture production in urban environments

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**Project code:**

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### Project:

Feasibility study into opportunities for high-technology horticulture production in urban environments (HA19005)

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# Content

# Executive Summary

## Background

High-technology horticulture is being implemented in urban areas internationally to serve a variety of purposes including economic development, community engagement and environmental benefits. Systems include vertical farm systems, container farms, glasshouses, and nearly fully automated production. Amongst the global landscape, Australia has been slow to take up high-technology urban horticulture due to several barriers including high initial capital investment, zoning limitations, lower population densities and lack of experience in the industry. However, there is growing interest in Australia as to how high technology horticulture in an urban environment could complement existing production systems.

This project has assessed new and emerging technology and its application in the Australian urban landscape to:

- Assess the feasibility of high technology horticulture in urban Australian considering technology opportunities, regulatory and planning factors, farm input and waste management and the supply chain
- Identify key opportunities and challenges relating to environmental and social benefits
- Recommend how the Australian horticulture industry can realise opportunities and build the capacity of this sector.

## Approach

Assessing the feasibility of High Technology Urban Horticulture (HTUH) in Australia has included:

- Review of current literature on HTUH in Australia and internationally
- Modelling of potential systems and their applicability in Australia
- Economic analysis of systems and assessment of how changes to cost and revenue impact on the profitability of these systems
- Consultation with industry stakeholders to inform the modelling and economic analysis.

The information derived from these activities has been analysed and discussed within this report to develop recommendations on action required to drive HTUH activity in Australia.

## Operating Context

### Planning

Urban planning and regulations often overlook urban agriculture. With food production pushed to the periphery of cities and rural areas, urban development and planning often do not consider the potential of urban food production, despite calls to reintegrate farming into urban planning. This is particularly evident in Australia, where residential development in peri-urban areas has resulted in market gardens transitioning to more regional areas.

Within Australia HTUH is not integrated into development projects or integrated into planning provisions (notably standard Local Environmental Plans). This has also been noted in other countries where regulatory barriers to urban agriculture have included:

- Zoning ordinances that exclude urban agriculture or are unclear about agricultural uses
- Lack of access to land and secure tenure (urban agriculture is often perceived as a transient use for vacant lots that will be redeveloped)
- Regulations on built structures (maximum allowable building heights, floor-to-area ratios and structure setbacks, fire and energy codes).

### Institutional support

Currently there is minimal institutional support for HTUH in Australia. International examples from Paris, Shanghai, Singapore, and Amsterdam demonstrate how a HTUH industry can be supported and guided. Lessons learnt from these examples include the importance of:

- Establishing policy objectives related to HTUH
- Collaboration between universities, government agencies and private businesses through public-private partnership, to foster the development of a HTUH 'ecosystem' made up of start-ups and businesses able to develop new technologies and services
- Providing grants and financial support to start-ups and existing businesses, which can help overcome the barriers of initial capital investment and enable the upgrade of equipment and systems
- Facilitating access to physical space to farm through competitive calls for proposals.

While Australia does not have the level of institutional support for HTUH that other international cities do, there has been progress made in the integration of green spaces into urban policies and planning. The design framework for New South Wales focuses on green spaces but does provide a pathway and potential strategies that could be applied for integrating HTUH into urban planning.

### Business models

To cover the high establishment and operating costs of HTUH business models need to focus on attracting a premium price for product. Operators in Australia and elsewhere have focused on:

- Developing relationship based markets where supply is direct to customers, food service sector and independent grocers in their immediate area
- Marketing which promotes the positive characteristics of HTUH produce including high quality, nutritious, clean and safe
- Supply chain integration to reduce post-harvest costs (establishment of HTUH within agri-food precincts such as the Aerotropolis proposed in Western Sydney will facilitate supply chain integration further)
- Development of pre-packaged 'convenience' food such as ready-made salads.

This generates sufficient revenue to cover the costs associated with this type of production.

## Feasibility assessment

### Modelling

Greenhouses used to dominate the 'indoor farming industry', however over the past fifteen years, adoption of new systems has increased, to include:

- Vertical farming which can be defined as a 'fully enclosed and opaque room with a vertical hydroponic, aeroponic, and/or aquaponic system' (approximately 38% of CEA)
- Container farms, which are a 'standardized, self-contained growing unit that employs vertical farming systems and artificial lighting' (approximately 6% of CEA).

Greenhouses still constitute approximately 40% of CEA worldwide[1].

The six systems or types modelled under Australian conditions as part of this study are outlined in Table ES-1. These include vertical farms (also known as a Plant Factory with Artificial Lighting or PFAL), container farms and glasshouses on rooftops and floating platforms.

*Table ES-1: HTUH systems modelled under Australian conditions*

| | Location | Building integration and synergies | Space utilisation | Name |
|---|---|---|---|---|
| 1 | Rooftop | Integrated with building (synergies) | Vertical | Rooftop Glasshouse (Vertical) |
| 2 | Rooftop | Integrated with building (no synergies) | Horizontal | Rooftop Glasshouse (Horizontal) |
| 3 | Container | Not integrated with building | Vertical | Container Farm |

[1] Autogrow & Agritecture Consulting 2019, Agrilyst (2016)

| | Location | Building integration and synergies | Space utilisation | Name |
|---|---|---|---|---|
| 4 | Inside building | Integrated with building (no synergies) | Vertical | Plant Factory with Artificial Lighting (PFAL) |
| 5 | Floating | Not integrated with building | Horizontal | Floating Glasshouse |
| 6 | Building facade | Integrated with building (no synergies) | Vertical | Building Facade |

Agritecture performed a resource analysis to determine the input use of the six systems described above. The context for the modelling, based on discussion with the project team, was that the modelling would be:

- Based in urban locations in Sydney
- Focused on commercial production (where community benefit is not the primary purpose)
- Based on year-round production and use butter lettuce as the comparative product line.

Pairwise comparison of the data generated by the modelling was conducted to identify the most suitable HTUH system according to environmental, social and economic performance. The analysis was conducted several times to assess how changing the priority (weight) of social, economic and environmental factors changed the 'performance' and hence ranking of the systems. Under each of the scenarios run (where the priorities were altered), the Building Façade was scored and ranked as the best HTUH system for Australia followed by the Rooftop Glasshouse (modelled as a PFAL system).

### Economic analysis

Analysis of the modelled data using a Discounted Cash Flow (DCF) and Net Present Value (NPV) evaluation returned mixed results, with the Container Farm (CF) and Glasshouse (GH) returning a negative NPV, while the Building Façade (BF) and PFAL (PFAL) systems were both positive. The negative results for the CF and GH systems were largely driven by a relatively high operational and capex cost to output/income ratio, with labour and site purchase being the large contributors. After consultation with stakeholders, it was agreed that these systems would be more profitable if a higher value crop was used, and systems refined to drive further productivity.

The BF and PFAL systems returned a positive NPV and Modified Internal Rate of Return (MIRR). Our model shows these systems are worth further consideration and are likely to perform well in the Australian economic context. There are, however, likely 'normal' market fluctuations that will impact productivity and profitably that have not been accounted for in our research. Further, a MIRR below 10% invites substantial downside risk and as these systems are relatively untested within the Australian context these results should be treated with caution.

Internationally there is limited evidence as to the profitability of HTUH and the ability of these systems to generate revenue are dependent on management and markets. In 2017, 51% of controlled environment farms in the United States were not financially profitable. This is partially attributable to the fact that urban farms are capital intensive, and most of them are likely still paying back their initial investment.

HTUH has some advantages over field-based production in that climate can be controlled and production is not constrained to certain seasons. There is also the potential to produce higher yields per unit of area. However, factors that increase the cost (and hence reduce the profitability of HTUH) include high land prices (due to production in city centres where land is expensive) and high establishment costs particularly for glasshouses built inside or on top of buildings.

The success of individual enterprises will also depend heavily on the product line chosen, the business model used and the skill and aptitude of the farm manager. HTUH, like any other agricultural enterprise, is a business that requires careful planning and good management.

### Social considerations

The social acceptability of commercially focused HTUH can be negatively impacted by perceptions that:

- It is not 'real agriculture' due to its localisation in urban settings and the nature of the farming operations
- Its produce is unnatural and unhealthy
- It is highly resource intensive and unsustainable

- There may be health risks due to air pollution and water contamination
- Only wealthier members of society will be able to buy HTUA produce, and it will contribute to the gentrification of the neighbourhood in which it is implemented reducing the equity of HTUH produce.

Support for HTUH needs to come from urban communities who have a desire for 'locally grown food' and seek to engage in food growing projects and spaces. The path forward for this in Australia has been demonstrated by the increasing integration of green spaces into urban policies and planning in NSW however, increased government support is required to drive this for food, and developers incentivised to include this in new urban developments.

#### Environment

The environmental benefits of HTUH over field-based production are still being researched. In general, HTUH is perceived as being more water efficient than field-based production however the energy requirements are often much higher than field-based production. It is also dangerous to compare HTUH with field-based production as the management practices associated with field-based production can be highly variable and the environmental impact varies accordingly. Australia is a climatically vulnerable and water scarce country, HTUH offers benefits as it is water efficient and resilient to extreme weather events. Therefore, rather than viewing HTUH as a competitor to field based production, it may be more relevant to assess how it can complement land-based agriculture, which will be increasingly affected by extreme weather events and water scarcity.

HTUH also represents an opportunity for the development of circularity around heat/air, wastewater (water and mineral fertilisers) and organic waste in cities. Several barriers currently exist to the use of those techniques however, which means that they have not been widely adopted.

### Opportunities

Although there are challenges that limit the expansion of HUTH in Australia currently, emerging trends which provide opportunities for HTUH to address include:

- A changing natural resource context where the frequency and intensity of extreme weather events, such as droughts, bushfires and floods will increasingly threaten food production. HTUH is well placed to continue secure and sustainable food production due to its ability to control the production environment.
- Increasing consumer concern for the provenance of produce, their health and environmental performance, as well as their social and ethical dimensions. HTUH offers a system of production with low food miles, efficient resource use, traceability, and quality control of food.
- An aging agricultural workforce which is struggling to attract new people into the industry. HTUH may attract a younger, more technology-oriented generation towards farming and offer opportunities for technology-based graduates to join the industry.
- An increased focus on the use of technology to enable agriculture. HTUH industries can leverage this interest in technology to reduce operating costs within production systems.

### Recommendations

Despite the opportunities that HTUH may provide Australia, uncertainties remain regarding its economic viability, and the ability of businesses to scale up and make a significant contribution to food production. It is also unclear as to how environmentally sustainable it is. While reduced water and land use are a positive feature, most systems also use more energy. Challenges limiting the expansion of HUTH in Australia include:

- Low profitability due to high capital and operational costs
- Urban planning not accounting for food production in cities and a lack of incentives to incorporate HTUH into new developments
- Minimal institutional support for the development of HTUH by entrepreneurs
- Uncertainty by communities as to the acceptability and equity of HTUH.

Recommendations for addressing these challenges are focused on the social, economic, and environmental considerations of HTUH are outlined in Table ES-2 over the page.

*Table ES-2: Recommendations to improve the feasibility of HTUH in Australia*

| Consideration | Recommendation |
|---|---|
| Economic | The financial viability of HTUH could be improved by:<br>• Reducing capital costs to establish HTUH by developing and locating 'precincts' in peri-urban areas where land prices are lower (such as the proposed Aerotropolis in Western Sydney)<br>• Utilising any current or future unused space in urban environments such as car parks as we transition to a low carbon economy<br>• Utilising business models that focus on selling produce at a premium based on their local provenance, environmental credentials and nutritional value to direct consumers, the food service sector and green grocers<br>• Incorporating value-adding activities such as educational tours of the farm, workshops and community events on the farm.<br>Investing in innovation that reduces the costs associated with HTUH such as:<br>• Automation, and use of data analytics and sensor networks, to reduce labour costs and facilitate greater economies of scale by enabling farmers to manage several farms at a distance<br>• Genetic improvement to develop plant varieties that are better suited to HTUH production systems with reduced height, shorter development cycles and rapid fruit development<br>• Advancing LED lighting systems that have lower energy consumption, low waste heat generation as well as optimised spectra of plant growth.<br>Building the capacity of HTUH entrepreneurs by increasing their understanding of:<br>• The crops that will perform best in HTUH environments<br>• Refining the production system through manipulation of temperature, lighting periods, and CO2 levels to achieve the highest number of plant cycles<br>• Marketing, supply chain and business management. |
| Planning and government support | Fostering a more supportive regulatory and institutional environment for HTUH by drawing on the experience of cities internationally, that have successfully developed HTUH, as well as on the Australian experience of integrating green infrastructure into the urban fabric.<br>Integrating food production, and in particular HTUH, into urban policy and planning and providing incentives for developers to integrate HTUH into new development projects. |
| Environment | Assessing how HTUH can complement land-based agriculture, which will be increasingly affected by extreme weather events and water scarcity, to develop a more sustainable food production system for Australia. This includes investigating how alternative sources of energy such as geothermal or urban waste heat for heating, and renewable energies, such as solar photovoltaics, for energy can be more easily applied to HTUH systems. |
| Social | Promoting community engagement in the design and planning of HTUH projects to improve social acceptance and awareness.<br>Investigating opportunities to improve the food security of remote communities through the development and application of high technology systems such as container farms in regional areas. |

# Keywords

High technology urban horticulture, urban agriculture, urban farming, Controlled Environment Agriculture, CEA, economic analysis, modelling, lettuce.

# 1 Introduction

## 1.1 Overview

A recent increase in demand for locally grown produce has generated an interest in the application of emerging technologies for controlled environment horticulture in urban areas. New technology in controlled environment production systems has the potential to modify the local food supply chain through unique and novel opportunities such as flat supply curves (year-round supply), improved water and chemical use efficiency and reduced supply chain costs. Specific to Australia, it also provides the opportunity to optimise labour requirements through the use of technology. Urbanised horticulture may bring value to local communities by providing opportunities for strengthening social bonds, expressing and maintaining cultural heritage, and engaging in activities promoting social well-being[2]. In addition, recent supply chain disruptions due to COVID-19 may prompt a rethinking of localised production systems and food security at a local level.

However, urban horticulture is also very capital and energy intensive. To date, most of the world's high technology urban farming is in densely populated countries. In Australia, it is uncertain whether the benefits justify the upfront capital investment as it does in these more densely populated countries.

High-technology horticulture is being implemented in urban areas internationally to serve a variety of purposes including economic development, community engagement and environmental benefits. Systems vary and include, but are not limited to, vertical farm systems, container farms, glasshouses, and nearly fully automated production. Amongst the global landscape, Australia has been slow to take up high-technology urban horticulture due to several barriers including:

- High initial capital investment required
- Zoning limitations
- An abundance of fertile land
- Lack of experience in the industry.

However, with high returns after establishment, high-technology horticulture in urban areas may have potential to play a significant role in increasing Australia's horticulture sector value. Therefore, it is worth investigating if, and what role, high-technology urban horticulture may play in the future of Australian horticulture.

