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Authored by: Energy Sciences and Evergreen Consulting Group

# DTE

# Community Grow Pilot Market Research Report

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# Executive Summary

Food quality, supply chain, and human health have become popular topics in news headlines within the last few years. While many traditional agriculture sectors are on the decline, crops grown in controlled environments show great promise for Michigan's modern-day food and supply chain challenges. Consumers are noticing the endless benefits of locally and efficiently grown produce: better food quality, mitigation of pandemic supply chain issues, more nutritious foods, lower carbon footprint, more equitable access, weather protection, pest prevention, and extended growing seasons. Demand for fresh, locally grown food continues to grow globally due to population growth, an increase in at-home dining, and the desire for more plant and food options. Although the national and global need for food has increased, the number of vacant greenhouses has also increased throughout the U.S., including Michigan, shifting towards a reliance on mass-produced, non-organic and non-local vegetables. To better understand and support local Michigan greenhouse businesses, the DTE Community Grow Pilot (Grow Pilot) was created.

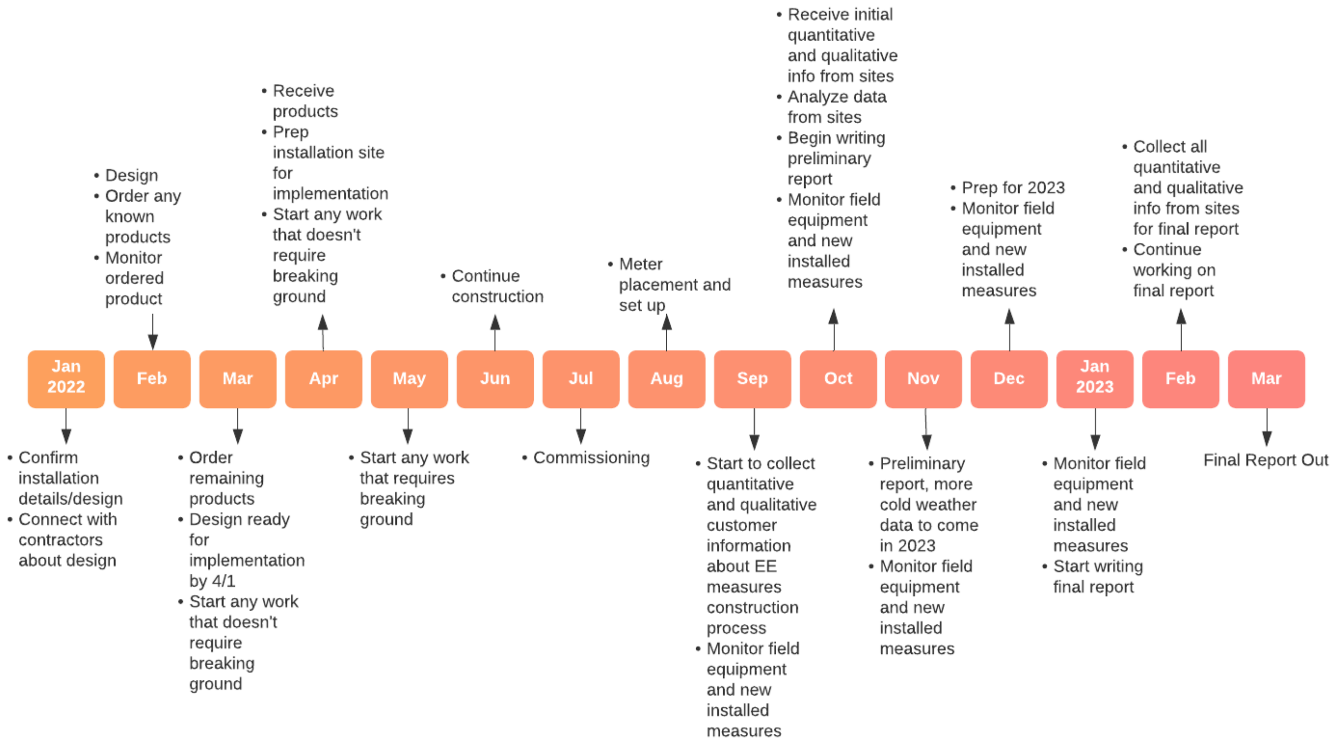
DTE is passionate about providing a comprehensive spectrum pilot that addresses the needs of their community. The DTE Community Grow Pilot will explore various community infrastructure options to financially support greenhouse facilities operations. This DTE Community Grow Pilot Market Research Report will lay the technical groundwork and identify potential 2022 demonstration sites and options for the next phase of the pilot. DTE has a goal to assist the greenhouse community in their territory by implementing the most impactful and proven energy efficiency measures. This work will not only benefit greenhouse growers, but it will also address the need across DTE's territory for access to fresh, locally grown foods. Both household and restaurant level consumers will benefit from access to food grown locally in efficient, thriving greenhouses.

The Market Research Report presents findings from greenhouse interviews, site visits, and technical research on potential energy efficient (EE) measures, as well as the development of a future program to support the Michigan greenhouse sector. Energy Sciences and Evergreen Consulting Group (IC) have worked together to use all relevant findings to identify two potential greenhouse pilot projects. The two chosen greenhouse sites will be leveraged in 2022 as case studies and examples for other greenhouses to flourish and increase their efficiency in DTE's territories. Throughout this

report, IC will demonstrate exciting and new proposed measures, innovative ideas, and potential for increased DTE market participation in a historically underserved customer segment.

The goals and conclusions of this DTE Community Grow Pilot Market Research Report are summarized in the table below.

| Short-term Goals | Conclusions |
|---|---|
| Evaluate existing greenhouse stock through interviews and site visits. | Michigan has hundreds of year-round greenhouses growing diverse crops. Although the total greenhouses in Michigan are decreasing, several customers were planning on expansions or owned multiple successful locations already. Site visits and interviews were completed for 14 greenhouses. |
| Provide DTE with recommendations for energy efficiency measures that the benefit the community grow market. | Some greenhouse energy efficiency (EE) measures are already supported through DTE, and growers would appreciate even more support. Additional measures were recommended for further investigation: low-intensity infrared (IR) heaters, insulating jackets, geothermal heating systems, roof and ridge vents, and multi-wall polycarbonate panels. |
| Identify two greenhouse locations for 2022 demonstration sites and associated costs. | Three greenhouses surveyed were proposed as potential demonstration sites for 2022. See Section 5. Potential Pilot Participants for details. |
| Establish mutually beneficial relationships with local and national supply chain for smoother implementation. | The team interviewed local and national greenhouse specialists and established relationships for future collaboration on EE projects, education, rebates, and more. |
| **Long-term Goals** | **Conclusions** |
| Develop a sustainable strategy to stimulate Michigan's agriculture businesses. | If DTE can engage with greenhouses regularly, it will be easier to annually update programs to meet customer needs. This steady economic support over time will help stimulate the Michigan agriculture sector and promote innovation in controlled environment agriculture (CEA). |
| Create measurable positive impact within Michigan communities: increased local food resources, positive economic impacts across Michigan, and increased DTE customer satisfaction. | DTE is supporting this research to first understand greenhouse growers' needs and challenges. By prototyping and developing new EE measure opportunities alongside community-based greenhouses in 2022, DTE is on track to provide the best service possible for these CEA customers while delivering innovative, cost-effective savings. Measuring this impact will be core to the success of the Grow Pilot. |
| Leverage supply chain relationships to help with technical details and fill project pipelines. | Supply chain and industry partners interviewed contained a wealth of knowledge in markets, technologies, contacts, and EE opportunities. Maintaining these relationships will be crucial to DTE's success in promoting rebates and engaging customers across the supply chain. |

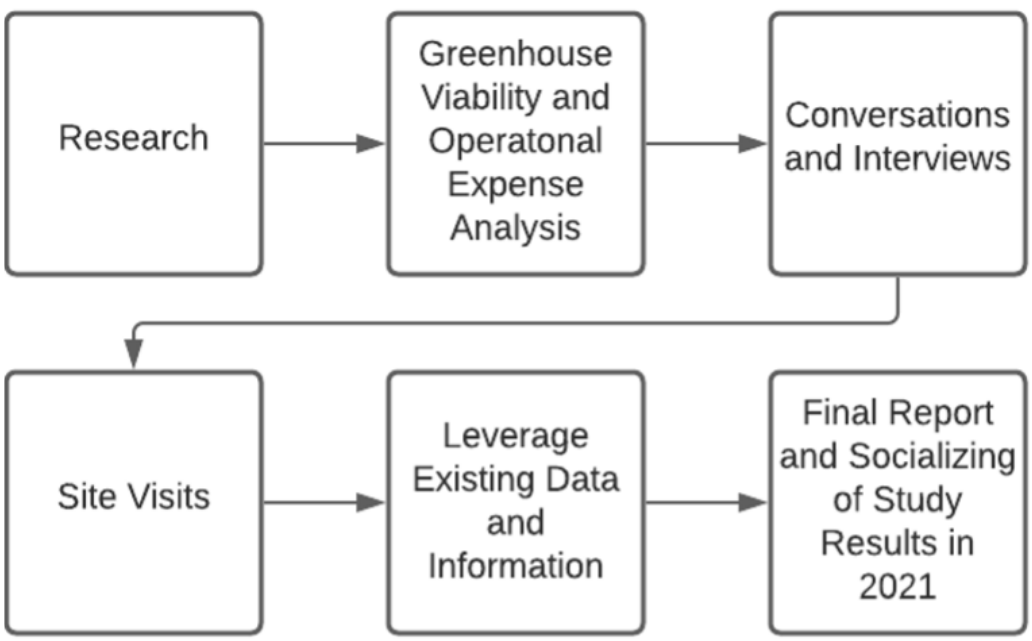



This is a proposed project timeline for the 2022 demo projects. The timeline is extended into 2023 for several reasons: a) consideration of international supply chain challenges, b) extensive design needed for geothermal heating systems, and c) consideration for the growing and construction season for MI greenhouses.

# Market Data

The first phase of the Grow Pilot was a comprehensive study on greenhouse stock and market conditions, conducted from August to November, 2021. During this time, IC reviewed existing DTE greenhouse stock and prioritized community-based produce operations over other greenhouse types. To provide a comprehensive report of the Michigan greenhouse market, community-based produce greenhouses, greenhouses growing flowers (floriculture), and greenhouses growing a combination of both produce and flowers were studied. By visiting multiple greenhouse operations, IC determined estimated costs for EE upgrades and prioritized relevant and cost-effective greenhouse technologies that can be implemented at the selected pilot locations. Below is a summary of the findings and recommendations for the program design and implementation of the demonstration pilot projects.

Figure 1. Phase 1, Illustrated



# Greenhouse Research

A comprehensive study of Michigan greenhouse stock and market conditions was completed utilizing data provided by DTE for both natural gas and electric customers. Figure 1 shows the DTE Service Territory Map and Figure 2 demonstrates locations for the researched greenhouse sites. IC used the data to sort the greenhouse market by DTE annual invoice; small, medium, and large. It should be noted that these size designations may not be an accurate representation of the size of the greenhouse facility. DTE data is designated by billing amount or usage and it is important to note that this is not necessarily representative of the physical size of the building or site.

Figure 2. DTE Service Territory Map

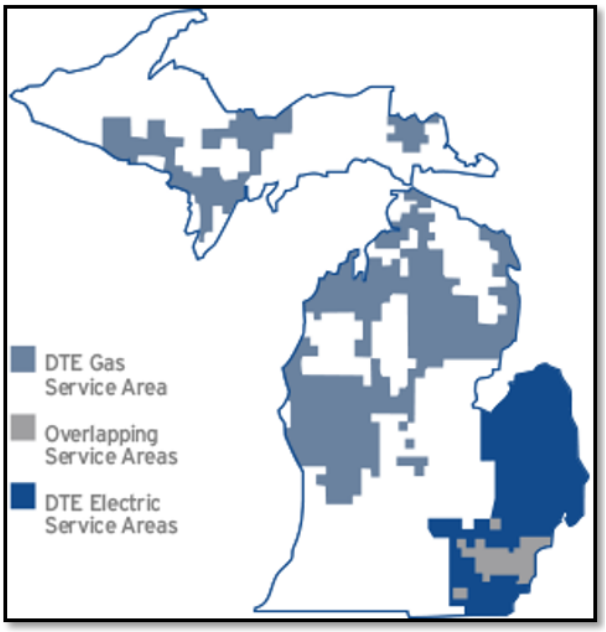
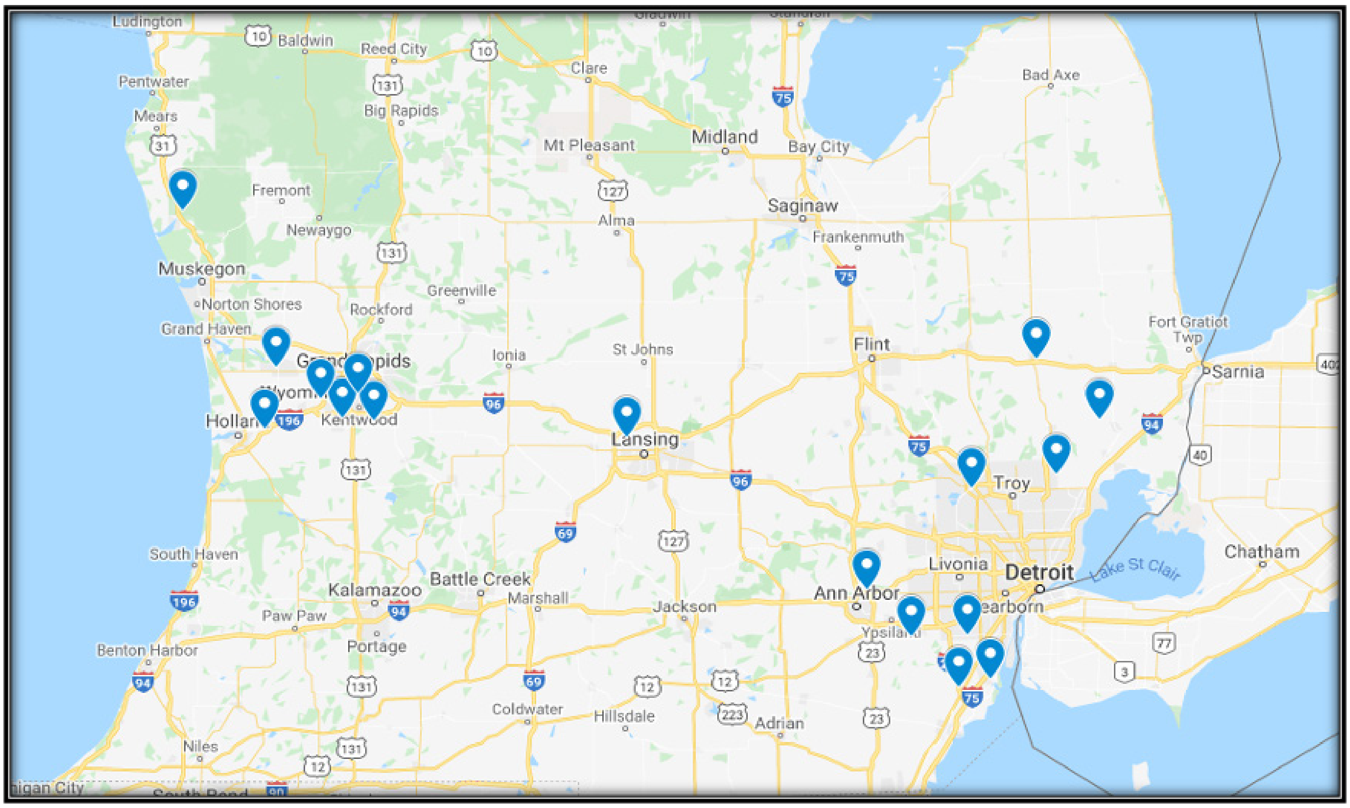


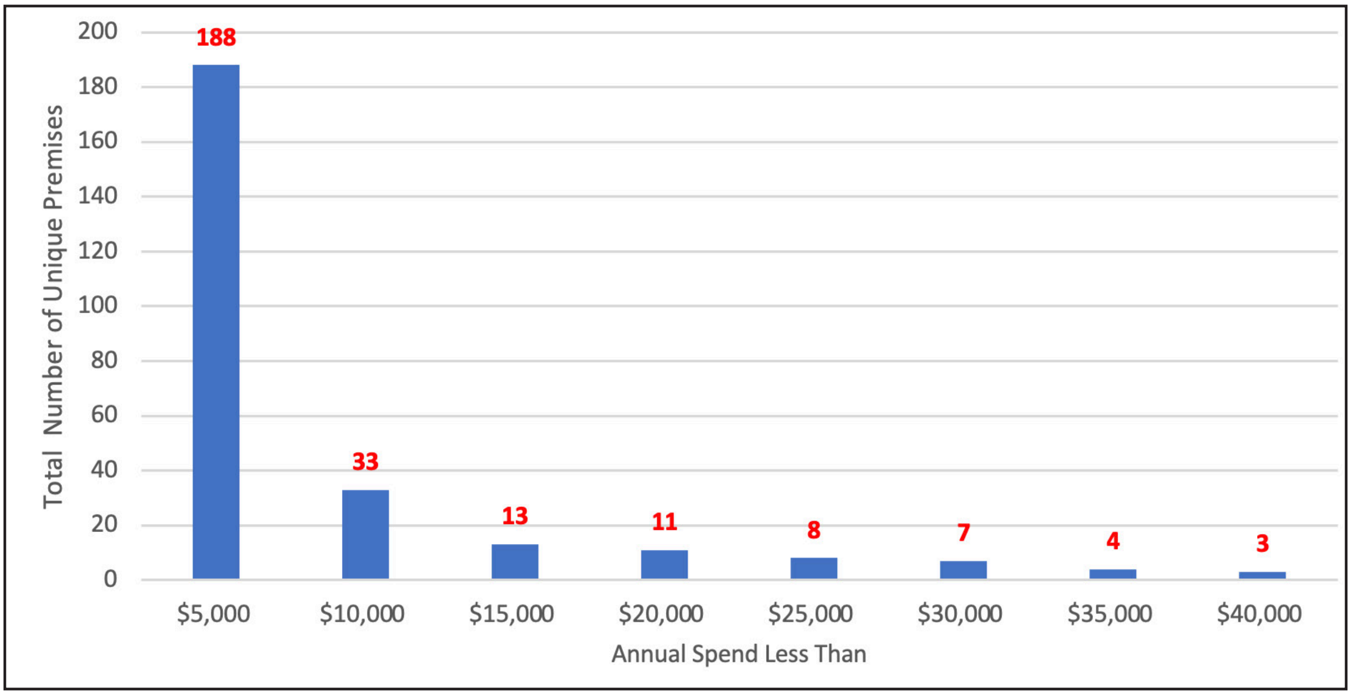

Figure 3. Greenhouse Locations for Researched Sites



The figures below represent the data findings of the DTE provided greenhouse sites; 267 sites made up this greenhouse dataset. While analyzing the data, it was discovered that 90% of greenhouse owners spend less than $40,000 annually on their DTE bills. This data set was then sorted to find the total number of greenhouse sites per annual DTE bill amount (Figure 4).

