**GCRI Trust: 'Towards Net Zero Emissions in Protected Horticulture'**

**2021 Desk Study Competition Entry**

# Attracting investment to eliminate fossil fuel usage on small-scale ornamental nurseries in the UK.

**Janet Mobbs**
**Lineside Nursery**
**Warwickshire**

- Maintaining optimum temperatures in polytunnels and glasshouses is a constant challenge.
- Producing heat by burning fossil fuels, or wood, releases harmful carbon dioxide.
- Solar panels, wind turbines and ground-source heat pumps are all readily available alternatives but are expensive to install.
- Investors are needed to pay for the installation of these items in return for an annual rental, with capital repayment when a nursery is sold.

## Contents

## Background

The entire lifecycle, from seed to decay, of a plant growing naturally outdoors is a carbon-neutral process. It is only man's desire to grow plants faster, to make them flower at specific times, and to grow non-native species, that has led to the need for polytunnels and glasshouses, and for them to be heated for all or part of the year.

Currently the heat energy used in horticulture mainly comes from the burning of fossil fuels, which are transported to nurseries in, or on, heavy vehicles which are also powered by fossil fuels. This releases tonnes of carbon dioxide into the atmosphere.

Applying the reduce, re-use, recycle principle, we need to: 1) minimise the need for artificial heat and maximise the use of alternative energy resources. 2) where possible, capture any carbon dioxide produced and introduce it to plants when they need it for photosynthesis. 3) if necessary, store the carbon dioxide in a different chemical form.

### 1a) Minimise the need for artificial heat

Reducing the need for heat could theoretically be achieved by increasing insulation or by increasing the amount of heat storage capacity, such as using gravel in polytunnels.

Totally eliminating the need for heat could only be achieved by dramatically changing customer expectations of what plants or flowers to buy and at what times of the year.

### 1b) Use alternative energy resources

In common with other industries, switching from burning fossil fuels to using wind, solar or ground-sourced or air-sourced energy would dramatically reduce the amount of carbon dioxide released into the atmosphere.

Alternatively, if nurseries are to continue to use combustion to generate heat, is it feasible to burn material which might be burnt on site in any case, such as hedge trimmings?

### 2) Capture any carbon dioxide produced

Re-using the carbon dioxide produced by combustion is a possibility. Already some nurseries pump carbon dioxide into closed system glasshouses to aid photosynthesis. However, the process of burning fuel would only be carbon-neutral if all the carbon dioxide were used by the plants at a time when carbon dioxide concentration was their limiting factor. Otherwise, the freshly produced gas would simply replace the gas that the plant would otherwise have extracted from the atmosphere.

### 3) Store the carbon dioxide for future use

Hardy nursery stock growers could store the carbon dioxide produced in the winter months for use the following summer. This could either be done directly, in gas cylinders or other pressurised containers, or indirectly in a medium such as lime pellets.

This study details the feasibility, and the potential impact on carbon dioxide emissions, of each of these proposals. It also proposes that, as part of diversified portfolios and with potential Environmental, Social & Governance (ESG) benefits, investors could be attracted to provide the necessary capital expenditure via a Horticultural Energy Investment Fund.

# Reduce

## Reduce the need for heat

### Change customer expectations

Unheated polytunnels and glasshouses can protect a vast range of garden plants in an average winter in the UK. So, in theory, the production of hardy nursery stock, which accounted for 69% of the £1.4 billion worth of ornamental plants and flowers grown in the UK in 2019[i], should require no artificial heat.

However, the British weather is too unpredictable for growers to be able to guarantee that varieties such as Ceanothus and Rosemary will survive every winter. Plants which do survive, and then grow away rapidly at the arrival of Spring, can easily succumb to an unexpected late frost. And the British public will always desire varieties which are unusual, which remind them of their foreign holiday, or which need special nurturing for them to thrive.

*Left: Young plants which have mostly successfully overwintered in an unheated polytunnel.*

*Right: young Spiraea japonica 'Genpei' plants with bent tips caused by frost damage in an unheated polytunnel. Easter 2021*

Timescales also drive the need for heat. To help cashflow, finished stock ideally needs to be ready early in the growing season to coincide with peak demand. In turn, this leads some retail nurseries to expect their deliveries of liners[1] in February and March, which necessitates the liner producer over-wintering more plants or using heat and light to advance the growth of seedlings at the beginning of the year.

Growers of cut-flowers, bulbs and flowering houseplants are even more restricted by the need for their crop to be at its best at just the right moment, whether that is Mothers' Day, Christmas or the next RHS flower show. Temperature control, combined with day length, is critical for success.