This project has assessed new and emerging technology and its application in the Australian urban landscape to:

- Assess the feasibility of high technology horticulture in urban Australian considering technology opportunities, regulatory and planning factors, farm input and waste management and the supply chain
- Identify key opportunities and challenges relating to environmental and social benefits
- Recommend how the Australian horticulture industry can realise opportunities and build the capacity of this sector.

## 1.2 Glossary

- HTUH – High Technology Urban Horticulture
- HTUA – High Technology Urban Agriculture
- CEA – Controlled Environment Atmosphere
- HVAC – Heating, Ventilating and Cooling
- PFAL – Plant Factory with Artificial Lighting
- PRG – Project Reference Group

The systems discussed in this study are interchangeably referred to as Controlled Environment Atmosphere (CEA), High Technology Urban Agriculture (HTUA) and High Technology Urban Horticulture (HTUH). For the purposes of this study, we have chosen to use High Technology Urban Horticulture or HTUH for short.

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[2] Controlled Environment Food Production for Urban Agriculture; Gomez (2019).

## 1.3 Disclaimer

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# 2 Approach

Assessing the feasibility of High Technology Urban Horticulture (HTUH) in Australia has included:

- Review of current literature on HTUH in Australia and internationally
- Modelling of potential HTUH systems and their applicability in Australia
- Economic analysis of HTUH systems and assessment of how changes to cost and revenue impact on the profitability of these systems.

The information derived from these activities is reported and analysed within this report to develop recommendations on action required to drive HTUH activity in Australia.

## 2.1 Literature Review

A review of the scientific literature on HTUH published between 2015 and 2020 was conducted, using Scopus and Google Scholar, as well as a snowballing process (identification of new references via references identified in Scopus and Google Scholar). This component was led by UTS. The search was expanded to include agriculture (as a search term) as well as horticulture after consulting with stakeholders as it was viewed that using horticulture only would exclude literature relating to agriculture. The review of scientific literature was complemented with selected review of grey literature and reports, as well as relevant press articles. Findings from the literature reviewed was presented to stakeholders and feedback sought for further refinement and input, including relevance to the Australian operating environment. The outcomes of the literature review have been included throughout this report.

## 2.2 Development of systems

### Development Of Urban Agricultural Systems Typology

As part of the literature review UTS developed a typology of urban agricultural systems informed by existing typologies. Seven sub-categories were identified and organised in three overarching categories to identify the diversity of both low-tech and high- tech urban agricultural systems. These included the:

- **'where'** of urban farming:
  - Urban/peri-urban
  - On-ground farming/zero-acreage farming (such as rooftop containers, unused and used buildings)
- **'how'** of urban farming (the techniques and systems used to produce food):
  - Soil-based/soilless techniques
  - Unconditioned/conditioned/controlled environment
  - Building- integrated/non-building integrated
  - Horizontal/vertical
- **'why'** of urban farming (purpose of the operation):
  - Commercial/community.

Based on this typology nine types of (low-tech or high-tech) urban agricultural systems were identified and are presented in detail in Appendix 1 and Figure 0-1. High-tech agricultural systems were defined as systems that have at least one of these characteristics:

- Soilless techniques
- Controlled environment
- Building integration and/or vertical farming.

These systems are interchangeably referred to as Controlled Environment Atmosphere (CEA), High Technology Urban Agriculture (HTUA) and High Technology Urban Horticulture (HTUH). For the purposes of this study, we have chosen to use High Technology Urban Horticulture or HTUH for short.

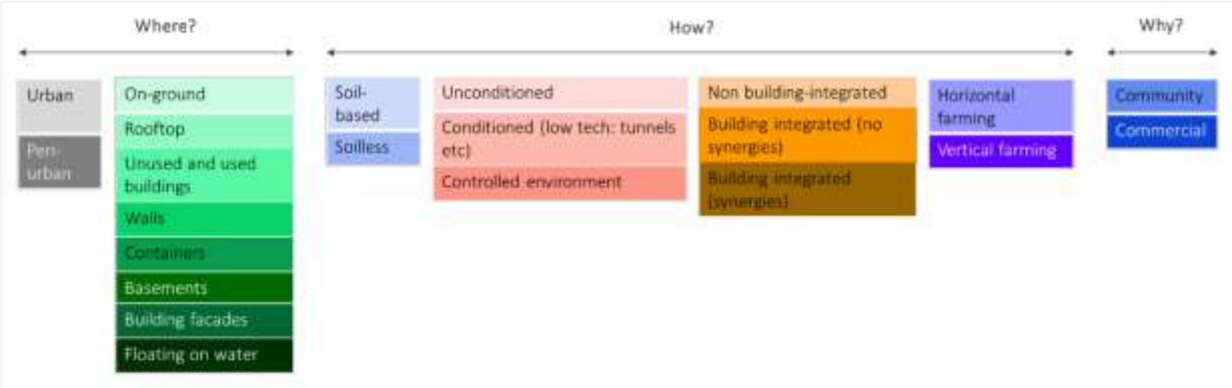


*Figure 0-1: A typology of urban agriculture systems*

### Development of systems to be modelled

Based on the typologies identified by the project team with input from the stakeholders, six HTUH 'systems' were developed for analysis as shown in Table 0-1. These systems were chosen to reflect a range of current operations within Australia and internationally (such as a rooftop, containers, and inside buildings). Two non-commercial (as of yet) systems were also chosen (floating and building facade) to explore future opportunities.

All systems analysed are soilless (don't use soil as a growing medium) and use automated technology to control the production environment. To maximize space most of the systems use vertically stacked production except for the second rooftop system and the floating system. The systems are either:

- A stand-alone unit (no integration with any other structure)
- Integrated with an existing building but there are no synergies (with use of wastewater or heat)
- Integrated with a building where synergies have been achieved using exchanged waste heat and water.

These systems have been chosen as they are most reflective of the 'high technology urban horticulture' definition used in this study.

*Table 0-1: Systems modeled*

| | Location | Building integration and synergies | Space utilisation | Name |
|---|---|---|---|---|
| 1 | Rooftop | Integrated with building (synergies) | Vertical | Rooftop Glasshouse (Vertical) |
| 2 | Rooftop | Integrated with building (no synergies) | Horizontal | Rooftop Glasshouse (Horizontal) |
| 3 | Container | Not integrated with building | Vertical | Container Farm |
| 4 | Inside building | Integrated with building (no synergies) | Vertical | PFAL |
| 5 | Floating | Not integrated with building | Horizontal | Floating Glasshouse |
| 6 | Building facade | Integrated with building (no synergies) | Vertical | Building Facade |

### System definition

Concepts 2 and 5 were modelled by Agritecture as a conventional greenhouse and concepts 1, 3, 4 and 6 as plant factories. The main differences in the energy balance of each approach are shown in Figure 0-2. The conventional greenhouse has been modelled using mechanical ventilation to exchange energy between the inside and outside environment.

The main heat fluxes involved in the open system simulation are the heat of radiation, conduction through the glazing, ventilation, transmission of heat through the floor, heat produced by the interior equipment and latent heat coming from the plants and evaporative cooling system. The system glazing is simulated as transparent (greenhouse cover) with a constant transmissivity. The temperature of the growing media is assumed equal to the outside air temperature. The ventilation rate of the extraction fans is assumed constant and activated based on a static setpoint. A lower ventilation rate (25% of ventilation rate) is assumed when the evaporative cooling solution is activated.

Heating and mechanical cooling is simulated with no external ventilation (closed greenhouse) and activated based on a static setpoint. In these conditions, the result of the energy balance is the total energy that the system must add or remove based on the temperature setpoints.

The main heat fluxes considered in the plant factory are the heat coming from the lights and the latent heat flux from the plant to the air. The grow room is assumed to be highly insulated and without windows (except for type 6, where the surface on top of the plants is simulated as highly insulated glass with a constant transmissivity); the conduction through the envelope of the building is neglected. The humidity reclaimed by the cooling system is assumed to be disinfected and recirculated in the system. The heat produced by the lights is assumed equal to the energy consumed by them.

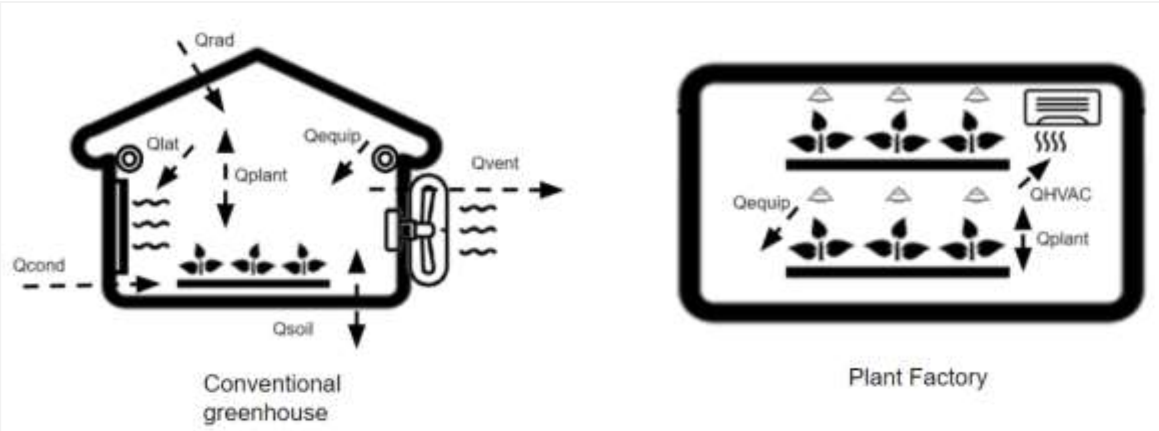


*Figure 0-2: Energy flows considered in the energy balance for open and closed systems*

## 2.3 Modelling

### 2.3.1 Approach

Agritecture performed a resource analysis to determine the input use of the six systems described above. A steady-state energy and mass balance hourly calculations based on the Typical Meteorological Year (TMY) of the region was used to simulate the resource requirements of the six systems and estimate the potential impact on the crop's yield. The HVAC loads, water, $CO_2$ consumables, and labour requirements for the concepts were determined by the size, location, design elements, physical attributes of the production space, and crop type.

Based on discussion with the project team it was decided to:

- Base the model on the climatic conditions of Sydney
- Focus on urban locations
- Focus on commercial production (community benefit is not the primary purpose)
- Consider year-round production
- Use butter lettuce as the product.

A summary of the most relevant climatic variables was used to identify the extreme weather periods in the studied location. The climate analysis is performed using a Typical Meteorological Year (TMY)3 of a 10-year time series. The variables used to select the typical month are global horizontal irradiance, air temperature, and relative humidity.

The simulation is limited to the growing area of the facility and includes one year of production. In the case of a

[3] Typical meteorological year (TMY): TMY data sets consist of one year of climatic data selected from a long time series of data spanning many years (normally 10 or more). The TMY is constructed by choosing data for each month from different years so that the data for a given month is the most "typical" among the years present in the long-term data set. (Huid et al 2018) It is commonly used to calculate the heating or cooling requirements of new or refurbished buildings.

greenhouse, only one control strategy was assessed based on standard control methods suitable for the region studied. The climate control requirements of adjacent rooms were not included.

### 2.3.2 Inputs

The inputs for the systems were defined as follows:

- Power – the power demand of the systems is expressed in kWh/year and includes the electricity used for:
  - Climate control
  - Supplemental lighting
  - Pumps and
  - Processing
- Water – the water requirements of the systems only include the cooling requirements (in the case where evaporative cooling is included) and the irrigation of the crops and is expressed in Litres per year (L/year)
- $CO_2$ – the $CO_2$ requirements is expressed in kg/year and includes the amount necessary to achieve the required concentration in the growing area. This will depend on the crop needs and ventilation rate and strategy.
- Labour – the labour requirements are based on the minimum necessities for production operations such as seeding, transplant, harvest, packaging and maintenance; these are expressed in hours per kg produced yearly (hr/kg)
- Consumables – the consumables are defined as the physical inputs required for production and include: seeds, substrate (or slab), plugs, fertilizer and packaging. These are expressed in the amount per number of plants produced yearly and depend on the crop cycle and growing system. The simulation is limited to one irrigation and nutrition strategy.

### 2.3.3 Yield

The yield obtained from each scenario is expressed in kg/year. The average yield is initially assumed under optimal conditions and is influenced by the climate conditions in the growing area and an assumed wastage rate.

### 2.3.4 Output Data

The data developed during the resource analysis and information provided in the financial tables were used to inform the detailed economic analysis.

## 2.4 Economic Analysis

A Discounted Cash Flow (DCF) and Net Present Value (NPV) evaluation was undertaken to assess the economic performance of the six systems. A Modified Internal Rate of Return was also used to value each investment relative to other uses of money within the economy4. Several key elements were incorporated into the model including:

- Case study information
- Advice and data from the key industry stakeholders, including the Project Reference Group
- Spreadsheet modelling to analyse the biophysical and economic performance of each growing system.

The assessment considered the operating profit (gross income minus variable costs and overhead costs, excluding interest and tax) as well as all growing infrastructure, and capital expenditure. The analysis was conducted in the steady state (i.e. once operation is fully implemented). The product chosen was butterhead lettuce and the price estimated at current local market value. This was cross-referenced with industry stakeholders. Once baseline estimates of profitability were calculated scenario analysis was performed on yield and price estimates as well as labour and capital costs, with the aim of determining potential ‘research gaps’ for the horticulture industry.

[4] As described by Makeham J, Malcolm L, 2005 – The farming game. (Cambridge University Press: Melbourne, Vic).

### 2.4.1 Assumptions

The main economic assumptions used in the DCF are described in Table 0-2. All farming systems were assumed to have no initial debt and input prices were based on feedback from the PRG. All financing and interest costs have been excluded from the model.

*Table 0-2: Economic assumptions*

| Assumption | Description | ASSUMPTION | Description |
|---|---|---|---|
| Discount rate | 7% | Depreciation | $14,194 |
| Time (years) | 10 | Salvage value | 50% |
| Finance rate | 3% | Months of operation (annual) | 12 |
| Reinvestment rate | 10% | Electricity (kWh) | $0.22 |
| Price ($/kg) | $10 | Water ($/litre) | 0.003 |
| Yield (kg/m2) | 80 | CO2 ($/kg) | $1.40 |

The benefits and costs of each option are expressed in two ways. First, the NPV calculation was used to quantify the discounted net benefits of each option over the 10–year period. The NPV was calculated by adding all the benefits and subtracting all costs for each year. The annual net benefits were discounted at the at a rate of 7 per cent (in-line with department of treasury and finance current guidelines) and summed over a 20–year period to yield the NPV for the respective option. The formula used for NPV is[5]:

$$\frac{R_t}{(1+i)^t}$$

The MIRR is the second way of expressing the benefits and costs of each management option. It is the ratio of discounted benefits over discounted costs and was computed (in 2009 dollar values) for the three options. T the formula used to compute the MIRR for each option is[6]:

$$\sqrt[n]{\frac{FV\ (cashflow, reinvestment\ rate)}{-PV(negative\ cash\ flows, finance\ rate)}} - 1$$

The NPV and MIRR were used as evaluation methods because they provide different information. The NPV is an estimate of the absolute magnitude of the present value of net benefits resulting from the use of resources. The MIRR is a relative measure of net benefits. It measures the relative difference between benefits and costs – the greater the MIRR, the greater is the net return per dollar of capital invested[7]. The NPV was used to rank projects, and the MIRR was used to comment on the efficiency of resource use under each management option.

