RESOURCE INNOVATION INSTITUTE

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COLOCATING DATA CENTERS & GREENHOUSES

Feasibility Report

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OVERVIEW

The Commonwealth of Virginia is the top data center jurisdiction in the world, and, by multiple measures, leads recent US market development among US states for controlled environment agriculture (CEA). Resource Innovation Institute (RII) was hired to evaluate if colocating data centers and high-tech production greenhouses is technically feasible and strategically valuable to the economic development interests of Southern Virginia, a rural part of the Commonwealth rich with farming heritage.

This project was funded by a grant from the GO Virginia Region 3 Council, managed by the Institute for Advanced Learning (IALR) in Danville (VA), and conducted between December 2024 and May 2025. GO Virginia is a state-funded economic development initiative that encourages regional collaboration to drive private-sector growth, create high-wage jobs, and diversify Virginia's economy.

This project is highly relevant to current economic development considerations related to data centers, energy infrastructure, food systems, and community resilience.

EXECUTIVE SUMMARY

Introduction

Against the backdrop of AI-driven growth, data centers are rejecting more waste heat - and economic potential - to the atmosphere than ever before. As Southern Virginia's localities attract data center growth from Northern Virginia, GO Virginia Region 3 is evaluating a potential economic development strategy whereby data centers and greenhouses colocate to improve the competitiveness of both sectors through waste heat and other resource exchanges.

Partnership Exploration

A number of market actors, many with economic interests in Virginia, provided expert input into the potential for colocating data centers and greenhouses. Stakeholders are familiar with the concept, agree on its potential, and are interested in collaborating to find public-private solutions.

Lessons Learned

While technically feasible, colocating a data center with one greenhouse is not functional due to a significant mismatch of heatloads. However, colocating data centers with multiple, large-scale greenhouses and other complementary industrial businesses would provide a number of economic and quality of life benefits for Virginia communities. AgriportA7, a development in The Netherlands, is the most applicable clustered agtech development model for the Commonwealth to adapt. A detailed case study and other findings are featured in this report.

Optimal Design Conditions

While a simple connection of a data center to an individual greenhouse via a heat exchange-only model is possible, it is economically limited. Therefore, optimal design conditions are achieved with an integrated Farm Park model that utilizes a combined heat and power (CHP) microgrid to provide cooling of the data center water loop while providing power, heating, cooling, and CO2 enrichment for the greenhouse and other colocated businesses in the Farm Park hub. The Farm Park also holds the potential to generate energy to offset demand on Region 3's grid resources.

Economic and Workforce Development Impacts

While data centers bring significant local and state tax revenues but limited permanent jobs after construction, greenhouses offer greater job creation potential for Virginia's rural economies. Each 65-acre greenhouse siting would create 140-270 total jobs, ranging from grower to engineer. A Farm Park featuring a set of strategic business investments - such as a data center, multiple greenhouses, biomass processing facilities, a distribution center, adjacent IT and agtech operations, and additional interconnected businesses attracted to the lower cost structures provided by the resource exchange infrastructure (e.g., a brewery benefiting from CO2 loops) would generate local, regional and state economic multipliers, through job creation, diversifying the local and regional economies, and taking advantage of existing economic and workforce development investment. The IALR's CEA Innovation Center is a ready partner for such an undertaking.

Conclusion

The Commonwealth has a number of existing investments and active opportunities to initiate one of the nation's first Farm Parks. A logical next step would be for the CEA Innovation Center to facilitate a feasibility study to identify, screen, and prioritize locations in Southern Virginia/GO Virginia Region 3 that may be suitable to host a demonstration project for investors/developers data centers and greenhouses.

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SCOPE ITEM 1

PARTNERSHIP EXPLORATION

The subject of colocation of data centers and greenhouses is emerging in today's economy. Several categories of market actors are exploring the idea, from greenhouse producers to energy developers to data center operators.

However, actual colocation - and functional integration - of data centers and greenhouses has been attempted a small number of times in a small number of places. Therefore, the research conducted for this project primarily relied on targeted interviews with qualified subject matter experts (SMEs). SMEs were drawn from the networks of RII, GO Virginia Region 3 staff , and IALR's CEA Innovation Center leadership.

In total, 16 confidential interviews were conducted. These interviews included:

- Eight (8) potential partners, including energy developers, data center market actors, and greenhouse operators
- Four (4) public officials, including state, county, and local economic development officials from the US and The Netherlands, and a data center efficiency expert from Lawrence Berkeley National Laboratory
- Four (4) other relevant stakeholders, including real estate brokers, energy engineers, broadband providers, and business park operators with experience in both sectors

Interview notes, transcript summaries, and links to full transcripts and recorded zoom meetings are available in the **Appendix A**.

In addition to interviews, a number of dialogues with advisors to the US Dept. of Energy sponsored CEA Market Accelerator informed the findings in this report. Advisory body discussions leveraged include the Stakeholder Engagement, Education, and Deployment (SEED) Team, the High-Tech Greenhouse Knowledge Transfer Working Group, the Colocation Working Group, and the Site Feasibility Committee.

Scope Item 2

LESSONS LEARNED

Key Findings from RII Interviews

1. Despite the differing operational priorities of data centers and commercial greenhouses, it appears that existing technologies can be integrated for a successful colocation. One model that will be described is a heat exchange-only model, involving just the data center and the greenhouse. The second, and more optimal model, is a “farm park” of multiple agricultural industries, with “districtized” utilities of energy, heating water, chilled water, and CO_2.

2. For integration to succeed, specialized knowledge across sectors is required. This systems-thinking approach requires expertise from both industries and beyond. Upon completion of the interviews, it became apparent that all of the “pieces of the puzzle” had been put together before, nothing new would have to be invented, and success would be determined by bringing together the right partners.

3. Data centers primarily pursue colocation for "*public image and community acceptance rather than direct economic benefits*," helping address growing resistance to their high power consumption and limited job creation. One interviewee noted that data centers face increasing "*pushback across the US because they're taking all the power and they're not bringing labor*," making greenhouse partnerships attractive since these can bring a fair amount of jobs and a sustainability commitment. This is particularly important for rural communities without much economic diversification, but that have the necessary infrastructure and labor force to make such colocations viable.

4. The emergence of AI computing has dramatically increased heat generation in data centers, creating higher-quality waste heat that makes integration with greenhouses more technically viable.

5. A fundamental mismatch exists in both scale and operational priorities. Even medium-sized data centers (30-50 MW) produce substantially more waste heat than large greenhouses can utilize. One industry expert noted, "*If you put a 10-hectare greenhouse next to it, then we need 10 megawatts. They have 50, so from the 50, we only use 10.*"

6. Furthering the mismatch, the waste heat exchange-only model also needs to address diurnal and seasonal variability in greenhouse energy needs compared to data centers' consistent demands. "*A data center is a very flat load profile versus a greenhouse has wild variability*," explained an energy expert, adding that "*if you can do multiple industries or get some kind of energy storage system in place, those types of things start synergizing very well.*"

7. "*Data centers prioritize 'five nines' (99.999%) uptime and will reject any integration that might compromise system reliability*," requiring solutions that extract waste heat without affecting core operations or construction timeline.

8. Physical security is paramount for data centers, requiring clear separation between facilities. The industry's transition from air to liquid cooling systems creates more opportunities for secure waste heat recovery, as the buildings won't need to be joined.

9. The optimal infrastructure model involves a "district heating" approach rather than joining the buildings or combining the heating/cooling liquids. As one interviewee explained, "*We don't tap into it directly. We always do an interface*" with a substation containing heat exchangers and meters to maintain clear operational boundaries. Another stated that "*it's a potential to set up a smaller CHP [Combined Heat and Power] that doesn't power the IT infrastructure of the data center, but powers part of the cooling or all of the cooling*," with the greenhouse connected to this shared heating/cooling loop.

10. Given industry priorities, a phased implementation approach where data centers are built first with "CEA-ready" intermediary infrastructure appears most practical. One interviewee advised against coordinating simultaneous development, noting that data centers "*don't want another thing that's equally the size of them potentially impacting their construction timelines... stay out of my way*."

11. For viable colocation models, standardized specifications (similar to "solar-ready" building codes) for "CEA-ready" data centers would facilitate broader adoption. Developing clear technical standards and integration points that preserve operational independence for both facilities is essential.

12. Local governments must weigh various factors in approving colocation projects. As one county administrator explained, "*When you're a government official making decisions, you're looking on the cost benefit... what's the return back for the community?*" Another challenge is that "*greenhouses don't assess or appraise for much value in terms of tax assessments*," creating potential economic disincentives for localities unless broader benefits are considered. The key is making the "other" economic impacts from a Farm Park known to the local governing body. An economic impact study would be logical for a farm park developer to prepare in support of a favorable local land use outcome.

13. Water management offers additional sustainability benefits. Some existing colocation sites integrate only at the water management level – "*collecting rainwater in underground reservoirs that they're selling to the data centers at a premium and also selling to the greenhouses.*"

14. Rural counties seeking economic development may find these pairings particularly attractive as they combine high-tax revenue generators with a modernized evolution of their agricultural legacy. *"A facility like this would generate the job portion*," potentially addressing energy and food security concerns in underserved areas.