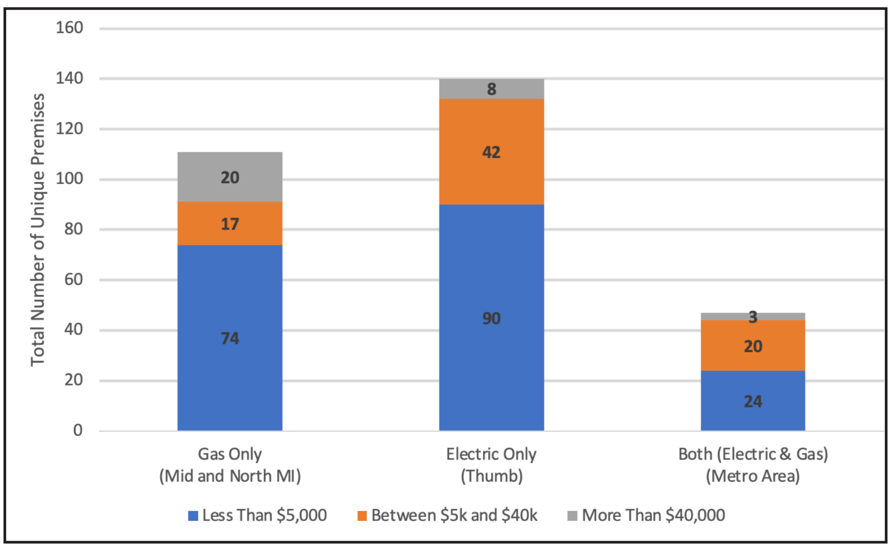
The original data pull of DTE greenhouse customers yielded over 550 sites. However, thorough research of each site demonstrated that many sites did not have greenhouses or produce grown on site. Examples of these businesses may be gravel companies or landscapers that have access to nursery plants, but do not do any indoor cultivation at their site. After paring down the original dataset, the 267 sites were considered viable greenhouse operations.

Figure 4. Breakdown of DTE Customer Spend




Next, the data set was refined to the DTE service type; natural gas only, electric only, and a combination of natural gas and electric service (Figure 5). This allowed IC to target specific greenhouse sites based on DTE service types and annual utility costs. This led to strategic outreach that was targeted and effective.

Figure 5. Annual Spend by Service Type



# Greenhouse Annual Bill Amount

The table below shows the breakdown of greenhouses into three usage categories.

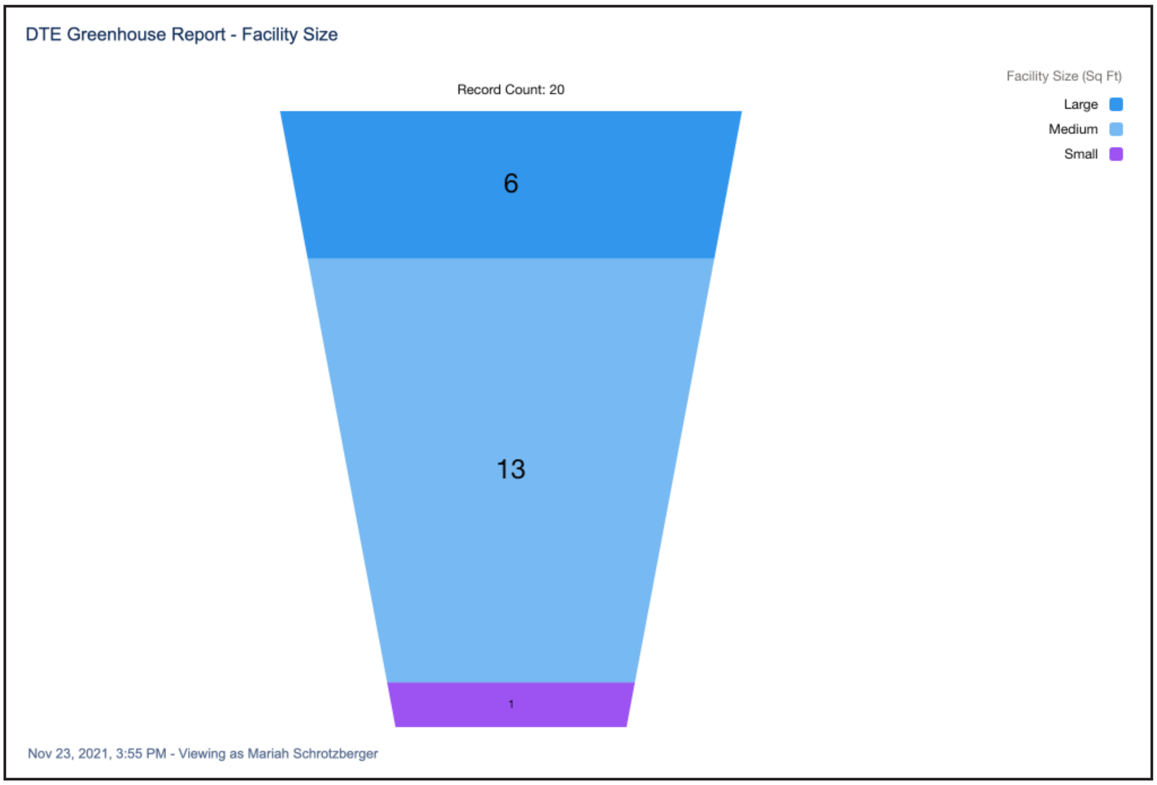
Figure 6. Preliminary Greenhouse Sorting by Spend

| Annual DTE Bill Amount | Number of Sites | Percentage of Stock Data |
|---|---|---|
| Less than $5,000 (Small) | 188 | 63% |
| $5,000 to $40,000 (Medium) | 79 | 26.5% |
| More than $40,000 (Large) | 31 | 10.5% |

65% of the 31 sites that had a $40,000+ annual DTE spend are natural gas only

After sorting the greenhouses, a total of 31 large sites were identified. The IC conducted outreach and scheduled site visits with the large greenhouses first, followed by the medium and small greenhouses second. It was important to the team to first focus on those with the highest billing amount, therefore the most potential for savings. Figure 7 shows the breakdown of greenhouse facility size recorded in the interviews.

Figure 7. Greenhouse Facility Size

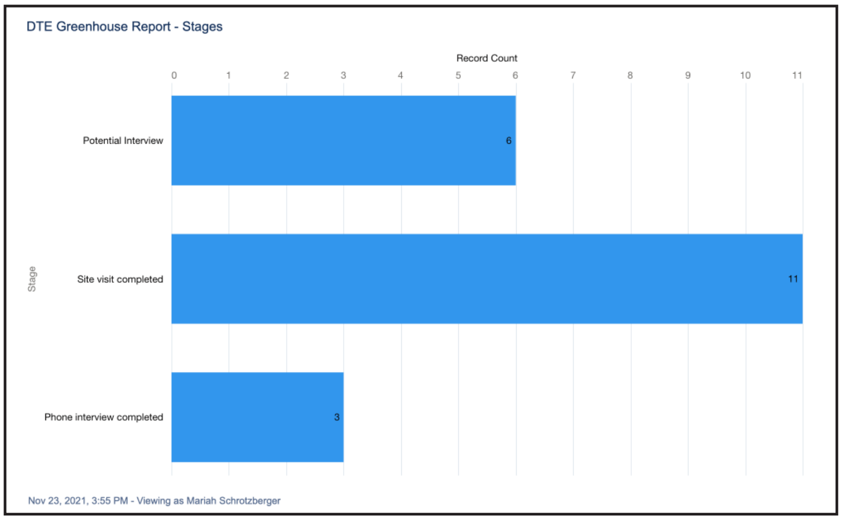


# Outreach

Initial outreach for interested greenhouse participants was conducted through email, phone calls, and physical site visits. IC created an online Greenhouse Questionnaire that was linked to their internal Salesforce system for data collection and tracking purposes. Twenty greenhouses were successfully contacted in some form. Several other greenhouses were contacted but did not result in an interview. Interviews of medium greenhouses provided more useful data while the small greenhouse outreach captured a holistic picture of the Michigan greenhouse market. As shown in Figure 8, there were three stages in the process.

- **Potential interview:** team is still anticipating an interview, some communication and interest in a site visit
- **Site visit completed:** full on-site interview and questionnaire completed
- **Phone interview completed:** detailed greenhouse questionnaire covered via phone call

Figure 8. Greenhouse Outreach Stages




Greenhouses were contacted regardless of fuel type. Interviews were conducted with ratepayers that have DTE electric, gas, and service for both fuels.

Figure 9 shows the breakdown of fuel type from greenhouses surveyed.

Figure 9. Greenhouse Fuel Types

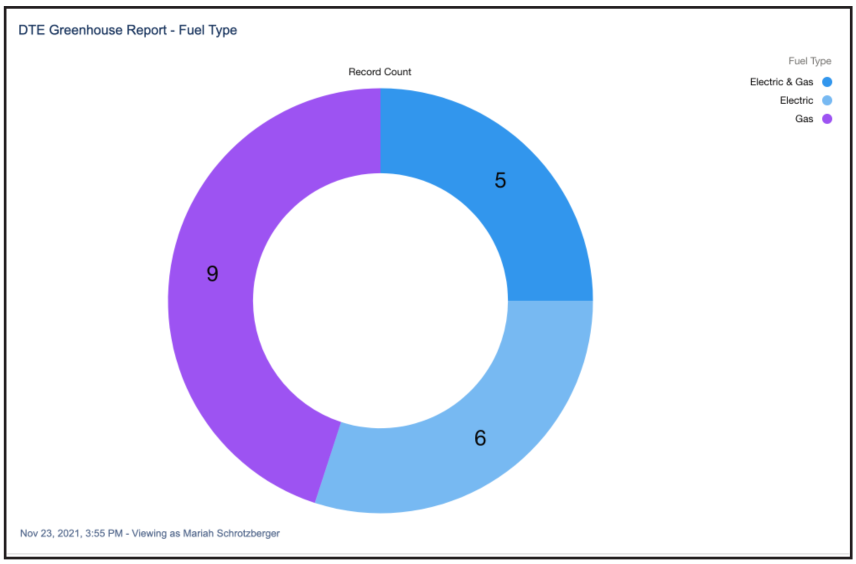
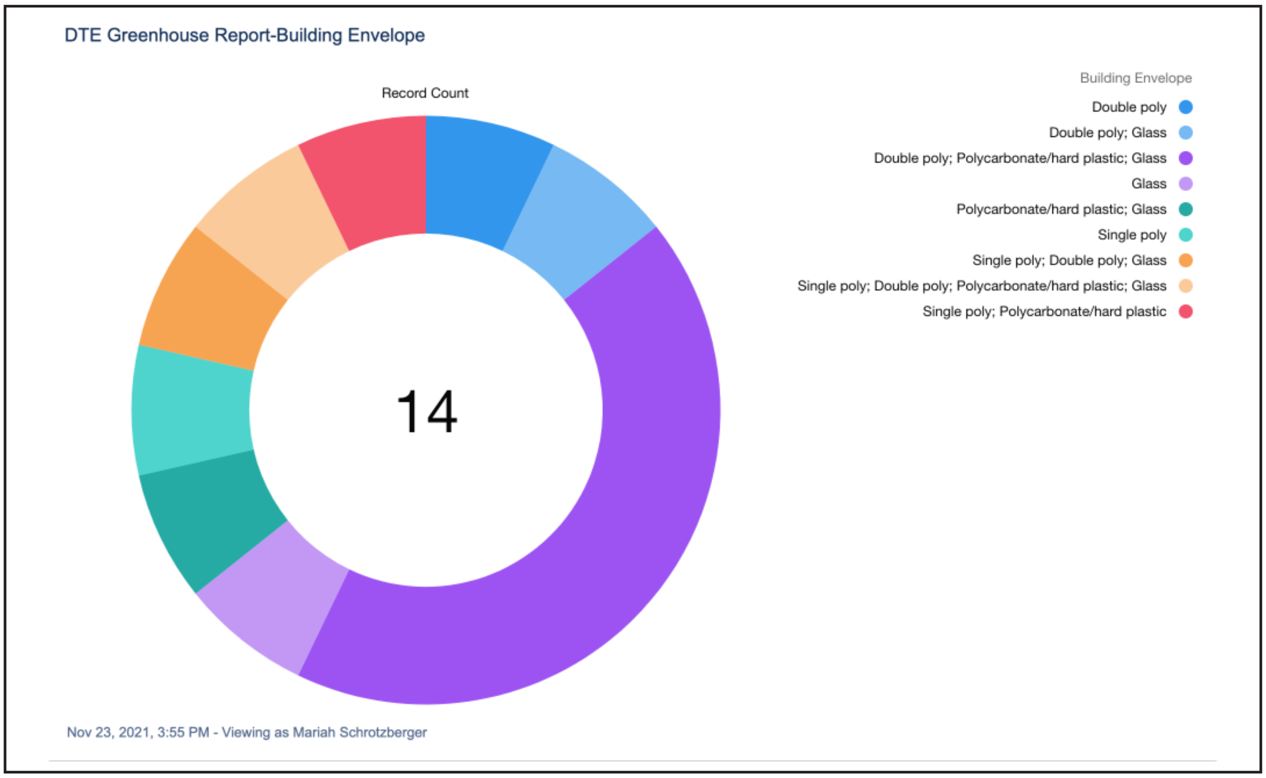


Figure 10 demonstrates that for some questions in the survey, the answers were varied. For example, there were many different combinations of building envelopes, even at one site.

Figure 10. Greenhouse Building Envelope Types

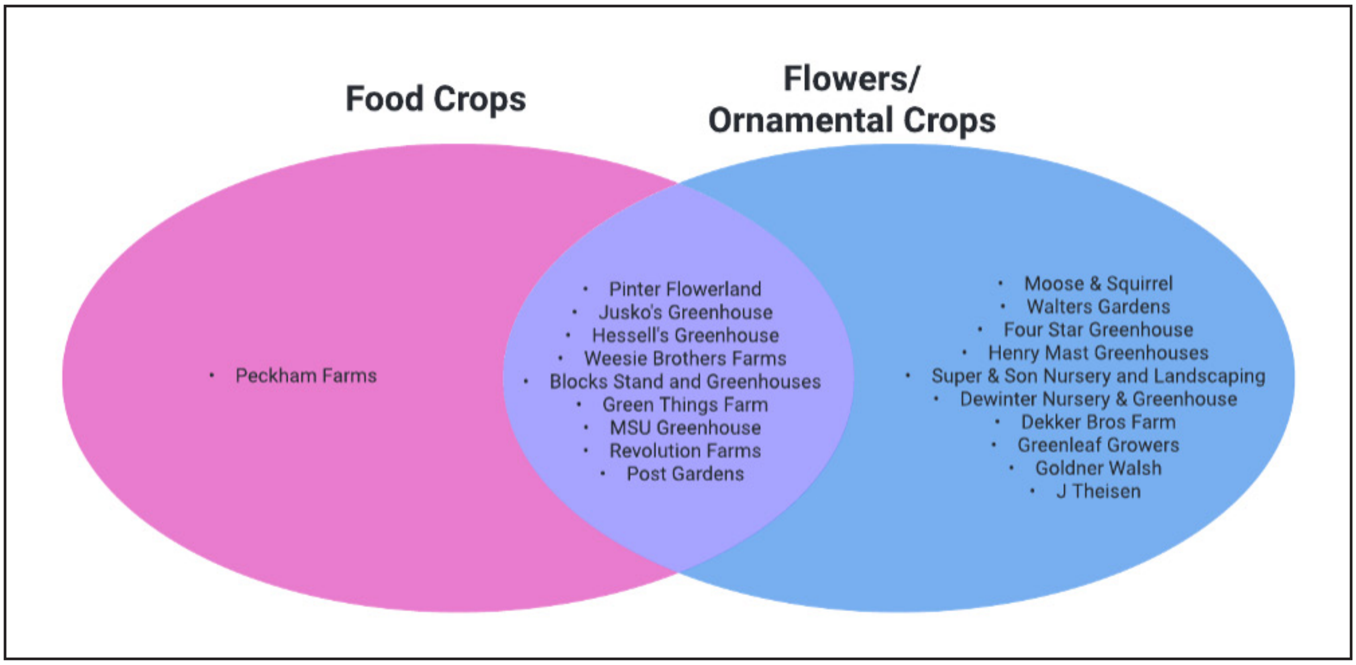



## Produce Versus Flower or Ornamental Greenhouses

Preference for the selected greenhouse pilot participants was given to produce-centric sites with a community-based focus. While conducting outreach and research, it was discovered that there was more focus on flower and ornamental plants versus produce-only greenhouses. Part of the reason for this diversification was due to the seasonal changes for year-round greenhouses. Due to differing light, temperature, and scheduling, it is likely that most greenhouses produced flowers, fruits, and vegetables depending on what had the highest demand and was viable to grow during that season. The Venn diagram below (Figure 11) illustrates the crop types identified by the greenhouses surveyed. Diversification also offered growers resilience in case one crop performed poorly or had an illness.

The benefits of cross-pollination of species was seen as a more sustainable practice than growing a monoculture of the same type of cucumber across thousands of acres, for example. Ninety-five percent of growers grew flowers at some point in the year. Some only produced flowers, while some produced both food and flowers.

Figure 11.


Food Crops
Flowers/ Ornamental Crops
Peckham Farms
Pinter Flowerland
Jusko's Greenhouse
Hessell's Greenhouse
Weesie Brothers Farms
Blocks Stand and Greenhouses
Green Things Farm
MSU Greenhouse
Revolution Farms
Post Gardens
Moose & Squirrel
Walters Gardens
Four Star Greenhouse
Henry Mast Greenhouses
Super & Son Nursery and Landscaping
Dewinter Nursery & Greenhouse
Dekker Bros Farm
Greenleaf Growers
Goldner Walsh
J Theisen


# Technical Research

Technical research templates were created and completed for all reviewed greenhouse technologies. The completed templates provided an in-depth review of each greenhouse technology. The collection of technical research templates will be available upon request. Researched technologies included root temperature control, HVAC systems, greenhouse envelopes, farm automation controls, high-efficiency fans (HAF), refrigeration, and lighting.

The table in Figure 12 represents the technologies that were considered and researched for the Grow Pilot. Each technology is examined in greater detail throughout the remainder of this section. Specific technologies were found to have existing incentives already in place and were identified along with the incentive catalog number in the below table.

Greenhouse locations that had site visits conducted are identified on the right side of the table. A green shaded box indicates that a specific technology was already being utilized at the location. A checkmark indicates that the site could potentially benefit from the implementation of a particular technology. Boxes that are shaded green and contain a checkmark indicate that the technology is already installed at the facility, and there are additional applications possible at the facility. For example, the greenhouse already has some thermal curtains, but would benefit from more thermal curtains to cover a larger square footage of growing space.