### 2.4.2 Systems Analysed

The financial tables that were used to inform the economic analysis were based on the modelling conducted by Agritecture. Out of the six systems modelled, financial tables were developed for only four of the systems. Due to the similarity in the rooftop glasshouse and floating glasshouse these two systems were analysed as a glasshouse. The rooftop glasshouse integrated with the existing building and the PFAL were analysed as a PFAL.

[5] *t* is the time of the cashflow and i is the discount rate.
[6] Where *FV* is the future value of modelled cashflow, PV is the present value of modelled cashflow and n is time.
[7] Department of Primary Industries 2010.

*Table 0-3: Systems aanalysed*

| SYSTEMS USED FOR ECONOMIC ANALYSIS | SYSTEMS MODELLED |
|---|---|
| Container farm | Container farm |
| Glasshouse | Rooftop (no integration with existing building) and floating glasshouse |
| Vertical facade | Vertical facade |
| PFAL | Rooftop glasshouse integrated with existing building and indoor building PFAL |

### 2.5 Stakeholder Consultation

A Project Reference Group (PRG) comprising of growers, subject matter experts, research providers and Hort Innovation staff was established to provide advice to the project in relation to high-technology urban horticulture and areas relevant to the delivery of this feasibility study.

*Table 0-4: Project reference group*

| # | Name | Organisation | Position Title |
|---|---|---|---|
| 1 | Kristen Stirling | RMCG | Project Lead |
| 2 | Tristan Wardley | RMCG | Senior Consultant |
| 3 | Federico Davila | UTS | Research Principal |
| 4 | Laure-Elise Ruoso | UTS | Research Principal |
| 5 | Alberto Lopez | Agritecture | Systems Engineer |
| 6 | Henry Gordon Smith | Agritecture | CEO |
| 7 | Graeme Smith | Graeme Smith Consulting | Founder |
| 8 | Jess Miller | City of Sydney Council | Councillor |
| 9 | James Pateras | Modular Farms Australia | Director |
| 10 | Hugh McGilligan | Sprout Stack | CEO |
| 11 | Bianca Cairns | Hort Innovation | R&D Manager |
| 12 | Vino Rajandran | Hort Innovation | R&D Manager |

The PRG met three times during the project to discuss outcomes and provide relevant industry feedback and recommendations.

Other industry personnel consulted during the project include:

- Matthew Plunkett – Deputy Chair of Protected Cropping Australia
- Dr Elio Jovicich – Senior Horticulturist for the Queensland Government Department of Agriculture and Fisheries who is currently developing the Australian Protected Cropping RD&E Strategy
- Carl van Loon – CEO of Power Plants.

# 3 Operating Context

A critical success factor for the expansion of HTUH in Australia is the establishment of an operating environment which is conducive to its development. This includes:

- Regulation and planning which supports the inclusion of high technology horticulture in urban environments
- Support from the government (through tax incentives and planning)
- Use of business models which enable high technology systems to operate profitably in an urban context.

Examples of where this support has been provided internationally is discussed in Section 3.2 and the current operating environment for Australia discussed in Sections 3.1 and 3.2.1.

## 3.2 Planning

Urban planning and regulations often overlook urban agriculture[8]. With food production pushed to the periphery of cities and rural areas, urban development and planning often do not consider the potential of urban food production, despite calls to reintegrate farming into urban planning[9]. This is particularly evident in Australia, where residential development in peri-urban areas has resulted in market gardens transitioning to more regional areas. Analysis by UTS shows that in Sydney, under a business-as-usual scenario, total food production in the Sydney basin could drop by 60%[10] due to peri-urban pressures.

Within Australia HTUH is not integrated into development projects or integrated into planning provisions (notably standard Local Environmental Plans)[11]. This has also been noted in other countries where regulatory barriers to urban agriculture have included:

- Zoning ordinances that exclude urban agriculture or are unclear about agricultural uses
- Lack of access to land and secure tenure (urban agriculture is often perceived as a transient use for vacant lots that will be redeveloped)
- Regulations on built structures (maximum allowable building heights, floor-to-area ratios and structure setbacks, fire and energy codes.

In order to overcome regulatory barriers Blakthumb (2020), who studied the integration of controlled environment agriculture into urban spaces for the City of Sydney, provided a range of recommendations to better integrate HTUH in development projects and planning provisions, including:

- Determining a 'category' for HTUH (such as a type of infrastructure) to integrate it more easily into development projects
- Providing an incentive for the integration of HTUH in development projects. For example, it could count towards eligibility for a Floor to Space Ratio Bonus.
- Developing operational models that show developers how high-tech urban agricultural systems can be integrated into development projects (i.e. Blakthumb's 'Three Scenario Operating Model')
- Integrating HTUH into planning provisions, notably standard Local Environmental Plan, and considering it as an 'exempt of complying development' due to the low impact of the activity.

[8] Castillo et al. 2013; Meenar, Morales & Bonarek 2017; Sarker, Bornman & Marinova 2019.
[9] Pothukuchi & Kaufma 2000.
[10] Cordell, Jacobs & Wynne 2016.
[11] Blakthumb (2020).

## 3.2 Institutional support

Currently there is minimal institutional support for HTUH in Australia. International examples which demonstrate how this type of industry can be supported and guided are discussed below.

**AMSTERDAM**

In Amsterdam the demand for healthy and sustainable food and the increasing interest in circular economy have created a conducive environment for HTUH. The development of this type of farming has mostly been led by start-ups and incumbent businesses from Amsterdam. However, this 'bottom-up' development of HTUH has been made possible by the Dutch sectorial policy, which promotes the cooperation of government, universities, and private businesses in HTUH through public-private partnerships. The co-investment of government in projects minimises financial barriers for start-ups and enables the development of new products and services. In addition, financial support is also available in the form of subsidies and incentives, at the European, national, and local level. One company, Philips, played a central role in the development of HTUH by developing lighting technologies that became the standard in farms in Amsterdam. While this has contributed to the development of the sector, it has also prevented other start-ups or companies to play a role in those technologies.12

*Urban Farmer's glasshouse development (UF002 De Schilde) sits on top of an empty 1950s office block in The Hague with a fish farm operating on the floor below.*[13]

[12] Farhangi et al. 2020

[13] https://www.theguardian.com/cities/2016/apr/27/inside-europes-biggest-urban-farm

**SHANGHAI**

In Shanghai a top-down approach has been employed by government to promote HTUH. The Chinese Academy of Agriculture Science and state-owned companies played a crucial role in this transition by enabling, through subsidies, the development of large-scale vertical farms and plant factories in Shanghai. This approach enabled a transfer of technologies, as well as the development of large-scale experimental projects. As a limitation the approach prevented small private businesses from receiving support from the government and they often went bankrupt. More support for the private sector through public-private partnerships could have supported the development of start-ups[14].

*The Sunqiao Urban Agricultural District is set to introduce vertical farming to the country's biggest city, Shanghai. The district has been producing food with conventional methods since the 1990s but is now being expanded to integrate vertical farming systems, research and public outreach. Plans to expand the district to cover 100 hectares were announced in 2017 and construction is still ongoing. In addition to vegetable-growing vertical farms, the plan includes the development of algae farms, floating greenhouses, green walls and seed libraries[15].*

[14] Farhangi et al. 2019
[15] Sasaki (2021) https://www.sasaki.com/projects/sunqiao-urban-agricultural-district/

## SINGAPORE

In the land-constrained city-state of Singapore, food security is a priority for the government. 'Three National Food Baskets (objectives)' have been identified to ensure the food security of the city-state, one of which is to increase local food production[16]. One of the early initiatives that contributed to ramping up local food production was the 'Community in Bloom' program set up by the National Parks in 2005[17] which encouraged the development of low-tech community gardens around Singapore. More recently, the Agriculture Productivity Fund has provided support to the development and optimisation of high-tech urban farms by providing financial aid for the purchase of equipment and automated and integrated farming systems to help farmers increase their productivity, as well as cash advancements, which are meant to help farmers with cash flow. Additionally, Singapore also helped farmers to find space to farm by opening fixed-price tenders in 2017/18 which provided farmers with an opportunity to access land[11]. More recently, the government committed to locally produce 30% of the country's nutritional needs by 2030[18]. This led to the development of accelerators and incubators, the provision of grants for start-ups, as well as additional R&D funding.

*Temasek Holdings is partnering with Bayer AG in a new venture called Unfold which will focus on innovation in vegetable varieties with the goal of lifting the vertical farming space to the next level of quality, efficiency, and sustainability. As a company focused on the vertical farming industry, Unfold will combine leading seed genetics with agtech experts in order to advance productivity, flavour, and other consumer preferences[19].*

[16] Montesclaros, Liu & Teng 2018
[17] Wood, Wong & Paturi 2020
[18] MEWR 2020
[19] Bayer (2020) https://www.igrow.news/igrownews/temasek-bayer-form-joint-vertical-farming-venture-in-california

**PARIS**

Paris has had programs since the early 2000s to support urban agriculture. These programs focused on community agriculture rather than on high-tech commercial urban farms. This changed in 2016, when the 'Objectif 100 hectares' [100 hectares goal] charter was adopted. The objective of this charter, which was signed by the City of Paris and 74 public-private sector partners, was to support urban agriculture projects and contract lease agreements with green spaces to make them possible. To select projects, a competitive program called Les Parisculteurs was put in place. While Les Parisculteurs does not only focus on high-tech and commercial urban farms it can constitute a pathway towards the development of these types of operations in Paris[20].

*The 14,000 square-metre Nature Urbaine situated on top of the Parc des Expositions building, will eventually produce around 30 different species of plants, including tomatoes, strawberries, eggplants, basil, radishes, and chard served in a farm-to-table menu on site and distributed to businesses across the capital. The complex, which opened in July 2021 also has a bar and restaurant[21].*

Based on these international examples, several key factors that appear to be conducive to the development of high-tech urban farms include:

- The establishment of policy objectives related to HTUH. In the case of Singapore for example, policy objectives are set to enhance food security.
- The collaboration of universities, government agencies and private businesses through public-private partnership, to foster the development of a HTUH 'ecosystem' comprised of start-ups and businesses able to develop new technologies and services

[20] Reynolds & Darly 2018.

[21] Nature Urbaine https://www.timeout.com/news/the-worlds-largest-urban-farm-has-opened-on-a-rooftop-in-paris-080520

- The provision of grants and financial support to start-ups and existing businesses, which can help overcome the barriers of initial capital investment and enable the upgrade of equipment and systems
- Facilitating the access to physical space to farm through competitive calls for proposals.

### 3.2.1 Australia

While Australia does not have the level of institutional support described in the international examples above, 'tools' that could be used by government to support HTUH include:

- Financial (tax) incentives for investors
- Financial support for high-tech urban farms (such as employment schemes, funding and grant programs, incubators and accelerators)
- Integration into policies (such as integration into City Deals, major Precinct Planning, innovation policies, food security policies)
- Integration into planning provisions (such as State Environmental Planning Policies, Local Environmental Plans).

A pathway for implementing these types of reforms in Australia has been demonstrated by the increasing integration of green spaces into urban policies and planning. In 2020, the New South Wales government published Greener places: An urban green infrastructure design framework for New South Wales. This document stresses the need to integrate green infrastructure into the NSW strategic planning framework, and to consider them as an essential component of planning for strategic growth and infrastructure.

Funding the development of green infrastructure currently occurs through grant programs from Federal and State funds and developer contributions such as local or special infrastructure contributions or voluntary planning agreements.

- New ways to fund green infrastructures could occur by:
- Making green infrastructure an essential infrastructure in the NSW (the relevant state) Strategic Planning Framework
- Putting an economic value on green infrastructure
- Integrating green infrastructure into existing grey infrastructure funding.

While this design framework focuses on green spaces in NSW, and does not include HTUH, integrating high-tech urban farms as a form of green space, or applying some of the strategies developed for green spaces to high-tech urban farms may be a useful strategy in Australia.

## 3.3 Business Models

Business models play an important role in the profitability of HTUH as operating costs of high-tech urban farms are high. To compensate, the price received for HTUH produce needs to be higher than that of field grown produce.

The PRG stated that agricultural produce developed in high-tech urban farms in Australia is usually 15 to 20% more expensive than produce coming from rural farms. Different business models can generate the revenue required to support HTUH.

Potential business models include:

- **Attracting a premium for HTUH produce** by identifying characteristics for which consumers will pay higher prices. This could include a preference for 'clean and safe' produce which has been cultivated in conditions which avoids soil contamination and the accumulation of metals in food or the use of pesticides and fertiliser. In countries where field production uses best practice and are considered relatively 'safe' such as Australia and the Netherlands this type of marketing is unlikely to attract a large premium.
- **Supply chain integration.** If high-tech urban farmers are able to grow, harvest, package and transport their produce to a retailer without any intermediaries, they might be able to reduce their post-harvest costs, which would compensate for the higher production cost. This is particularly viable for large high-tech urban farms that could become the main supplier of a retailer for certain produce. Retailers may be convinced to rely on one large high-tech urban farmer because high-tech urban farming is insensitive to climate making

the likelihood of crop failure close to nil[22]. Smaller farms may be able to sell directly to restaurants or to consumers who will accept paying a premium for their produce. In addition to vertical integration, horizontal integration can also be a strategy, with high-tech urban farms collaborating with other producers (urban, rural or both) to market their produce.

- **Assembled convenience food** such as already made salads. Salads are often composed of fresh produce (e.g. leafy vegetables) and produce with a longer shelf life (e.g. nuts). As product produced in high-tech urban farms has a long shelf life and can remain on the shelf for longer, retailers may pay a higher price for this green salad, to reduce wastage.

Other options for product diversification and generating revenue are:

- Production of transplants (where transplants are grown from seed and then used for greenhouse production)
- Production of medicine or plant-based compounds (for example the production of medicinal cannabis which requires very specific growing conditions and the ability to control the quality of the final product)
- Incorporating value-adding activities such as educational tours of the farm, workshops and events on the farm. Farmwall, a high-tech urban farm in Melbourne, organises 'twilight urban farming' on Fridays, where community members can undertake some farming[23].

Another business model that may be suitable for Australia is the export of produce from high-tech urban farms to Asia. The development of high-tech agrifood precincts in proximity to road infrastructures and airports would enable the production, harvesting, packaging and exportation of food produce in an efficient manner This is already happening around Sydney, where the development of a high-tech Agribusiness Precinct is planned in proximity to the new airport in Western Sydney[24.]