Swaying customer opinion and breaking habits or traditions is a long, arduous process, which would need industry-wide agreement, so is probably not a realistic option for reducing the need for heat.

### Reduce heat loss

There are various ways to reduce heat loss:

[1] Liners are young plants, traditionally grown in lines in outdoor beds, but now often grown in pots, initially under protection.

- **Insulation** reduces the amount of fuel needed to achieve the desired temperature rise. However, if it is not easily removable, it will continue to act in the summer months when overheating becomes a threat to plant health. Instead, retractable energy-saving screens can be suspended high up in a polytunnel or glasshouse, effectively reducing the volume of air needing to be heated. These are most useful where light intensity is not of paramount importance as the retracted shade will cast a shadow during the day. It is stated that a 47% energy saving can be achieved with only an 11% drop in light transmission.[ii] These screens are expensive but straightforward to install in glasshouses and multispan tunnels but are difficult to engineer for the curvature of a single span.
  The table below shows the U-values for greenhouse glazing alternatives.[iii] The U-value is a measure of the rate of heat loss, so the lower the number the better.

**Energy Savings Table**

| Type of glazing | Product | U Value {BTU/(ft².°F.h)}ß |
|---|---|---|
| Keder Cladding | Polydress LP-Keder Air Bubble Film | 0.5 |
| Single glazing | Glass covered greenhouse (0.12'') | 1.4 |
| Single sheeting | PE- Film (5.9 mil) | 1.4 |
| Double glazing combination | Polycarbonate covered greenhouse (0.2'') | 0.9 |
| Double glazing combination | Polyethylene Double Layer inflated (w2'' air gap) | 0.7 |

- **Siting** will also affect the U-value. See table below.

**U-values for single, double or triple glazing in different wind speeds.**

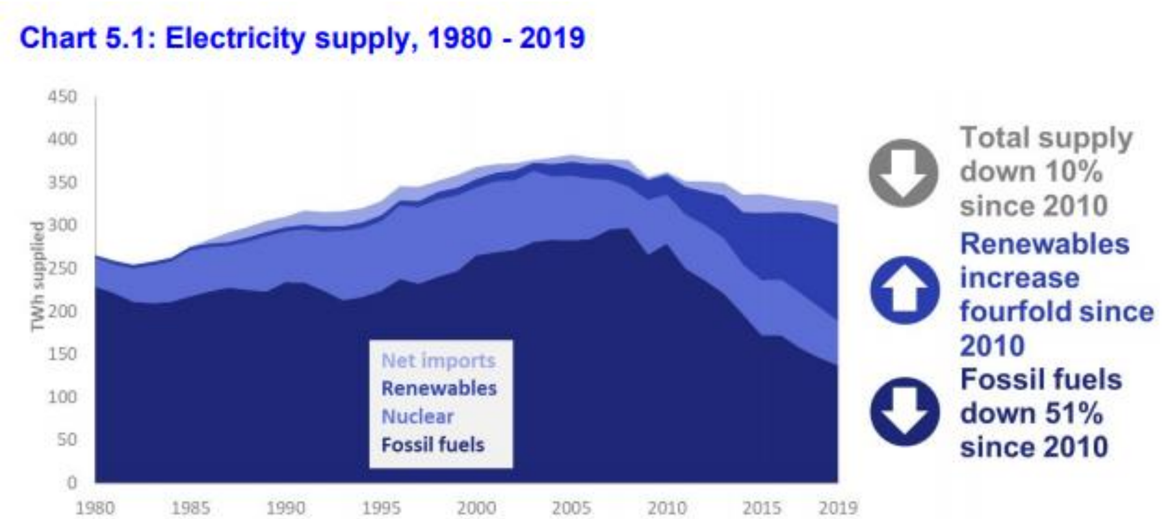
| Construction | Location | | |
|---|---|---|---|
| [iv] | Sheltered | Normal | Severe |
| **Single** window glazing | 5 | 5.6 | 6.7 |
| **Double** window glazing with 12 mm airspace | 2.8 | 3 | 3.3 |
| **Triple** window glazing with 12mm airspace | 2 | 2.1 | 2.2 |

- **Frame construction** should also be considered. Metal frames are far more practical than wooden ones, but metal conducts heat away from the structure at a much faster rate.
- **Heat sinks** allow thermal energy (heat) to be stored for several hours. Gravel floors, concrete paths and sand beds can be a relatively cheap way of reducing the night-time temperature drop following a sunny day. Synthetic carpets or mattresses, which are waste products that are currently expensive to dispose of, have much higher specific heat capacities than commonly quarried materials. For example, 2500J/kgK for carpet and mattress, 840 for gravel or soil[v]. However, mattresses are far less dense than gravel and would therefore take up far more room in the tunnel for the same heat holding capacity.
  With a specific heat capacity of 4182 J/kgK, water retains heat exceptionally well. Is it practical to site rainwater-harvesting irrigation tanks under every polytunnel at the construction stage? This could be particularly beneficial in areas prone to flash flooding.
- **Heating at ground level** is more efficient than heating the air higher up.[vi]

### Reduce $CO_2$ emissions

Having determined that some heat will be needed for at least part of the year on most nurseries in the UK, the next task is to persuade the industry to switch from combustion to 'clean' electricity.