An asterisk next to a technology indicates that the system could theoretically be sourced with a geothermal loop. However, more site-specific design and research is needed.

Figure 12. Technical Research Data Collection

| Category | | Technology | Prescriptive Already Available? | Fuel Impacted | | Potential Applicaton | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Elec | NG | Post Gardens | Four Star | Greenleaf Growers | DeWinters | Walters | Moose & Squirrel | Goldner Walsh | Weesies Bros | Henry Mast | Green Things Farms |
| HVAC | Root Temperature Control | In-Floor/Ground Heat Systems* | AG-28 & 29 | | X | ✓ | | ✓ | | ✓ | ✓ | | ✓ | | ✓ |
| | | Under bench heating systems* | AG-28 & 29 | | X | ✓ | | | | | ✓ | | ✓ | | ✓ |
| | Other HVAC | Dehumidifier | | X | | | | | | | | | | | |
| | | Condensing Unit Heaters | HG3 & 4 | | X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| | | Radiant Heaters | HG-7 | | X | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Insulating Jackets | | | | | | ✓ | ✓ | | | | ✓ | ✓ | |
| | | Geothermal | | X | X | ✓ | | | | | | | | | ✓ |
| Envelope | | IRAC Plastic Film | IG-6 | | X | | | | | | ✓ | ✓ | | | |
| | | Roof Vents | | X | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Twin Wall Polycarb to Replace Single or Glass | | | X | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | |
| | | Shade Curtains | | X | | ✓ | | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| | | Thermal Curtains | IG-5 | | X | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Other | | Farm Automation Controls | AG-27 | | X | | | | | | ✓ | | | | |
| | | HAF High Efficiency Fans | | X | | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |

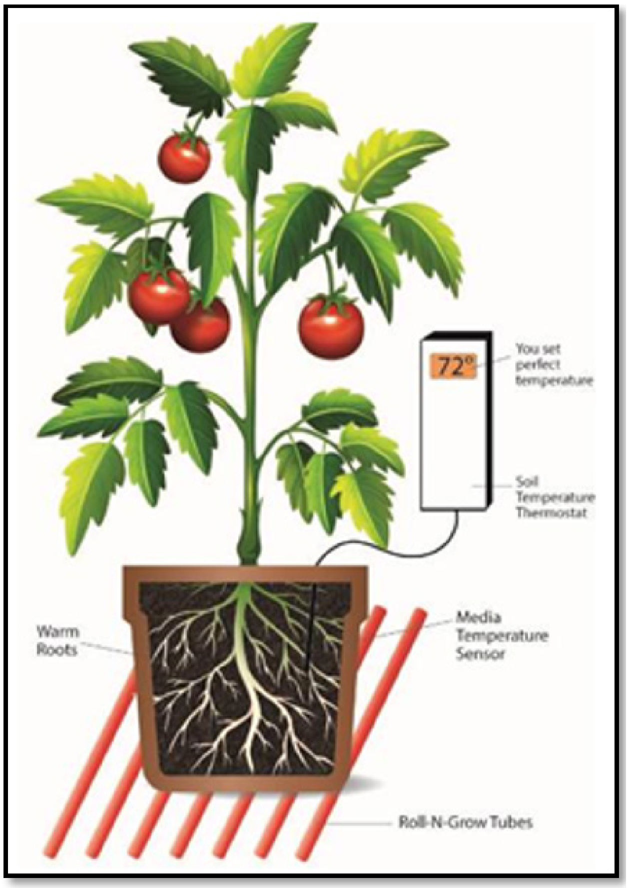
# Root Temperature Control

## In-Floor/In-Ground Heating Systems

Maintaining proper temperature of plant roots can be critical for producing high-quality crops. Proper temperature of plant roots can be achieved through traditional forced-air or convection heating systems, both of which maintain the necessary air temperature throughout the greenhouse structure to warm the roots. Alternatively, an in-floor heating system can be used to maintain the root temperature while reducing required energy consumption.

An in-floor system uses hot water, typically produced from a condensing boiler, to circulate water through piping which is either in a concrete slab floor or laid directly on a soil floor. Planters are in direct contact with the warmed floor, or piping, and absorb the heat first. A temperature sensor is installed in the soil to control the amount of heat provided. This method is both energy efficient and more precise in controlling root temperatures. See Figure 13 for an example.

Figure 13. Root Temperature Control



A key to realizing energy savings for the root temperature control technology is to reduce the space temperature in the facility. It should be noted that throughout the surveyed facilities, some growers had existing in-floor heating and were reducing space temperatures while other growers were not. The reduction of space temperatures is dependent on the grower and what they believe their plants require to produce a successful yield.

In Photo A, a on-floor heating system is shown where the heated pipes are running along the floor with the plants placed on top. In Photo B, the heated pipes are buried under concrete in order to heat the slab where the plants will be placed. In every installation, pipes were heated with hot water. There was no glycol used in any of the surveyed greenhouses.

**Photos A and B. Examples of Root Temperature Control in Existing Greenhouses**

**Photo A**

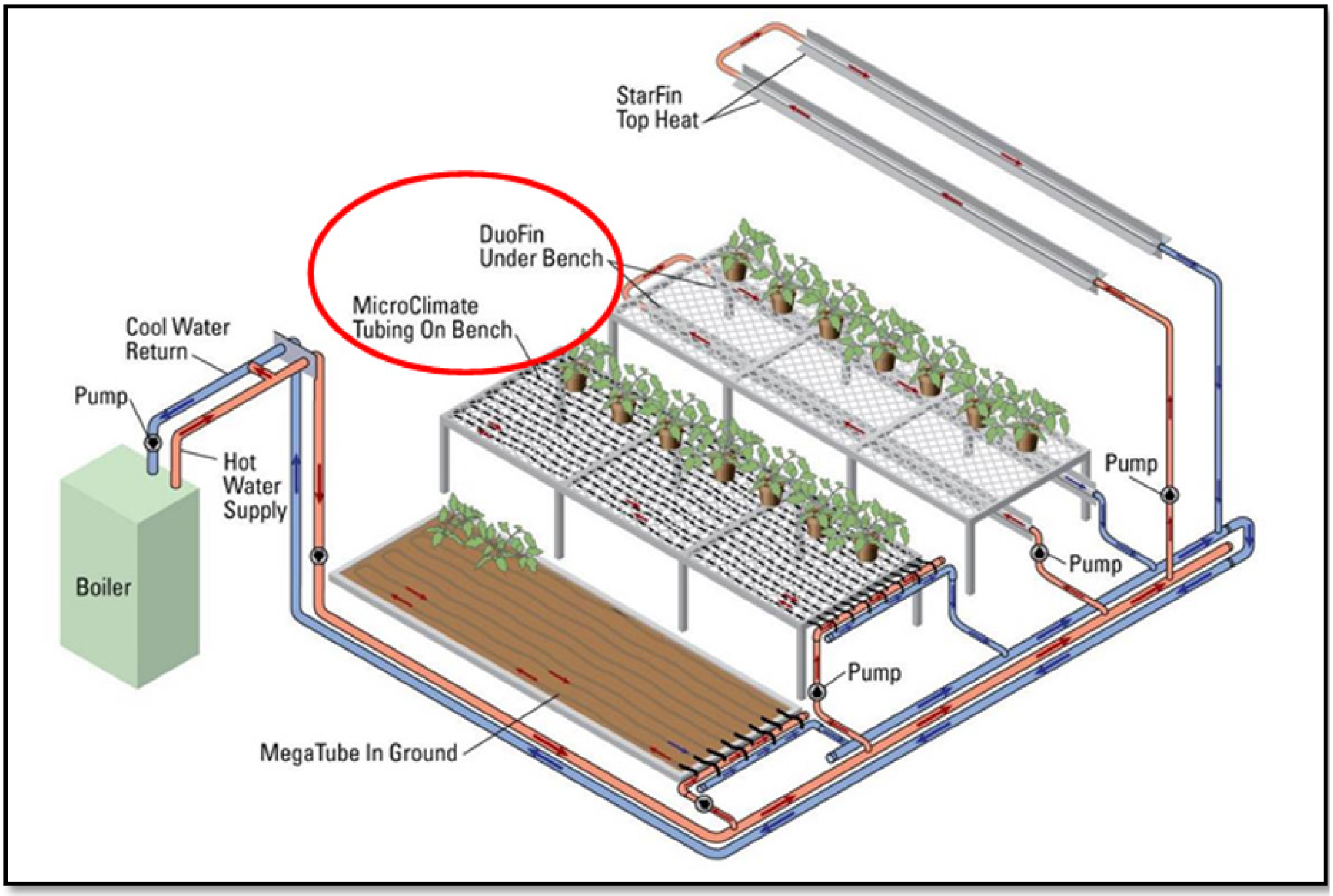
**Photo B**

An example of a greenhouse structure from the site surveys was used to calculate energy savings and to estimate implementation costs. Based on the savings calculated, and the budget cost provided by a manufacturer, the simple payback for this retrofit application was estimated at 8.9 years. It is expected that the financial return on the incremental cost for new construction greenhouses would be better than the retrofit option for existing greenhouses.

## Under-Bench Heating Systems

Like the in-floor heating systems described above, under-bench heating systems maintain plant root temperatures, allowing the surrounding air to be cooler while maintaining high-quality crops. Figure 14 illustrates several types of greenhouse heating systems, including a root temperature control system.

Figure 14. Under-Bench Heating Systems




There are numerous types of bench heating systems. Photos C and D were taken from site surveys performed during the development of this report and show both a piped system (Photo C) and a radiant system (Photo D). There are additional types of bench heating systems, with some manufacturers offering an "on" bench system that lays on top of the benches. While electric systems are available, hot water systems were found to be prevalent and were considered in this technical analysis.

**Photos C and D. Examples of Under-Bench Heating Systems in Existing Greenhouses**

Photo C

Photo D

While the savings from a heated bench system is similar to an in-floor heating system, the cost of a heated bench system is much greater. This is based on budget information provided by a manufacturer for both system types. Due to the higher cost of the under-bench heating system, the payback increased to over 17 years for this technology.

For one of the greenhouse site visits, it should be noted that one grower had insulated the benches by covering them with a ground cloth (Photo E). This created a barrier, essentially trapping the heat under the bench which heated the roots and surrounding soil more efficiently. There may be an opportunity to expand on this technique and develop a new offering to insulate the heated benches, creating an even more efficient heating system.

**Photo E. Example of insulated Bench Heating System in Existing Greenhouse**

Photo E

# HVAC

## Dehumidifiers

Greenhouses may have a need for removing excess moisture from the air to facilitate proper plant growth. This is typically accomplished using mechanical supercooling dehumidification units. These are standard air handling units that draw in room air, or a mixture of room and outside air, across a cooling coil, which cools the air down to 55°F before supplying it to the room. When room air relative humidity is high, the dewpoint of the air is above 55°F. Cooling the air down to this level will condense moisture out of the air, thereby dehumidifying it.

New dehumidification-specific units can perform the same task using less energy. The metric that is used to determine the efficiency of a dehumidification unit is "pints/kWh", or the amount of water removed from the air in pints per kWh of electricity input. Standard efficiency dehumidifiers, or standard air handling units that perform dehumidification, can operate in the range of 3.0 to 5.0 pints/kWh. High-efficiency units, such as the Quest 506 model shown in Photo F, can remove up to 8.0 pints/kWh.

**Photo F. Example of Quest Model Dehumidifier**


**Photo F**

The capacity of these dehumidifiers is measured in "pints/day" or by the total number of pints of water that can be removed from the air if the unit is in operation for an entire day. The Quest 506 model can remove 506 pints per day, while the Quest 165, a smaller unit, can remove 165 pints per day.

It appears the cutoff between "standard" and "energy-efficient" dehumidifiers is approximately 5.0 pints/kWh. The cost-effectiveness of upgrading to higher efficiency units is a function of how often the air needs to be dehumidified, and how much moisture needs to be removed from the air. During the greenhouse site visits, no dehumidifiers were observed. Due to the absence of dehumidifiers at the existing greenhouses, implementing a dehumidification measure for the demonstration projects is not recommended. A payback assessment was not conducted for dehumidifiers since they were not utilized in the Michigan greenhouse market.

## Condensing Unit Heaters

In the greenhouses surveyed, the predominant heating system was condensing unit heaters (UH). Unit heaters are simple to operate and maintain while providing a reliable heat source. The ages of observed UHs varied widely, even within a single greenhouse. All the UH systems were natural gas fired.

**Photos G and H. Examples of Condensing Unit Heaters in Existing Greenhouse**

Photo G

Photo H

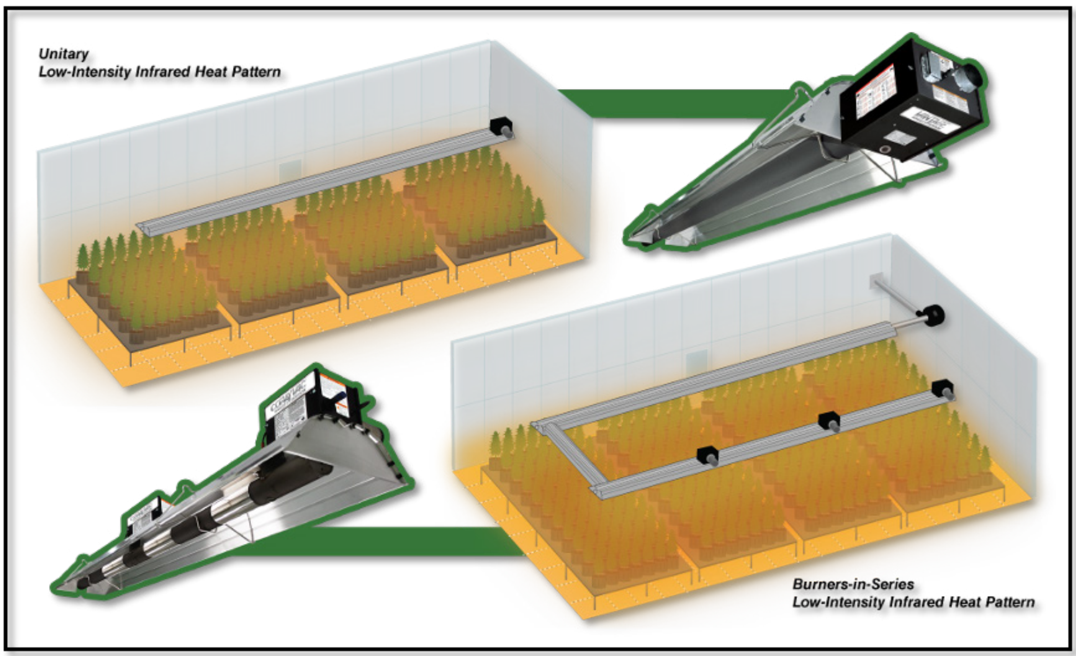
There are a variety of configurations and efficiencies available for UHs. With heating being the major energy consumer in a greenhouse, heating system efficiency improvements can have a significant impact on greenhouse utility costs. While some growers have begun switching to condensing UHs, others cannot upgrade due to the additional cost of the high-efficiency units.

Since many growers indicated that they purchase UHs online, costs were estimated using online resources. Some growers installed UHs themselves, however, a labor cost was included in the estimate used for this analysis. Energy savings were calculated using equivalent full-load heating hours based on local weather data. Overall, the simple payback exceeded the expected life of the high-efficiency UHs. However, the incremental cost of this technology when replacing a UH at the end of its life will be substantially less and will have a much higher return on investment (ROI).

## Radiant Heaters

Low-intensity infrared (IR) heaters warm objects, instead of spaces, allowing the surrounding air to be cooler, while people or objects such as crops, still feel warmer.
For quite some time, IR systems have been successfully installed in warehouse and garage-type spaces to achieve energy savings. At least one IR company is marketing infrared heaters to the greenhouse industry and claiming successful implementations. Multiple greenhouse trade publications have cited low-intensity IR heaters as a potential energy-saving technology for the industry.

Figure 15. Low-Intensity Infrared Heaters



Although low-intensity IR heaters appear to be a potential solution for greenhouses, none of the surveyed greenhouses were utilizing this technology. IR heaters were repeatedly discussed with the growers, and several had a negative perception of the technology and indicated they would be hesitant to implement it. A more detailed discussion with Dr. Runkle of Michigan State University revealed additional details and insight around the fears of some growers concerning IR technology, which included:

1. Desire for consistent environmental conditions throughout the greenhouse
    - Fear that the IR tubes, which may be hotter on one end than the other, and would not provide consistent conditions
    - As plants grow, they may prevent the heat from the IR heater from reaching the lower stem and soil, leading to uneven heating for the plants
2. Possible shading concerns since the IR heaters are typically suspended from the ceiling

Some of the above concerns may be addressed through thoughtful design. For example, installing "series" burners provides a much more uniform temperature across the IR tube. Working with the manufacturers, other issues may be overcome through the advanced design of the systems. Based on the estimated costs and energy savings presented in the attached research documents, this technology has the potential of a 2.3-year simple payback, making it one of the most opportunistic heating solutions available if the issues above can be properly addressed.

## Insulating Jackets

When greenhouses use hot water or chilled water distribution systems, it is important to keep the pipes well insulated to prevent energy waste. Even when straight pipes are well insulated, very often valves, connectors, and flanges are not insulated as shown in Photo I.

**Photo I. Example of Insulated Pipes in Existing Greenhouse**


**Photo I**

**Photo J. Example of Valve Jacket**


Several manufacturers make custom valve jackets that are designed to block heat loss for these specific situations. Valve jackets are designed to fit over specific dimensions of pipe while allowing access when needed. Some valve jackets have zippers or Velcro seams and can be easily removed for operations and maintenance as in Photo J. Energy savings can be calculated as a function of the temperature difference between the pipe and the room, and the surface areas covered.

## Geothermal Heating Systems

Geothermal heat pumps, or ground source heat pumps, are a highly efficient renewable energy technology that is gaining wide acceptance in both residential and commercial markets. Geothermal heat pumps can be used for both space heating and cooling, as well as water heating. The benefit of ground source heat pumps is they use the naturally constant heat of the earth rather than producing heat through the combustion of fossil fuels. Geothermal heat pump systems can operate as high as 32 SEER (Seasonal Energy Efficiency Ratio) and 10.0 HSPF (Heating Seasonal Performance Factor), which can save 40% to 80% over baseline air source and natural gas systems.

Geothermal systems use water source heat pumps at the air handling unit or fan coil unit. The heat pumps use a condenser water loop to provide heat removal, connected to an underground open loop or closed loop piping system. Open loop systems use underground water, or aquifers, directly pumped to the water source heat pumps for heat removal or addition. These are very efficient and inexpensive systems but are only an option if an underground water source is available. The other type of geothermal loop is a closed loop. There are three basic types of closed loops: horizontal, vertical, and pond.