[22] Van den Dool 2018.
[23] Schwarz 2019.
[24] Brown 2019.

# 4 Feasibility assessment

## 4.1 Modelling of HTUH systems

### 4.1.1 Systems

Greenhouses used to dominate the 'indoor farming industry', however over the past fifteen years, adoption of new systems has increased, to include:

- Vertical farming which can be defined as a 'fully enclosed and opaque room with a vertical hydroponic, aeroponic, and/or aquaponic system' (approximately 38% of CEA)
- Container farms, which are a 'standardized, self-contained growing unit that employs vertical farming systems and artificial lighting' (approximately 6% of CEA).

Greenhouses still constitute approximately 40% of CEA worldwide[25].

The six systems or types of HTUH modelled under Australian conditions as part of this study are outlined in Table 0-1. These include vertical farms (also known as a Plant Factory with Artificial Lighting (PFAL), container farms and glasshouses on rooftops and floating platforms).

*Table 0-1: HTUH systems modelled under Australian conditions*

| | Location | Building integration and synergies | Space utilisation | Name |
|---|---|---|---|---|
| 1 | Rooftop | Integrated with building (synergies) | Vertical | Rooftop Glasshouse (Vertical) |
| 2 | Rooftop | Integrated with building (no synergies) | Horizontal | Rooftop Glasshouse (Horizontal) |
| 3 | Container | Not integrated with building | Vertical | Container Farm |
| 4 | Inside building | Integrated with building (no synergies) | Vertical | PFAL |
| 5 | Floating | Not integrated with building | Horizontal | Floating Glasshouse |
| 6 | Building facade | Integrated with building (no synergies) | Vertical | Building Facade |

Agritecture performed a resource analysis of the six systems to determine the input use over a ten-year period. The HVAC loads, water, $CO_2$ consumables, and labour requirements for each of the concepts was determined by the size, location, design elements, physical attributes of the production space, and crop type. The outcomes of this resource analysis are provided in Appendix 2.

The first year of input use was analysed to develop three units of measurement related to (i) environmental, (ii) financial, and (iii) social performance. These are outlined in Table 0-2 and provide an indicative assessment of how each of the six systems perform according to these three considerations.

[25] Autogrow & Agritecture Consulting 2019, Agrilyst (2016).

*Table 0-2: Indicative measure of environmental, social and financial performance of six HTUH systems analysed under Australian conditions*

| | Environmental | | | Social | | Financial | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **Water use** | **Energy use** | **Space use efficiency** | **Job opportunity** | **Visual amenity** | **Improved food security for remote communities** | **Operational expenditure** | **Capital expenditure** | **Revenue** |
| **Unit** | **Litres/m2/year** | **kWh/m2/year** | **Yield/m2/year** | **Total labour hours** | **1,2,3** | **kg/$AUD** | **$AUD/m2/year** | **$AUD/m2** | **$AUD/m2/year** |
| Rooftop Glasshouse (vertical) | 161.88 | 951.71 | 105.46 | 13.965 | 2 | 0.075 | 1,399.92 | 1,509.3 | 987.18 |
| Rooftop Glasshouse (horizontal) | 587.38 | 41.44 | 63.22 | 12.579 | 2 | 0.051 | 1,245.23 | 772.0 | 591.72 |
| Container Farm | 232.67 | 1550 | 151.6 | 1.380 | 3 | 0.03 | 5,109.5 | 3,781.5 | 1,418.9 |
| PFAL | 161.88 | 951.71 | 105.46 | 13.965 | 1 | 0.075 | 1,399.92 | 1,509.3 | 987.18 |
| Floating Glasshouse | 587.38 | 41.44 | 63.22 | 12.579 | 3 | 0.051 | 1,245.23 | 772.0 | 591.72 |
| Building Façade | 89.83 | 509.28 | 97.66 | 13.965 | 2 | 0.109 | 893.29 | 1,992.9 | 914.06 |

### 4.1.2 Results

**Financial**

Review of the data in Table 0-2 shows that Container Farm generates the highest revenue, but it also costs the most to establish per square meter and operate.

**Social**

According to the data in Table 0-2 the Building Façade and PFAL systems require the highest labour hours and therefore create the highest job opportunity.

Visual amenity, ranked as either 1, 2, or 3 depending on how visible the system was to the community was highest for the PFAL system which is largely hidden from view.

The ability of the systems to provide food for remote communities was measured according to the cost to produce a kilogram of food. The Container Farm performed best in this category and would be a suitable option for a high technology horticulture system established in a remote area to provide food for regional communities who might not have access to fresh produce.

**Environmental**

The three indicators developed to measure the environmental performance of the six systems were energy use, water use and space use efficiency.

As shown in Figure 0-1 the rooftop (horizontal) and floating glasshouses used the least energy (due to high natural light load) but had the highest water use (as they were ventilated). The Container farm used the most amount of energy and the building façade used the least amount of water.

Space was used efficiently in all the systems with the PFAL and rooftop glasshouse (vertical) producing the highest yield of product per square meter.

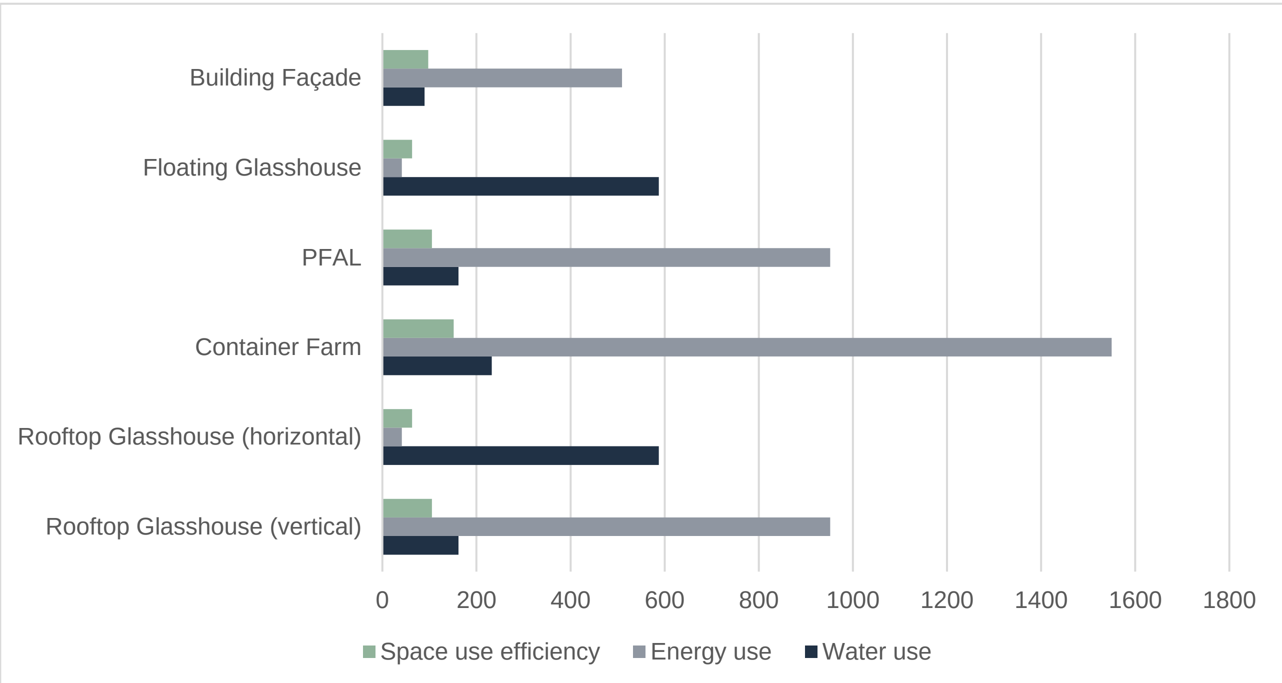


*Figure 0-1: Environmental performance of systems*

Pairwise comparison of the data presented in Table 0-2 was conducted to identify the most suitable HTUH system according to environmental, social and economic performance. The outputs of this analysis are provided in Appendix 3. The analysis was conducted three times with the weight of the three influences (social, economic and environmental) changed to analyse the data according to a different emphasis. Under each of the scenarios run (where the primary priority was changed from social, to environmental to economic), the Building Façade was scored and ranked as the best HTUH system for Australia followed by the Rooftop Glasshouse (PFAL).

A detailed economic analysis of the six systems was conducted using the data generated by the Agritecture modelling and is discussed in Section 0. The social and environmental performance of the six systems modelled are discussed in Sections 0 and 0 respectively, along with discussion of HTUH performance in these areas generally.

Members of the PRG felt that the input metrics used to model the viability of butter lettuce production in the six systems was conservative, impacting on overall productivity and feasibility. All HTUH producers will develop and refine their operating system to optimise productivity and hence profitability. Factors that can be modified include length of lighting, temperature, $CO_2$ and labour efficiency.

When viewing the outputs of the modelling, consideration should be given to the fact that a conservative base was used for comparison, and that the productivity and profitability of each system will depend on the refinements made by individual operators. This could include increasing the:

- **Current lighting** conditions of 275umol/m2/s intensity (16mol/m2/day DLI with a 16hour photoperiod) to 400umol/m2/s and 18hour photoperiod (26mol/m2/day) which would deliver an approximate 61% yield increase with minimal impact on Capex or Opex
- **Temperature** from the 18–20$^0$C used in the model to an average 24 hour temperature of 25$^0$C to match a higher light and $CO_2$ profile
- **$CO_2$** level to 800ppm to match an increased light and temperature profile
- **Number of plant cycles** based on the increased light, $CO_2$ and temperature profile from 8 per year to 12.8 per year
- **Number of layers** within a 40’ container to increase the production area.

Above modelling assumes a 40’ high-top container is fully utilised with production and all of the ancillary technology and requirements (e.g. germination, nursery, packing, irrigation, HVAC) are externally located in an adjoining 20’ container.

## 4.2 Economic analysis of HTUH Systems

### 4.2.1 Summary

The economic analysis returned mixed results, with the Container Farm (CF) and Glasshouse (GH) returning a negative NPV, while the Building Façade (BF) and PFAL (PFAL) systems were both positive. A summary of results is shown in

Table 0-3.

The negative results for the CF and GH systems were largely driven by a relatively high operational and capex cost to output/income ratio, with labour and site purchase being the largest contributors. After consultation with the PRG, it was agreed that these systems would be more profitable if a higher value crop was used and systems were 'tweaked' (as discussed above) to drive further productivity26.

The BF and PFAL systems returned a positive NPV and Modified Internal Rate of Return (MIRR). Our model shows these systems are worth further consideration and are likely to perform well in the Australian economic context. There are, however, likely 'normal' market fluctuations that will impact productivity and profitably that have not been accounted for in our research. Further, a MIRR below 10% (see Figure 0-2) invites substantial downside risk and as these systems are relatively untested within the Australian context these results should be treated with caution.

[26] As is often the case in Australia currently.

*Table 0-3: Economic summary*

| Description | Container Farm | Glass House | Building Façade | PFAL |
|---|---|---|---|---|
| Capex | $136,451 | $1,111,665 | $2,152,298 | $1,992,314 |
| Opex | $20,239 | $652,624 | $363,138 | $299,944 |
| Labour | $64,000 | $338,481 | $ (322,123) | $362,123 |
| Income | $56,755 | $946,749 | $1,096,867 | $1,096,867 |
| NPV | ($337,131) | ($2,103,870) | $245,606 | $791,788 |
| MIRR | −15% | −4% | 7% | 9% |
| Capex $/M2 | $1,997.81 | $842.14 | $1,630.53 | $1,509.33 |

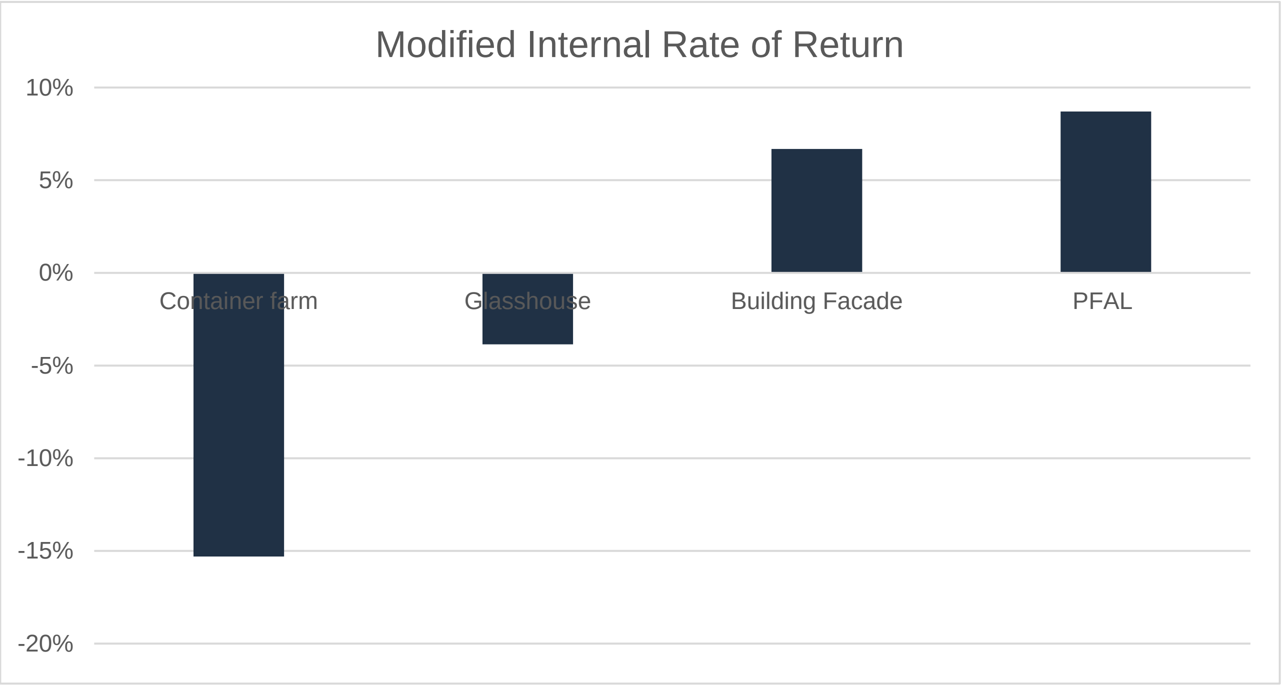


*Figure 0-2: Modified internal rate of return for all modelled systems*

### 4.2.2 Container farm

The container farm returned the lowest MIRR (–15%) and had a negative NPV ($337,145). Ultimately, income was not sufficient to cover operational and capital expenditure. Economies of scale are? also likely working against this system with the highest capital expenditure per meter of growing area (

Table 0-3).