15. Energy economics significantly impact colocation viability. Cogeneration of Heat and Power (CHP) systems used in the optimum multi-industry "district heating" approach (details in later section) require consistent utilization to achieve acceptable returns: "*You need to be able to monetize the electric and thermal to get a good ROI. If you're just a greenhouse operator and you look at CHP to lower your utility bill, it's not going to work.*"

16. Local jurisdictions play a crucial role through local land use decisions, economic and workforce development incentives, expedited permitting, and potentially economic and regulatory incentives

for waste heat utilization. As one official noted, "*Virginia has the VDACS program (Virginia Department of Agriculture and Consumer Services) ... they have funding for agricultural and agribusiness projects*" that could potentially support colocation initiatives.

17. The optimal design starts with energy integration rather than retrofitting existing facilities. "*When you're designing the farm parks, if you want to integrate with other industries, including data centers, if you're doing it from the get-go, there's a possibility to design something* (optimally)." Another expert reinforced this: "*The greatest efficiencies emerge from projects designed for colocation from inception.*" Locating in an industrial or commercial business park with requisite infrastructure, fiber connectivity, and access to markets makes *speed to market* viable for the colocation of data centers and greenhouses.

18. Creation of durable corporate partnerships using multiple capital revenue streams is essential for project viability. "*Integrating with manufacturing is really important*" to create sufficient jobs and economic activity. One industry participant explained: "*We are developing industrial projects that integrate all of these different components*" to optimize energy utilization and reduce operating costs.

19. Land values significantly impact economic feasibility. In Northern Virginia, land for data centers can cost "*$1-2 million an acre,*" while rural sites might be "*$45,000 an acre.*"

20. Beyond energy and climate benefits, successful colocation projects offer workforce development opportunities by creating diverse employment across technical and agricultural sectors. As one interviewee put it: "*Bringing all these things together, it just makes much more sense.*" Southern Virginia and Region 3 have in existence a number of successful workforce development programs from middle school to community college that can be used to support data center and greenhouse operators.

21. Clear contractual frameworks between parties are critical, with financial and operating responsibilities and contingencies clearly delineated. Successful demonstration projects with comprehensive performance metrics will be essential to overcome skepticism in both industries and establish viable implementation models.

22. Early and collaborative public sector involvement appears essential for widespread adoption. Beyond financial incentives, local, regional, and state government agencies can provide long-term planning coordination, standardization, regulatory flexibility, and project validation that private entities struggle to achieve independently. As one participant noted, colocation represents "*what the future of CEA will be if we do it this way*."

Literature Review Summary

The rapid expansion of data centers, driven by digitalization and AI growth, has created significant untapped energy potential through waste heat generation. Modern data centers convert 33-42% of consumed power into waste heat, typically ranging from 45-55°C, which is conventionally rejected to the atmosphere despite representing a substantial energy resource.

Virginia, hosting the world's largest concentration of data centers at approximately 3.4 GW capacity, presents a compelling case study. Regional analysis indicates that fully utilizing waste heat from Virginia's existing data centers could support 6,000-8,500 acres of high-tech greenhouse operations, potentially meeting 80-120% of the state's fresh tomato demand while offsetting 370-495 million cubic meters of natural gas annually.

Data center waste heat characteristics vary significantly by system type. Legacy air-cooled systems produce 30-40°C output unsuitable for thermal recovery, while modern water-cooled systems generate 45-55°C waste heat appropriate for much of a greenhouse's heating season. The shift toward liquid cooling systems—projected to reach 38.3% of enterprises by 2026—produces higher-grade waste heat more suitable for agricultural applications. Emerging AI/HPC-optimized systems produce even higher temperatures (55-70°C), and experimental two-phase refrigerant systems used by companies such as NVIDIA reaching up to 90°C. These nascent technologies could provide suitable greenhouse heating on even the most frigid winter days, which typically requires 75°C. Furthermore, adsorption coolers could utilize 90°C water to generate chilled water for greenhouse cooling and dehumidification.

TABLE 1. DATA CENTER WASTE HEAT BY TYPE

Data Center Type	Typical Outlet Temperature	Cooling Method	Notes
Legacy Architecture (Not Designed for Reuse)	30–40 °C (86-104 °F)	Air-cooled or low-temp chilled water loops	Dominant in older data centers; waste heat not reused; not suitable for thermal recovery.
Standard Water-Cooled (Non-AI Workloads)	45–55 °C (113-131 °F)	Rear-door heat exchangers, direct-to-chip liquid cooling	Used in many modern enterprise/cloud data centers; suitable for low-grade heat reuse. Supplemental heating systems required on coldest days.
AI/HPC-Optimized (High-Density Workloads)	55–70 °C (131-158 °F)	Direct liquid cooling, immersion cooling	Emerging trend in AI data centers; high outlet temps enable efficient heat recovery and reuse applications. May not require supplemental heat.
AI/HPC with Two-Phase Refrigerant Systems	Up to 90 °C (Up to 194 °F)	Direct liquid cooling, immersion cooling for experimental or mobile deployments	Liquid refrigerant that boils into vapor upon absorbing heat; would not require supplemental heat.

International examples demonstrate feasibility of colocation, with successful pilots in the Netherlands, Denmark, Sweden, and Canada. European implementations often integrate with district heating networks, while proposed U.S. systems would use intermediary heat exchange substations located up to 0.6 miles from data centers to maintain security while transferring heat through decoupled water loops.

However, significant challenges exist. The primary obstacle for a data center-greenhouse colocation is supply-demand mismatch: data centers operate year-round while greenhouse heating demand is seasonal and weather-dependent. This mismatch reduces system efficiency and requires additional infrastructure like thermal storage or heat pumps to boost temperatures.

See **Appendix A** for the full literature review and **Appendix B** for footnoted references.

Scope Item 3

OPTIMAL DESIGN CONDITIONS

Two models have emerged from our research, one that extracts heat from the data center cooling loop to provide greenhouse heating while reducing the cost of chiller operation at the data center. The second is an integrated Farm Park model that utilizes a CHP microgrid to provide cooling of the data center water loop while providing power, heating, cooling, and CO_2 enrichment for the greenhouse and other colocated industries. The Farm Park also holds the potential to generate excess energy to offset the high energy center demand on Region 3's grid resources.

Waste Heat Exchange Model

As described in the 'Lessons Learned' section, colocating with an air-cooled data center does not appear practical. An optimum configuration for integrating a water-cooled data center with a greenhouse relies on direct thermal coupling through heat exchangers. Because greenhouse heat demand and data center heat output won't always align, the most optimal designs for this model incorporate heat pumps, thermal storage or supplemental systems.

To better enable year-round waste heat utilization, the design may include a low-temperature absorption or adsorption chiller to generate chilled water for greenhouse cooling. In addition to controlling temperature within the greenhouse, a dual-loop of hot and chilled water would allow the simultaneous use of hot and chilled water for humidity management. This configuration reduces the need for additional mechanical systems, improves thermal reuse, and maintains operational independence for both facilities.

Crucially, an unsolved challenge that greatly reduces the practicality of the heat exchange-only model is *supply–demand mismatch*. Furthermore, because the data center emits no CO_2, this system would not provide the CO_2 enrichment that gas boilers do. So even with perfect heat integration, growers would still need a separate CO_2 source (often from combustion or biogas) to boost crop productivity.