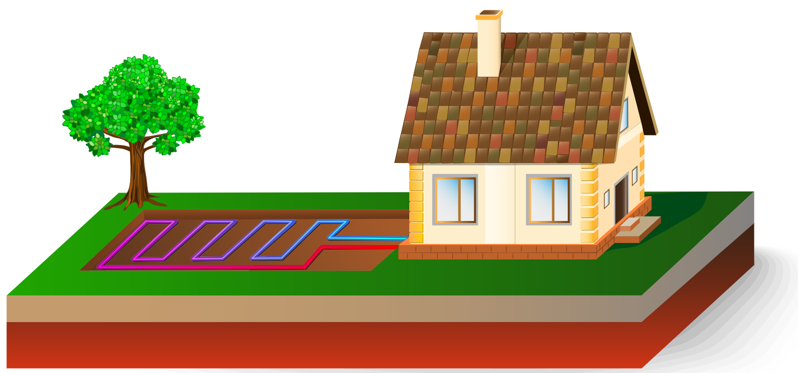
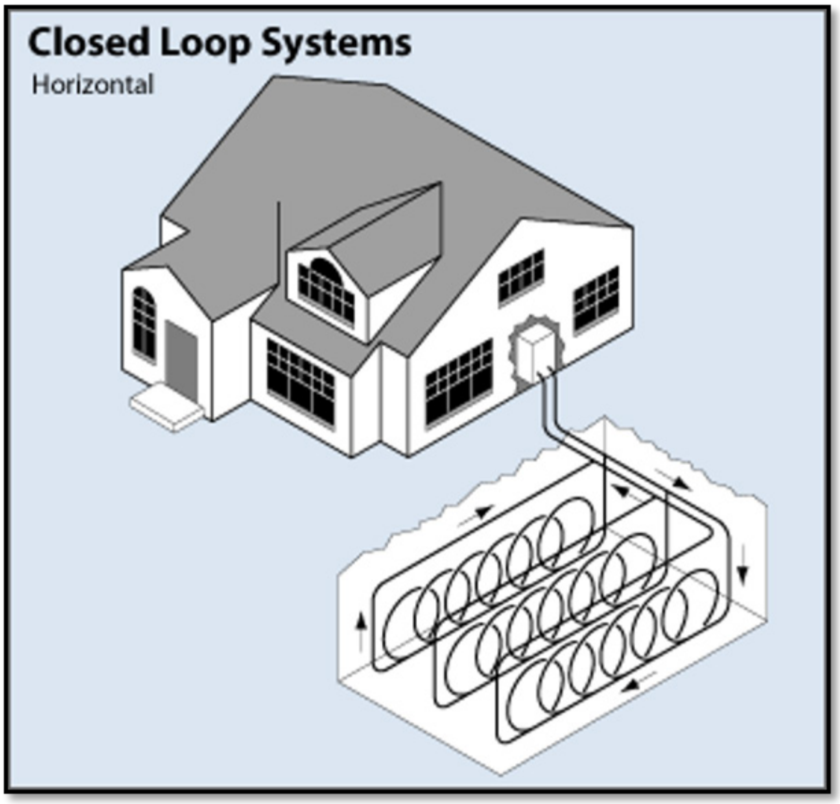


Figure 16. Geothermal Closed Loop System – Horizontal



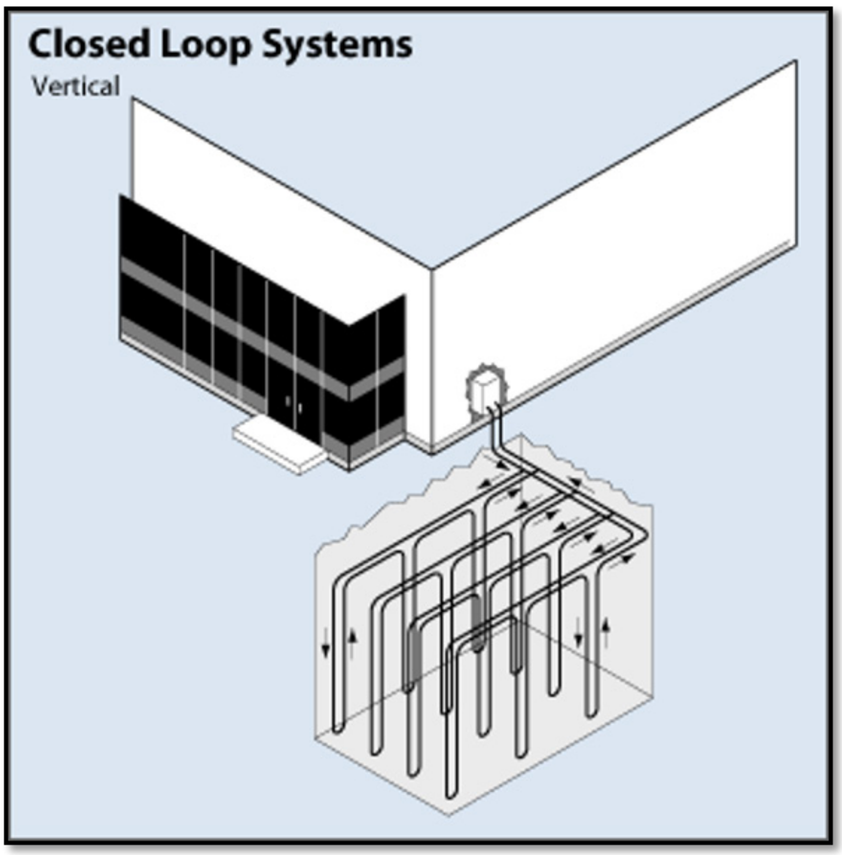

## Horizontal Loops

If the site has a lot of open land available, horizontal loops are the least costly option. Horizontal ground loops require a substantial amount of open ground space for the installation of pipes. The loop pipes are buried in trenches 6 feet or deeper, and around 100 feet long per each ton of cooling. The piping for the ground loop is often coiled and stacked to provide more area for heat transfer.

## Vertical Loops

If there is not a lot of land available, vertical loops can be utilized. A vertical ground loop is installed in holes drilled deep into the ground, usually to a depth of 400 feet or more. The loop pipes are placed into these holes, which are typically placed about 20 feet apart. Circulation of the heat-exchange medium occurs as it does in a horizontal loop, except the water or antifreeze solution may need additional pressure to keep it moving in an up-and-down direction.

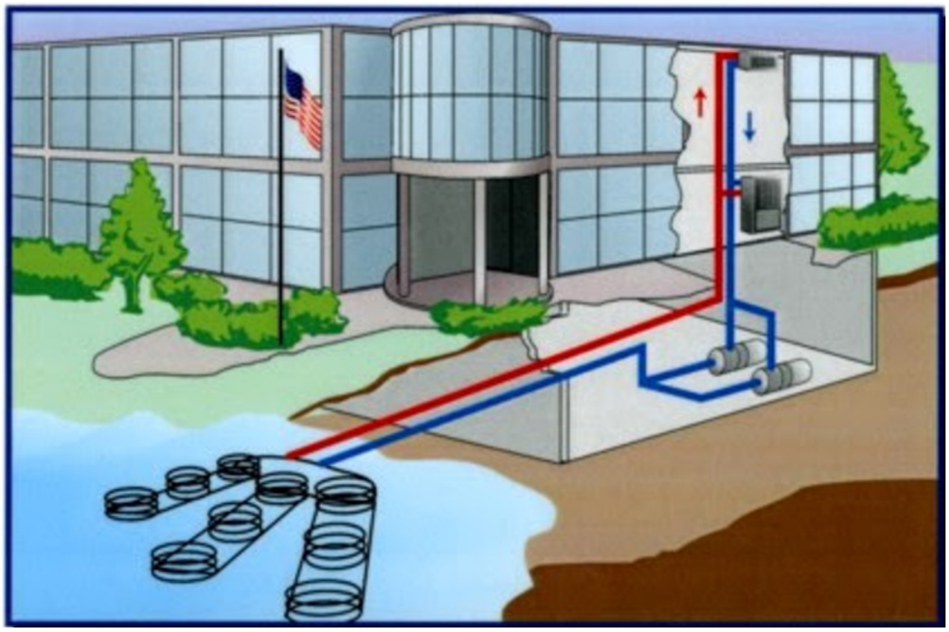
Figure 17. Geothermal Closed Loop System – Vertical



## Pond Loops

If there is a storm retention pond or another type of pond available, another efficient and less expensive option is a pond loop heat exchanger. With this type of geothermal system, coils or heat exchangers are laid at the bottom of the adjacent pond, which provides heat removal and addition. This type of system is much less expansive since there is no drilling or trenching needed. As a requirement, a minimum pond size of 1 acre is needed, and the pond must be close to the greenhouse structure.

Figure 18. Geothermal Closed Loop System – Pond



Geothermal systems are significantly more expensive than standard direct expansion (DX), gas or air-source heating and cooling systems. Geothermal can be cost-effective if there is a large heating and cooling load in the building year-round. Incentives such as renewable energy tax credits and USDA REAP grants could help customers pay for renewable energy upgrades.

# Building Envelope

## Infrared/Anti-Condensation (IR/AC) Film

IR/AC films were found to be commonly used throughout the greenhouses that were surveyed for this report. The IR properties maintained high levels of light transmittance into the greenhouse and reduced heat loss when the outdoor temperature was colder than inside. In addition to the IR coating, there was an AC (Anti Condensation) layer which reduced moisture collection on the material. This AC layer was critical as the greenhouse was typically very humid and the envelope material very cold in the winter, creating condensation which then “dripped” onto the crops.

Many of these double polyethylene films were inflated with a small pump so there was an air barrier between the two layers. Most of the greenhouses used a large number of small blowers to accomplish this. A couple of the larger greenhouses had consolidated the small blowers into a centralized system. One greenhouse even measured the air pressure between the layers and used a variable frequency drive (VFD) to adjust the pressure based on wind speeds and other factors.

**Photos K and L. Examples of Infrared/Anti-Condensation Film in Existing Greenhouse**


**Photo K**

**Photo L**

While there are savings associated with upgrading from single to double poly systems, particularly when an IR/AC coating is used, this seemed to be the baseline technology throughout the Michigan greenhouse market. The estimated costs and energy savings were not calculated since this technology was widely adopted and there was already a DTE prescriptive incentive available for IR/AC film.

However, it should be noted that conversations with growers revealed a significant difference in the incentive amount provided by DTE and Consumers Energy for this same technology. The existing DTE incentive (IG-6) is $0.05 per square foot while Consumers Energy provides owners with an incentive of $0.15 per square foot.

## Roof and Ridge Vents

Natural ventilation reduces electricity consumption and helps to maintain a more consistent temperature in a greenhouse. When ventilation is necessary, for either high space temperatures in the summer or high humidity in the winter, exhaust fans operate to create a flow of outdoor air through the greenhouse.

Along with roll-up sidewalls or large-end wall doors, roof vents can provide natural airflow while eliminating the need for motorized exhaust fans. Typically, the vents are connected to a farm control system to automatically open and close as necessary. While it is easier to install during new construction, an existing greenhouse can be retrofitted with roof vents in some cases.

**Photos M and N. Examples of Roof Vents in Existing Greenhouse**

Photo M

Photo N

Savings have been estimated to be between 0.5 to 1-kWh per square foot per year. Costs were highly variable due to the custom nature of this retrofit and the various types of construction available. A budget of $30 to $50 per linear foot aligns with what many growers indicated the correct cost would be. This resulted in an 8 to 16-year simple payback for this technology. It should be noted that several greenhouses specifically asked about roof vent incentives, which demonstrated an interest in the technology, but also the need for capital for these types of retrofit projects.

## Multi-Wall Polycarbonate

A twin, triple, or multi-wall polycarbonate panel is a tough, durable, and lightweight plastic building material. It is commonly used as roofing panels and translucent walls in greenhouses. It provides a strong building envelope with thermal properties, light transmittance, and ultraviolet (UV) protection. These multi-wall panels can replace single-layer corrugated polycarbonate panels, or glass panels, significantly increasing the insulation value.

Figure 19. Multi-Wall Polycarbonate Comparison Table

**Table 1.** **Comparison of glazing material properties**

| Material | % light transmission | U-value[1] | % thermal transmission[2] | Life expectancy (years) | Flammability[3] |
|---|---|---|---|---|---|
| **Glass** | | | | | |
| Single | 88–93 | 1.1 | 3 | 25+ | none |
| Double | 75–80 | 0.7 | < 3 | 25+ | none |
| **Acrylic** | | | | | |
| Single | 90 | 1.13 | < 5 | 30+ | medium |
| Double | 84 | 0.49–0.56 | < 3 | 30+ | medium |
| **Polycarbonate** | | | | | |
| Single | 90 | 1.1 | < 3 | 10–15 | low |
| Double (6–10 mm thick) | 78–82 | 0.53–0.63 | < 3 | 10–20 | low |
| Triple (8–16 mm thick) | 74–76 | 0.42–0.53 | < 3 | 10–20 | low |
| **Polyethylene film** | | | | | |
| Single | 87 | 1.2 | 50 | 3–4 | varies |
| Double | 78 | 0.7 | 50 | 3–4 | varies |
| Double, with IR | 78 | 0.5 | < 20 | 3–4 | varies |

**Sources:** *Energy Conservation for Commercial Greenhouses* (NRAES-3) and product literature.

[1] The lower the U-value, the less heat lost through a given material.

[2] Refers to the amount of infrared radiation (heat) that travels through the material and out of the greenhouse.

[3] Reflects the likelihood of the material being easily ignited if directly exposed to a flame.

While the insulating value increases, the light transmittance of the material will typically decrease. This must be closely evaluated when considering this retrofit to ensure that adequate light for crop growth is maintained. If light transmittance is not an issue, then significant heating savings can be realized.

Costs were estimated based on common materials which can be found online and installed by the grower. Using the differences in U-values shown above, savings were estimated per square foot of envelope material to be replaced. This resulted in a 15.7-year simple payback.

## Shade Curtains

While obtaining enough light can be a challenge for growers in the winter, the opposite can be true in the summer. Growers will often shade the greenhouse during the summer to reduce light transmittance, water loss, and reduce heat stress on the plants. The two most common shading strategies used in commercial greenhouses to reduce solar radiation are:

1. applying a shading compound to the external envelope or,
2. installing one or more layers of retractable shade curtains.

**Photos O and P. Examples of Shading Compound and Shade Curtains in Existing Greenhouse**

Photo O

Photo P

Shading compounds (Photo O) act as washable paint that is applied to the roof of the greenhouse. Each year the grower must reapply the compound as it will wash away with rain and snow throughout the year. While this is a low-cost option for growers, many would prefer to have shade curtains installed.

Shade curtains (Photo P) offer better performance and more uniform shading. These curtains are typically connected to an automated control system that can schedule their opening or closing depending on the time of day or conditions in the greenhouse. They can reduce solar radiation by as much as 50% in the greenhouse while providing on/off functionality and flexibility not possible with the shading compound. Additionally, shade curtains can have thermal properties which help keep heat in at night or can be paired with intentional thermal curtains which are more effective for trapping heat (see Thermal Curtain section).

The energy savings associated with this technology is limited. Shade curtains will only eliminate a small amount of fan energy during a limited time of the year. However, one grower was inquiring about utilizing shade curtains at night to "keep light inside" the greenhouse. This greenhouse had considered the addition of grow lights but has met some resistance due to the potential light pollution for the surrounding community in the winter. Using shade curtains would allow them to operate the grow lights at night, during off-peak hours, without disturbing the local community.

## Thermal Curtains

Thermal curtains, also known as heat curtains or screens, are fabrics that are placed between the crop and the greenhouse roof to reduce nighttime heat loss in cold weather climates like Michigan. Curtain systems save energy in three ways:

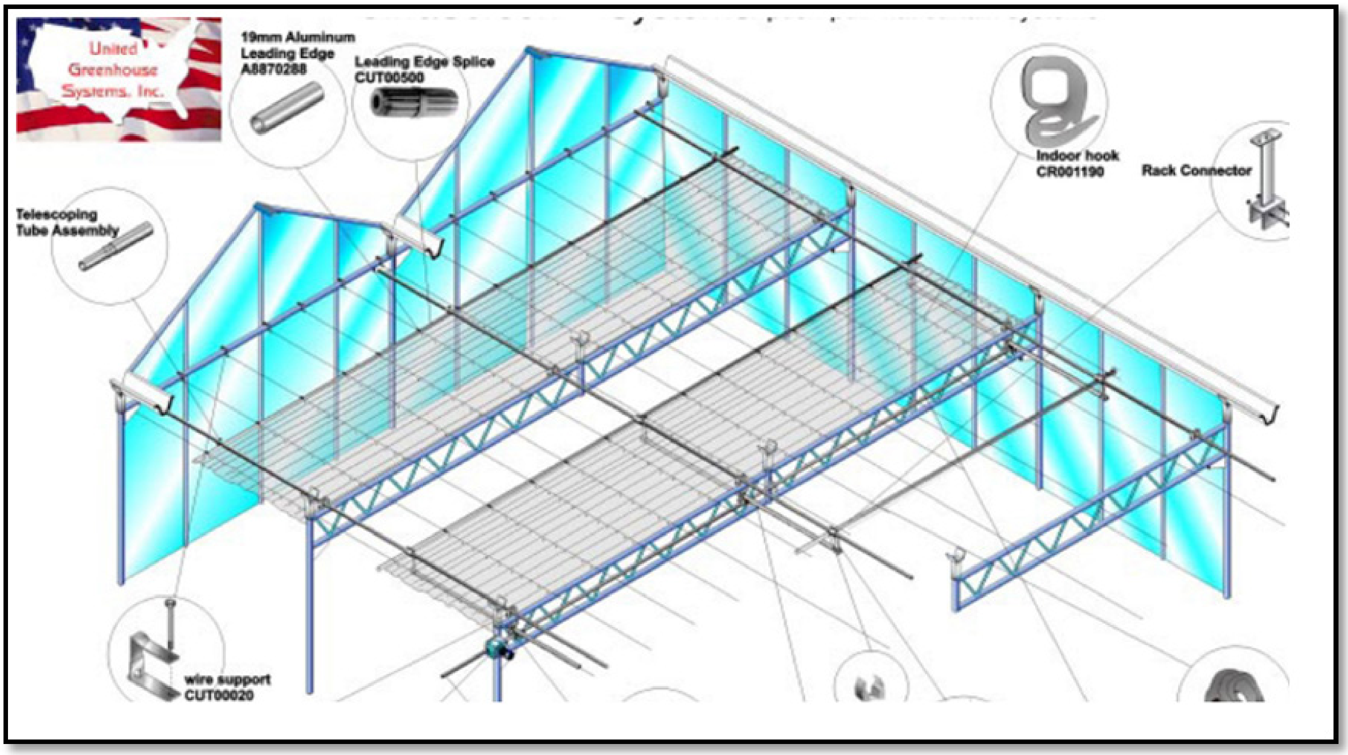
1. Curtains trap an insulating layer of air between the curtain and the greenhouse roof,

2. They reduce the volume of greenhouse air that must be heated between the crop and the curtain, and,

3. Some curtains have special fabrics woven with aluminum strips that help reflect heat coming from the greenhouse floor or general space to stay within the smaller volume instead of escaping through the roof.