Threshold analysis was performed to investigate the yield and price requirement to make this growing system profitable i.e. required operating profit to break even. Results from the threshold analysis are shown in Table 0-4: Container farm results. To meet our defined required rate of return (7% discount rate) income would need to be $104,700 in this scenario.

*Table 0-4: Container farm results*

| Economic Indicator | Result | Required Increase | Required Operating Profit | Required Income |
|---|---|---|---|---|
| Required price (per kg) | $19.20 | 85% | **$16,300** | $104,755 |
| Required yield (per meter) | 147 | | | |

Scenario analysis was then performed to identify the impact of changing price and yield combination on annual operating profit. Results are shown in Table 0-5. Red text identifies a negative result, green is positive. The scenario analysis highlighted that to return a positive annual operating profit, price would need to be a minimum $14 per kg and yield would need to increase to 8,789 kg in total per year, alternatively any combination highlighted in green would return a positive cashflow.

*Table 0-5: Scenario analysis – Operating profit over a range of price and yield combinations. Container farm*

| Operating Profit ($/Year) | Units sold (Total Kg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 5,457 | 6,003 | 6,603 | 7,264 | 7,990 | 8,789 |
| Price ($/kg) | 10 | (31,714) | (26,038) | (19,795) | (12,928) | (5,374) | 2,935 |
| | 11 | (26,038) | (19,795) | (12,928) | (5,374) | 2,935 | 12,076 |
| | 13 | (12,928) | (5,374) | 2,935 | 12,076 | 22,130 | 33,190 |
| | 14 | 12,076 | 22,130 | 33,190 | 45,356 | 58,739 | 73,459 |

### 4.2.3 Glasshouse

The Glasshouse farm returned a negative NPV (–2,100,900) and MIRR (–4%). This system however, shows high potential, as the MIRR was only slightly below positive. As with the Container Farm, our model showed that total income, in this modelled state, was not sufficient to cover operational and capital expenditure.

Threshold analysis was performed to investigate the impact of increasing price and yield and to what extent these variables would need to change for the system to be profitable i.e. required operating profit to break even. Results from the threshold analysis are shown in Table 0-4. To meet our defined required rate of return (7% discount rate) income would need to be $1,246,300 In this scenario.

*Table 0-6: Glasshouse farm results*

| Economic Indicator | Result | Required Increase | Required Operating Profit | Required Income |
|---|---|---|---|---|
| Required price (per kg) | $13.69 | 32% increase | **$230,300** | $1,246,300 |
| Required yield (kg/per meter) | 91 | | | |

Scenario analysis was also performed to identify the impact of changing price and yield combination on annual operating profit. Results are shown in Table 0-5. Red text identifies a negative result, green is positive. The scenario analysis showed that to return a positive annual operating profit, price would need to be a minimum $11 per kg and yield would need to increase to 100,137 kg in total per year, any other combination highlighted in green would also return a positive operating cashflow. The results show that this system would be profitable with minimal changes and therefore a likely target for future RD&E as most combinations of price and yield return a net positive result.

*Table 0-7: Scenario analysis – Operating profit over a range of price and yield combinations. Glass house farm*

| Operating Profit ($/Year) | | Units sold (Total Kg) | | | | | |
|---|---|---|---|---|---|---|---|
| Price ($/kg) | | 91,034 | 100,137 | 110,151 | 121,166 | 133,282 | 146,611 |
| | 10 | (69,265) | 25,410 | 129,552 | 244,109 | 370,121 | 508,735 |
| | 11 | 25,410 | 129,552 | 244,109 | 370,121 | 508,735 | 661,210 |
| | 13 | 244,109 | 370,121 | 508,735 | 661,210 | 828,932 | 1,013,427 |
| | 14 | 661,210 | 828,932 | 1,013,427 | 1,216,371 | 1,439,610 | 1,685,172 |

### 4.2.4 Building façade

The building facade model returned a positive NPV ($245,600) and MIRR (7%). The analysis shows that this system has the potential to be profitable and is worth further investigation. The analysis has shown that the operating profit is sufficient to cover operating and capital costs as well as return a market comparable rate of return[27].

Threshold analysis was not required for this system as our analysis returned a net positive result. Cumulative cashflow and investment 'payback' period have identified that the investment has the potential to break even after 9 years, with an annual operating profit of $300,100. Results are shown below.

*Table 0-8: Indoor facade results*

| Economic Indicator | Result |
|---|---|
| Payback period | 9 years |
| Annual operating profit | $300,100 |
| NPC | $245,606 |
| MIRR | 7% |

[27] When compared with other investments of similar risk within the economy.

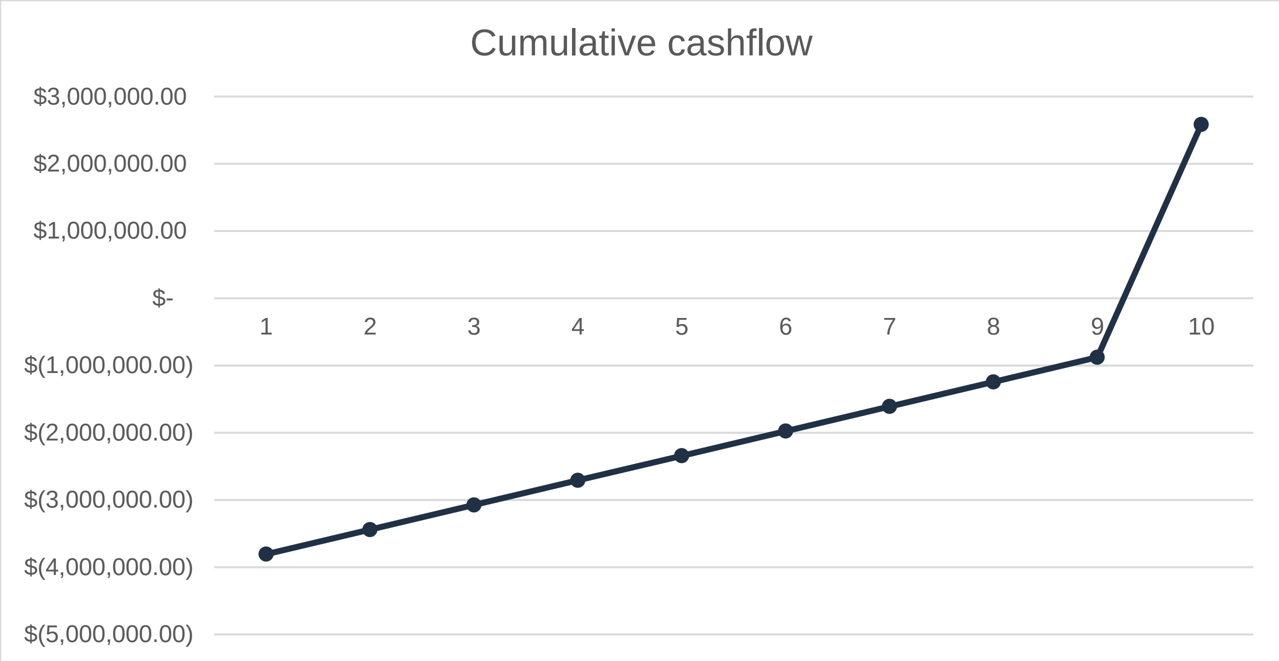


*Figure 0-3: Cumulative cashflow, building facade farm*

Scenario analysis was performed to identify the impact of changing price and yield combinations on the investments Rate of Return (Table 0-9). This table shows the potential performance of the building façade under a range of scenarios.

*Table 0-9: Scenario analysis – Modified internal rate of return, building facade farm*

| **Modified Internal Rate of Return** | **Units sold (Total Kg)** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Price ($/kg)** | MIRR | 105,468 | 116,015 | 127,616 | 140,378 | 154,416 | 169,857 |
| | 10 | 7% | 9% | 11% | 13% | 15% | 18% |
| | 11 | 9% | 11% | 13% | 15% | 18% | 20% |
| | 13 | 13% | 15% | 18% | 20% | 23% | 25% |
| | 14 | 20% | 23% | 25% | 28% | 32% | 36% |

### 4.2.5 PFAL

The PFAL returned the highest NPV ($791,800) and MIRR (9%). The analysis shows that this system has the potential to be profitable and is worth further investigation. This analysis has shown that the operating profit is sufficient to cover operating and capital costs as well as return a market comparable rate of return[28].

Threshold analysis was not required for this system as our analysis returned a net positive result. Cumulative cashflow and investment ‘payback’ period have identified the investment has the potential to break even after 6 years, with an annual operating profit of $390,900. Results are shown below.

[28] When compared to other investments of similar risk within the economy.

*Table 0-10: PFAL results*

| Economic Indicator | Result |
|---|---|
| Payback period | 6 years |
| Annual operating profit | $390,900 |
| MIRR | 9% |
| NPV | $1,509.33 |

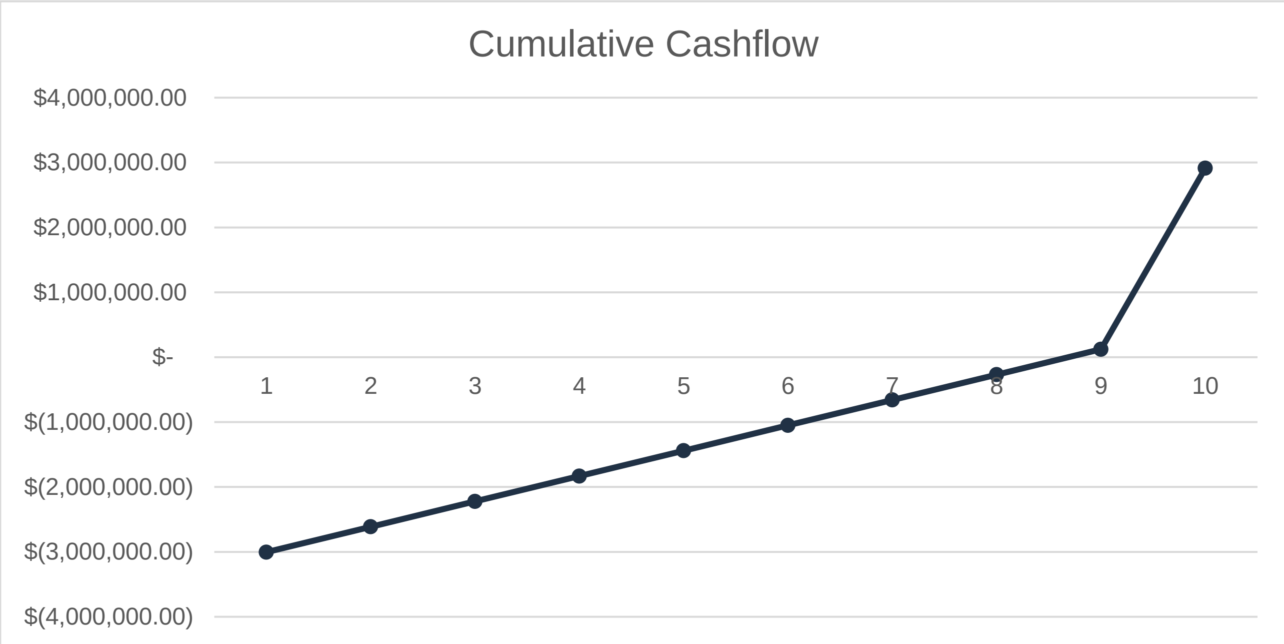


*Figure 0-4 Cumulative cashflow, PFAL*

Scenario analysis was performed to identify the impact of changing price and yield combinations on the investments Rate of Return. This table shows the potential performance of the PFAL farming system if investment in research was targeted at increasing yield or marketing improved prices.

*Table 0-11: Scenario analysis – Modified internal rate of return, PFAL system*

| Modified Internal Rate of Return | Units sold (Total Kg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | MIRR | 105,468 | 116,015 | 127,616 | 140,378 | 154,416 | 169,857 |
| Price ($/kg) | 10 | 9% | 11% | 14% | 16% | 19% | 21% |
| | 11 | 11% | 14% | 16% | 19% | 21% | 24% |
| | 13 | 16% | 19% | 21% | 24% | 27% | 30% |
| | 14 | 24% | 27% | 30% | 34% | 39% | 45% |

### 4.2.6 Profitability of HTUH

Urbanised horticultural production within Australia is a new and evolving space. The economic analysis for this project has highlighted the potential for successful systems within the Australian context and a need for future investment in R&D to address capital and operational costs. It should also be noted that we have modelled a small proportion of the currently available technology in a very particular scope. There are many different growing systems that can be applied to many scenarios, and there is no one system that will suit every situation. As is often the case with evolving and emerging technologies, the best option for a particular situation will be determined on the merit and characteristics of the market, management, and institutional support.

This analysis has incorporated risk through the chosen discount rate, however, there are likely 'normal' market fluctuations that will impact productivity and profitably that have not been accounted for. Although two of the systems that were modelled have returned a positive result, a MIRR below 10% invites downside risk and these results should be treated with caution.

Internationally there is limited evidence as to the profitability of HTUH and the ability of these systems to generate revenue are dependent on the factors discussed above. In 2017, 51% of controlled environment farms in the United States were not financially profitable. This is partially attributable to the fact that urban farms are capital intensive, and most of them are likely still paying back their initial investment29.

HTUH has some advantages over field-based production in that climate can be controlled and production is not constrained to certain seasons. There is also the potential to produce higher yields per unit of area. However, factors that increase the cost (and hence reduce the profitability of HTUH) include:

- High land prices (due to production in city centres where land is expensive)
- High establishment costs particularly for glasshouses built inside or on top of buildings.

The success of individual enterprises will also depend heavily on the product line chosen, the business model used and the skill and aptitude of the farm manager. HTUH, like any other agricultural enterprise, is a business that requires careful planning and good management.

Options for increasing the profitability of HTUH include:

- Increasing productivity through automation, and use of data analytics and sensor networks, to reduce labour costs and facilitate greater economies of scale by enabling farmers to manage several farms at a distance
- Lowering costs, particularly those associated with energy consumption through use of LED lighting systems that have lower energy consumption, low waste heat generation as well as optimised spectra of plant growth
- The use of alternative sources of energy such as geothermal or urban waste heat for heating, and renewable energies, such as solar photovoltaics, for energy
- Optimisation of the system by choosing the mix of crops that will perform best in the chosen environment. A trial of the Rotating Living Wall[30] found that radish produced on average four times more than basil. Finding the right balance between the amount of soil-less media, plant growth and costs is important, as beyond a certain threshold, adding media might lead to a small increase in fresh weight, but a large increase in costs.

The development, and use of, more performant technologies, can reduce operating costs and improve the profitability of HTUH. However, more sophisticated technology and engineering also costs more to establish, require greater skill to manage, and can lead to higher risk. It was noted by the PRG that there is an increasing interest by new entrants in HTUH systems that have lower levels of technology which are easier to manage and pose lower investment risk.