In 2019, only approximately 11% of electricity generated by UK companies came from wind, wave and solar photovoltaics, while more than a third came from gas power stations.[vii]



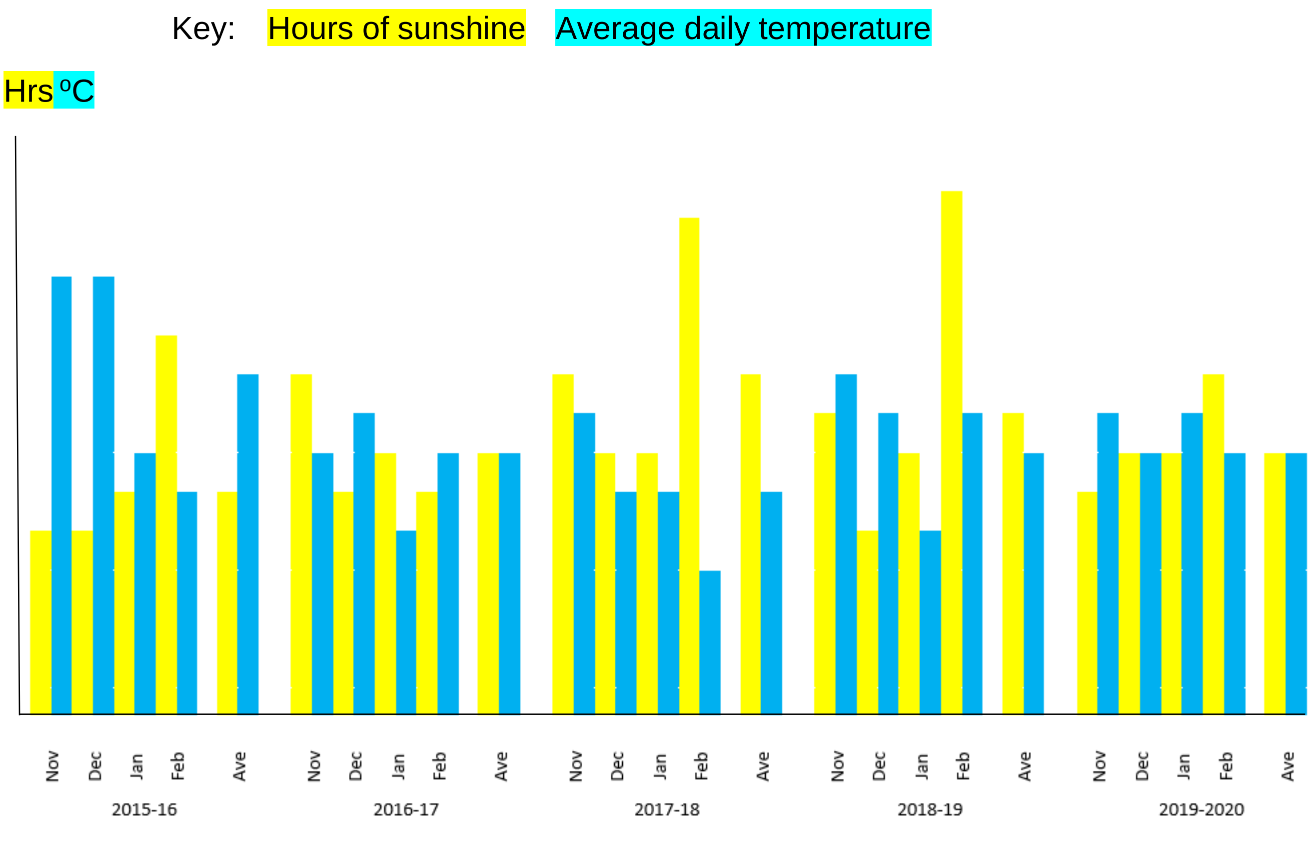

[viii]Because the UK is a net importer of electricity, it makes sense for nurseries to generate their own electricity and to sell any surplus to the National Grid. Unlike most industrial, commercial or domestic usage, horticultural demand is greatest at night. It is also greater in the winter than in the summer. At first sight, this pattern of usage broadly coincides with wind strength rather than sunshine. However, frosty nights are rarely windy. In the past 5 years, there were 2 months in the UK when the wind speed was more than 2 knots faster than average.[ix] These coincided with average monthly temperatures of 9.5°C and 6.4°C. By contrast, the average temperatures in the 4 winter months when the wind speed was more than 2 knots slower than average were 5.8°C, 4.3°C, 4.2°C and 6.5°C.[x]