In cold climates like Michigan, 70% to 80% of greenhouse heating occurs at night, so growers could see substantial savings on their heating by using thermal curtains after dark. This was one of the most requested upgrades during our site surveys and interviews with growers.

Figure 20. Thermal Curtain Illustration




Savings were estimated using the USDA greenhouse energy self-assessment tool for a typical 30x96 size greenhouse. Costs were estimated based on discussions with the growers and suppliers. Using these figures, a simple payback between 8 and 16-years was anticipated for thermal curtain technology.

# Other Technologies Considered

## Farm Automation Controls

Farm automation controls are essentially Building Automation Systems (BAS) that are specifically designed for farms and greenhouses. Weather stations are used to measure dry-bulb temperatures, wind speed and direction, humidity, rain events, and available sunlight. Utilizing these key parameters, intelligent decisions about greenhouse operations such as the opening and closing of roof vents or the dimming of lights are made automatically.

Almost every greenhouse site that was evaluated had some type of automation system already in place. The locations which did not have an automation system did not have the proper infrastructure in place to take full advantage of the system capabilities. For example, at one location the roof vents were inoperable and in need of repair before a control system could be beneficial to the ventilation system. Although present at many locations, these systems were not always adequately utilized, controlled, or covering the entire greenhouse.

**Photos Q and R. Examples of Farm Automation Controls in Existing Greenhouse**

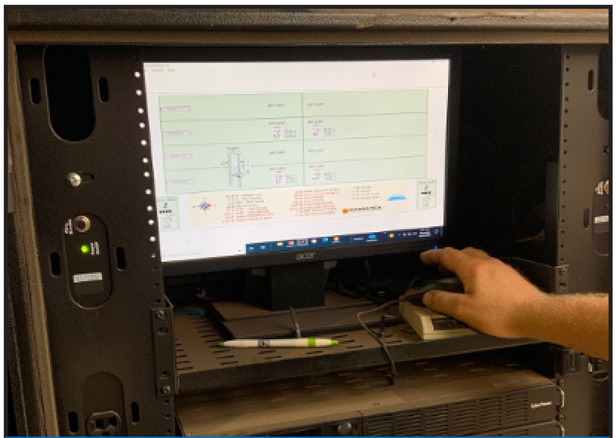


Photo Q


Photo R

Natural gas savings can be realized in several ways by implementing farm automation controls. In the winter, more precise control of the indoor humidity levels will result in less ventilation needed and therefore less heating of the cold outside air. Additionally, if the grower is willing to setback space temperatures at night, these control systems can automate this function and maintain more precise control than the operator can. In addition to natural gas savings, a small amount of electric savings can be realized through reduced operating hours of the exhaust fans.

While a simple payback is shown in the technical research data attached to this report, the actual simple payback is highly dependent on the specific systems at the greenhouse and the grower’s preferences for temperature and humidity.

## HAF High-Efficiency Fans

Horizontal airflow (HAF) fans were found in every greenhouse surveyed. HAF fans are fractional horsepower fans that are used to circulate air throughout the greenhouse. Numerous fans are installed throughout the greenhouse to create a circular motion of air. This is done to maintain a constant temperature throughout the greenhouse as well as to promote crop health by simulating a small amount of wind to replicate the natural outdoors in the greenhouse.

**Photos S and T. Examples of HAF High-Efficiency Fans in Existing Greenhouse**

Photo S

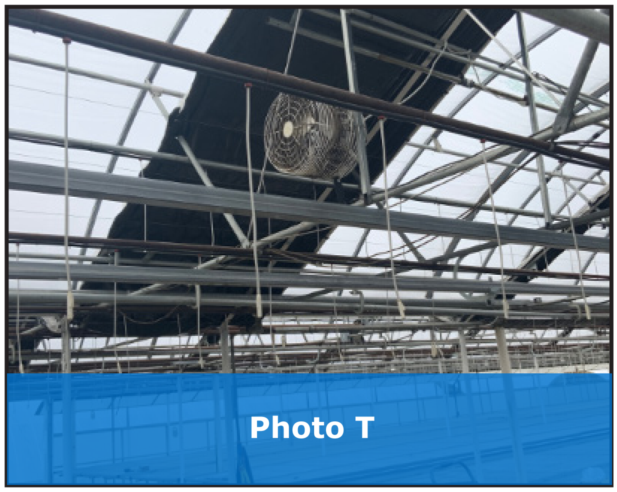
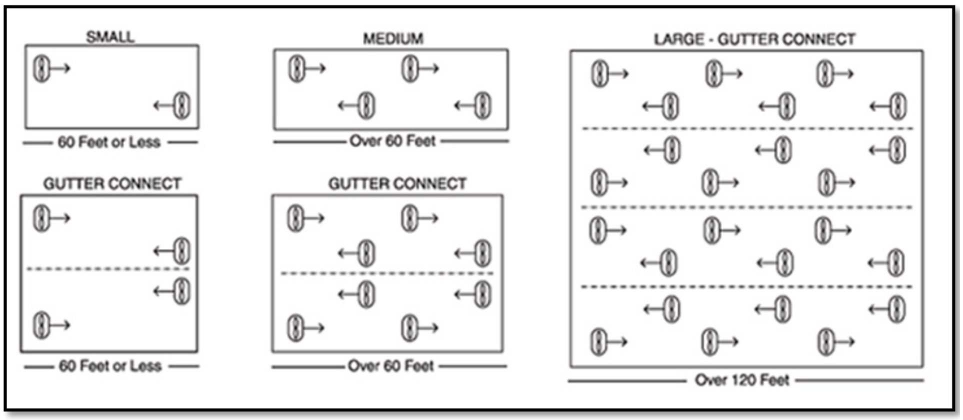


Photo T

Different fan designs will produce varying amounts of airflow for every watt of power the fan consumes. This airflow is measured in cubic feet per minute or CFM. Although high-efficiency HAF fans do cost more, a lower number of high-efficiency fans are needed in the same space as legacy fans. It should be noted that there appeared to be an “art” to the placement of the fans as well. More than one grower indicated that the manufacturers may engineer a layout, but they typically installed fewer based on a “feel” for the space. Figure 21 shows some typical layouts from one fan manufacturer.

In addition to the efficiency of the fans, a variable frequency drive (VFD) can be installed to fine tune the airflow to what is needed or required for the space. Since these fans are small, a single VFD can be used to operate a few fans simultaneously.

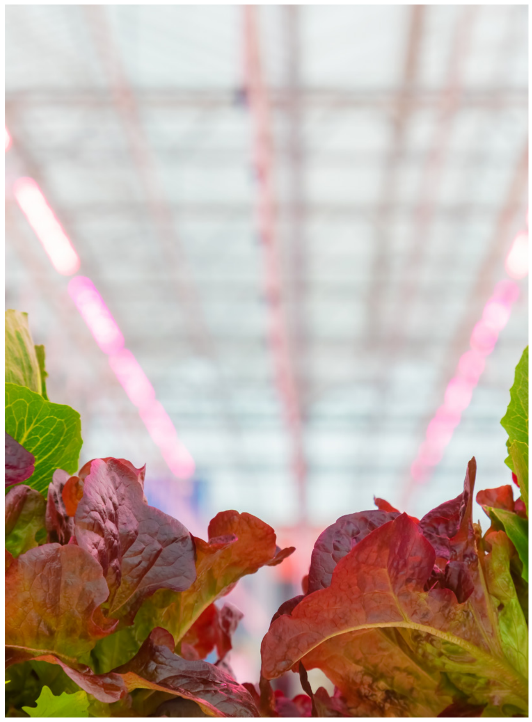
Figure 21. HAF High-Efficiency Fans – Typical Layouts




Based on the estimated savings and equipment costs found online, a 4.1-year simple payback was estimated for this technology. The energy savings assumption was that fewer fans can be installed and a VFD can be used to reduce speed.

## Refrigeration

Several greenhouses had refrigeration systems, some of them significant in size. Many of these systems were only used during strategic times throughout the year, limiting the annual operating hours. Farms often had walk-in coolers to store fruits, vegetables, and flowers after harvest and before sale to the consumer. These walk-ins varied in size, efficiency, and age. SA larger facility had a cooled packing room that was used to box up produce before shipment. These refrigeration applications could be a good opportunity for targeted outreach at greenhouse farms where other projects were already underway. It is likely that any of these systems could be handled through the prescriptive refrigeration incentives at DTE. Due to the limited applicability of refrigeration throughout the greenhouse industry, the limited operating hours in many cases, and the existing prescriptive incentives for refrigeration technologies this analysis does not address refrigeration systems in detail.



## Lighting

In greenhouse applications, using natural daylight will decrease the need for supplemental electric light when compared to a complete indoor operation. Supplemental lighting for greenhouses can be applied in three ways:

1. supplemental light in addition to natural light throughout the day,
2. supplemental light to lengthen the shorter days in the winter, and
3. a combination of both.

Annual hours and loads of supplemental lighting will be lower than a complete indoor grow operation because it is only used for lengthening light on shorter days. Fixture spacing increases if used as supplemental light throughout the day. Once the lighting system is properly tuned, desired light levels can be achieved, and the lighting can become an automated, efficient system that harvests natural daylight while maintaining consistency throughout the plant growth cycle.

Below are important variables that are needed for healthy plants and growth when it comes to a supplemental lighting system:

**Light Levels** The amount of Photosynthetic Photon Flux Density (PPFD) or measurable light the plant needs to live and grow.

**Usable Light** The light a plant absorbs to grow or Photosynthetic Active Radiation (PAR).

**Time** The dose of light for a specific time per day or Daily Light Integral (DLI). Plants need a certain light level, spectrum, and dose of light to thrive.

**Transmittance** Crops need a specific amount of light. The material used to enclose a greenhouse will have a transmittance number, meaning the amount of natural daylight that penetrates through the material. The greenhouse envelope needs to be considered when designing for natural and supplemental lighting systems to ensure that there is enough light in the "worst-case" situation. A simple field test using a light meter can determine transmittance by taking a reading inside the structure, then outside the structure. Dirt depreciation, material breakdown, and other factors will decrease transmittance if the greenhouse envelope is not maintained.

The Controlled Environmental Agriculture (CEA) industry standard for legacy lighting is high wattage high-pressure sodium (HPS) lighting systems. LED lighting systems are now commonplace and seen as a viable technology for greenhouse growers.

Of the surveyed greenhouses, very few had existing lighting systems. There were a small number of existing LED lighting systems compared to existing HPS systems. Some growers expressed interest in upgrading or adding a LED lighting system to their greenhouses.

**Photos U and V. Examples of High-Pressure Sodium Lighting in Existing Greenhouse**

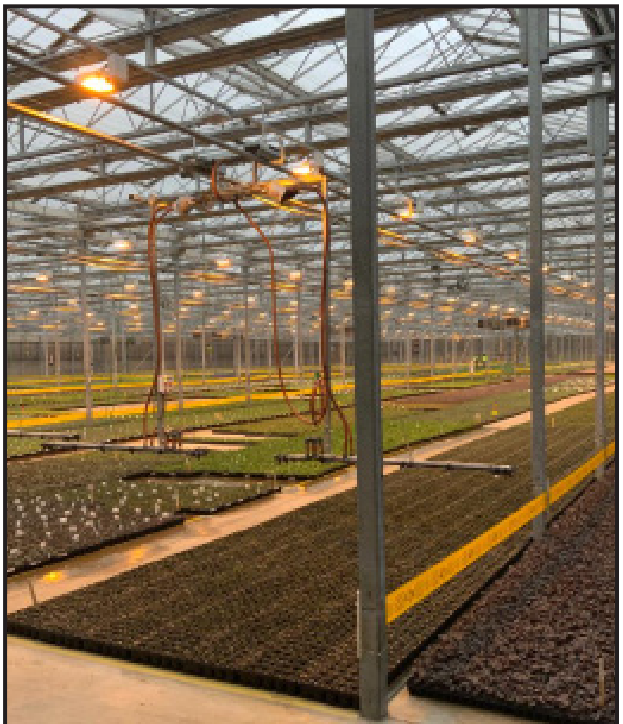


Photo U

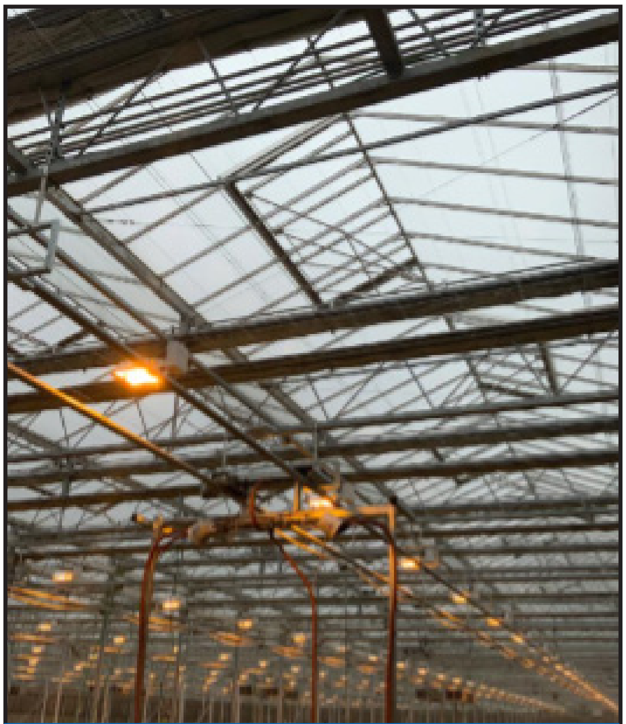


Photo V

**Photos W and X. Examples of LED Lighting System in Existing Greenhouse**

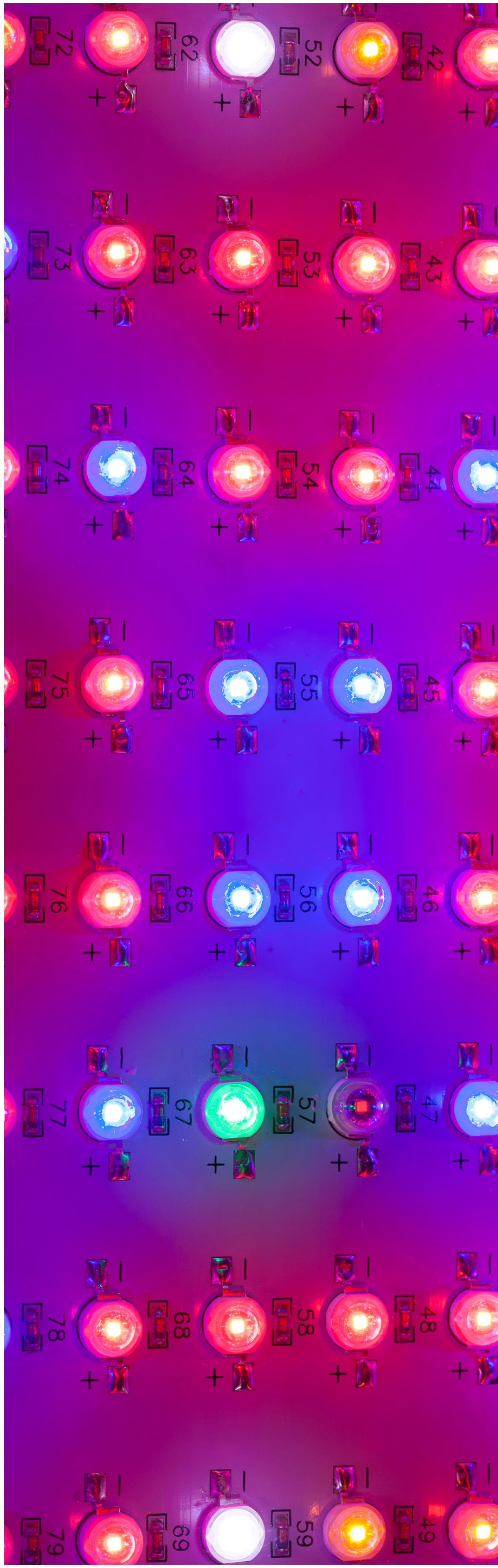
Photo W

Photo X

LED lighting systems are widely deployed today in the CEA market. Lighting tends to be one of the quicker payback projects for EE upgrades. The price of upgrading to a LED lighting system depends on the manufacturer and wattage or light output of the proposed LED fixture. The costs for Design Lights Consortium or DLC qualified LED grow lights are higher than non-qualified fixtures. This is due to the commercial-grade quality and product warranties of DLC listed LED grow lights.

In addition to the greenhouse structures, there may be opportunities to retrofit the existing commercial spaces at a greenhouse facility (offices, garden center, warehouses, exterior lighting, etc.). DTE currently has prescriptive incentives for both commercial and CEA lighting projects. The current incentive for greenhouse lighting is $0.05 per kWh saved. Incentives could also be provided for daylighting controls and daily light integral (DLI) sensors. Energy savings from controls will need to be verified.

Costs were estimated based on DLC qualified LED grow lights and past CEA lighting project installations. Energy savings from converting an HPS lighting system to a new LED lighting system was estimated at 35% to 50%. The simple payback for a LED lighting system was estimated at 3 to 8 years.




# Partner Organizations

For guidance with the Michigan greenhouse market and potential EE measures, IC reached out to several partner organizations. Conversations with partner organizations were conducted via video or phone calls and provided insight into the greenhouse sector. Outreach to partner organizations happened in tandem with the greenhouse site visits to better understand technologies and methods that were commonly seen in the field. Reaching out to partner organizations and connecting with subject matter experts (SME) allowed for a better understanding of the Michigan greenhouse market and viable EE measures for these facilities. Below is a list of partner organizations and specific contacts that provided advice and useful resources to move the Grow Pilot forward.

# Michigan State University (MSU)

## Erik Runkle, Ph.D.

*Professor, Department of Horticulture*

- Believes lighting is the first and best opportunity for greenhouse EE projects, followed by heating (HVAC).
- Shared input on lighting, HVAC, geothermal systems, thermal curtains, building envelopes, and vertical farming in greenhouses.
- Provided contact information for A.J. Both of Cornell University. A.J. Both is a Ph.D. who possesses technical knowledge around HVAC systems for greenhouses.
- Provided the greenhouse research articles below.
    - How Do I Use Less Energy To Heat My Greenhouse?
    - Challenges of Growing Vertically in Greenhouses

## Dan Bulkowski and Jessica Wright

*MSU Plant Sciences Greenhouses Tour*

- DTE Intern Julia Martin reached out to the MSU Plant Sciences Greenhouse for a tour of the facility. Julia conducted a site interview and completed a greenhouse questionnaire that is included in the Grow Pilot research.
- During the tour, Julia Martin discovered that the greenhouses had a wish list of EE upgrades that include fan system upgrades, shade curtains, and upgrading existing fluorescent lighting to LED.
- Plant Sciences Greenhouses operate year-round and are used as “teaching greenhouses” to educate students on horticulture.
- The greenhouses sell the plants, crops, perennials, succulents, and cacti that the students grow. The money from these sales goes back into the MSU Plant Sciences Program.