## 4.3 Social considerations

### 4.3.1 Social Acceptability of HTUH

The ability to develop HTUH will depend in part on its social acceptability and is therefore an important consideration as to feasibility in Australia. Low-tech urban agriculture on the ground or integrated into buildings (e.g. rooftops), which have a community and social orientation are seen as providing a range of social benefits such as enhancing community ties,

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[29] O'Sullivan et al. 2019.
[30] GreenTowers, Gumble, Berghage & Stearns (2015).

providing a way to reconnect to agriculture and food production, and enhancing mental and physical health through gardening. HTUH focused predominately on economic outcomes may be viewed less positively. The factors affecting social acceptability include:

- HTUH may not be considered as 'real agriculture' due to its localisation in an urban setting, and the nature of the farms (small scale, sometimes soilless farms)[31]. Some individuals retain a conservative framing of agriculture and consider that it should be restricted to the countryside. Others, on the contrary, believe that it could play a role in repurposing old buildings and could be aesthetically pleasing (e.g. greenhouse on industrial buildings)[32].
- Urban agriculture is more acceptable when it has a community orientation and pursues social (recreational or educational) and environmental goals, and less so when it is a commercial activity directed at increasing food production in the city, through the use of technologies[33]. In Barcelona, food co-ops, urban gardeners, NGOs, and staff from the administration often see urban agriculture as a social activity and prefer traditional, soil-based urban gardens. In contrast, other stakeholders, such as architects, see high-tech commercial agriculture as a way to produce food in the city, while providing economic, social and environmental benefits[34].
- HTUH is sometimes perceived as unnatural and unhealthy, notably when soilless systems are used. Indeed, research has shown that stakeholders consider soilless techniques as artificial, detached from the land and providing products of poor quality, in terms of taste and nutritional value. In addition, some stakeholders worry that soilless techniques prevent farmers from implementing sustainable practices, such as organic farming[35].
- HTUH is not perceived as environmentally and economically sustainable. Indeed, some individuals consider HTUH as highly resource intensive, due to the building material used and the high energy input necessary for production. As a result, they have doubts regarding the reduction in carbon footprint that could be offered by HTUH. In addition, some have doubts regarding the economic feasibility of those farms.
- HTUH is perceived as competing with preferred economic activities. For example, regarding rooftops, some individuals are worried that food production competes with renewable energy or rainwater harvesting. They are also worried that high-tech urban products enter into competition with traditional peri-urban and rural agricultural products[36].
- Urban agriculture, including HTUH, is considered as representing health risks. Many stakeholders worry about risks related to air pollution from road traffic, soil contamination with heavy metals, and water contamination from the potential reuse of wastewater in agricultural systems[37].

Regarding HTUH systems it was identified that aquaponics and vertical farming systems are preferred to urban rooftops, and rooftop projects are more likely to be preferred to projects on the ground[38].

### 4.3.2 Equity of HTUH

Social research on HTUH identifies concerns related to the equity of food produced using these systems including that:

- HTUH produce may not be accessible to all local residents as it can be priced 15 to 20% higher than food produced in land-based rural farms[39]
- It will contribute to the gentrification of the neighbourhood in which it is implemented (including an increase in real estate prices)[40]
- High-tech agricultural farms, due to their high costs, are taken over by large enterprises focussed on profit, rather than the contribution of the business to the neighbourhood and the community
- An increase in popularity of HTUH leads to soil-based urban agriculture becoming less socially acceptable and considered as 'deviant' in some way

31 Sanyé-Mengual et al. 2016; Specht & Sanyé-Mengual 2017; Specht, Siebert & Thomaier 2015.
32 Specht, Siebert & Thomaier 2015.
33 Sanyé-Mengual et al. 2016; Specht et al. 2016.
34 Sanyé-Mengual et al. (2016).
35 Specht & Sanyé-Mengual 2017.
36 Specht & Sanyé-Mengual 2017; Specht, Siebert & Thomaier 2015.
37 Sanyé-Mengual, Martinez-Blanco, et al. 2018; Specht et al. 2016.
38 Sanyé-Mengual, Specht, et al. (2018).
39 Sanyé- Mengual et al. 2015; Specht, Siebert & Thomaier 2015.
40 Carolan 2020; Specht & Sanyé-Mengual 2017; Specht, Siebert & Thomaier 2015.

- Traditional farmers may be excluded from the transition to HTUH. High-tech urban farming requires very different skills than traditional farming. Some respondents are worried that traditional urban farmers are excluded from this transition, due to a lack of relevant skills. However, the emergence of a new type of farmers who would not have entered farming if it did not involve technologies may also be a positive, as it may enrich the food movement.

Strategies to improve public acceptance of HTUH include:

- Running public access and social and educational activities by high-tech commercial farmers, in order to integrate the farm into the neighbourhood
- Carry out information campaigns on HTUH, particularly regarding its environmental sustainability. This includes the dissemination of research results, pilot and demonstration projects as well as educational tours of existing farms.
- Developing quality standards and certification schemes to minimise worries around health risks related to high-tech agricultural products
- Ensuring that the design and planning of HTUH projects is as inclusive and participatory as possible[41].

### 4.3.3 Modelling

The visual amenity, job creation and ability to provide food security for remote communities was assessed for the six HTUH systems to measure their social performance. As outlined in

Table 0-12 all the systems required a similar level of labour hours, with the Building Façade and PFAL systems requiring the highest labour hours and therefore creating the highest job opportunity.

Visual amenity, ranked as either 1, 2, or 3 depending on how visible the systems was to the community was highest for the PFAL system which is largely hidden from view.

The ability of the systems to provide food for remote communities was measured according to the cost to produce a kilogram of food. The Container Farm performed best in this category and would be a suitable option for a high technology horticulture system established in a remote area to provide food for regional communities who might not have access to fresh produce.

*Table 0-12: Social performance of six HTUH systems*

| Systems | Job Opportunity | Visual Amenity | Improved Food Security for remote communities |
|---|---|---|---|
| | Total labour hours | 1–3 (from low visual amenity to high visual amenity) | $/kg |
| Rooftop Glasshouse (vertical) | 13,965 | 2 | 0.075 |
| Rooftop Glasshouse (horizontal) | 12,579 | 2 | 0.051 |
| Container Farm | 1,380 | 3 | 0.03 |
| PFAL | 13,965 | 1 | 0.075 |
| Floating Glasshouse | 12,579 | 3 | 0.051 |
| Building Façade | 13,965 | 2 | 0.109 |

41 Specht & Sanyé- Mengual 2017.

## 4.4 Environmental considerations

In this section, we discuss the ability of HTUH systems to manage inputs (such as energy and water) efficiently and identify opportunities for improved circularity and biodiversity conservation.

### 4.4.1 Water efficiency

The ability to tightly control water, temperature and humidity within HTUH provides opportunities to minimise and be highly efficient with the water used to grow crops. The main systems used to irrigate crops within HTUH include:

- Hydroponics
- Aeroponics
- Aquaponics.

These three systems (Table 0-13) are designed to use water efficiently by directing water to where it is needed, reusing water and helping plant roots absorb water.

*Table 0-13: Features of main systems used to irrigate HTUH crops*

| System | Features |
|---|---|
| Hydroponics | Water demand of lettuce grown hydroponically has been shown to be far less than field grown lettuce[42] making hydroponics systems less water intensive than traditional land-based agriculture. In addition, the water demand of hydroponics systems may continue to diminish as technologies improve. For example, cylindrical hydroponics systems enable the re-distillation and reuse of the nutrient liquid used to feed plants, while the closed liquid reservoir brings evaporation near zero. Another technique, ultrasonic foggers, where roots are provided with nutrient enriched fogs, encourages the growth of root hairs, which enhances the ability of the roots to absorb water and nutrients. The use of such a technique would reduce by 50% the use of water and nutrients in comparison to a traditional hydroponic system[43]. |
| Aeroponics | Aeroponic systems require even less water than hydroponics system, as they use nutrient rich mist instead of water for plant growth. Overall, hydroponic and aeroponic systems, require 95% less water than traditional land-based farming, because in the latter water is not always absorbed by the roots[44]. |
| Aquaponics | Aquaponic systems are not widely commercialised as of yet. These systems consist of closed water circulating between the hydroponic and the fish farming system, making it a highly water-efficient system[45]. |

#### Modelling

The modelling conducted by Agritecture identified that of the six systems assessed, the Building Facade and PFAL systems were the most water efficient using the least amount of water per m2 per year. The floating glasshouse and rooftop glasshouse were least efficient requiring the most water to produce lettuce. This is largely due to the fact that the water that is transpired (assumed to be 90%) cannot be recycled in these ventilated systems.

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42 Barbosa et al. (2015).
43 Al-Kodmany 2018.
44 Al-Kodmany 2018; Kalantari et al. 2018; Benis, Reinhart & Ferrão 2017a.
45 Benis & Ferrão 2018; Thomaier et al. 2014.

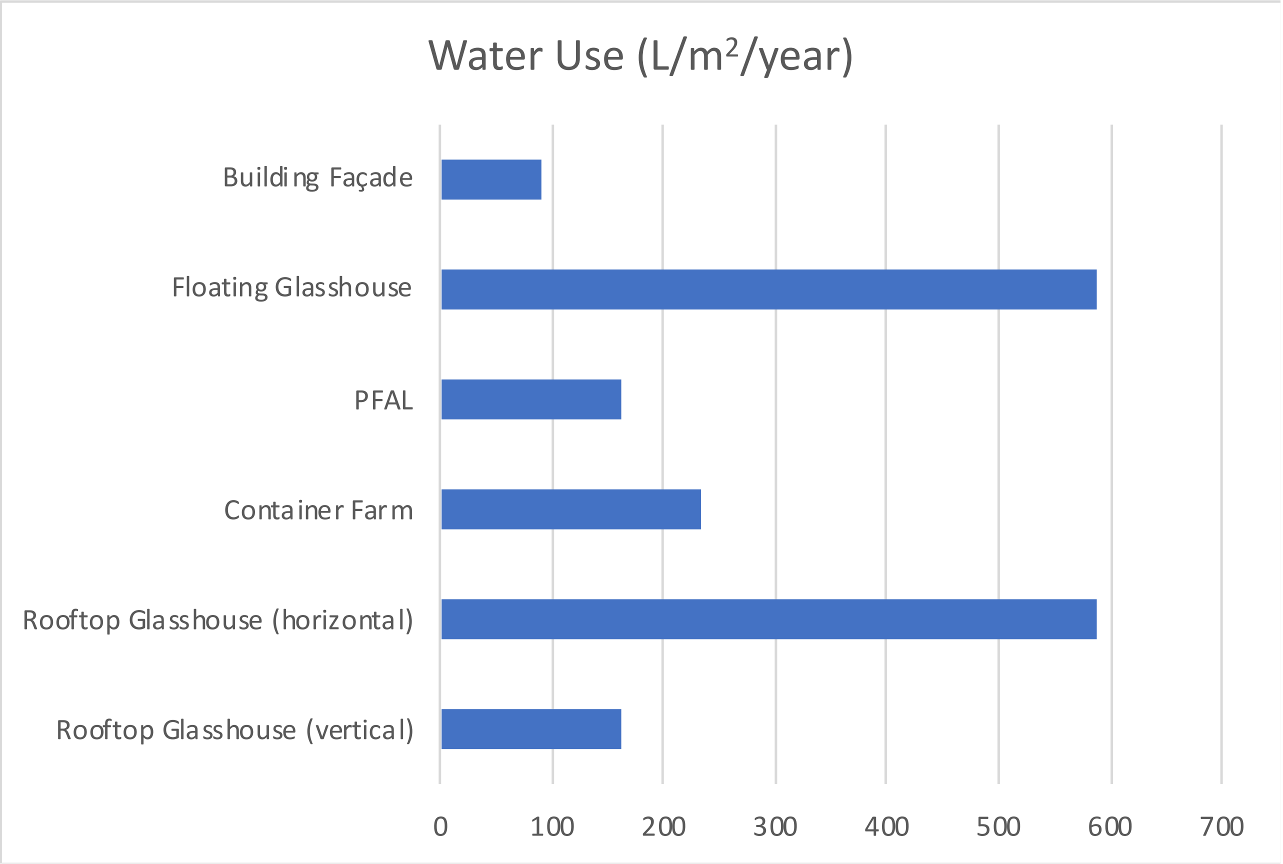


*Figure 0-5: Water use by six systems modelled under Australian conditions*

### 4.4.2 Energy consumption

HTUH has a high energy demand[46]. Although urban proximity reduces energy use associated with transportation, the energy required to grow crops using high technology systems is often higher than field-based production. In addition, structural requirements for some types of high-tech urban farming, in particular rooftop greenhouses, can also lead to substantial energy consumption[47].

Energy use by HTUH, and its environmental impact, will depend on the local climate, the farming system used, and the crops produced[48]. For example, in cities with warmer climates, higher radiation levels and short supply chains, the use of shipping containers (which have no natural light) to grow tomatoes contributes to global warming and has a negative environmental impact[49]. However, systems such as rooftop greenhouses or vertical farms which incorporate skylights and windows require less energy and have less of an environmental impact.

There is no clear answer on whether HTUH represents a more energy efficient option than traditional land-based production systems and their associated supply chain. This depends on the local climate, the farming system, the crops grown and the sustainability of field-based production and supply chain. However, it is certain that HTUH electricity demand at the production stage is higher than for traditional land-based agricultural production. Therefore, diminishing electricity demand should be a priority if the environmental performance of high-tech urban farms is to improve.

Many strategies to reduce energy needs are being developed including:

- Improving the energy efficiency of LED lighting. For greenhouses, greenhouse-integrated photovoltaics can be used, which enables both electricity production and agriculture on the same roof.
- Using passive conditioning, such as thermal insulation and natural ventilation
- Using a shell with enhanced thermal properties, in the case of greenhouses

46 Farhangi et al. 2020.
47 Weidner, Yang & Hamm 2019.
48 Benis & Ferrão, 2018.
49 Benis, Reinhart & Ferrão (2017a.

- Using renewable energies, such as wind turbines, photovoltaic panels, geothermal energy
- Enhancing the physiology of crops to maximise yield in regard to energy
- Using rotatable stacked trays of plants, for plants to benefit as much as possible from natural radiation
- Creating symbiotic relationships between the high-tech urban farm and the host building.

### Modelling

The modelling conducted by Agritecture identified that of the six systems assessed, the Rooftop Glasshouse and Floating glasshouse were most energy efficient using the least kilowatts per m2 per year. This is due to the high level of natural light these systems receive and horizontal production, reducing the need for artificial light. The container farm had the highest energy use followed by the PFAL and rooftop glasshouse (with a vertical production system). All these systems would require higher levels of artificial lighting and HVAC equipment which increases the amount of energy used for production.