This data confirms that the coldest nights are unlikely to coincide with the strongest winds. Also, a nursery will be positioned such that the glasshouses and polytunnels have maximum exposure to sunlight and minimum exposure to gusting winds.

While some nurseries are in remote locations, some are situated close to houses. Will neighbours accept a noisy, dominating wind turbine as readily as a silent array of solar panels?

A more detailed look at the weather data reveals that, during the winter months, sunniest days generally coincide with the coldest temperatures. Over the last 5 years, the only month which has seen an average minimum air temperature below freezing was February 2018[xi], which was also the sunniest winter month during the same period. Could solar photovoltaic panels, connected to a battery, store enough electricity to heat a polytunnel overnight?

**Sunshine hours compared with temperature for UK winter months over the last 5 years**




[xii]

Assuming that an uplift of 15°C might be needed for frost protection on the coldest night of the year in the Midlands, a 40kW electric heater would be needed for each polytunnel.[xiii] Several websites[xiv] quote figures close to 250 m$^2$ as the area covered by a 40kW array of solar panels – considerably larger than the size of the polytunnel that it would heat. To justify that magnitude of investment in land and money, the array would have to be able to export surplus electricity to the National Grid as well as storing surplus electricity generated during daylight hours to use at night. But if mains electricity was already in the vicinity, then a much smaller array could be used, with extra power being drawn from the grid only when needed.

Ground source heat pumps are also a possible alternative. In the UK, the temperature of the Earth a few metres below our feet is constant, around 8-11°C. The purpose of ground source heat pumps is to absorb heat from one place and transport and release it to another location.[xv]

Where space is available, pipes are installed in a horizontal trench and typically buried at 1.2M – 1.5M below ground. For every 1kW of electricity used to operate a heat pump, 3kW to 5kW of heat energy is produced and available on demand for heating.[xvi] This suggests that to produce the same temperature rise as a 40kW heater, 10 kW of electricity would need to be drawn from the mains during times of peak demand. As with the solar panels, a smaller ground source heat pump system could be installed, with the mains as a booster only when needed.

Photo left:

Ground source heat pump pipework

https://www.thermalearth.co.uk/agriculture

Where the required amount of space is insufficient, the system can be installed vertically. It is even possible to lay the system as a water-source heat pump, with heat being absorbed from a nearby water resource, such as a pond or a lake. Could a small one be incorporated in a rainwater harvesting tank or irrigation tank?

If minimal land is available, then an air source heat pump could be considered. These act in the opposite way to a refrigerator, require minimal maintenance, but are slightly less efficient than a ground source heat pump. Finn Geotherm's website states that "the efficiency of an air source heat pump varies as the outside temperature changes. Overall, we would expect most systems to generate 3.5kW of heat for every 1kW of electricity used."[xvii] The figures are for general heating and not for frost protection alone, which would probably be considerably more efficient as a much lower temperature rise is required.

The huge advantage of ground source heat pumps and air source heat pumps in horticulture is that they can be reversed, providing a cooling system for polytunnels during the summer months.