## GLASE at Cornell University

**Erico Mattos, Ph.D.**
*Executive Director, Greenhouse Lighting and Systems Engineering (GLASE) at Cornell University;*
*CEO of Candidus*

- Recommended USDA census report (see USDA section below).
- Shared information for New York State greenhouse database and benchmark tool.
- Study in partnership with USDA on advanced greenhouse lighting controls currently operable in Michigan at three greenhouses (Candidus):
    - Henry Mast
    - Walters Gardens
    - Revolution Farms

## Resource Innovation Institute (RII)

**Gretchen Schimelpfenig, PE**
*Technical Director, Resource Innovation Institute (RII)*

- Currently in partnership with USDA to administer an estimated $600,000 over three years to non-cannabis support. Funding cannot be used to directly incentivize technologies and any funding provided should be met with funding from private industry (for example, a manufacturer). Opportunities to stack this funding with utility incentives.
- CEA market characterization report and recording of the webinar with USDA and ACEEE.
- Recommended looking at PowerScore analysis from past editions of The Benchmark for cannabis Ranked Data Set insights comparing indoor to greenhouse KPIs. This information will be national because PowerScore does not have any Michigan records in the Ranked Data Set (there are no energy regulations for cannabis cultivators, and benchmarking is not required).
- 2020 Cannabis Business Times article with Nick Collins on Boulder, CO greenhouses compared against MA indoor facilities.
- 2021 Greenhouse Grower articles by Gretchen discuss controls, envelope, HVAC, and lighting approaches:
    - Optimizing Systems for Cannabis Greenhouses
    - Empowering Plants with Environmental Controls Systems

# U.S. Department of Agriculture (USDA)

### Rick Vanderbeek

*REAP Specialist, USDA Rural Development*

- USDA 2017 Census
    - Floriculture and Bedding Crops, Nursery Crops, Propagative Materials Sold, Sod, Food Crops Grown Under Glass or Other Protection, and Mushroom Crops: 2017 and 2012

- Floriculture Growers Council had organized education and upgrades several years ago for that group, but there may be a gap in the produce growers.

- Rick believed there was a greater opportunity in Southeast Michigan or outer Detroit areas for efficiency upgrades.

- Rural Energy for America Program (REAP) – provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses for renewable energy systems or to make EE improvements. Agricultural producers may also apply for new EE equipment and new system loans for agricultural production and processing. Opportunities to stack REAP funding with utility incentives, especially for geothermal heat pumps.

# Dr. Greenhouse, Inc.

### Nadia Sabeh, PhD., PE, LEED AP

*President and Founder of Dr. Greenhouse*

- Approaches to greenhouse efficiency and operation have been extremely different across the U.S.

- Nadia works with mostly cannabis operations, but other produce as well.

- Michigan tends to be more heat driven than California clients, but humidity in the summer is a major challenge for Michigan. Customers are often looking for ways to increase airflow, ventilation, and dehumidification.

- Ridge fans and roof vents are good ways to control airflow and humidity. Ridge fans are easier to retrofit than roof vents.

- Electronically Commutated Motors and VFDs on fans can save energy. Twin or triple-wall polycarbonate insulates and performs better than single-layer corrugated polycarbonate. Nadia made a special request for rebating twin-wall polycarbonate.

## Energy 350

### Justin Hovland

*HVAC Engineer and Specialist*

- Dehumidifiers are a definite opportunity for savings with a clear threshold of baseline technology versus efficient technology at 3.1 pint/kWh. Customers are likely to use dehumidifiers in winter when they do not want to ventilate heated air.
- Discussed gas unit heaters, condensing boilers, thermal curtains, and IR/AC film in greenhouses.

## Michigan Department of Agriculture & Rural Development (MDARD)

- Reached out via website and contacted Molly Mott without success.

## Vegetables Growers Council

- Michigan vegetable industry facts are available on the website.
- Heavy emphasis on Great Lakes Fruit, Vegetable, and Farm Market Expo – December 7-9, 2021

## Michigan Greenhouse Growers Council

- A helpful list of participating growers is available on the website.

### Other Growers' Councils

Metro Detroit Flower Growers Association

Michigan State Horticultural Society

Michigan Ag Council

Michigan Floriculture Growers Council

# Partner Organization Market Data

Considering source fuel, most savings opportunities in greenhouses come from heating. Figures 22-2 and 23-2 were presented in a Cannabis Business Times article and the responses came from Boulder County Cannabis Cultivator Energy Efficiency Assessments. When growing the same product, in this case, cannabis, indoor operations use a vast majority of their energy on lighting for the plants. Of course, greenhouses have the solar radiation benefit, and only need to use supplemental lighting if desired by the plant and/or grower. Even with high-powered grow lights, natural gas or heating is the primary form of energy used in greenhouses in cold climates.

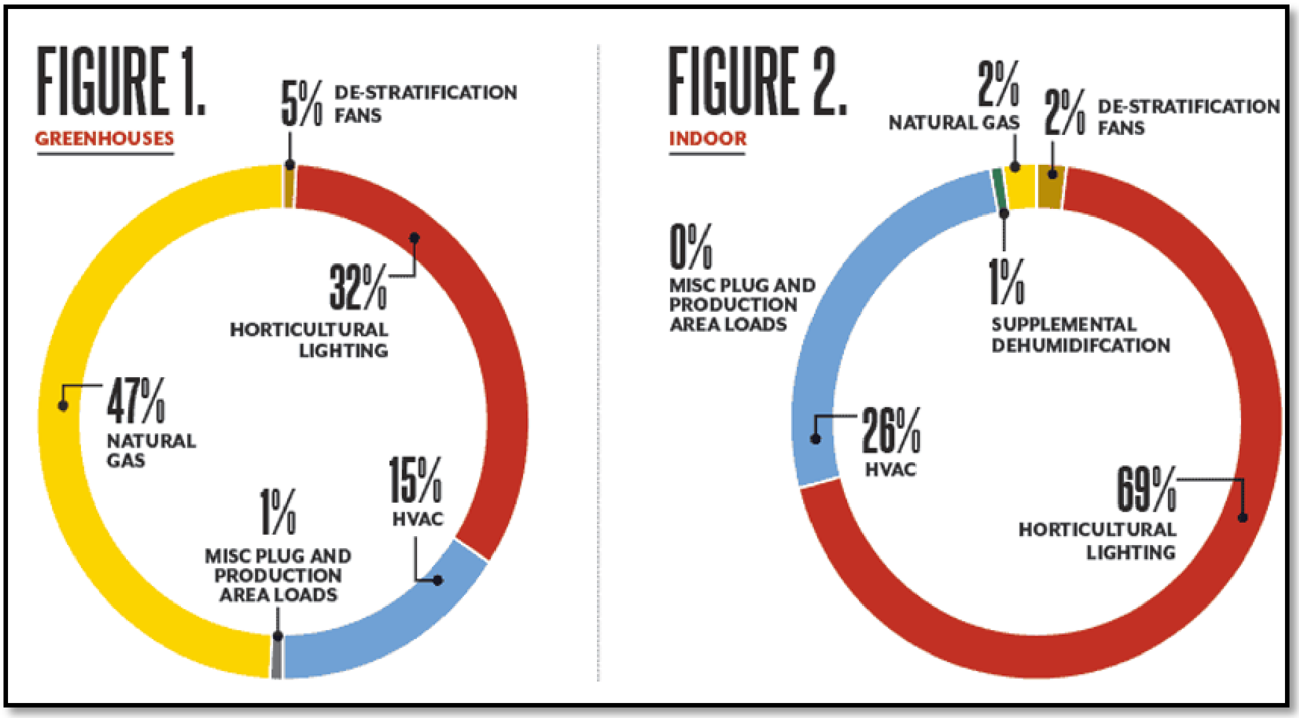
To take this one step further, utilities could consider targeting customers within certain electric and gas territories. It might be most efficient to point DTE resources towards:

1. Heating efficiency for greenhouses within the gas territory

2. Indoor growing facilities (food crops as well as cannabis) within the electric territory

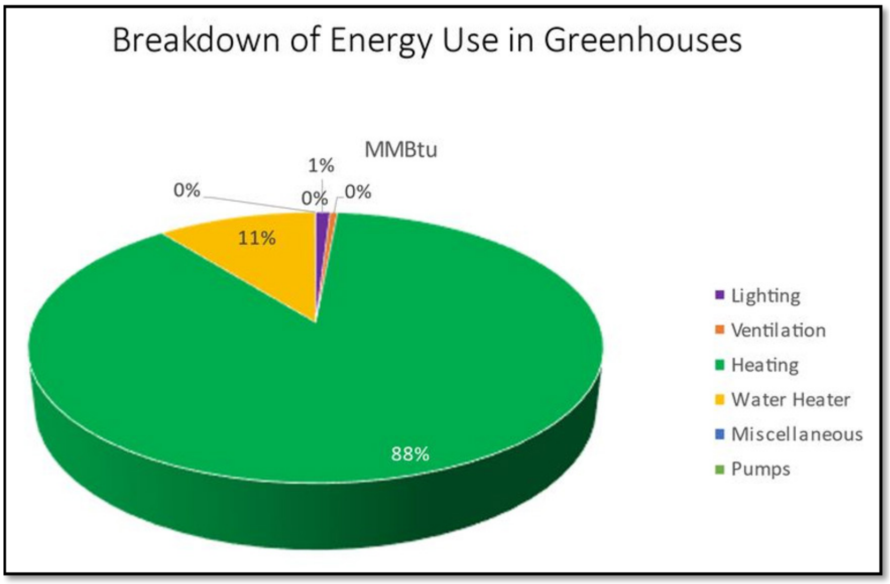
Those two segments would incorporate most of the savings available in DTE's Michigan CEA sector. In areas where the greenhouse fuel type is different than natural gas, we can assume that the largest load in a greenhouse would still be the heating system.

Figure 22. Michigan Greenhouse and Indoor Grow Technologies



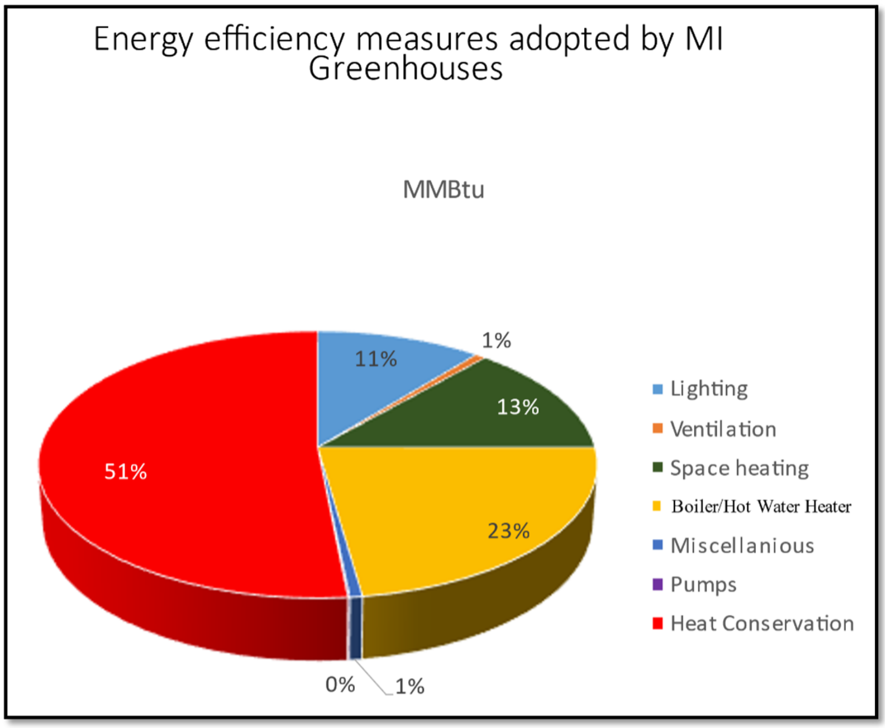
Some MSU research showed that the breakdown of energy in greenhouses in Michigan was overwhelmingly from heating since not all greenhouses use lighting and those that do are transitioning to LED grow lights (Figure 23).

Figure 23. Typical Energy Use in Greenhouses




According to MSU, greenhouses have already been installing efficiency measures. The most common upgrades are thermal curtains, then hot water upgrades, followed by space heating, as shown in Figure 24. Lighting is ranked fourth with pumps, ventilation, and other miscellaneous loads coming in at 1% or less each.

Figure 24. Measures Adopted by Michigan Greenhouses

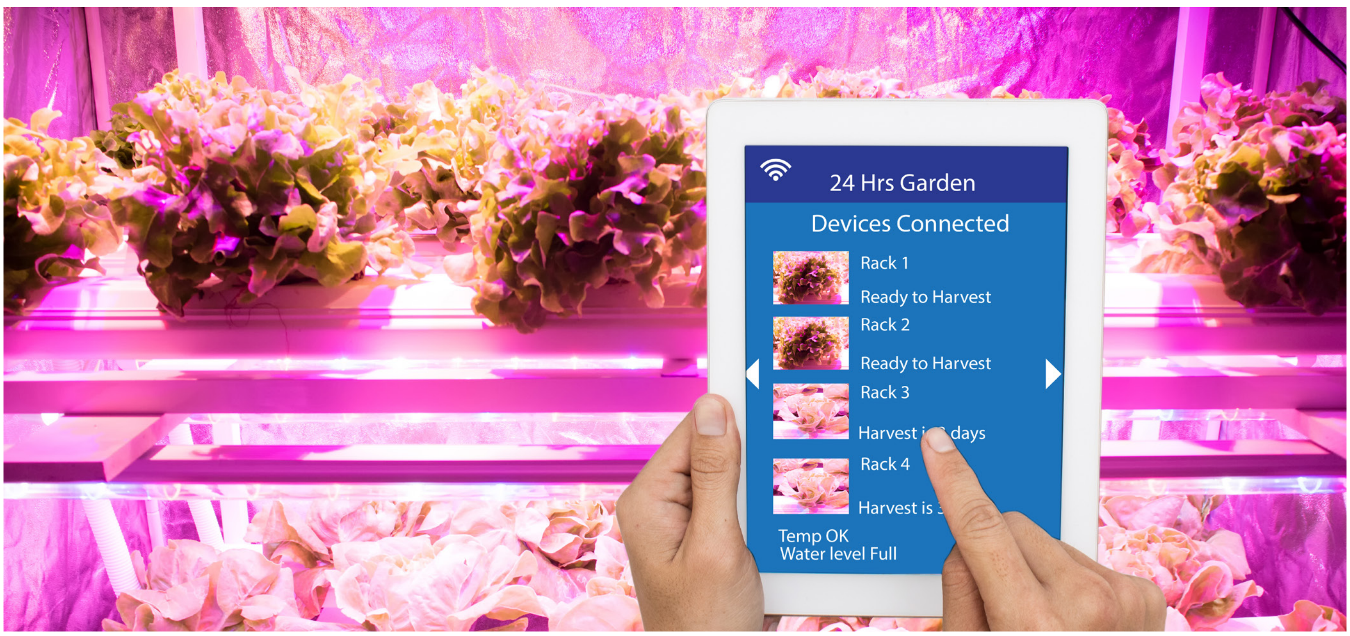


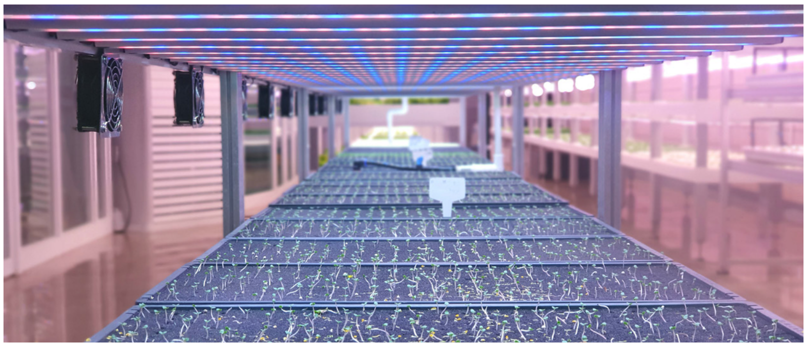
## Greenhouse Supply Chain

DTE Co-op Student Julia Martin is currently studying at Michigan State University and will specialize in industrial engineering with an emphasis on supply chain management. Julia took an in-depth look into the greenhouse supply chain and below are the findings of her report.

## Overall Scope

The greenhouse supply chain is one that is dynamic and unique compared to that of other industries. While certain companies can have inventory sitting on shelves for months, the best quality produce can only be on shelves for days. In addition to the short shelf life is the seasonality of certain items. Growing year-round and integrating high-end technology is not always an option for smaller-scale greenhouses. This makes the systems and processes complex with many aspects needing to be considered. One way that greenhouses have strived to improve the supply chain of produce distribution is through lean flow techniques. In other words, finding methods that eliminate waste, and that are distributed to the consumer in the most efficient way possible. As a result of implementing these techniques, inventory can be managed more efficiently while increasing the service at the same time. Another efficient technique that greenhouses have been implementing is to observe history and forecast. In doing so, a better grasp of certain sale and customer trends can be recognized and thus, applied to the supply chain process to make further improvements. Moreover, studying trends is the best way to plan and predict future scenarios that the greenhouse may encounter. Throughout this report, the downstream and upstream processes of the supply chain for commercial greenhouses are analyzed and examined.





## Pre-Harvest and Production Supply Chain

When planning to start a commercial greenhouse business, it is important to understand the materials and components needed to effectively begin producing crops. Additionally, before starting to grow, it is important to decide the target market and customers, the growing period, and the types of products that will be grown. These fundamental decisions will influence the scale of the greenhouse and help growers determine what materials and resources are needed. Here, the pre-harvest aspects will be analyzed.

## Materials and Seeds

For a mid- to large-scale greenhouse, materials are easier to obtain in bulk. Depending on the produce that is being grown, certain manufacturers or retailers may be better than others, therefore, it is important to understand the scale of the greenhouse and the demand of the customers. Determining how much inventory to buy, such as fertilizers, soils, and seeds, can be done based on history and data from past growing seasons. Analyzing and creating a forecast for how much an item is predicted to sell, as well as during what time of the year, will help reduce unnecessary costs. Since these products have a short shelf life, it is crucial that the amount produced meets the customers' demands. Moreover, this will also ensure consistent profits.

## Growing and Farming

Another important aspect to consider is the labor that will maintain and ensure that the quality produce is grown and harvested efficiently. As mentioned before, depending on the scale, this will determine how many employees are needed to do this work. It is also important to understand that produce is very particular and sensitive. Therefore, people with higher knowledge and background in this field is necessary to be successful, along with part-time and work-driven employees. Consistency in growing practices and defining an effective farming regimen ensures that produce will be harvested and on the shelves in a timely manner to be purchased by the customers.