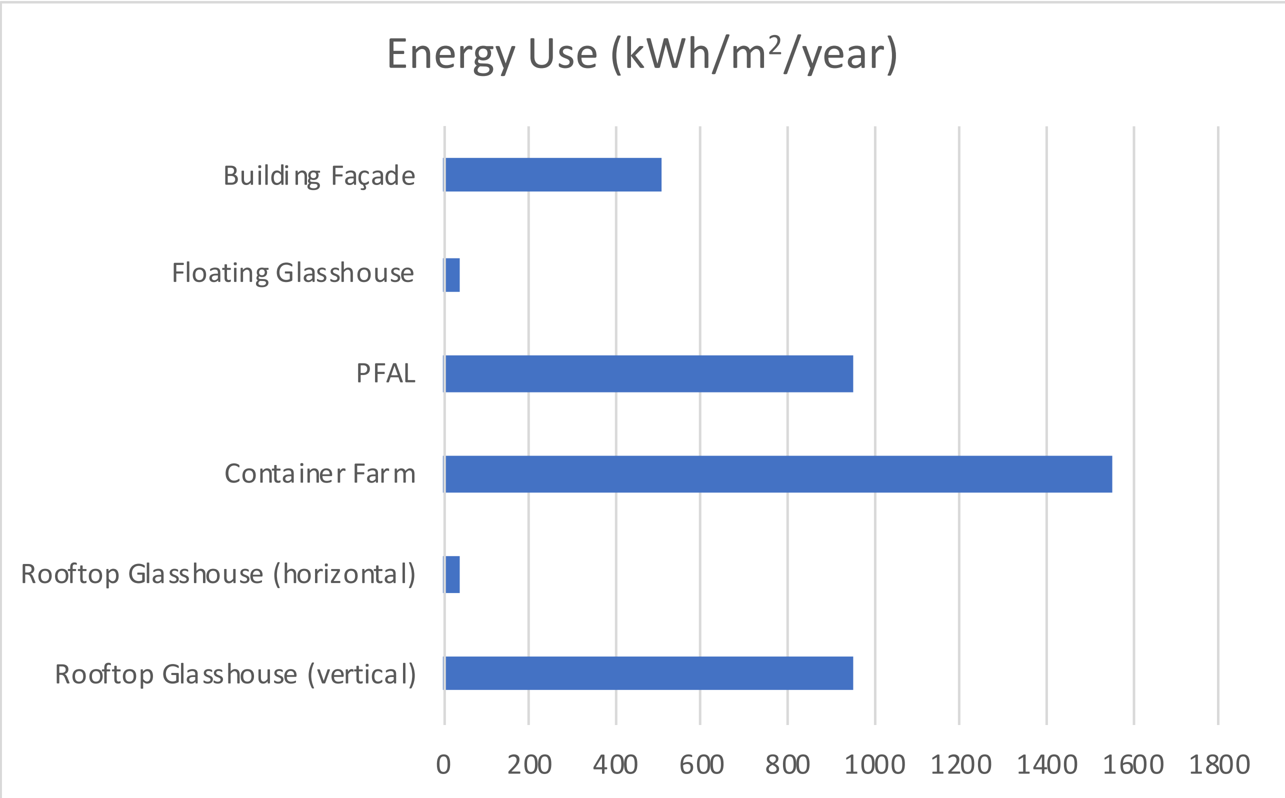


*Figure 0-6: Energy use of systems*

## 4.4.3 Circularity and HTUH

Developing symbiosis between the farm and the host building, where the losses of one system becomes the resource for another one, appears to have important potential for the environmental sustainability of HTUH. These connections between farm and host form part of current debates on the potential contributions of circular food production systems to wider sustainability.

### Air and heat

In cold climates residual air/heat from buildings could be used by rooftop greenhouses to maintain or increase their temperature[50], while in warm climates, it could increase crop yield with no further energy consumption. Some urban farms have already implemented systems to recover air/heat. The Vinegar Factory in New York City uses the heat generated by a bakery to heat the greenhouses[51].

50 Sanyé-Mengual, Martinez-Blanco, et al. (2018).
51 Thomaier et al. 2014.

Conversely, the implementation of a rooftop greenhouse also diminishes the energy requirements of the host building, by reducing summer cooling load and heat loss in winter. This is particularly true for buildings that are poorly insulated, where the energy requirements can be reduced by up to 41%[52].

#### Wastewater

Recycling wastewater for irrigation of HTUH crops, particularly for farms not using hydroponics, aeroponics or aquaponics could be a way of reducing water use. In addition, nutrients present in wastewater (such as phosphorus) could be used to replace or complement the use of mineral fertilisers. However, currently, the two potential options for phosphorus recovery in wastewater (source separation and decentralised treatment, and recovery from sewage sludge ash) are often not viable, as they require newly built infrastructure, or present issues related to cost and recovery efficiency53. The use of wastewater as irrigation and fertiliser for agricultural production also poses questions in terms of food safety and environmental protection. These factors have led to limited adoption of these practices.

#### Organic waste

Organic waste can be separated at the household or industry level and then used for compost and anaerobic digestion to derive nutrients and heat. The recovery of heat from organic waste for use in agricultural production is already implemented by SUEZ in France, where the heat generated by waste incineration has been used to grow greenhouse tomatoes54. In the high-tech urban farm, The Plant, in Chicago, food waste composted with the help of an anaerobic digester is used to create heat that is used to fuel equipment used for food production and processing.

Deriving nutrients from organic waste is possible but requires that procedures and infrastructures are in place to make sure that the nutrients are free from contamination (e.g. glass, plastic, metal) and that they are suitable for use in soilless agricultural systems (i.e. organic waste that has high levels of certain nutrients may negatively impact on plant growth). Some recycled organic products have worked, such as poultry digestate and fertilisers using fish, corn, oyster and ash of coconut shell55.

#### Biodiversity conservation

HTUH can have a positive effect on surrounding ecosystems and biodiversity habitats as it utilises urban spaces, instead of rural land (which may have been altered from its natural state). Utilising urban land could therefore contribute to releasing some pressure on the natural environment and contribute to the enhancement of biodiversity. It might also avoid some of the common negative impacts of agricultural practices on the natural environment, such as erosion and soil contamination[56].

## 4.5 R&D opportunities

There are opportunities to invest in research and development (R&D) that will reduce the costs associated with HTUH production and improve their profitability and sustainability. These include development of technology associated with:

- Lighting
- Materials
- Energy sources
- Genetic improvement
- Blockchain
- Internet of Things
- Robotics and automation.

### 4.5.1 Lighting

International research on lighting technologies is often conducted at much lower radiation loads than those found in Australia. This may affect adoption and importation of lighting technologies by Australian businesses since there is a gap in understanding if certain research and technology is directly applicable to an Australian context.

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52 Weidner, Yang & Hamm 2019.
53 Weidner, Yang, & Hamm, 2019.
54 Weidner, Yang & Hamm 2019.
55 Weidner et al., 2019.
56 Al-Kodmany 2018.

Typically, large scale CEA farms use either high-pressure sodium (HPS) lamps or LED. Unlike HPS which has red-yellow emission, LED has red and blue wavelengths which are better suited for plant photosynthesis[57]. Advances in LED lighting technology has enhanced their size, adaptability in usage, integration with digital controls, and reduced waste heat.

There are several companies (such as Panasonic, Toshiba, Philips) that are currently working to improve lighting systems for HTUH. Philips has produced LED systems with a 68% efficiency (compared to the efficiency rate of 28% of currently available LED lighting systems), which should lead to diminishing operating costs. There are emerging induction lighting technologies, which only provide the light spectra that are useful for plant photosynthesis, limiting energy waste[58].

LED adoption is predicted to further increase as the technology advances and prices drop in two distinct adoption groups[59]. These include:

- Affordable fixtures with fixed spectra, often fixed emission rate, high efficacy, and simple on/off controllers
- Custom-made fixtures with advanced controllers to manipulate emission rate, spectral control, and/or with sensor integration.

The adoption of the technology will be determined by the commercial viability due to increased yields and quality of the final product.

- Further international research into LED technology will include:
- Adjusting the wavelengths of LED (red/blue colours) to observe differences in plant growth to maximize yields and quality (a study in in 2012 found that adding a period of supplemental LED red lights to HPS lighting increased the antioxidant content of leafy vegetables such as spinach, parsley and dill[54]
- Use of intra-canopy lighting to increase yield (several studies have shown intra-canopy lighting to increase yields in crops like cucumber and cowpea by approximately 50% and 11% respectively. Furthermore, researchers are studying the effect of intra-canopy far-red light on the yield and quality of fruits, which have shown in tomatoes increasing lycopene concentration[60].

Little research has been conducted in Australia examining the possible targeted use of LED lighting and its application at different wavelengths. Although Australia has high radiation loads, targeted light use may still provide opportunities.

### 4.5.2 Energy sources

HTUH can be more energy intensive than field-based agriculture. However, there are opportunities to use alternative energy sources such as solar panels, roof-top wind turbines, storage batteries and reusing waste heat to reduce reliance on fossil fuels. Solar glass technologies are currently being studied in Australia by Swinburne University which aim to regulate light and capture it through a photovoltaic transparent material.

### 4.5.3 Materials

Three innovative technologies which have application for HTUH include:

- Cover material – The reflectance, transmission and absorbance of light can vary depending on the material used for greenhouses. Cover material is being investigated the Edith Cowan University's electron Science Research Institute which is developing a glasshouse using newly developed solar glass and the Swinburne University of Technology is leading a project on smart glass which can adjust to different light intensities as well as on a semi-transparent photovoltaic glass that could simultaneously adjust light intensity and generate electricity[61].
- Nano-technology – Sensors for soil analysis, biochemical sensing and control, and water treatment by effectively removing pollutants have application for HTUH and could be effective in storm water integration in ZFarming
- 3D printing – could change equipment supply chains by allowing on-site printing of parts.

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57 Daukantas, 2017.
58 Al-Kodmany (2018).
59 HortScience (2019).
60 Gomez & Kuack, 2017.
61 Montagu, 2018.

### 4.5.4 Genetic improvement

Genetic improvement provides the opportunity to develop plant breeds which develop faster, enabling a higher number of crop cycles per year. This could be achieved through a range of technologies including gene editing to identify and modify genes associated with plant development and reproduction. Identification of genes associated with stem length, flowering and precocious growth termination has been identified in tomatoes62 and could be applied to other species to generate dwarf varieties that exhibit continuous/or precocious flowering. Other successful trials have been conducted on grapevines and kiwifruit.

### 4.5.5 Blockchain and Internet of Things (IOT)

In agriculture the application of distributed ledgers, the basis of blockchain technology, is ideally implemented with Internet of Things (IoT). Currently, the commercial applications of distributed ledgers identified for the agriculture industry are tracking supply chains, food safety issues, production practices and compliance. All these can be successfully adapted to urban agriculture settings. The aim is to increase the transparency of the supply chain and by doing so access a differentiated and premium production market. Urban high-technology agriculture may be suited to trial this technology since it doesn't have the same barriers to entry that rural areas have such as connectivity, scalability and lack of skills and capabilities in the technology sector in rural areas63.

Uptake challenges include:

- Potential lack of market viability since it is unclear if the consumer will pay premiums for increased transparency and other blockchain enabled attributes[59]
- Technological barriers including automated accurate data collection and high power requirements.

There has been a high level of adoption of IoT technologies within the HTUH sector to control and monitor production systems. Sensor prices are predicted to decrease from around $50 per device for today's technology to $0.05 in 202464. This will result in significant market adoption, similar to that previously seen with LED since it has the potential to significantly increase yields and reduce labour costs for growers.

In protected cropping, manipulation of temperature, humidity and CO2 have been studied extensively. Climate control can enable year-round harvests adding a further yields and competitiveness with non-CEA. Urban farms rely on control over growing conditions to maximize yield per unit area to be commercially viable.

CO2 enrichment has been part of the high-tech end of protected cropping for decades. Further research needs to focus on the optimal levels of CO2, temperature and air humidity for plant growth and quality. Thus, there is an opportunity for using IoT real time data to modify the CO2 concentration in systems to maximize the positive impact of the technology without the increased adaptation to high CO2 environments. Further studies on breeding and sink-source relationships may provide ways in which CO2 enrichment can increase yields by ensuring translocation of photoassimilates to the harvestable portion of plants.

However, data itself is not sufficient value to producers. Data needs to be embedded into actionable decisions. Where possible these decisions should be automated and can be easily implemented with the assistance of technologies such as big data, AI and robotics and automation65.

### 4.5.6 Robotics and automation

Robotics in agriculture is an area of rising interest in Australia due to a relatively expensive workforce in short supply in the sector as well as the opportunity of increasing efficiency, reliability, safety and productivity of their farming operation. Urban high-tech agriculture is well suited to incorporate this technology since it is an intensive activity needing high yields that require a large amount of labour especially during planting and harvesting. The potential use of robotics and automation is vast and can be easily integrated with other technologies such as IoT, AI and drones.

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[62] Kwon, et al., 2019.
[63] GHD & AgThentic, 2018.
[64] GHD & AgThentic, 2018.
[65] O'Sullivan et al., 2020, Montagu, 2018, Gómez et al., 2019, GHD & AgThentic, 2018.

As technology advances, there is potential for farms to gain productivity on a plant-by-plant basis. This will need automating and leads to multiple opportunities in R&D. Currently in Australia, the CSIRO have developed a "phenomobile Lite", a mobile instrument combining lidar with RGB and hyperspectral imaging to measure the growth and ageing of crops. In addition, it measures the canopy temperature to assess plant stress and water uptake.

Virgo is a robotic harvesting system developed by Root AI in Massachusetts. Virgo is a standard industrial-grade robot on a mobile platform combined with computer vision for sight, custom end-of-arm tools for grasping a variety of fresh produce, and onboard intelligence that enables the unit to do dextrous work. Virgo is in product testing at indoor farms around the U.S. Currently the robot is picking ripe tomatoes, but they are also looking at other specialty crops such as strawberries and grapes[66].

Internationally some plant factories benefit from robotic systems for sorting, transferring, and handling of plants, as well as quality control and post-harvesting. In Australia it is likely that high-tech protected cropping will import the majority of robotics and automation technologies required, with some local contributions.

Introducing robotics and automation into urban systems is likely to be slow due to the high initial capital costs which are hard to justify without sufficient economies of scale. Consultation with industry identified that some new entrants into the industry are choosing to focus on lower technology systems that present less risk and lower capital costs[67].

### 4.6 Assessment Conclusions

Little information is available on the high-tech urban farming systems that are the most widely used internationally. However, review shows that greenhouses dominated the industry until fifteen years ago. More recently, two other types of systems, indoor vertical systems (PFAL) and container farms have become more commonplace.

Modelling indicated that for Australia the Building Facade and PFAL systems are the most suitable systems and perform best economically, socially, and environmentally.

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[66] Cultivating Robotics and AI for Sustainable Agriculture (2019) T.M. Anandan

[67] Pers comms – industry consultation (2021)

This was confirmed by the economic analysis which demonstrated that the Building Façade and PFAL systems were profitable while container farms (CF) and glasshouses (GH) were not. The negative results for the CF and GH systems were largely driven by a relatively high operational and capex cost to output/income ratio, with labour and site purchase being the large contributors. After consultation with the PRG, it was agreed that these systems would be more profitable if a higher value crop was used and systems refined (as discussed in Section 4.1) to drive further productivity[68].