## Re-use

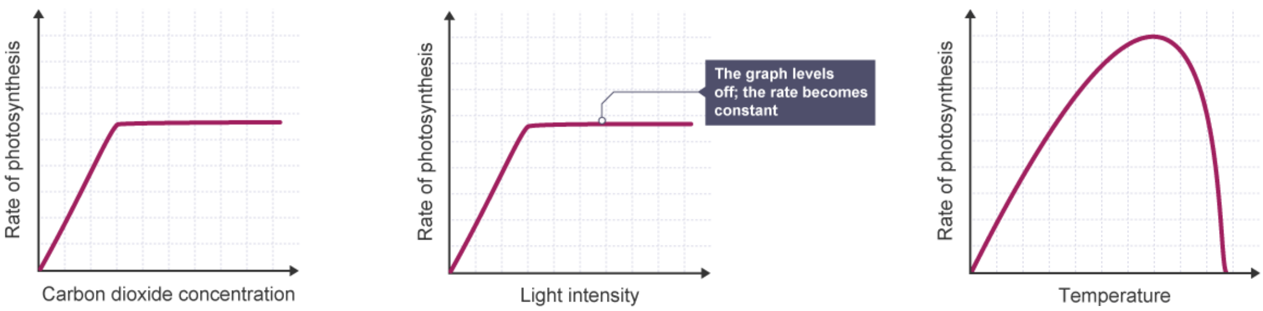
### Heat from hedge-trimmings

If sufficient heat cannot be produced by any means other than burning, then can the fuel used be a source which would be burnt on the nursery regardless of the need for heat? In the UK, field hedges should only be trimmed during the winter months, which is when the need for heat in polytunnels and glasshouses is greatest. Current wood-burning heaters are designed for use with wood pellets of a consistent composition. Meanwhile, hedge trimmings are being burnt on bonfires as a convenient method of disposal. If the trimmings could be shredded, compressed and burnt in a boiler, with the heat produced being conveyed into a polytunnel, no extra carbon dioxide would be released into the atmosphere, assuming that the electricity powering the shredder and compressor was produced by ‘green’ means.

Similarly, could unsold woody plants, and the prunings from stock plants, be used in this way rather than being composted?

### Carbon dioxide for photosynthesis

Alternatively, if carbon dioxide production cannot be eliminated, can this waste product be re-used? There are three main factors which limit a plant’s ability to photosynthesise: temperature, light and carbon dioxide.




[xviii]

Plants need to photosynthesise to produce glucose, which is essential for providing energy.

Less photosynthesis = less glucose production = less plant growth = less profit.

In the UK, for most of the year, without artificial light or heat, low carbon dioxide concentration will not be a problem. But there are occasions on warm, sunny days in a structure that is densely packed with plants, that carbon dioxide will be the limiting factor. Since these days will never coincide with the need for artificial heat, then collection, storage and subsequent application of the carbon dioxide produced are the issues.

Capturing carbon dioxide is now done on an industrial scale at several sites across the world, but it is not a simple process and will probably never be scaled down to general horticultural level.

However, using captured carbon dioxide to boost crop growth does already take place in closed system glasshouses in the UK. But even this has potential drawbacks. For example, B Grodzinski et al found that “in some herbaceous species, prolonged exposure to high $CO_2$ results in remobilization of nitrogenous reserves (i.e. leaf protein degradation) and reduced rates of mature leaf photosynthesis.”[xix]

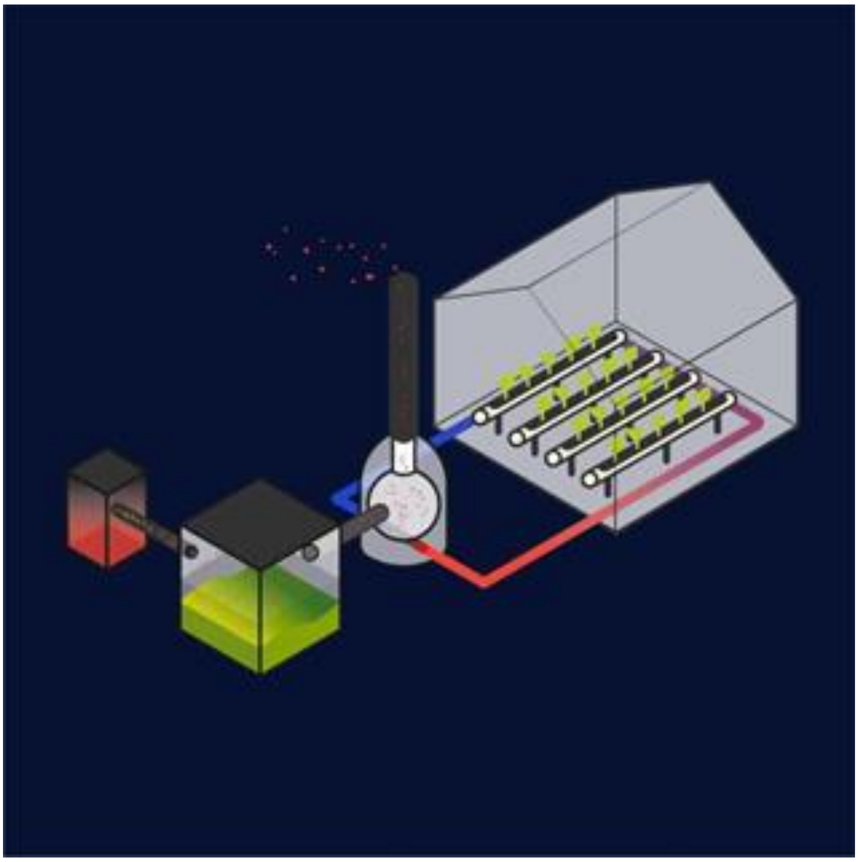
Closed systems are unlikely to be practicable on the average family-run hardy nursery stock nursery, so can carbon dioxide be delivered to plants in a polytunnel at the exact time and rate that it is needed? Carbon dioxide is heavier than air so, in theory, if the gas is released just above the height of the plants, it should filter down through the foliage and be taken in through the leaves. Carbon dioxide sensors can determine when the gas release should occur and technologists would be able to advise on the desired rate of release.