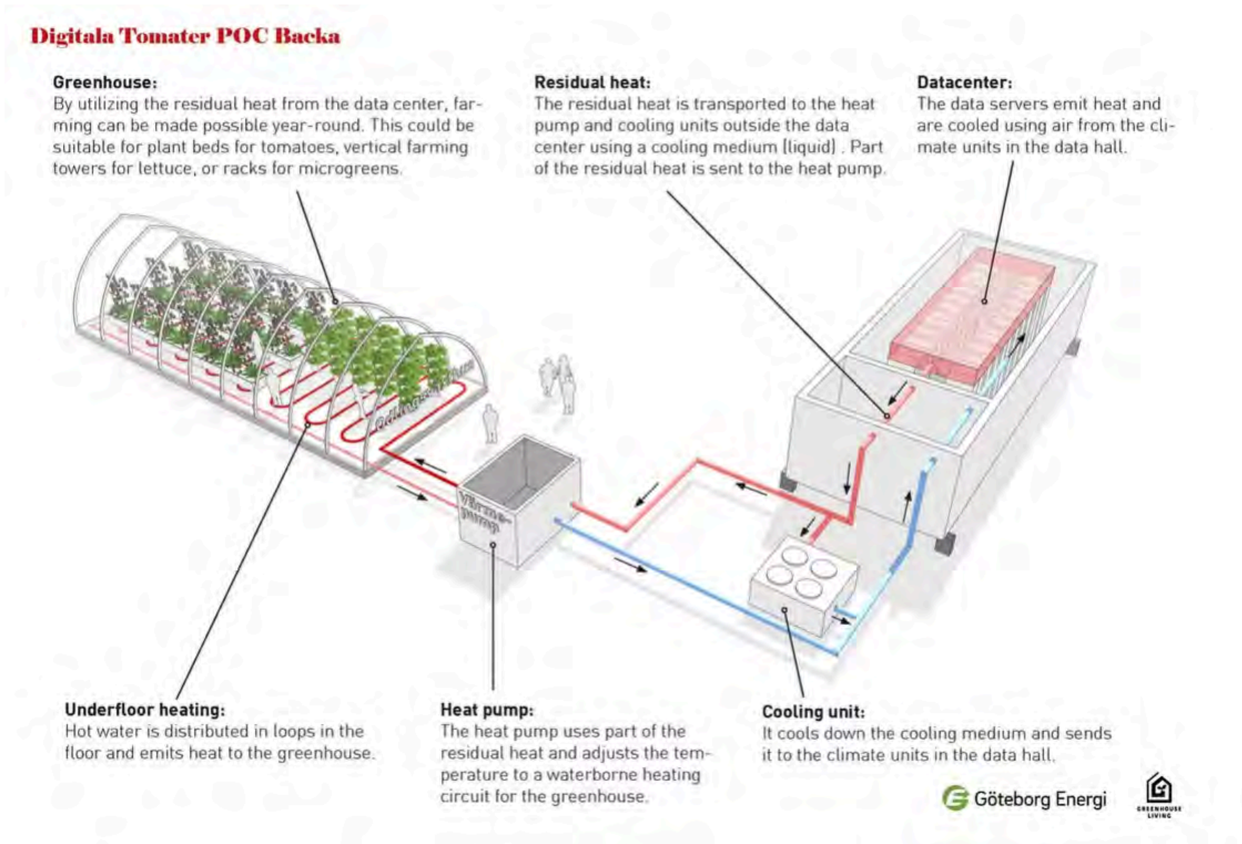


FIGURE 1. RENDERING OF A HEAT EXCHANGE MODEL WITH INTERMEDIARY HEAT PUMP SUBSTATION BETWEEN GREENHOUSE AND DATA CENTER

Another Approach to Colocation: Integrated "Farm Park" and CHP Model

A broader vision is the **Farm Park** concept: a campus combining a data center, greenhouses, and other food/ag/energy industries, all integrated with a Central Resource Hub (CRH) of "districtized" utilities, including supply/return loops of heating water, chilled water, compressed air, and CO_2, along with electrical and optical fiber communication grids. In this model, a central combined-heat-and-power (CHP) plant, powered by gas or biogas, provides power and cooling to the data center while providing the greenhouse with power, cooling, heating, and a stable supply of CO_2 to increase crop yields via increased photosynthesis.

Multiple greenhouse firms and indoor farms could locate in the Farm Park, drawn by reduced cost of production and the advantage of colocated support infrastructure: product packagers, cold storage, warehousing, and transportation. Other industry sectors would be incentivized by close proximity to the greenhouse and data center anchor tenants, while also benefiting from reduced cost of operation from centralized resources. For example, food retailers would establish distribution and logistics centers on site. HVAC, equipment, and robotics providers would colocate to win service contracts with the anchor tenants. IT companies requiring powerful computing with low-latency would tap into the service fiber loop network leased by the data center. More examples will be detailed in the next section.

This diverse set of Farm Park tenants would solve the supply-demand mismatch problem of the waste heat exchange model by increasing the cooling supply (heat exchange) for the data center and stabilizing the heating energy demand across day/night cycles, weather events and seasons. More jobs encompassing assorted trades and disciplines would be created in service of this food production hub, while the addition of more IT companies would provide additional tax revenue to Region 3.

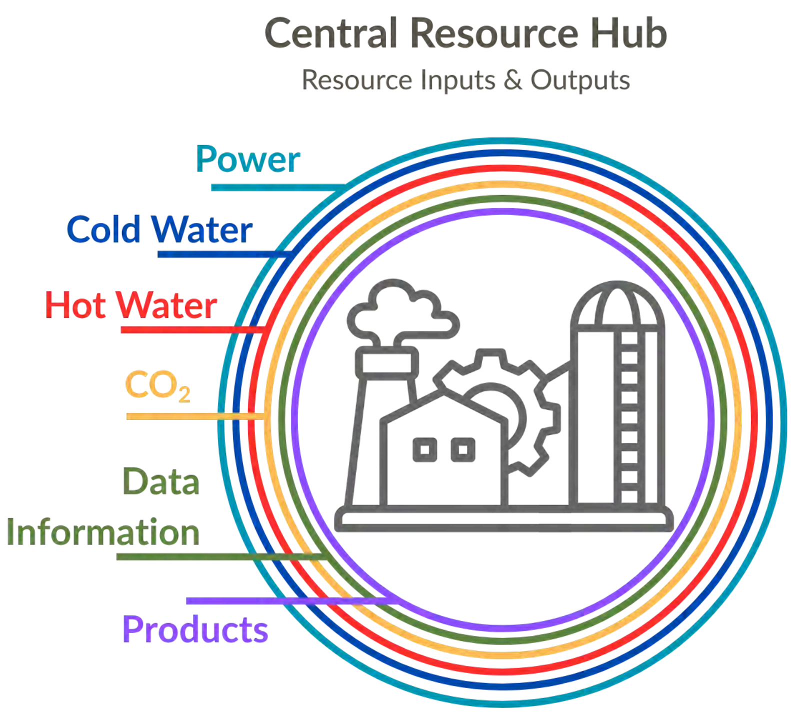
The Importance of a Central Resource Hub

Central Resource Hubs are common at hospitals, universities, and military bases, reducing the costs and inefficiency of each building needing equipment and staff for providing heating, cooling, logistical operations, water treatment and compressed air. **Figure 2** depicts a Central Resource Hub with resource inputs and physical infrastructure relevant to agriculture operations.

FIGURE 2: CENTRAL RESOURCE HUB AGRICULTURE EXAMPLE INCLUDING INPUTS AND INFRASTRUCTURE

Figure 3 represents a Farm Park CRH, with input and output flows color-coded. 'Information' is the activity of the optical fiber system leased by the data center, while 'Products' is the greenhouse produce ready for market. The hub diagram in the center represents the core facility of utility equipment, as well as the supply/return loop and grid infrastructure.

FIGURE 3: CENTRAL RESOURCE HUB WITH ASSOCIATED RESOURCE INPUTS AND OUTPUTS



The core concept of a Farm Park is the housing of the physical infrastructure to support the inputs and outputs of the businesses it supports. **Figure 4** represents the circularity of inflows and outflows of the data center and greenhouse. The greenhouse demands multiple utilities, and supplies plant products to the packaging and shipping support infrastructure.

In some cases, the greenhouse may also provide plant waste to a biowaste digester of the core facility to generate power and CO_2. The data center demands power and cooling, and supplies hot water and information.

FIGURE 4: RESOURCE EXCHANGE WITH CENTRAL HUB AND GREENHOUSE

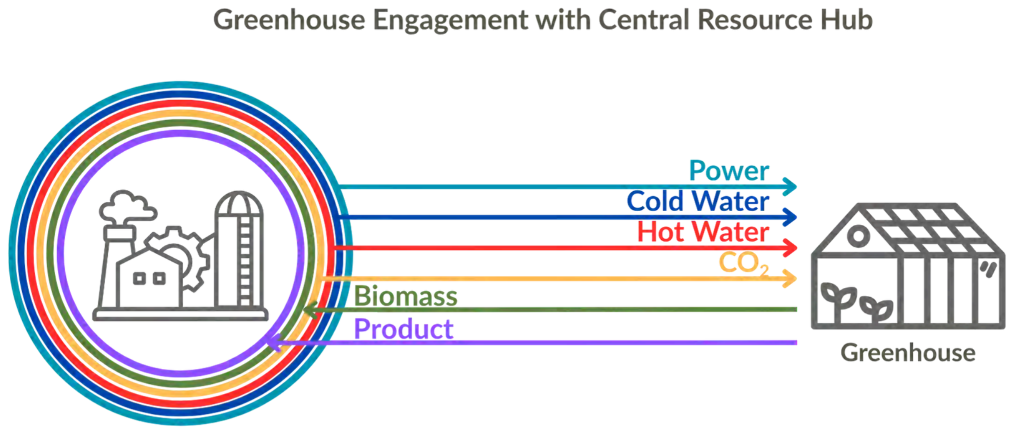
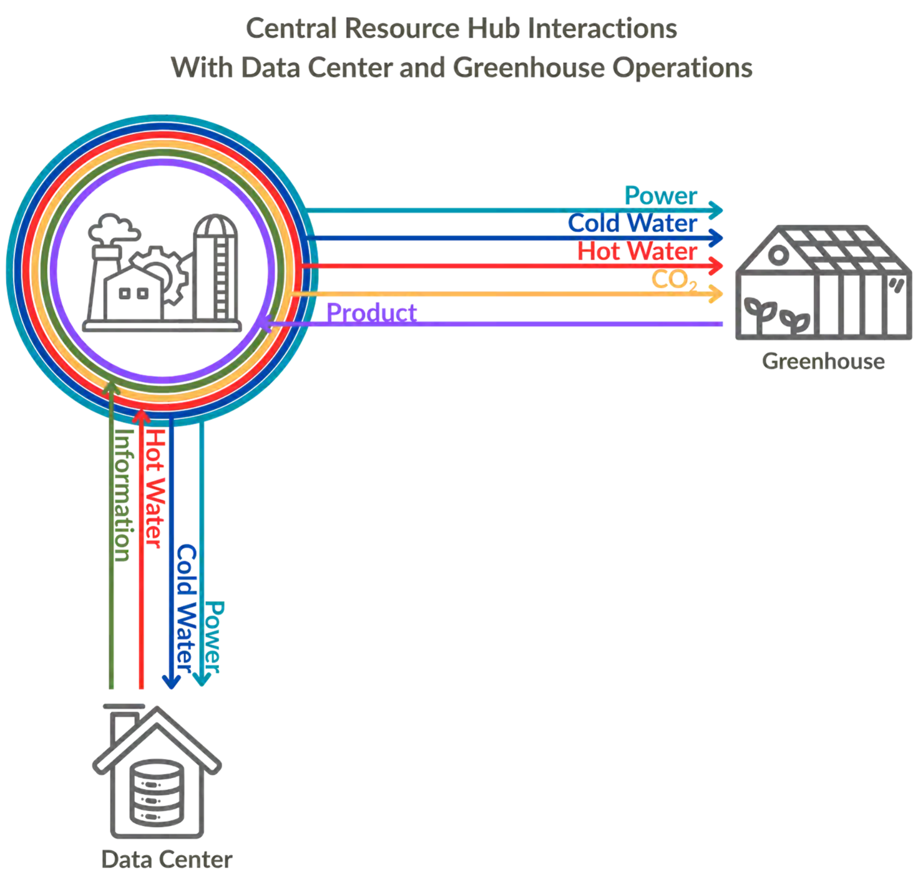