The lack of consistency of data on farm size, crops and facility type makes it impossible to get a full understanding of the geographical spread of CEA. However, in general it is countries that face food security challenges (like Singapore) or have supporting government policies, and a competitive innovation space (such as the United States) where HTUH has developed the most.

In contrast, Australia is considered slower in the adoption of HTUH and the focus is mostly on the development of modular growing systems, such as container farms. This review has identified that in Australia HTUH is challenged by a range of economic, social and environmental factors.

### 4.6.1 Economic

The production of food using HTUH systems is challenged in Australia by our relatively high energy and labour costs and the cost of real estate in urban areas. These factors increase both the capital and operating costs associated with HTUH production.

To be profitable, HTUH producers need to achieve a relatively higher price for their produce. Operators in Australia are currently achieving this by:

- Focussing on production of premium products that suit HTUH systems (such as herbs, micro greens and leafy green mixes)
- Branding, packaging, and marketing that appeals to the target demographic
- Utilising business to customer (B2C) and business to business (B2B) models which focus on developing relationships with the service sector and restaurants in their local area.

This allows them to achieve the higher prices required to cover their capital and operating costs.

To improve the economics of HTUH research and development into technology that reduces operating costs will be of greatest benefit, in particular innovation that reduces energy and labour costs.

R&D that has application for HTUH includes:

- Improvement in LED lighting to reduce energy use and cost
- Use of genetic improvement to develop plant varieties that are better suited to HTUH production systems with reduced height, shorter development cycles and rapid fruit development
- Use of nano technology and the IoT to further refine production systems and develop sensors that will further automate production.

### 4.6.2 Social

Within the community there needs to be a demand for product that is focused on quality and freshness but may cost more. This will appeal and be a viable proposition for certain market segments but may be 'out of reach' for other sectors of the community.

Support for HTUH needs to come from urban communities who have a desire for 'locally grown' food and seek to engage in food growing projects and spaces. The path forward for this in Australia has been demonstrated by the increasing integration of green spaces into urban policies and planning in NSW however increased government support across all states is required to drive this for food, and developers need to be incentivised to include this in new urban developments.

### 4.6.3 Environment

The environmental benefits of HTUH over field-based production are still being researched. In general, HTUH is perceived as being more water efficient than field-based production however often the energy requirements are much higher than field-based production. It is also dangerous to compare HTUH with field-based production as the management practices

68 As is often the case in Australia currently.

associated with field-based production can be highly variable and the environmental impact varies accordingly. However, Australia is a climatically vulnerable and water scarce country. HTUH offers benefits as it is highly water efficient and resilient to extreme weather events. Therefore, rather than viewing HTUH as a competitor to field based production, it may be more relevant to assess how it can complement land-based agriculture, which will be increasingly affected by extreme weather events and water scarcity.

HTUH also represents an opportunity for the development of circularity around heat/air, wastewater (water and mineral fertilisers) and organic waste in cities. However, several barriers currently exist to the use of those techniques exist, which means that they have not been widely adopted.

# 5 Monitoring and evaluation

| Logic level | What to monitor | Performance expectations (KPIs) | Data collection method and source | Reporting |
|---|---|---|---|---|
| Activities | ▪ Literature review of high-technology urban horticulture in Australia and internationally<br>▪ Appropriateness of modelled scenarios and BCA's<br>▪ Level of industry input into project (via the PRG)<br>▪ Gaps identified and addressed. | ▪ Completion of bi-monthly meetings with PRG<br>▪ Identification and prioritisation of gaps in Australia<br>▪ Identification of Australia's capacity for high-technology urban horticulture<br>▪ Identification and modelling of realistic scenarios and BCA of potential applications of high-technology horticulture in urban Australia. | ▪ Record keeping from project team<br>▪ Feedback from PRG<br>▪ Feedback from industry associations<br>▪ Feedback from Hort Innovation. | ▪ 3 meetings held with PRG<br>▪ Gaps for HTUH in Australia identified (see report)<br>▪ Australia's capacity for HTUH identified (see report)<br>▪ Six HTUH systems modelled<br>Economic analysis of four systems. |
| Outputs | ▪ A robust feasibility assessment<br>▪ Identified key opportunities and challenges and environmental and social benefits<br>▪ Recommendations on realising opportunities. | ▪ Situation and outlook described and documented<br>▪ Three realistic scenarios modelled. | ▪ Project records and documents<br>▪ Feedback from PRG. | ▪ Situation and outlook described and documented in final report<br>▪ Six systems modelled<br>▪ Economic analysis of four systems. |
| Short-term outcomes | ▪ Change in knowledge of opportunities and challenges for high-technology horticulture in urban environments. | ▪ Increased knowledge / use of information by industry members involved in the development of high-technology urban horticulture<br>▪ Greater awareness by horticulture industries of high-technology urban horticulture capability and options within Australia. | ▪ Observations<br>▪ Feedback from industry associations<br>▪ Feedback from PRG. | ▪ To be developed upon communication of final report. |
| Medium-term project outcomes | ▪ New information and resources generated to assist in greater intensification of production for growers. | ▪ Number of new high-technology urban horticulture developments and RD&E projects<br>▪ Establishment of collaborative RD&E opportunities (nationally and internationally). | ▪ Feedback from industry associations. | ▪ To be developed upon communication of final report. |

# 6 Opportunities

While the challenges identified in this report will constrain the adoption of HTUH in Australia, this may change as Australia adapts to the impacts of a changing climate, relatively high labour costs, and evolving consumer expectations for high quality, healthy, hyper local products.

Improving localised food security has often driven the adoption of HTUH internationally. Australia, as a net food exporter, is in a unique position. The country produces enough food to feed its 25 million inhabitants, as well as an additional 60 million people through food export[69]. For this reason, HTUH is unlikely to play an important role with regards to addressing food insecurity in Australia. Factors that may drive the development of HTUH in Australia include:

- **Changing natural resource context**: Changes in environmental systems and climate change continue to present challenges to food production in Australia. The frequency and intensity of extreme weather events, such as droughts, bushfires and floods will increasingly threaten food production. Coupled with this is the increasing pressure on limited freshwater systems. Consequently, food production needs innovative strategies to adapt and mitigate these environmental changes. In rural landscapes, weeds and pests are increasingly resistant to herbicides and pesticides, making farming operations vulnerable. While HTUH is not the only existing strategy to tackle those issues, its protected environment makes it less vulnerable to weather events, pest outbreaks and weed invasion, and its high water efficiency makes it a viable candidate in a dry country like Australia.
- **Changing consumer preferences**: Consumer behaviour is a major mega-trend affecting Australian agriculture. This change is characterised by an enhanced concern for the provenance of produce, their health and environmental performance, as well as their social and ethical dimensions. HTUH offers a system of production with low food miles, efficient resource use, traceability and quality control of food. These items may enhance consumers' trust in the products.
- **Labour requirements**: The agricultural workforce in Australia is, on average, 56 years of age70. This is 17 years older than the average worker age across all other sectors. HTUH may attract a younger, more technology oriented generation towards farming, and offer opportunities for technology-based graduates to join the industry. The urban location of these new food production systems may also make it more attractive to future workers.
- **Growing technology focus as an enabling environment**: Australia has been focusing and investing in agricultural technologies, which is anticipated to become a $100 billion industry by 2030, showing its willingness to be ahead of the curve when it comes to innovation related to food production. HTUH industries can leverage this interest in technology to expand production systems.

[69] Commonwealth of Australia 2020.
[70] Commonwealth of Australia 2020.

# 7 Recommendations

This feasibility study has identified several areas where further work is required to enable HTUH in the Australian context. Recommendations for further investigation relating to the four areas of economics, social, environment and innovation are detailed below.

## 7.1 Economics

In Australia, high land prices in city centres will challenge the competitiveness of HTUH. Opportunities to address this could include:

- Developing and locating 'precincts' in peri-urban areas where land prices are lower. Purchase or lease of land within these precincts could also be subsidised by government to lower the capital costs to establish HTUH businesses. The agri-food precinct proposed for development near the new Western Sydney airport is an example of where government support in combination with proximity to road infrastructures and airports would enable the efficient production, harvesting, packaging and exportation of food produced in HTUH systems.
- Utilising any current or future unused space in urban environments such as car parks. The transition to a low carbon economy and the rise of autonomous vehicles may free some spaces in the city, notably carparks, that could be used for HTUH. COVID-19 gave the impetus to rethink city planning and reemphasise the importance of proximity, notably through the concept of '20 minutes neighbourhood'. '20 minutes neighbourhoods' may create opportunities to include HTUH in urban city plans, as its new residents have a likely willingness to pay for local food produced on high-tech farms.
- To be profitable, product grown using high technology systems needs to:
- Achieve a premium price (by focussing on the local provenance, environmental credentials, and nutritional value of HTUH product to establish a 'point of difference')
- Be sold in relationship based markets (direct to consumers, the food service sector and green grocers)[71].
- Export to Asia could present an opportunity where safety and cleanliness are highly valued characteristics. However, Australian produce in land-based farms is already benefitting from their reputation as safe and clean produce. The question remains to know whether international consumers will differentiate higher cost high-technology urban produce from other Australian agricultural produce.
- Other options for product diversification and generating revenue are:
- Production of transplants (where transplants are grown from seed and then used for greenhouse production)
- Production of medicine or plant-based compounds (for example the production of medicinal cannabis which requires very specific growing conditions and the ability to control the quality of the final product)
- Incorporating value-adding activities such as educational tours of the farm, workshops and events on the farm. Farmwall, a high-tech urban farm in Melbourne, organises 'twilight urban farming' on Fridays, where community members have the opportunity to do some farming.

## 7.2 Social

### 7.2.1 Institutional Support

Australia needs to foster a more supportive regulatory and institutional environment for HTUH. To do so, Australia could draw on examples of cities internationally, that have been successfully developing HTUH, as well as on the Australian experience linked to the integration of green infrastructure into the urban fabric.

[71] Personal Communication with industry stakeholders (2021)

Based on these international examples, several key factors that appear to be conducive to the development of high-tech urban farms include:

- The establishment of policy objectives focussed on food security in land scarce countries (such as those used in Singapore to drive food production in urban environments)
- The collaboration of universities, government agencies and private businesses through public-private partnership, to foster the development of a HTUH 'ecosystem' made up of start-ups and businesses able to develop new technologies and services
- The provision of grants and financial support to start-ups and existing businesses, which can help overcome the barriers of initial capital investment and enable the upgrade of equipment and systems
- Facilitating the access to physical space to farm through competitive calls for proposals.

### 7.2.2 Regulation and planning

Recommendations to better integrate HTUH in development projects and planning provisions, include:

- Including HTUH in local planning schemes as an allowable use or complying development to enable its inclusion in new developments
- Providing an incentive for the integration of HTUH in development projects. For example, it could count towards eligibility for a Floor to Space Ratio Bonus.
- Developing operational models that show developers how high-tech urban agricultural systems can be integrated into development projects

A pathway for implementing these types of reforms in Australia has been demonstrated by the increasing integration of green spaces into urban policies and planning. In 2020, the New South Wales government published Greener places: An urban green infrastructure design framework for New South Wales. This document stresses the need to integrate green infrastructure into the NSW strategic planning framework, and to consider them as an essential component of planning for strategic growth and infrastructure.

Funding the development of green infrastructure currently occurs through grant programs from Federal and State funds and developer contributions such as local or special infrastructure contributions or voluntary planning agreements.

New ways to fund green infrastructures could occur by:

- Making green infrastructure an essential infrastructure in the NSW Strategic Planning Framework and other relevant state planning instruments
- Putting an economic value on green infrastructure
- Integrating green infrastructure into existing grey infrastructure funding.

While this design framework focuses on green spaces in NSW, and does not include HTUH, integrating high-tech urban farms as a form of green space, or applying some of the strategies developed for green spaces to high-tech urban farms may be a useful strategy in Australia.

### 7.2.3 Community Support

Although low tech urban horticulture developed for community purposes offers a range of social benefits, there are some negative perceptions regarding high technology horticulture developed for commercial purposes that may affect its social acceptance[72]. Concerns have also been raised regarding the equity of food produced this way.

[72] Sanyé-Mengual et al. 2016; Specht & Sanyé-Mengual 2017; Specht, Siebert & Thomaier 2015

Strategies to improve public acceptance of HTUH could include:

- Running public access and social and educational activities by high-tech commercial farmers, to integrate the farm into the neighbourhood
- Conducting information campaigns on HTUH, particularly regarding its environmental sustainability. This includes the dissemination of research results, pilot and demonstration projects as well as educational tours of existing farms.
- Developing quality standards and certification schemes to minimise worries around health risks related to high-tech agricultural products. Looking into the possibility of certifying high-tech agriculture produce as organic could also be considered, as organic produce are often well perceived by the public.
- Ensuring that the design and planning of HTUH projects is as inclusive and participatory as possible[73].

## 7.3 Environment

Australia is a climatically vulnerable and water scarce country. HTUH is highly water efficient and resilient to extreme weather events. Therefore, it may be relevant to assess how HTUH can complement land-based agriculture, which will be increasingly affected by extreme weather events and water scarcity. While HTUH is not the only existing strategy to tackle those issues, its protected environment makes it less vulnerable to weather events, pest outbreaks and weed invasion, and its high-water efficiency makes it a viable candidate in a dry country like Australia.

To address the energy needs of HTUH there are opportunities to use alternative energy sources such as solar panels, roof-top wind turbines, storage batteries and reusing waste heat to reduce reliance on fossil fuels. Solar glass technologies are currently being studied in Australia by Swinburne University which aim to regulate light and capture it through a photovoltaic transparent material.

## 7.4 Innovation

Innovation in the areas of technology and production that reduces the costs associated with the adoption of high technology systems will help enable HTUH in the Australian context. Innovation geared towards increasing the viability of HTUH include:

- Increasing productivity through automation, and use of data analytics and sensor networks, to reduce operational costs (e.g. labour costs) and facilitate greater economies of scale by enabling farmers to manage several farms at a distance
- Lowering costs, particularly those associated with energy consumption through use of LED lighting systems that have lower energy consumption, low waste heat generation as well as optimised spectra of plant growth. The use of alternative sources of energy such as geothermal or urban waste heat for heating, and renewable energies, such as solar photovoltaics, for energy (O'Sullivan et al. 2019).
- Refining current production system by understanding the mix of crops that will perform best in the chosen environment, and through the manipulation of temperature, lighting periods, and CO2 levels to achieve the highest number of plant cycles.

[73] Specht & Sanyé- Mengual 2017

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# Intellectual property, commercialisation and confidentiality

This project report is intended for public dissemination.


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# Appendices

Appendix 1: Typology of systems and technologies for urban agriculture

Appendix 2: Resource analysis of six HTUH systems performed by Agritecture

Appendix 3: Pairwise comparison outputs by Agritecture