This assumes that the gas being delivered is pure carbon dioxide. However, 78% of air is nitrogen, which remains unchanged during combustion and is therefore a major component of the exhaust gas, with carbon dioxide probably being in the region of 10-15%.[xx] Either the nitrogen would have to be removed or the volume of gas stored would have to be up to ten times greater if the nitrogen is still present. In addition, if the impurified exhaust gases were introduced to the growing crop, the rate of flow would need to be ten times greater to deliver the same quantity of carbon dioxide in any given time. This would, in turn, increase the ‘wind’ speed and hence the rate of water loss from the plant, which is particularly undesirable during the summer months.

## Recycle

As well as storing carbon dioxide in its pure form, it can also be trapped by reacting it with other compounds. The chemical process is then reversed when the gas is needed. Again, this is already being trialled in closed systems.

Secondary school pupils learn that the test for carbon dioxide is to bubble the gas through limewater. Insoluble calcium carbonate forms and is seen as a white suspension, making the limewater appear milky or cloudy. A similar application can be used to trap the carbon dioxide present in the exhaust gases produced by combustion. Instead of limewater being used, the gas flows through a vessel containing lime pellets (shown in green in the diagram below). These pellets trap the carbon dioxide, but nitrogen and other exhaust gases do not react with them. Heat is extracted from these waste gases before they are released back into the atmosphere. Subsequently, hot air is blown through the lime pellets to release the trapped carbon dioxide, which is then piped into a glasshouse.


xxi

## Advantages and Disadvantages

Reduce (in purple), re-use (*in green italics*) or recycle (**in blue bold**)?

| Proposal | Advantages | Disadvantages |
|---|---|---|
| *For brevity, carbon dioxide is shown in this table in symbol form: $CO_2$* | | |
| Stop using heat | Effective reduction of emissions.<br>Cost saving. | Stock losses.<br>Limits consumer choice. |
| Improve cladding and add thermal screens | Reduces the amount of heat needed.<br>Relatively cheap. | Reduced light levels.<br>Extra cost.<br>Limited effect. |
| Add a heat store within each tunnel or glasshouse. | Absorbs heat during the day, releases it at night.<br>Gravel, sand and concrete are readily available and are routinely used as ground components in polytunnels and glasshouses. | Limited effect.<br>Environmental impact of extracting / manufacturing and transporting these components. |
| Rainwater harvesting tank under each polytunnel. | Absorbs heat during the day, releases it at night. | Safety. Access to tank for maintenance.<br>Expensive to install.<br>Limited effect.<br>Cannot be retrofitted. |
| Wind turbine | No $CO_2$ emissions once installed.<br>Surplus electricity can be sold to the grid.<br>Existing technology. | Most needed on stillest nights.<br>Expensive to install.<br>Maintenance costs.<br>Mains back-up needed to each polytunnel.<br>Planning permission needed.<br>Visually intrusive and noisy.<br>Unsuitable for sheltered locations. |
| Solar panels | No $CO_2$ emissions once installed.<br>Surplus electricity can be sold to the grid.<br>Existing technology. | No sun at night.<br>Vast shadowless area needed.<br>Expensive to install.<br>Maintenance costs.<br>Mains back-up needed to each polytunnel.<br>Planning permission sometimes needed.<br>Visually intrusive.<br>End-of-life disposal? |