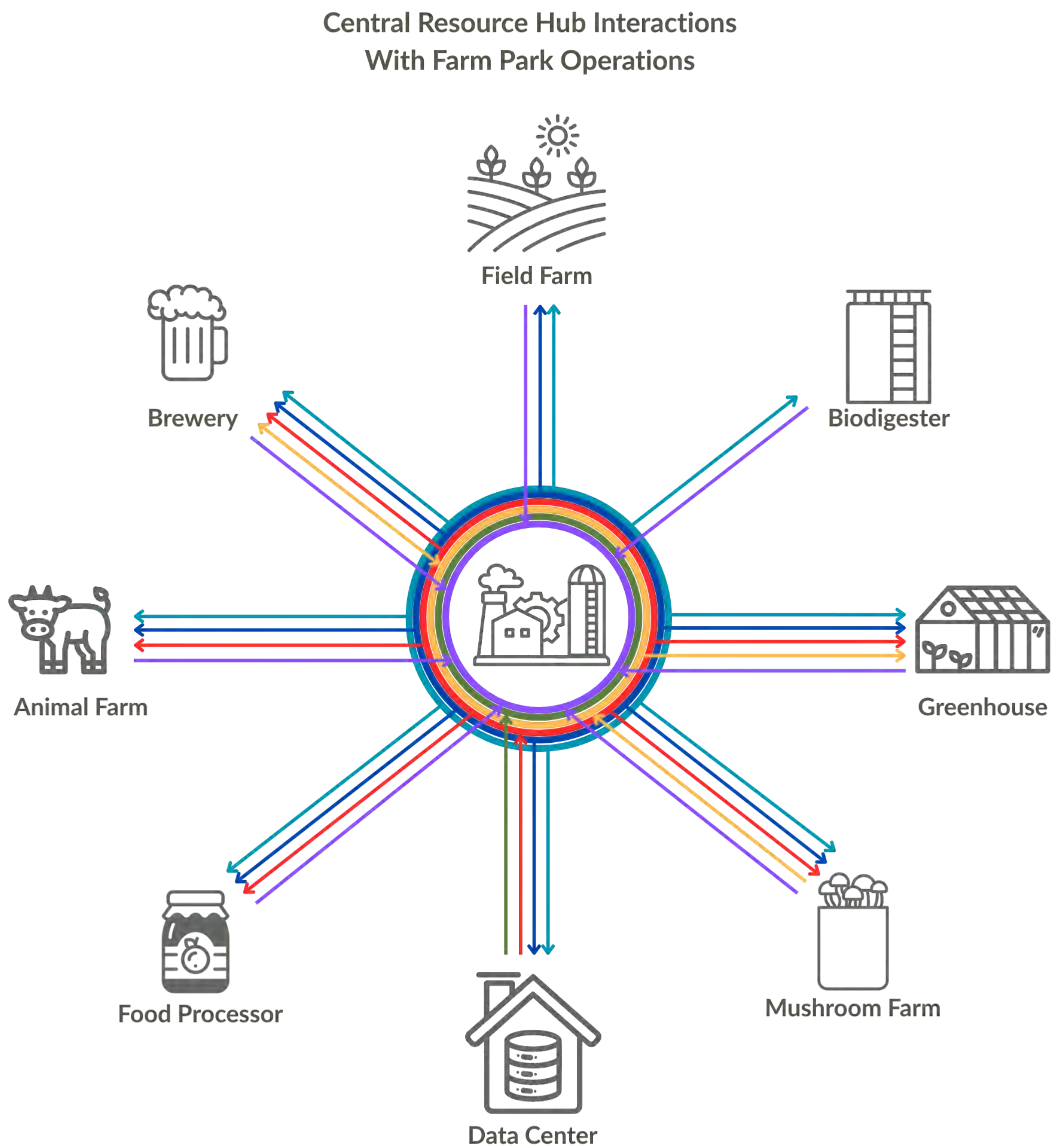
Figure 5 shows the resource input and output flows from the Central Resource Hub to the data center and greenhouse. In this case, shared resources are delivered from the Central Resource Hub to both industries, while the outputs from the industries vary.

FIGURE 5: RESOURCE EXCHANGE WITH CENTRAL HUB TO DATA CENTER AND GREENHOUSE



Lastly, **Figure 6** provides this circular analysis for colocated agricultural operations in the Farm Park.

FIGURE 6: RESOURCE EXCHANGE IN FARM PARK



It must be stated that implementing this integrated system requires substantial investment and regulatory support from the public sector to augment private investment. A CHP plant, hot-water distribution network, and utility loops must be built. Institutional coordination is needed among landowners, developers, utilities, and local government. CHP plants can generate excess power and sell it back to the utility grid through Power Purchase Agreements, with this additional revenue reducing the ROI to an acceptable period. One barrier is that CHP using conventional natural gas may not qualify as "renewable" in most states (including Virginia, from our research), so exporting excess power to the grid can be restricted by net-metering rules.

Renewable Biogas and Regulatory Factors

In many jurisdictions, *biogas* (from anaerobic digestion of organic waste) instead of fossil gas can be a key enabler. Biogas is a "renewable natural gas," so CHP systems fueled by it are often classified as zero-carbon or renewable under state incentives. The Farm Park could legally sell excess electricity to the grid without violating non-renewable export bans. In Virginia (as elsewhere), policies are evolving: some states now explicitly encourage "zero-carbon CHP" with low-carbon fuels, offering incentives or favorable net-metering for systems running on biogas or hydrogen. Thus, coupling a data center–greenhouse complex with a CHP plant that can burn animal or agricultural waste (perhaps from the greenhouse) could satisfy regulatory requirements and earn clean-energy credits. The anaerobic digester would consume green waste (food scraps, plant residues, farm animal manure) to produce biogas, closing the nutrient loop and providing a continuous fuel source.

In practice, a Farm Park would likely rely on natural and digester gas. The biogas portion makes the system "renewable" enough to push policies in its favor, while natural gas supplements during peak times. Such a system could meet nearly all the park's heating, power, and CO_2 needs on-site. It would require public-private investment for infrastructure (buildings, pipes, CHP, digester) but promises large, long-term energy savings: substituting renewable fuel for the gas that would otherwise heat thousands of greenhouses separately.

Farm Park Industry Mix Creates Uniform Demand for Data Center Waste Heat

Farm Parks are the optimum colocation because they provide benefits that a mere waste heat exchange cannot, both technically and economically, and for their ability to unlock public funding and utility incentives. Below are some potential industries for inclusion.

1. **Packaging Facilities (Food Packaging & Materials Production)**
   Energy Demand Profile: Packaging manufacturing (e.g., making boxes, bottles, or plastic trays) often runs continuously with high, steady energy use. Smaller on-site packing houses (sorting and packing produce) have more moderate loads, peaking during harvest/processing shifts, but are usually daily operations year-round, especially if tied to a steady greenhouse output.

   Synergy with Greenhouse: Co-locating packaging reduces travel and time to pack produce, preserving freshness. The greenhouse can send freshly harvested vegetables or fruits next door for immediate cleaning, grading, and packing. The packing facility's waste can be returned for compost or bio-digestion to fuel the CHP.

2. **Cold Storage & Refrigerated Warehousing**
   Energy Demand Profile: Refrigerated and frozen storage facilities have a fairly steady 24/7 electrical demand.

Synergy with Greenhouse: Refrigerated storage on-site allows immediate cooling of harvested produce, which is vital for shelf life. A countercyclical seasonal profile helps balance energy use: the greenhouse needs more heat in winter (when the cold store needs a bit less cooling), and in summer, the cold store's load rises (just as greenhouse heating needs drop), smoothing the overall park demand.

3. Food Processing & Preservation Facilities
Energy Demand Profile: Vegetable canneries, frozen food processors, dairy pasteurization, or beverage bottling are energy-intensive with a mix of electricity and thermal needs. The demand is relatively steady, though some facilities may run higher during certain product cycles. Many large food plants run continuous processes or daily batch cycles, making their load less weather-dependent than a greenhouse. This regular demand makes it ideal for them to absorb energy when greenhouse usage dips.