## Utilities

Electricity, gas, and water usage should be evaluated in greenhouse planning. The cost of providing electricity to power certain technologies and processes will be added to the total costs of operation. Regarding water, consider the supply to be adequate to meet peak load demands. For instance, a typical amount of water to support a mid- to large-scale greenhouse is around 0.3-0.4 gallons/square foot per day. However, this is a situational amount and further testing should be done so that the proper amount is available. Lastly, examinations should be done on the water's pH levels, along with other sediments and alkalinity to verify that water is suitable for the produce to grow.

## Greenhouse Equipment Supply Chain

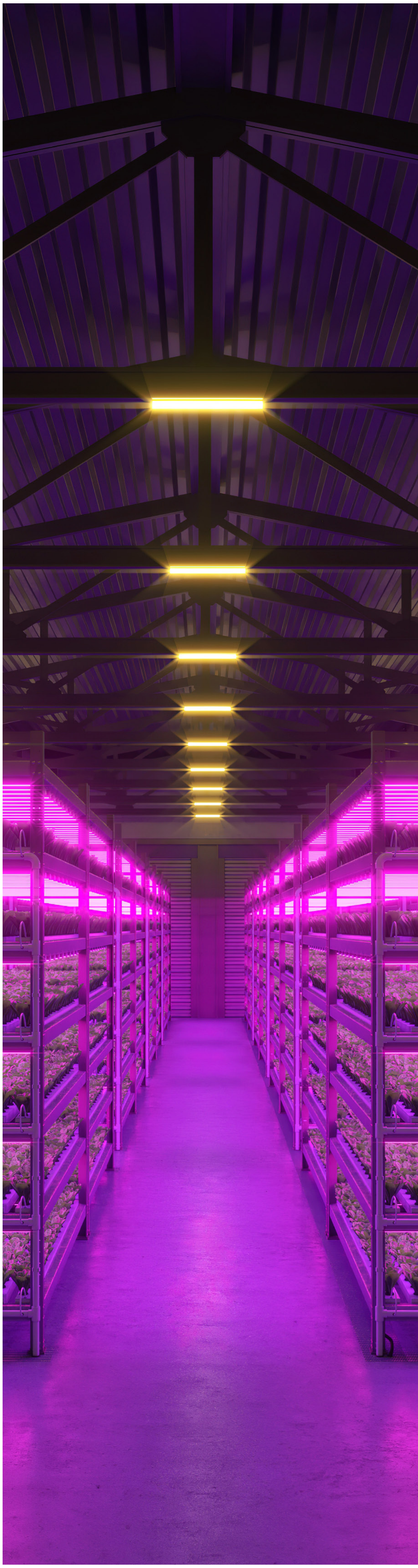
Now having determined the materials, utilities, and scale of the commercial greenhouse, there is a variety of technology, lighting, and irrigation aspects that will contribute to successfully growing produce. The importance behind the technology is the ability to continue growing despite the climate conditions. This section further examines numerous greenhouse technologies. Again, technology usage is based on the size of the greenhouse and the number of products being grown. Moreover, researching multiple distributors, contractors, and manufacturers for these techniques will be useful in finding the most cost-efficient technologies.

## Lighting

Certain produce may require high-intensity grow lights, while others may only require general-purpose LED lights. Scoping out the canopy area that is to be covered by a lighting fixture will determine how many fixtures are needed. Each crop will require a certain amount of daily light integral (DLI), a function of intensity and duration of light received per day. Lighting is often purchased directly from the grow light manufacturer or through a greenhouse equipment supply house.

## Cooling and Ventilation

For cooling, utilizing natural ventilation when possible can be effective in reducing costs. However, this is not a reliable technique for the entire year. Therefore, integrating fan and louver systems will help produce more positive ventilation. Additionally, this will help the temperature control within the greenhouse. Evaporative cooling through fans and pad or fog will use the provided moisture to pick up excess heat that is exhausted by fans. Lastly, horizontal airflow systems will provide adequate air movement and uniform temperature throughout the greenhouse. Smaller fans placed strategically remove moisture from the leaves to control the carbon dioxide levels within the plants.



## Heating

As mentioned in the Technical Research above, heating systems can vary widely by size and design. Heating remains the largest energy user in most greenhouses. Common heating systems include forced hot air or unit heaters, in-ground or in-bench systems, infrared heaters, or geothermal heat pumps. These systems are usually purchased from greenhouse suppliers, and can also involve a manufacturer depending on the complexity of the design or layout.

## Controls

For small-and large-scale greenhouse operations, thermostats and electronic controllers to mediate heating and ventilation can be extremely useful in maintaining the moisture levels and growth process of the plants. Setting different timers so that processes of a crop can be repeated or adjusted improves the efficiency and maintenance of the plant's development. Controls are often purchased directly from the manufacturer but can be purchased through a supplier.

## Irrigation

The use of effective irrigation is another important technology to ensure that the growth of the produce is successful. For instance, using computerized systems programmed to hydrate certain sections of the greenhouse at specific rates will eliminate hand watering. As a result, costs will decrease for labor, and in the long run, increase savings.

## Greenhouse Envelopes/Coverings

Greenhouse envelopes and coverings are one of the most important aspects of a greenhouse's functionality. These materials impact the level of quality and light available to the crop. How thick the coverings should be (how many sheets of polycarbonate), when they should open, and when they should close are all aspects to consider when deciding which is right for a greenhouse. Depending on the climate and light intensity of the location will determine what option is most efficient. Polycarbonate envelopes have a lifespan of 10-15 years and reduce heat loss by 40%. While these have an expensive initial cost, it will be a more cost-effective way of maintaining the temperatures of the greenhouse throughout multiple growing seasons. Greenhouse coverings are usually available through a specialty greenhouse supply house like BFG Supply.

## Post-Harvest Supply Chain

Once the produce is harvested, it is important to have an efficient system and process for storing, transporting, and distributing items. Understanding the market where certain products thrive and are successful will increase profit. Studying the history and patterns of a greenhouses' seasons will be useful in deciding what is most beneficial to focus on for consumer demand. The overall process by which produce makes it to the shelf is further observed.

## Storage

Plants must stay on the vine for as long as possible to reach maximum quality and typically are harvested 2-3 times per week depending on the plant. Therefore, designating a portion of a greenhouse to store materials and soils as well as produce once harvested ensures that items are of good quality before being purchased by consumers. This can be done using coolers and refrigerators to help maintain the quality of the produce since they have a short lifetime. The number of items that are harvested will measure how much space is needed in storage. Additionally, spacing crops out to guarantee enough time and space to store crops until transported is a necessary component.

## Transport

There are multiple ways to go about transporting crops, but first, know where the crops are going. Contacting local businesses, markets, restaurants, or designating a certain number of crops is necessary to make a profit. A process that has been successful for greenhouse operation is a lean-to structure outside the headhouse to provide cover for the trailer loading operation. In summary, this process utilizes the automation of a conveyor and robot that facilitates the movement of plants onto a trailer and senses when the truck is full. Another aspect of more efficient transportation is the containers that the plants are grown in. Growing plants in polystyrene (plastic) containers are most useful for mass production. In addition to being effective, they are also affordable and can be arranged in ways to get the most out of production. Lastly, the temperature of the trailer is important to maintaining the quality of the produce, so it is of the highest quality when it reaches the customer.

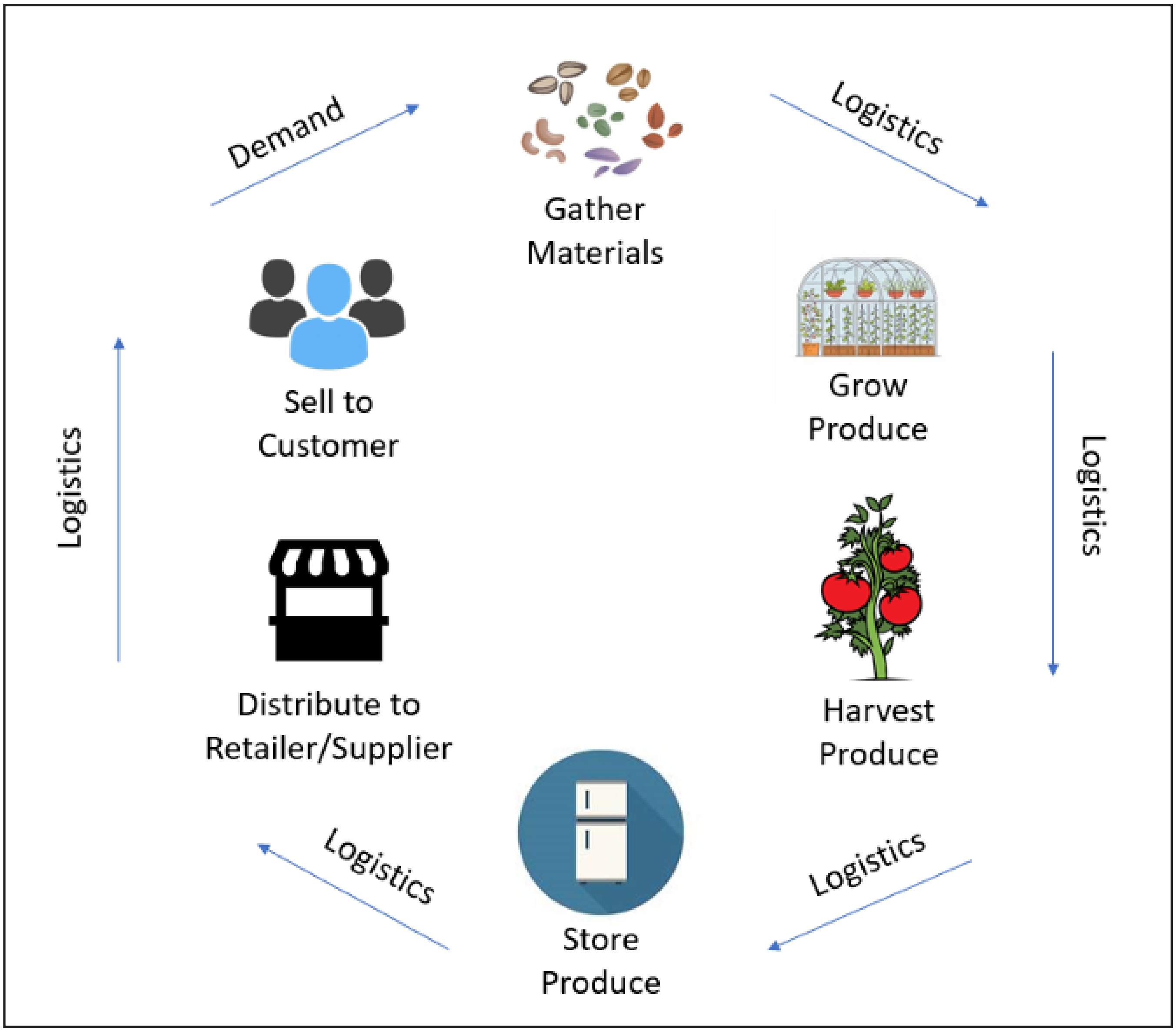
## Wholesale/Retail

Another decision that must be made is whether products will be wholesale or retail. Wholesaler refers to the selling of produce to customers such as industries, retailers, or others in bulk at a lower price. In other words, the items would be repurchased and sold to suppliers that would then repackage the crops and resell them. Therefore, there is a larger emphasis on the number of items and does not focus on brand or community involvement. n contrast, retail is the production of produce that is sold directly to the consumer. This results in higher prices and activities such as advertising, marketing, and brand developments factor into creating successful retail. Moreover, determining what kind of business will result from a greenhouse's production will decipher whether it is a retail or wholesale greenhouse.

## Consumers and Market

Understanding a target audience and market for the crops being produced is a factor that will affect a greenhouse's overall success. Experimenting with wholesale and retail options could be beneficial in the early stages to see what customers are more inclined to buy from the greenhouse. After analyzing customer patterns, decide whether extra funds need to be allocated to defining a brand. Additionally, the target customers will help gauge the lead time needed throughout the distribution process. These lead times include the duration needed to harvest and ship items, so they are readily available to customers. Lastly, establish a service that meets the demand of the customer. Setting realistic goals for how you can supply crops to customers will build trusting relationships between the supplier and the consumers.

**Supply Chain Representation**



## Supply Chain Report
## Potential Contact Information

HTG Supply Hydroponics & Grow Lights, Roseville MI, (586) 435-2335

Greenhouse Mega Store, (888) 281-9337

BFG Supply, Burton OH, (440) 834-1883

Bulk Seed Store, (855) 440-0556

RRR Transportation Company (800) 472-4714

USA Truckload Shipping (866) 353-7178

E Armata Inc. (718) 991-5600

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## Supply Chain Interviews
## Lighting Manufacturers

IC conducted interviews with two lighting manufacturers that provided insight on current supply chain issues. Obtaining insider knowledge on supply chain delays, product timelines, and part shortages will allow the Grow Pilot to set realistic project timelines. Below is a list of organizations and specific contacts who can help estimate crucial material order dates and installation timelines during the next phase of the Grow Pilot.

# Fluence by OSRAM

### Corinne Wilder, Vice President
### Global Commercial Operations

*Fluence, Greenhouse Market Input and General Notes*

- Majority of Fluence installations are cannabis, even in greenhouses.
- Fluence can support growers regarding spectrum or intensity concerns for certain crops; have been conducting research with horticulture universities for 6+ years.
- Greenhouse Retrofit Guide available on the website, contains helpful technical information on switching from HPS to LED.
- Fluence willing to do cost-shared demo installations for a case study in partnership with the utility.
    - Innovative installations can integrate with advanced controls like Candidus, Priva, and Argus.

*Fluence, Supply Chain Input*

- Supply chain bottlenecks industry-wide, not specific to Fluence.
- Causes of supply chain issues include:
    - Rare earth metal shortages
    - Labor shortages
    - Logistical/shipping issues
    - Increase in shipping rates
- Product bottlenecks include:
    - Chips
    - Drivers - up to 30 weeks lead time
    - Steel
- Soil and nutrients are not as impacted as mechanical equipment.
- In these uncertain times, planning for resiliency including purchasing surplus material in anticipation of COVID-related issues has been advantageous.
- Despite supply chain issues, demand continues to rise for products due to legalization and booming CEA industries worldwide.

## BIOS

### Doug Oppedal, President and Founder of Doug Oppedal Consulting

*BIOS, Supply Chain Input*

- Due to supply chain issues, typical product delivery timelines for BIOS LED grow lights are now taking a few months or longer.
- Currently, BIOS has products shipped from China. However, BIOS is switching its manufacturing to Mexico and has purchased a warehouse in California to try to build up stock. BIOS will have products come across the border instead of across the ocean. A lot of suppliers are starting to follow this model.
- From longshoremen to truck drivers, labor shortages are affecting the BIOS supply chain. The National Guard may be asked to step in to help unload the backlog of cargo ships.
- Installation timelines can be affected by local utility requirements. A utility in Arizona is requiring that the customer reapplies for incentives since the project will not be completed by the initial deadline in December. Another utility in Michigan is providing a project extension due to supply chain delays.
- At this point, all my LED grow lighting projects have expected delays due to supply chain issues.

# BFG Supply

**Jack Vansledright**
*Central Region Sales Manager*

- Customers include growers of all sizes including hydroponics retailers, CEA, cannabis, home and garden centers, direct to growers.
- Products include building envelope, irrigation, fans, fertilizer, heating systems, lights, everything growers need.
- Participate heavily with Franklin Energy and Consumer Energy contacts on rebates, DTE rebates are not as common.
- There is confusion around the eligibility of certain customers, especially if they participate in the DTE program where they can contract to purchase natural gas out-of-state.
- BFG is one of the largest distributors of grower/garden materials in North America, based out of Ohio, so there is a definite stronghold in the Midwest and Michigan markets.
- Expanding business model to include construction section of the business to support all growers' new construction needs.
- People typically stay with the same brand unless there is a 20% savings or gain.
- Modine heaters are by far most popular heating system sold, thousands of units every year. Should be replaced every 10-15 years and some growers are diligent about maintenance and replacement schedules while others never replace their systems. On larger farms, there is always something ready to be switched out or upgraded.
- Environmental controllers are not necessarily sold through BFG, that is one area where customers usually buy direct from the manufacturer like Wadsworth, Bartlett, Priva, or Argus.
- BFG has several locations for easy access in the region. They even have a warehouse that serves many different growers in a greenhouse region in Kalamazoo.

## Supply Chain Supplemental Article

A recent Wall Street Journal article outlined current supply chain delays and issues:
Cargo Piles Up as California Ports Jostle Over How to Resolve Delays

# Potential Pilot Participants

For guidance with the Michigan greenhouse market and potential EE measures, IC reached out to several partner organizations. Conversations with partner organizations were conducted via video or phone calls and provided insight into the greenhouse sector. Outreach to partner organizations happened in tandem with the greenhouse site visits to better understand technologies and methods that were commonly seen in the field. Reaching out to partner organizations and connecting with subject matter experts (SME) allowed for a better understanding of the Michigan greenhouse market and viable EE measures for these facilities. Below is a list of partner organizations and specific contacts that provided advice and useful resources to move the Grow Pilot forward.

All DTE customers have been consulted about the pilot opportunity and are interested in partnering with DTE to become more energy efficient. Financial aspects of each project will need to be reviewed throughout the year with each pilot site and DTE.

# #1 Green Things Farm Collective – Ann Arbor, MI

## Combined Electric and Natural Gas Service

Green Things Farm Collective is a small farming operation near Ann Arbor focused on bringing food to the local community in a sustainable manner. The owners have already invested in EE and sustainable technology, including a photovoltaic array on-site and condensing UTs. The owner is open to new and innovative ideas to advance their sustainability efforts, and they are also considering a renovation or replacement of their main heated greenhouse.

While mainly an open field farming operation, Green Things Farm has multiple small greenhouses onsite. Several of the greenhouses are unconditioned, while two are heated for part of the winter.

**Photos Y, Z, and AA. Green Things Farm Collective, Existing Greenhouses**


Photo Y


Photo Z


Photo AA

With a preliminary budget of $80,000, potential greenhouse upgrades for Green Things Collective Farm includes:

- In-Floor Heating System
- Geothermal Heating
- Roof Vents
- Thermal Curtains
- Farm Automation Upgrades
- HAF High-Efficiency Fans

*Please note, the preliminary budget does not include engineering costs which are estimated at $15,000.*

This location has open land near the greenhouse for a potential geothermal well field. The owner is open to the idea of a geothermal system. Roof vents were included in the potential upgrades above. However, discussions with the manufacturer will be necessary to confirm this structure can be retrofitted with this technology. It should also be noted that the owner currently utilizes a "homemade" farm control system. The rudimentary farm control system appeared to be working well, although this could create challenges in upgrading the system to include the new technologies.

# #2 Post Gardens - Rockwood, MI

## Combined Electric and Natural Gas Service

Post Gardens has two locations in Michigan. The Rockford location was surveyed and may be a potential site for the Grow Pilot. Both locations specialize in ornamental flowers and plants which are sold wholesale, although a small number of vegetables, mainly cucumbers, are produced as well.  This site has nearly 20 acres of greenhouse space, the demonstration project would focus on a small area near the main entrance.