| | | |
|---|---|---|
| Ground source heat pumps | No $CO_2$ emissions.<br>Out-of-sight.<br>Uses only ¼ of the electricity that would otherwise be needed.<br>Can be reversed to cool polytunnels in summer.<br>Existing technology. | Large area needed but it can be grassed over or agricultural crops can be grown.<br>Expensive to install.<br>Maintenance costs.<br>Mains supply needed. |
| Air source heat pumps | No $CO_2$ emissions.<br>Can be attached to a building.<br>Uses less than $^1/_3$ of the electricity that would otherwise be needed.<br>Can be reversed to cool polytunnels in summer.<br>Existing technology. | Expensive to install.<br>Maintenance costs.<br>Mains supply needed. |
| *Burning hedge trimmings* | *Free fuel.*<br>*Only releases $CO_2$ which would have been released anyway.*<br>*Heat is easily transportable to each polytunnel.* | *Shredding and compressing would use fuel or electricity.*<br>*Technology not yet available.* |
| *On-site trapping, storing and re-using $CO_2$ emissions* | *Fossil fuel heaters are easily portable to each polytunnel and are currently widely used in the industry.* | *Fossil fuels are a finite resource.*<br>*Technology not yet available.*<br>*Possible imbalance between the amount of $CO_2$ produced and the amount that can be used by the plants.* |
| **On-site trapping and recycling of $CO_2$ emissions** | **Fossil fuel heaters are easily portable to each polytunnel and are currently widely used in the industry.** | **Fossil fuels are a finite resource.**<br>**Technology not yet available on this scale.**<br>**Possible imbalance between the amount produced and the amount that can be used by the plants.**<br>**Space required for equipment.** |

## Expense

The table above shows that only 4 of the existing readily available technologies would allow the production of carbon dioxide to be eliminated when heating polytunnels and glasshouses in the UK. These are:

- wind turbines – in appropriate locations
- solar voltaic panels
- ground source heat pumps
- air source heat pumps

All involve a large capital outlay and, to maximise benefit, a mains electricity supply.
For comparison only, prices for a domestic installation are in excess of £15,000 for a ground source heat pump, £11,000 for an air source heat pump, £5,500 for solar voltaic panels and £20,000 for a wind turbine.[xxii] Payback times can exceed 20 years.

Outlay of this magnitude cannot be justified in an industry which is among the most poorly paid. 2019 figures provided by CareerSmart [xxiii] for UK horticulture show £35,457 as the average salary and 75 as the average number of hours worked per week, equal to £9.09 per hour. This is little more than the national minimum wage for most adults and is well in excess of what many would consider an acceptable number of hours worked. 47% of the industry's workforce is self-employed. These people probably work much longer hours than those who are directly employed, so it is unlikely that the owner of a family-run nursery is ever going to be in a position to invest in any of these technologies. This is reinforced by recent Horticulture Week statistics showing that the median salary for all horticultural vacancies is £30-40,000 whereas the figure specifically for growing is only £20-25,000.[xxiv]

## Investment

### Proposed Horticultural Energy Investment Fund

A solution would be to set up the Horticultural Energy Investment Fund. This would provide the capital needed to cover the full cost of installing one or more of the technologies mentioned above. In return, the Fund would receive a rental from the grower or, where applicable, an agreed proportion of the tariff received from selling surplus electricity to the National Grid.

In addition, when the nursery is sold, the initial installation cost would be paid back to the Fund from the proceeds of the sale. On any subsequent sale of the property, a smaller repayment would be made. The amount would depend on the anticipated remaining lifespan of the technology installed.

As with any major investment:

- the intention would be for the money to remain invested for decades rather than years.
- the return on capital could be fixed (with potentially a variable element related to electricity generation) which may be attractive to longer term investors, such as pension funds.

Added benefits for the investor:

- highly ethical
- loss of capital unlikely as it is linked to land value
- a specific nursery could be cited for an individual's investment
- pre-determined rental figure from completed installations

for the grower:

- carbon-neutral technology to heat their premises without the cost or hassle of purchasing fossil fuels.
- possibly, a proportion of the tariff received from selling surplus electricity.
- most of the cost is deferred until the nursery is sold.

for the electricity industry:

- more 'green' UK electricity generation.
- increased demand only at off-peak times, which would help to balance the Grid.

## Related Funding

The proposed Fund is similar to a residential lifetime mortgage equity release scheme with optional interest payments. However, rather than compounding interest, which is an unpredictable value, the rental rate and the final repayment amount would both be agreed at the outset.

Worldwide, there are currently various sources of funding available for energy efficient projects, but few are tailored specifically to the horticulture industry.

In South Korea, the Greenhouse Deployment Program allows each greenhouse owner to pay just 20% of the installation costs, with national government subsidising the capital costs by 60% and local government by 20%.[xxv]

The horticultural case study on the website of the Australian Government's Agriculture Energy Investment Plan,[xxvi] highlights a hydroponic tomato grower who produces three million kilograms of tomatoes every year. The six-megawatt system cost 600,000 Australian dollars, approximately £330,000.

Closer to home, but on a similar scale, the Scottish Energy Investment Fund[xxvii] initiates investment in large-scale and community energy schemes.

At the other end of the scale, grants or loans are available for community or domestic improvements rather than commercial ones. For example, the Community Energy Warwickshire Fund[xxviii] provides grants of up to £2000 for community and voluntary groups for projects such as making energy efficient changes to their buildings. Another example is the Green Deal Finance Company[xxix] which provides loans for domestic installations.