Synergy with Greenhouse: An on-site processing plant can take the greenhouse produce and add value. This closes the loop geographically – produce goes straight from vine to processing line, improving freshness and reducing transport emissions. There is also potential circularity: organic waste from processing can be composted or digested to generate biogas for the CHP.

4. Logistics & Distribution Centers
Energy Demand Profile: Warehouses, distribution centers, and fulfillment hubs typically have moderate but continuous energy needs. While not as energy-intensive as manufacturing, large distribution centers can still draw a few megawatts, especially if automated sorting systems or all-electric fleets are used.

Synergy with Greenhouse: Co-locating a distribution center streamlines the farm-to-market chain. The greenhouse's produce can be palletized and shipped directly from the adjacent logistics hub, reducing delays.

5. Aquaculture & Aquaponics Facilities
Energy Demand Profile: Recirculating aquaculture systems for fish or shrimp farming are essentially "underwater factories" with substantial 24/7 energy use. They require continuous water pumping and filtration, aeration, and often heating or cooling to maintain optimal water temperatures for the species.

Synergy with Greenhouse: Both operations share concerns like biosecurity and water use, so they can jointly invest in water treatment systems.

Other Potential Colocated Industries

Beyond the above, several other industries could fit into a CEA industrial park to utilize energy and provide circular benefits:

1. **Breweries & Beverage Production:** Breweries constantly need heat and cooling (fermentation at controlled temperatures), and they generate CO_2 during fermentation. Breweries could compost spent grains for greenhouse soil or feed them into an anaerobic digester, fueling the CHP.

2. **Biofuel or Biomass Processing:** Facilities like ethanol plants, biogas digesters, or wood pellet mills from Virginia's forestry industry are energy-intensive and could pair well. An ethanol plant produces tons of usable CO_2 and waste heat, as seen in Ontario, where an ethanol refinery's waste heat and CO_2 power an adjacent tomato greenhouse. The greenhouse could supply an anaerobic digester with plant waste to make biogas, which in turn fuels the CHP.

3. **Additional CEA or Agri-Tech Facilities:** The park could also host other farming systems that use energy differently, complementing the greenhouse. For instance, vertical farms or mushroom cultivation centers. A vertical farm (indoor plant factory) primarily uses electricity for LED lighting and HVAC. It can be scheduled somewhat flexibly – lights could be run at night when greenhouse lights are off, making a counter-cyclical electrical load. It would also use CO_2 enrichment similar to a greenhouse. Mushrooms, on the other hand, grow in the dark but in climate-controlled rooms. Mushroom farms generate a lot of CO_2 as fungi respire and produce heat while composting substrate, so they could supply CO_2 to the greenhouse and use the CHP's chilled water to remove excess heat.

In summary, the mix of industries can be tailored to local strengths, particularly the available skilled workforce, access to markets, and the cost of doing business. The guiding principle is to pair the greenhouse's variable, weather-dependent energy needs with industrial users that have consistent or timing-opposite demands, and to maximize use of all CHP outputs: electricity, heat, cooling, and CO_2. The result is an efficient ecosystem where one process's byproduct becomes another's input.

Agriport A7 Case Study

The most functional example of a dedicated Farm Park type of campus is Agriport A7 in The Netherlands. Much can be learned from the experience of the owners, tenants, and public sector officials who have collaborated over the past 20 years to shape the colocation and interconnection strategies among traditional agriculture, greenhouse production, data centers, and other industrial businesses.

Perhaps the biggest takeaway is the careful attention to establishing both a shared long-term vision for what the place could be, as well as a governance framework that addresses the use of the shared infrastructure.

To read more about Agriport A7 and its comparison to the Virginia market, reference **Appendix C**.

FIGURE 7. AGRIPORT A7 DATA CENTER AND GREENHOUSE COMPLEX IN MIDDENMEER, NETHERLANDS

Scope Item 4

ECONOMIC & WORKFORCE DEVELOPMENT IMPACTS

Colocating data centers with CEA greenhouses is not just an energy efficiency measure—it can drive economic growth in rural communities. For Region 3 and Virginia state-wide, this model offers both direct and indirect benefits that align with development goals.

Job Creation and Workforce Diversification

A single enterprise that combines a data center and a greenhouse yields a more diverse set of jobs than either alone. Data centers are capital-intensive but not labor-intensive; a large data center might employ tens of highly skilled technicians and engineers. Greenhouses, especially high-tech CEA facilities, are more labor-intensive in terms of operations (crop handling, horticulturists, quality control, packaging) and create ancillary jobs in distribution and agronomy. By colocating, a region can attract both types of employment. For example, a new 20 MW data center might bring ~50 IT jobs, and an adjacent 10-acre greenhouse could bring 40+ agriculture jobs, including roles for seasonal and part-time, semi-skilled workers, agricultural scientists, and managers.

From our research into USDA employment databases, we could predict the number of different types of greenhouse jobs according to the size of the facility, ranging from 1 to 100 acres, as shown in Table 2. Columns 3 and 4 compare our interpolated estimate of a 65-acre greenhouse against the employment numbers of the soon-to-be-built, Virginia greenhouse of the same size. Oasthouse Ventures Ltd. provided their estimates in a press release of 2/28/25. The comparison indicates our estimates are very conservative. Alternatively, Oasthouse's estimate may have included staffing for the onsite daycare facility noted in their press release.

Table 2. Greenhouse Staffing by Facility Size, Estimated and Reported

Job Category	1 Acre (estimated)	10 Acres (estimated)	65 Acres (estimated)	65 Acres (reported)	100 Acres (estimated)
Front Office & Admin	1	2.5	5	n/a	7.5
Skilled Growers & Technicians	1	4	8	n/a	12.5
FTE Total	2	6.5	**13**	**43**	20
Hourly Greenhouse Workers	2	25	100	n/a	175
Seasonal Labor	2	10	30	n/a	50
P-TE Total	4	35	**130**	**228**	225
All Jobs	6	41.5	**143**	**271**	245

Our estimates in Table 2 span different skill levels, from Phd.-level plant scientists to unskilled labor. This complements the workforce development objectives of Region 3, which seeks to create opportunities for a range of workers, including those transitioning from manufacturing or coal industries into new sectors. An analysis from Luleå University (Sweden) noted that coupling data centers with horticulture not only provides a circular resource use, but also *"with the creation of new and emerging work roles (e.g., urban farmers) and collaborations… comes the possibility to strengthen employment throughout the region,"* offering alternative livelihoods in areas needing economic revitalization. In Southern Virginia, where traditional farming has declined and new economy jobs are needed, CEA farms can absorb displaced workers with minimal retraining, and data centers can employ graduates from local community colleges in IT – a symbiosis in the workforce and energy.

Economic Multiplier Effects

Colocation projects can have strong multiplier effects in the local and regional economy. A greenhouse that produces high-value crops year-round will purchase seeds, nutrients, packaging, and services such as logistics and maintenance, often from local vendors. In the Farm Park approach to colocation, other industries would want to take advantage of the districtized utilities, or be near the greenhouse. Data centers similarly attract an IT ecosystem of information service providers, security services, maintenance contractors, and often network infrastructure upgrades that benefit the community.

Moreover, lowering the operating cost of greenhouses via free heat can make Virginia more competitive in attracting agri-tech companies. Leavering the CEA Innovation Center at the Institute for Advanced Learning and Research in Danville, Region 3 could become known as a hub for sustainable CEA, drawing companies that build greenhouse technology, HVAC systems, or sensors, especially if anchored by a demonstration of successful heat reuse. Cluster development is a hallmark of economic development success; in this case, the cluster would sit at the nexus of the tech sector and advanced agriculture. By leading in this niche, Virginia could capture new investments before other states.

Local Food Production and Resilience

A less direct but important economic benefit is enhanced food security and agricultural output. Region 3 and much of Virginia currently import a significant portion of fresh produce, especially in winter. Colocated greenhouses would boost local production of vegetables, greens, and possibly fruits. This can reduce import dependency, keep food dollars in the state, and stabilize prices. It also opens opportunities for branding Virginia-grown produce that is tech-enabled and sustainable. For localities in Region 3, having a high-tech greenhouse can revitalize the agricultural identity of the area in a modern way. Studies in subarctic Sweden found that a 10,000 m^2 greenhouse heated by a data center could provide about 7.6–8% of the region's vegetable self-sufficiency, a notable increase in local food supply. While Virginia's climate is far milder, meaning the percentage impact would differ, the concept is that each colocation adds to the state's capacity for year-round agriculture. This contributes to economic resilience: local produce supply is less subject to disruptions from severe weather, long-haul transport issues, or supply chain breakdowns, and the revenue from produce farming stays in local circulation.

The two models of colocation we have described vary greatly in their ability to create long-term community resilience. In the unlikely event that data centers close down after 20 years of operation, the greenhouse colocated with the data center by heat exchange would be dependent on it and unable to stay in business. By contrast, the Farm Park, once established, would remain operational without the data center. Of course, Region 3 would no longer have the tax revenue of the data center, but the jobs and community benefits would remain.

Tax Base and Investment in Region 3

Data centers, as capital equipment-intensive projects, significantly increase the local tax base (through property taxes, machine & tools tax, sales tax etc.), and increase the state revenues through corporate, income and sales taxes. Virginia localities have seen data center taxes fund schools and services in places like Loudoun County and Mecklenburg County. If data center growth can be recruited to Region 3 with the added incentive of colocation, those communities could see a similar influx of tax revenue to fund locally delivered services such as public education and public safety.