**Photos AB and AC. Post Gardens, Existing Greenhouses**

Photo AB

Photo AC

The greenhouse space to be highlighted is shown in Photos AB and AC. This space utilizes benches to grow crops, has a double poly building envelope, and can be partitioned off from surrounding spaces using retractable walls.
Additionally, there is a small pond outside this space that will be analyzed for a potential geothermal application.

**Photo AD, Post Gardens, Existing Pond for Potential Geothermal System**

Photo AD

With a preliminary budget of $116,000, potential greenhouse upgrades for Post Gardens includes:

- Under-Bench Heating System
- Geothermal Heating
- Roof Vents
- Thermal Curtains
- Farm Automation Upgrades
- HAF High-Efficiency Fans

*Please note, the preliminary budget does not include engineering costs which are estimated at $17,400.*

Once these upgrades are implemented for the participant, it is important that the space temperature setpoints in the greenhouse be reduced. Growers seem to have differing opinions on the impact of lower-space temperatures; however, this strategy is critical to realizing the desired savings of the under-bench heating system. If the participant is not agreeable, this upgrade could be removed from the scope of work, with the remaining technologies still being implemented.

There is also an opportunity with the installation of a new under-bench heating system to create zones and test the effectiveness of the "bench insulation" mentioned in the technology review section. Under an agreement with the owner, two distinct zones can be created and utilized by the grower equally throughout the test period. Data loggers would be installed to track the flow and temperature of hot water in these zones to allow an analysis of how much savings is realized by the addition of insulation. Please note, only one surveyed greenhouse had existing "bench insulation".

# #3 De Winter's Greenhouses - Grandville, MI

## Combined Electric and Natural Gas

De Winter's Greenhouses has two locations in Michigan. The Grandville location was surveyed and is assessed below. This family-operated business has been growing ornamental flowers and plants for decades and continues to expand. Their crops are sold wholesale to large landscapers and garden centers such as Menards. This owner has a strong focus on EE and makes a point to maintain tight greenhouse structures to limit infiltration, is installing condensing boilers as the equipment is replaced, and has been experimenting with different LED technologies.

The Grandville location has approximately 3.5 acres of greenhouses. As with all the sites visited, there are a variety of greenhouse structures and systems in place. This demonstration project would focus on the older glass roof greenhouses shown in the photos below. The structure has existing under-bench heating and thermal curtains; however, they have older UHs that are used for supplemental heat.

**Photos AE and AF. De Winter's Greenhouses Existing Greenhouses**



With a preliminary budget of $160,000, potential upgrades for De Winter's Greenhouses includes:

- Condensing Unit Heaters
- Glass to Double Wall Polycarbonate for roof

*Please note, the preliminary budget does not include engineering costs which are estimated at $12,000.*

Note that this entire range is approximately ½ acre consisting of six gutter-connected houses. This estimate assumes that only three of the six greenhouses would be included and that a partition can be installed between the upgraded and existing greenhouses as necessary to quantify savings.

# Pilot Budget

The goal of the Grow Pilot is to help offset the cost of the installation of EE measures. As the pilot developed, the below budget figures were created.

Figure 25. Grow Pilot Potential Participants and Budget

| Potential Greenhouse Site | Electric, Natural Gas, or Combined | Site EE Upgrades Include: | Estimated Total Project Cost |
|---|---|---|---|
| **#1 Green Things Farm – Ann Arbor** | Combined | On-floor heating system, ***geothermal heating***, roof vents, thermal curtains, farm automation upgrades, and high-efficiency fans (HAF) | $80,000 |
| **#2 Post Gardens – Rockwood** | Combined | Under-bench heating system, ***geothermal heating***, roof vents, thermal curtains, farm automation upgrades, high-efficiency fans (HAF) | $116,000 |
| **#3 De Winter's Greenhouses - Grandville** | Natural Gas Only | Condensing unit heaters, glass to double wall polycarbonate for the roof | $160,000 |
| ***Only 2 Sites will be chosen for the final Pilot.*** | ***Combined Preferred*** | ***Please note, there may be additional "engineering costs" associated with the geothermal systems.*** | **Total Cost for 2 Most Expensive Pilot Sites (#2 + #3)** $276,000 |

Please note, the team is still reaching out to small greenhouses such as Green Things Farm for research and a potential second pilot project option. Since Post Gardens and De Winter's are much larger greenhouse facilities, the estimated project costs are much higher. The pilot budget will go further and make a bigger impact with smaller greenhouse sites. IC has continued to conduct outreach to smaller greenhouses throughout November.

The selected pilot projects will be managed with the help of the greenhouse owners and operations staff. The performance of each site will be tracked with a robust feedback mechanism consisting of performance monitoring, customer satisfaction evaluations, and measuring program success metrics. Upon identifying the challenges and successes of each greenhouse, the results will inform future program development. As the Grow Pilot moves forward, IC will work with greenhouse customers to create a measure mix offering that will be both affordable and sustainable.

# Key Findings

## General

Growers had diverse technologies implemented at their sites. It was common to see several types and ages of building envelope, heating systems, and controls at each location. Growers have a constant list of equipment that is ready for replacement depending on performance and age of the equipment. If this sector is engaged regularly and effectively, there could be a fantastic opportunity for DTE to fill annual pipeline with greenhouse EE improvements.

DTE incentives are among a few that growers are interacting with at their sites. The existing downstream incentives are not cost effective enough to spend valuable resource time on completing applications. Supply chain partners were less familiar with DTE rebates than other utilities in Michigan.  DTE's rebates could be refreshed by using some of the following techniques: more consistent greenhouse engagement, relationships with supply chain, focusing limited budget dollars on cost-effective measures, retiring baseline measures, and offering more attractive and prescriptive rebates. DTE can partner with organizations contacted through this research and supplement DTE incentives with other funding sources including the USDA's Rural Energy for America Program, Resource Innovation Institute's USDA grant, and cost-shared demo projects with manufacturers like Fluence.

Involving key actors of the supply chain could create efficiencies within the system. Supply houses are facilities where all growers frequent, and creating a pseudo upstream model focused on the supply houses could efficiently communicate incentives and opportunities with mass amounts of growers.

Some Michigan greenhouse customers are experiencing increases in demand for greenhouse space. This is also evident nationally. Many greenhouse customers surveyed had expansions or new construction planned in the near future. As programs are developed for CEA in DTE territory, new construction should be included in the offerings.

Growers' crops were diversified throughout the year. Almost all growers were producing flowers for sale at one point in the year, but depending on the season, the crops change. Almost half of the growers were producing both flowers and food crops. Cannabis is another large opportunity for savings in greenhouses. Cannabis customers were not a focus of this research, so only one of the greenhouses interviewed was growing cannabis. Cannabis will have a higher energy use intensity per square foot than existing produce and flower growers.

## Measure Specific

1. Heating systems typically provide the largest opportunities for savings in greenhouses. However, only a portion of the usable square footage is heated. There are several reasons for this: heating more space may not be cost-effective, heating system upgrades are cost prohibitive, or some seasonal greenhouse businesses choose not to grow year-round.

2. Many growers would like to add thermal curtains. Most have some but would like help in getting more installed.

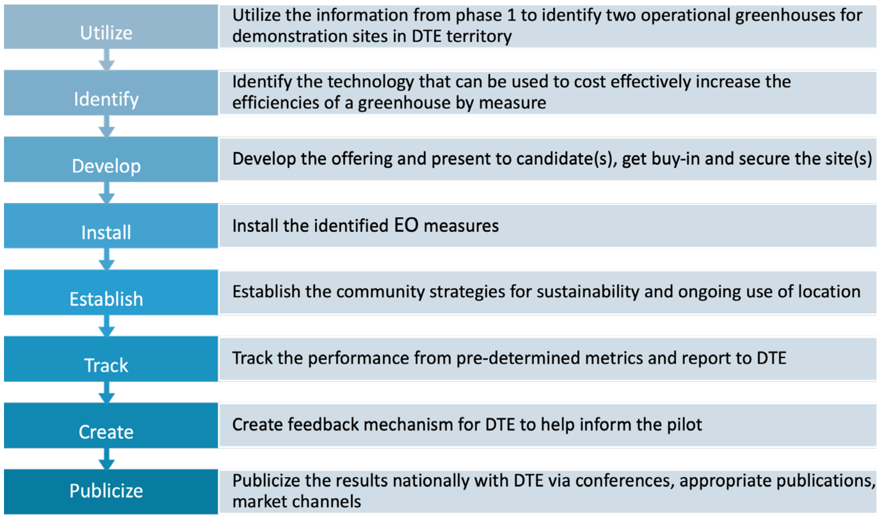
3. Most growers would like more roof vents. This is easiest to accomplish during new construction, although many structures can be retrofitted later.

4. New measures that are not represented in the current downstream DTE Agriculture Application[12] and warrant further investigation:
    - Low-intensity IR heaters
    - Insulating jackets
    - Geothermal heating systems
    - Roof and ridge vents
    - Multi-wall polycarbonate

5. Confusion exists regarding which measures are already supported through DTE custom and downstream agriculture programs and participation levels for the greenhouse market. For example, are shade curtains, dehumidifiers, refrigeration, and controls being supported through other DTE prescriptive or custom programs, and at what participation rate?

## Next Steps

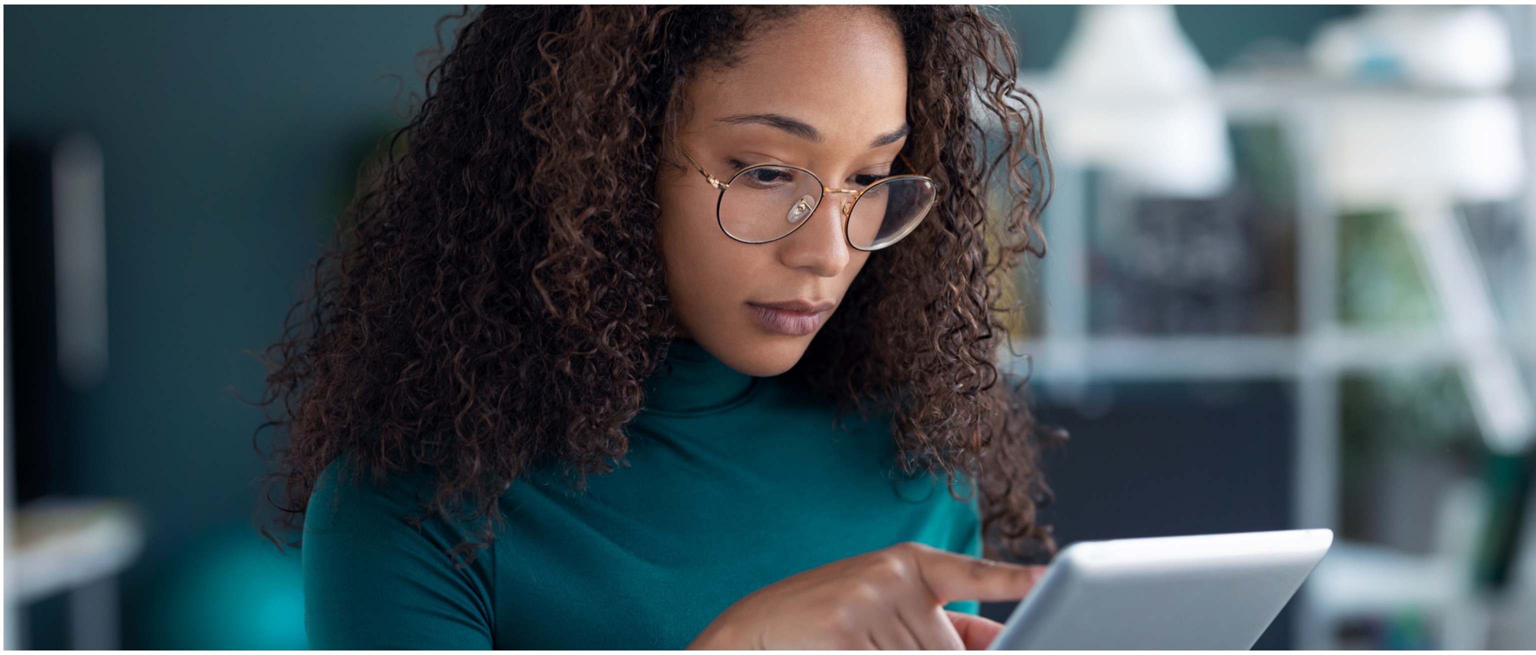
In terms of next steps, IC will continue interviewing small produce growers to potentially be included in the Grow Pilot. This will help to maximize the effectiveness of the budget. Small growers also make up the largest group in the market and may need more help affording EE projects than many of the medium and large greenhouses interviewed. Also, conceptual designs and savings of the pilot project will be developed for the specific potential sites. There will be a review with each owner to generate excitement and interest in the upgrades. The graphic to the right shows the high-level next steps for the Grow Pilot demo site.




Supply chain delays will continue to be monitored and the impacts on customers assessed. Potential impacts could include:

- Longer project lead times due to delayed equipment
- Surplus/bulk purchasing to avoid delays later
- Waitlisting for installation contractors
- Increased demand for products like locally grown food

Partner organizations will be contacted regularly to determine opportunities to collaborate on the 2022 demo projects and beyond. This could include stacking incentives for mutually beneficial technologies like geothermal heating systems.



# Supporting Documentation

## Appendices, DTE Co-op Student Projects
(contact IC for direct source link)

A. Community-Based Greenhouse Research
Paige Radman, Central Michigan University.

B. Reports/PowerPoints from DTE Interns
Julia Martin, Michigan State University
Paige Radman, Central Michigan University

## Appendices, Technical Research
(contact IC for direct source link)

C. Technical Research templates

D. Technical Research specification sheets

E. Greenhouse Questionnaire Link
Formstack Link/Salesforce

## Additional References and Resources
(contact IC for direct source link)

F. Partner Organization Contacts

G. Consultants

H. Reports

I. Case Studies

J. Utility Program References/Resources

# Resources

## Contributors

1. Michigan State University, Dr. Erik Runkle
2. Michigan State University, Plant Sciences Greenhouses, Dan Bulkowski & Jessica Wright
3. GLASE, Cornell University, Dr. Erico Mattos
4. Resource Innovation Institute, Gretchen Schimelpfenig, PE
5. United States Department of Agriculture (USDA), Rick Vanderbeek, REAP Specialist
6. Doctor Greenhouse, Dr. Nadia Sabeh, PE, LEED AP
7. Energy 350, Justin Hovland, HVAC Engineer & Specialist
8. Fluence by Osram, Corinne Wilder
9. Doug Oppedal Consulting LLC, Doug Oppedal, LC
10. BFG Supply, Jack Vansledright

## Sources/References


11. Wollaeger, Heidi. "Michigan's nursery and greenhouse industry – Part 2." Michigan State University, MSU Extension, 13 October 2016, https://www.canr.msu.edu/news michigans_floriculture_and greenhouse_industry_part_2. Accessed on 8 November 2021.
12. DTE – 2021 Agriculture Application https://webtools.dnv.com projects/Portals/8/Public%2 Files/Agriculture%20Application.
13. Efficiency Vermont – A Guide to Energy Savings for Greenhouses https://resourceinnovation org/wp-content/uploads/2020/03 GreenHouseGuide_FINAL.pdf

# Figures

**Figure 13. Root Temperature Control**
BioTherm Solutions – Website
https://www.biothermsolutions.com/shop/featured/roll-and-grow/

**Figure 14. Under-Bench Heating Systems**
BioTherm Solutions – Website
https://www.biothermsolutions.com/heat/

**Figure 15. Low-Intensity Infrared Heaters**
Roberts Gordon – Website
https://www.robertsgordon.com/greenhouse-infrared-heating

**Figure 16. Geothermal Closed Loop System (Horizontal)**
Department of Energy (DOE) – Website
https://www.energy.gov/energysaver/geothermal-heat-pumps

**Figure 17. Geothermal Closed Loop System (Vertical)**
Department of Energy (DOE) – Website
https://www.energy.gov/energysaver/geothermal-heat-pumps

**Figure 18. Geothermal Closed Loop System (Pond)**
Virginia Energy Services – Website
http://vesgeothermal.com/Geothermal3.html

**Figure 19. Multi-Wall Polycarbonate Comparison Table**
Energy Efficiency in Greenhouses – Report; Author – Scott Sanford
https://farm-energy.extension.org/wp-content/uploads/2019/04/2.-A3907-01.pdf

**Figure 20. Thermal Curtain Illustration**
United Greenhouse – Website
http://www.unitedgreenhouse.com/accessories/images/curtains.pdf

**Figure 21. HAF High-Efficiency Fans – Typical Layouts**
Greenhouse Megastore – Website
https://www.greenhousemegastore.com/equip/cooling/fans/green-breeze-haf-fan

**Figure 22. Michigan Greenhouse and Indoor Grow Technologies**
Michigan State University – Website
https://www.canr.msu.edu/news/how-do-i-use-less-energy-to-heat-my-greenhouse

**Figure 23. Typical Energy Use in Greenhouses**
Michigan State University – Website
https://www.canr.msu.edu/news/how-do-i-use-less-energy-to-heat-my-greenhouse

**Figure 24. Measures Adopted by Michigan Greenhouses**
Michigan State University – Website
https://www.canr.msu.edu/news/how-do-i-use-less-energy-to-heat-my-greenhouse

## Photos

**Dan Stein of Energy Sciences, 2021**
Photos were taken during greenhouse site visits in 2021. Includes all photos in report except for Photos F and J.

**Photo F, Example of Quest Model Dehumidifier**
Quest – Website
https://www.questclimate.com/dehumidifiers/

**Photo J, Example of Valve Jacket**
Unionfull Insulation – Website
https://www.fibreglassfabric.com/sale-12638123-high-performance-removable-fiberglass-insulation-jacket-flange-valve-protect-cover.html

## Report Abbreviations

| | |
|---|---|
| AC | Anti-Condensation |
| CEA | Controlled Environmental Agriculture |
| CFM | Cubic Feet per Minute (Air Flow) |
| DLC | Design Lights Consortium |
| DLI | Daily Light Integral (Lighting) |
| DX | Direct Exchange (Geothermal System) |
| EE | Energy Efficiency |
| HAF | Horizontal Air Flow (High Efficiency Fans) |
| HPS | High-Pressure Sodium |
| HSPF | Heating Seasonal Performance Factor (Heat Pumps) |
| IC | Independent Contractor |
| IR | Infrared (Infrared Heaters) |
| KPI | Key Performance Indicator |
| LED | Light Emitting Diode |
| PAR | Photosynthetic Active Radiation (Lighting) |
| PPFD | Photosynthetic Photon Flux Density (Lighting) |
| ROI | Return on Investment |
| SEER | Seasonal Energy Efficiency Ratio (Heat Pumps) |
| SME | Subject Matter Expert |
| UH | Unit Heaters (Condensing Unit Heaters) |
| VFD | Variable Frequency Drive |

DTE