The UK Government's Renewable Heat Incentive Scheme covered non-domestic as well as domestic buildings but only provided financial gain once a system was installed. On 31.3.21 it closed to new applications. Was a polytunnel a 'building'?

## The current investment market

In February 2020, as the seriousness of the coronavirus pandemic became apparent, share prices suddenly plummeted. Investors were desperate to convert into cash to reduce the likelihood of losses.

Now, however, the situation is totally different. In the words of Etoro: “Both private investors and financial institutions are now studying the current market conditions, trying to locate the segments that will show sustainable growth.”[xxx]

In addition, there is increasing pressure on investment funds to demonstrate that Environmental, Social and Governance (ESG) aspects have been considered in the selection of entities in which to invest. A fund such as that proposed in this submission could be a welcome addition to help investment managers demonstrate their environmental credentials.

It is my opinion that now is a good time to invest in UK horticulture, which has benefitted from the lockdowns, the ability to only meet up outdoors and the current difficulties associated with importing plants from the EU. Investing in sustainable technologies is always a great thing to do. A combination of the two could be very appealing.

# Summary

In polytunnels or glasshouses used to produce ornamentals, including hardy nursery stock, frost protection or higher temperatures are generally achieved by burning fossil fuels or wood. This releases carbon dioxide into the atmosphere. This study concludes that there are two main ways of reducing or eliminating these emissions.

Better insulation is the cheapest, but less effective, option, and is beyond the budget of some family-owned businesses. It also introduces disadvantages, such as reduced light intensity.

As with most industries, the ideal solution is to switch to alternative energy resources. Horticulture has the benefit that land is often available for installations such as solar panels, wind turbines and ground source heat pumps. However, the capital outlay required is prohibitive.

The formation of a Horticultural Energy Investment Fund could provide the necessary capital in return for an affordable rental charge and the repayment of the installation cost when the property is sold. Additional income would be generated by selling surplus electricity to the National Grid – with investor and grower each getting a share – and by any subsequent sales of the property within the lifespan of the products.

## Personal Statement

When Martin, my husband and proprietor of Lineside Nursery, first went self-employed in 1992 he rented an established nursery site and used the resident paraffin heater, set at 4ºC, suspended in the main multispan polytunnel. On moving to our own site in 2001, we set up a frost protection heater running off LPG in a single span. Within three days the 47kg cylinder was almost empty. Never again!

My interest in renewable energy resources was first sparked by teaching secondary science in 2003.

On several occasions since then we have investigated solar panels and wind generators, but the capital outlay cannot be justified and the payback time is too long, sometimes even longer than the expected lifespan of the installation.

This competition has focussed my mind on finding a solution to our problem, which could potentially benefit all growers currently using combustion to heat glasshouses or polytunnels.

## Contact Details

Janet Mobbs

Lineside Nursery

Current occupations:
All year: Horticultural assistant, working in polytunnels and office.
Autumn and winter only: On-line science tutor for disadvantaged children.

### Acknowledgements

I would like to thank these people for their input on the following topics:
My brother, Mike Longman – Investment
My husband, Martin Mobbs – Horticulture, and for showing me the competition details
Our son, Tristan Mobbs – UK electricity demand
Our friend, Keith Sinfield – Environmentally-friendly technologies and IT glitches

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[iii] The table is copied from Keder's website but the final column heading has been changed to reflect the description in their text and the accessibility issues highlighted by Microsoft Word have been resolved. https://www.kedergreenhouse.co.uk/Keder_Cladding

[iv] Data extracted from IES website.
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https://help.iesve.com/ve2018/table_6_thermal_conductivity__specific_heat_capacity_and_density.htm

[vi] Verbal communication from Ben Crossland of Crosslands Flower Nursery during a Zoom meeting with Brinklow WI April 2021

[vii] Calculated from data in DUKES 5.3. See link below.
[viii] https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

[ix] Data taken from the graph https://www.statista.com/statistics/322788/average-monthly-change-in-wind-speed-in-the-united-kingdom-uk/

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[xi] https://www.statista.com/statistics/584885/monthly-minimum-temperature-in-uk/ Published by Madhumitha Jaganmohan, Jan 8, 2021

[xii] Data for compiling the graph was taken from
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[xiii] Value derived by using the equation and data given on the Dantherm website:
https://www.danthermgroup.co.uk/ee_pdf/How_to_Choose_your_Master_Heater.pdf

[xiv] e.g. https://kenbrooksolar.com/system/40kw-solar-system-price
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