A key challenge to overcome in a colocation scenario is the lower property tax revenue potential of greenhouses for localities. Greenhouses themselves are not as large taxpayers as data centers (see **Appendix D**), though they do contribute through business taxes and by employing people who pay income and sales taxes, and generate indirect economic benefits to the community. The combination could improve overall long-term job creation and local tax revenues, to offset the cost of local investments made in infrastructure support and other related activities.

Recognizing this, a regional workgroup including the Southern Virginia Regional Alliance and other regional economic development organizations are involved in planning for these opportunities. Their involvement indicates the expectation of tangible economic gains if colocation projects proceed. The state could also see macroeconomic benefits: if these projects demonstrate cost savings and productivity gains, it can attract more companies, possibly turning Virginia into a net exporter of CEA technologies or expertise.

Alignment with Policy and Funding Initiatives

The colocation concept aligns with various policy goals, including energy efficiency, agricultural innovation, and rural development, which means it can tap into multiple funding streams. Federal programs from the Department of Energy and the USDA could be leveraged to support pilot projects. State-level initiatives around clean energy, such as the Virginia Clean Economy Act, and agricultural development could also provide grants or low-interest loans. This layered support can amplify the economic impact by reducing the capital burden on private players, effectively *de-risking* innovative projects.

In terms of workforce, the Institute for Advanced Learning and Research (IALR) in Danville has established a CEA Innovation Center already focused on training and research for high-tech greenhouse operations and is best positioned for the leadership role in workforce development support for projects involving the colocation site. The IALR and its K-12 public school and community college partners would provide a pipeline of qualified workers, a positive feedback loop for economic and community development.

As Virginia considers the steps it may take to kickstart a Farm Park type investment, it should look at how district energy (or district resource) projects are formed, governed, and funded. Given the range of resource exchange opportunities, the Commonwealth can evaluate public investment models related not just to waste heat, but also CO_2 and stormwater.

Community Benefits and Quality of Life

It's worth noting the community development aspect: A greenhouse next to a data center could make the latter more accepted by the adjoining property owners and the overall community. Data centers can face local opposition for being seen as noisy "server farms" that use lots of power without much community interaction. A greenhouse, by contrast, is an accessible, tangible food producer and typically welcomes school tours or public engagement. The colocation could thus indirectly improve community relations, offer local educational opportunities, and create needed jobs in an emerging business sector. Enhanced local produce availability can improve nutrition in the area by colocated farms partnering with local schools or food banks to supply fresh greens.

These quality-of-life improvements, while hard to quantify, contribute to making a region attractive for families and other businesses.

Air quality could be impacted by use of CHP, though perhaps less in a Farm Park than a single-sited data center, given the increased system efficiencies and grid contributions of a shared and managed Central Resource Hub. Site-specific environmental impact analysis should be conducted related to fuel type, combustion process, and local weather conditions.

When policymakers evaluate such projects, they should weigh these social benefits and impacts alongside the raw economic metrics.

Economic Development Strategy

Virginia and its localities should consider supporting advancing the packaging power, fiber, water, and labor accessibility within Farm Park developments to attract multiple symbiotic sectors. Offering improved sites and and other economic and tax incentives for Central Resource Hubs would be priority considerations for elected and appointed officials. In Farm Park scenarios,data centers should be viewed more broadly than single-site employers. With Farm Parks, data centers should be recognized as anchor tenants, with the Central Resource Hub the interconnection point within an overall hub-and-spoke model.

The waste heat potential, along with the managed interconnection, should attract greenhouse producers seeking lower and shared-cost infrastructure. It should be noted that community acceptance with these large-scale developments should improve if the initial and on-going communications emphasize the benefits of future Farm Parks, even while data center construction takes place before greenhouse construction.

A development sequence such as the following should be considered:

1. Concept clarification - Align public and private expectations, roles, and resources via a background document with site concept renderings and statistics featuring food production and economic potential
2. Community engagement - Communicate the Farm Park vision rather than centering data centers
3. Data center construction - Communicate as phase one of a Farm Park
4. Greenhouse construction - Invite the community to tour greenhouses under construction
5. Ongoing efficiency optimization - Fund technical assistance, education, and training

In summary, colocating data centers with CEA greenhouses can catalyze regional transformation. It builds upon and advances the historic legacy of agriculture production by bringing high-tech and agriculture together in a way that creates jobs across skill levels, increases the tax base, fosters innovation, and produces food for local consumption and export.

Region 3 stands to gain significantly by being a first mover in this space in Virginia given its existing economic and workforce development assets, and clear focus to promote business innovation. The economic and workforce benefits align well with Virginia's broader goals of balanced growth and establishing the Commonwealth as a leader in both tech and agriculture. As one sustainability study put it, industrial symbiosis like this leads to a circular model that "increases local economic competitiveness" and strengthens self-sufficiency. Region 3 can harness that dynamic to boost not only its economy but also the resilience and vibrancy of its communities.

CONCLUSION

There is market demand and technical expertise to serve a market that specializes in colocation of data centers and greenhouses, from engineering design to farm operations. However, what is missing is a public sector backed funding model to advance economically advantageous Farm Parks, along with a qualified set of site opportunities.

Farm Parks present unique opportunities to cultivate public outcomes, including local food production, job creation, grid stability, and overall community resilience. They also require coordinated public and private investment. Key initial considerations include siting analysis and funding model development. A range of public entities may be part of a targeted stakeholder engagement process on subjects including land hosting, funding coordination, policy and regulatory support, and governance of the Central Resource Hub infrastructure.

Region 3 has the opportunity to advance its priority data center and CEA sectors by demonstrating its commitment to evaluate the potential for launching the US's first Farm Park. Toward that objective, Region 3 has several key assets to be leveraged, including:

- Research and development at IALR
- The CEA Innovation Center
- Robust workforce development programs that can pivot to help with CEA skill building
- Mid-Atlantic Broadband Communities Corporation fiber network
- Ongoing data center market growth
- Potential funding partnerships, including local and regional economic development organization, public K-12 and community college partners, Virginia Dept. of Agriculture and Consumer Services, and Virginia Tobacco Region Revitalization Commission
- There are existing publicly owned industrial and commercial business parks in Region 3 that should be assessed and prioritized as potential sites to host a Farm Park demonstration project.

Stakeholder interviews for this project revealed interest among economic development agencies beyond Region 3, with references to specific sites and potential private sector partners. Related work conducted outside of this project has led to an understanding of a variety of models for funding Farm Park type developments, including identification of potential sources of federal military investment. Within those conversations, Fort Monroe and Camp Lejune have been mentioned among other military assets in the Northeast.

The overall conclusion of this project is that, if CEA Innovation Center, the Institute for Advanced Learning and Research, GO Virginia Region 3, and other Southern Virginia stakeholders could form a partnership with the Commonwealth to evaluate a potential Farm Park strategy, it should consider embarking on a feasibility study, including siting analysis, stakeholder engagement, and funding model development.

THANK YOU

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APPENDICES

APPENDIX A

Literature Review

APPENDIX A LITERATURE REVIEW

Data Center Growth, Energy Use, and Waste Heat

The global and regional data center industry has expanded rapidly in recent years, driven especially by digitalization and the rise of AI. Analysts project that this steep growth will continue: one study forecasts Northern Virginia would need over 11 GW by 2028 under conservative assumptions, and potentially far more when accounting for the heavy power requirements of AI workloads. Globally, data centers now consume roughly 1–1.5% of total world electricity.

Modern data centers convert **33-42%** of consumed power into waste heat. This vast low-grade heat stream – typically in the 45-55 °C range – is conventionally rejected to the atmosphere but represents a large untapped energy source. Among industries that could potentially utilize this waste stream is greenhouse food and flower production.

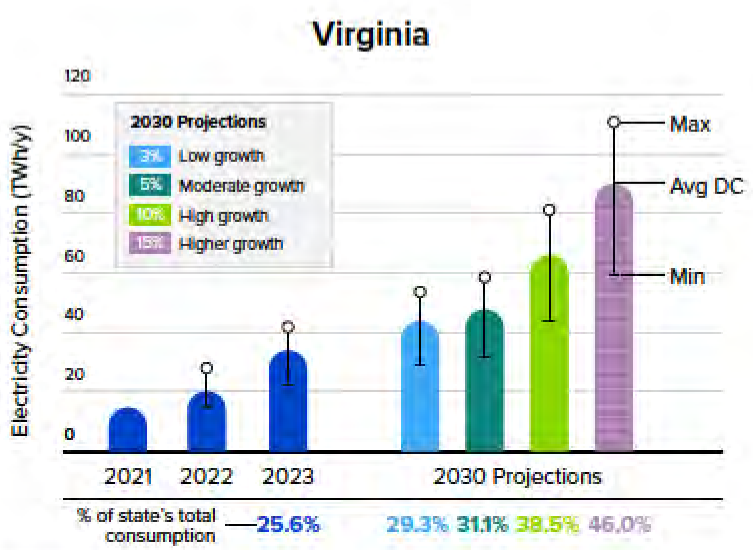


FIGURE 8. PROJECTED ELECTRICITY CONSUMPTION IN VIRGINIA DATA CENTERS

Potential Energy Savings and Fuel Offsets in Virginia

Analyses indicate substantial energy and fuel savings when data center waste heat displaces conventional heating, particularly in Virginia, which has the largest concentration of data centers in the world. As of 2023, Virginia hosts approximately 3.4 GW of data center capacity, primarily clustered in Loudoun, Prince William, and Fairfax Counties. One analysis notes that one specific 326 MW center in Virginia could heat 673 acres of greenhouse, a ratio of about 2 acres/MW. Based on regional modeling by Falk et al. (2025), if waste heat from *all* of Virginia's existing data centers were fully utilized, it could support approximately 6,000–8,500 acres of high-tech greenhouse operations. This would represent a major fraction of U.S. controlled-environment agriculture and could meet or exceed 80–120% of Virginia's fresh tomato demand.

Regarding energy displacement, the estimated reuse of 3–4 GW of Virginia data center waste heat could offset approximately 370–495 million m^3 of natural gas annually (roughly 3.5–4.8 trillion BTU) used to generate it.

Although detailed energy flows would vary by facility, coordinated heat exchange between data centers and greenhouses offers mutual energy benefits: greenhouses sharply reduce fossil fuel heating needs, while data centers cut cooling electricity and improve thermal efficiency. This synergy aligns well with Virginia's stated climate and energy policy goals, including greenhouse gas reduction and grid reliability improvements.

Uses of Data Center Waste Heat Globally

The Netherlands, Denmark, Sweden, and Canada have piloted data center-greenhouse colocations, but typically at a small scale. For example, TeleCity (now Equinix) successfully piped waste heat to a Paris-area nursery as early as 2010, and multiple projects in Sweden/Finland heat greenhouses with data center effluent. Notably, European sites often cluster data centers near existing horticultural clusters (e.g., the Netherlands' "Greenports"), while U.S. greenhouses are scattered and not coordinated with data center hubs.

In Europe, data centers are especially tied to *district energy networks* or industrial plants. "District heating" means a central plant (e.g., a boiler or chiller array) distributing hot water to many buildings via insulated pipes. For instance, Stockholm's Bahnhof data center supplies heat to the city's hot-water network, and Finnish firms (Telia, Ericsson Telecity, Yandex) feed their data center waste heat into municipal district-heating grids. Data centers can act as such centralized plants; in a Tallaght, Ireland pilot, a data center partnered with local utilities to use server waste heat as part of a hybrid district heating scheme. District heating is also common in the U.S., though not typically connected with data centers. According to a recent U.S. Energy Information Administration report, more than 660 district energy systems are operating in the United States, with installations in every state.

Other non-agricultural applications include using waste heat for local industry or residential heating. In one pilot, Norwegian operator Green Mountain heated a trout aquaculture facility with data center effluent heat. In Canada, projects are planned to run data center heat into vertical farms and breweries. As one industry summary notes, routing server heat into greenhouses or buildings creates a "win-win."

FIGURE 9. DISTRICT HEATING OF A EUROPEAN INDUSTRIAL PARK

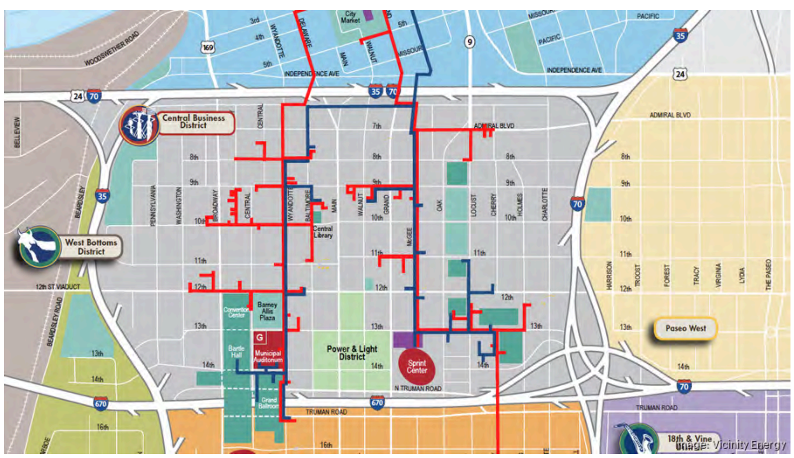


FIGURE 10. DISTRICT HEATING/COOLING SECTOR IN KANSAS CITY, MO

Greenhouse Environmental Requirements

Commercial greenhouses have specific energy, climate, and CO_2 needs. In temperate regions, they require substantial heating through the night and winter to maintain optimal plant growth. Typical setpoints might be ~18–24 °C during the day and no lower than ~12–15 °C at night (varies by crop). Conversely, in summer or on hot days, they require cooling or ventilation to prevent overheating. Humidity also must be managed: warm daytime air (e.g., 24°C) can hold a lot of moisture, but when temperatures drop at night, condensation can form on plants, leading to fungal and bacterial disease.

Greenhouses often enrich the CO_2 level inside because photosynthesis can be boosted above ambient concentrations (~440 ppm). Without enrichment, plants may deplete CO_2 to ~150–200 ppm during the day, constraining growth. By contrast, supplementing CO_2 to roughly 700–1000 ppm typically boosts yields by 18–100% for most vegetables and flowers. High-tech, commercial greenhouses routinely burn natural gas or use gas-fired boilers, producing both heat and CO_2 for enrichment. They circulate the 60–80 °C boiler-heated water through hydronic systems controlled by the greenhouse climate controller. Finally, greenhouse cooling for dehumidification may use vents, exhaust fans, and evaporative pads. Because dehumidification of greenhouses is typically insufficient in temperate climates during humid seasons, mechanical dehumidification using refrigerant or chilled water systems is an emerging technology for operations that can afford it.

Amount of Waste Heat is Dependent on Data Center Age, Function and Cooling System

Data centers can be air-cooled or water-cooled, and the cooling type affects the characteristics of waste heat. About 80% of existing data centers are air-cooled, exhausting large volumes of warm air near ambient temperature. But that trend is shifting quickly. Surveys indicate that by 2026, nearly 38.3% of enterprises plan to implement liquid cooling technologies in their data centers, up from 20.1% in early 2024.

Liquid-cooled servers (e.g., water-cooled racks or immersion systems) concentrate heat into a water loop. Where no colocation exists to use this wasted resource, a chiller removes heat from the water (or coolant) that has absorbed heat from the servers. It does this by using a refrigeration cycle to cool the water, then releases that heat into the ambient air through a condenser—often located outside the building. In air-cooled chillers, fans blow outdoor air over coils filled with hot refrigerant, which releases the heat to the atmosphere.

The more the servers need to be cooled, the more heat is transferred to the water loop. While many legacy data centers (air-cooled) produced an outlet water temperature of 30–40 °C, a typical data center built today produces 45–60 °C waste water. This hotter water is suitable for heating most greenhouses on all but the coldest days of the year. To reach full greenhouse heating capacity, either a backup heating system (such as a boiler) would be in place, or the wastewater temperature would be increased using a heat pump. According to one analysis, "*For heating of the greenhouse, the direct use of the data center surplus heat at 45-50 ˚C is feasible and will normally, dependent on the piping system, cover 70 to 90% of the total power requirement.*"

Extremely high-power systems used for High-Performance Computing (HPC) applications are emerging. HPC refers to the use of supercomputers or large clusters of computers to perform complex calculations at very high speeds—often for tasks like:

- Scientific simulations (e.g., climate models, physics, genomics)
- Financial modeling
- Engineering and design (e.g., crash simulations)
- AI training (especially large language models)
- Oil and gas exploration

HPC systems typically involve high-density racks, powerful CPUs/GPUs, and intensive cooling needs, which is why they often use liquid cooling and produce higher-grade waste heat of 55-70°C. Companies like Intel and NVIDIA may use two-phase refrigerant-cooled systems, which produce waste heat of up to 90°C.

TABLE 3. DATA CENTER WASTE HEAT BY TYPE

Data Center Type	Typical Outlet Temperature	Cooling Method	Notes
Legacy Architecture (Not Designed for Reuse)	30–40 °C (86-104 °F)	Air-cooled or low-temp chilled water loops	Dominant in older data centers; waste heat not reused; not suitable for thermal recovery.
Standard Water-Cooled (Non-AI Workloads)	45–55 °C (113-131 °F)	Rear-door heat exchangers, direct-to-chip liquid cooling	Used in many modern enterprise/cloud data centers; suitable for low-grade heat reuse. Supplemental heating systems required on coldest days.
AI/HPC-Optimized (High-Density Workloads)	55–70 °C (131-158 °F)	Direct liquid cooling, immersion cooling	Emerging trend in AI data centers; high outlet temps enable efficient heat recovery and reuse applications. May not require supplemental heat.
AI/HPC with Two-Phase Refrigerant Systems	Up to 90 °C (Up to 194 °F)	Direct liquid cooling, immersion cooling for experimental or mobile deployments	Liquid refrigerant that boils into vapor upon absorbing heat; would not require supplemental heat.

Connectivity Using a Heat Exchange-Only Approach

Though direct-air heat exchange (pushing hot server exhaust air into a greenhouse) has been successfully done in small-scale pilots, it is an impractical strategy due to operational and security issues. The two facilities would need to be connected, and forced air heating over long distances is non-uniform and challenging to hygienically maintain.

Conceptual studies suggest that using a water-cooled data center to transfer waste heat to a greenhouse is feasible if adapted to U.S. conditions. Security for the data center can be maintained by locating the high-tech greenhouse up to 0.6 miles away, with an intermediary substation between them. Here's how it would work:

- A substation housing a mechanical heat exchanger would be located between the greenhouse and the data center. This substation would be 100 - 500 meters from the data center and up to 500 meters from the greenhouse, providing a maximum 1,000 meters of separation, or 0.62 miles.
- The data center's cooling loop and the greenhouse's hydronic (heating water) loop would meet at this exchanger, allowing some of the heat from the data center loop to transfer to the greenhouse hydronic loop while remaining decoupled (no fluid mixing).
- The data center's cooling loop would supply 45-55 °C to a heat exchanger within the substation. If the temperature is insufficient for greenhouse heating, a water-to-water heat pump, also housed within the substation, would boost the heat to the ~60°C. Multiple heat pumps may be needed to reach ~75°C required for the most frigid regions.
- In the event of any malfunction, the data center's cooling loop simply bypasses the substation, and water is cooled using the backup chilling towers of other emergency systems. No mechanical or data connections exist beyond the intermediary substation.

Within the data center, capturing and reusing waste heat reduces the need for mechanical chillers and compressors, resulting in lower overall electricity usage. Emerging designs even envision the greenhouse's return cooling load supplementing the data center's HVAC systems, creating "free cooling" in certain seasonal conditions.

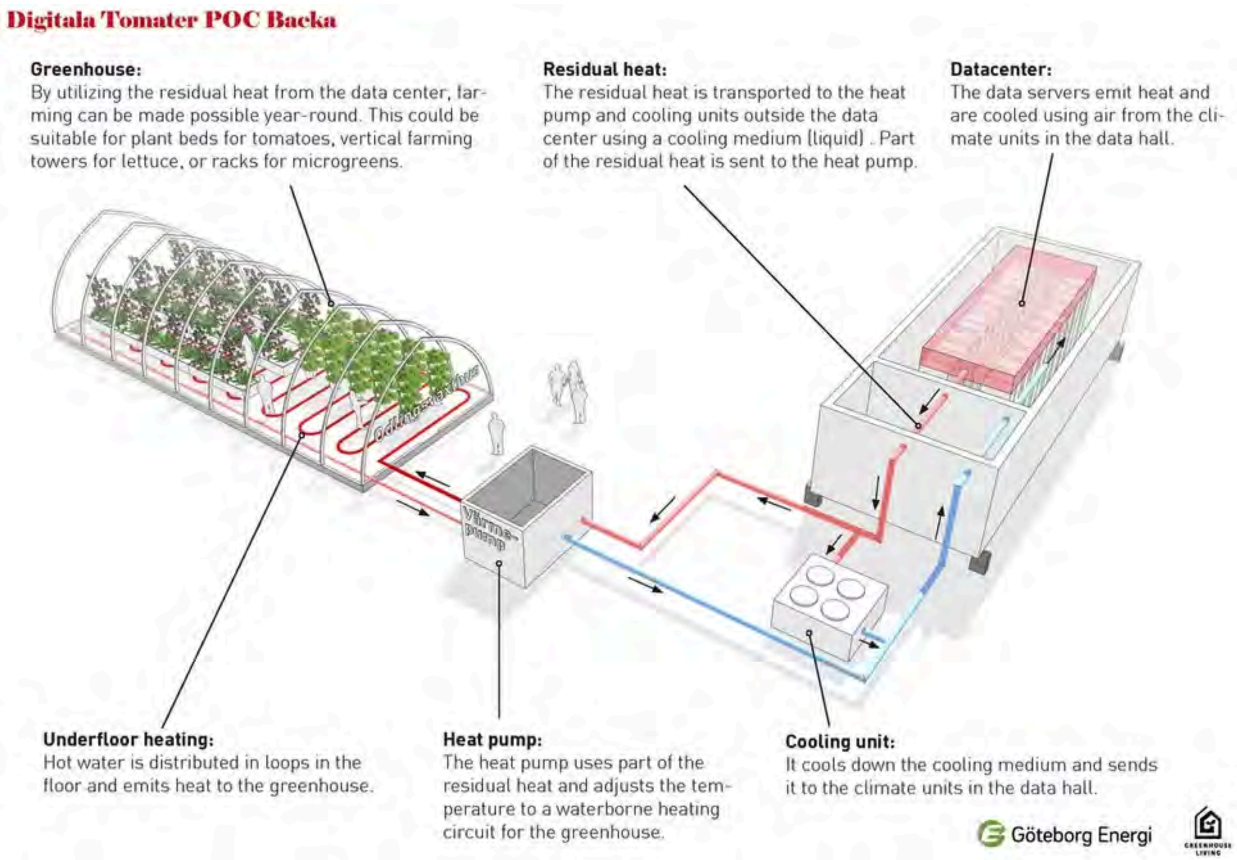


FIGURE 11. RENDERING OF INTERMEDIARY HEAT PUMP SUBSTATION BETWEEN GREENHOUSE AND DATA CENTER

Potential Greenhouse Modifications To Improve Heat Exchange Mismatch

To date, greenhouses have not been modified to accommodate lower heating water, so heat pumps would typically be required. It has been suggested that by strategically placing more and larger radiant heating pipes, the increased surface area for radiant heating would prove sufficient. One study calculates that the number of hot water pipes must be 3 times higher using 45 °C water in the greenhouse hydronic system compared to the standard 75 °C hydronic temperature.

In a fascinating development, recent industry trials have reported advanced greenhouses running their heating pipes at only ~45 °C (113 °F) without productivity loss, aligning well with even the lower end of the standard data center waste heat. In these trials, other environmental variables, such as airflow and energy curtain systems, were used to manage the reduced heating capacity. These studies will need to be repeated and their findings confirmed before they begin to be adopted by the CEA industry.

The Mismatch of Heat Supply-Demand Greatly Reduces Feasibility

An unsolved challenge that greatly reduces the practicality of a heat exchange-only model is *supply–demand mismatch*. Data centers operate year-round (often at high load in summer due to air conditioning loads). At the same time, greenhouse heat demand is seasonal (highest in winter, near zero in summer) and weather-related. The diurnal cycle also causes variation in greenhouse heating demand, with little or no heating required during sunny days, even in winter. This mismatch means that without alternative sinks, much data center heat could go unused much of the year. Large thermal energy storage (water tanks or underground) can buffer some, and oversizing the greenhouse (or adding other heat-intensive co-users) can smooth the balance. But fundamentally, data center waste heat alone may be excessive except in heating seasons.

Furthermore, the cost of using a heat pump to increase the temperature of the waste heat is high, and the efficiency of the systems is low.

Insulated hot water tanks can store excess heat produced during low-demand periods and release it during high-demand periods. Sizing depends on climate; in Virginia, diurnal storage (holding heat for 8–12 hours) might suffice to cover nighttime greenhouse heating. In practice, day-night greenhouse heating must be considered. During a winter day (especially sunny periods), greenhouses often rely on ventilation or radiation and may even require cooling. So, data center waste heat is less needed; surplus waste heat could be dumped or sent to heat storage (e.g., aquifer tanks).

Creating Chilled Water from Data Center Waste Heat: Improving the Match?

Given the mismatch described above, the capacity to both heat and cool the greenhouse would smooth the demand by the greenhouse on the data center waste heat, allowing for more uniform cooling of the data center loop temperature. Some have proposed **absorption (thermally-driven) chillers** using data center heat to cool greenhouses or labs.

An absorption chiller is a heat-driven refrigeration machine. Instead of using electricity and a compressor like standard chillers, it uses steam or hot water to drive a cooling cycle with a refrigerant/absorbent pair (commonly water/LiBr or ammonia/water). In this case, the idea is to use the data center's waste heat as the input to such a chiller. The absorption chiller would then produce chilled water to supply cooling and dehumidification coils in the greenhouse.

In principle, an absorption chiller can produce chilled water if fed hot water of typically 65–90 °C. In practice, the relatively low output temperature of most data center cooling means conventional absorption chillers struggle to run directly on it. Newer **adsorption chillers** using advanced materials may operate on 50–60 °C heat, but they have limited capacity and coefficient of performance (COP). They are even more niche but are sometimes used with solar or waste heat, where temperatures are low. Adsorption chillers could, however, produce maybe ~15 °C chilled water, which might suffice for greenhouse cooling (not as cold as the recommended 7 °C, but maybe enough to dehumidify or cool moderately). Alternatively, the adsorption chiller could be coupled with a conventional chiller to reach 7 °C.

Like the heat pumps, the cost of using an absorption/adsorption chiller to balance the waste energy use is high, and the system's efficiency is low.

In summary, literature and case studies show that booming data center waste heat can be an asset if creatively reused. Although few U.S. examples exist, the two referenced studies—the Virginia JLARC review and the Falk *et al.* analysis—underscore a huge latent potential. Data centers are growing rapidly and will produce ever more excess heat, yet current practice exhausts it to the ambient environment rather than using it.

Missing from the literature was the more holistic model suggested by many of our industry experts during their interviews. Integrating data centers more fully, beyond heat exchanges, with larger and more diverse agricultural industries and manufacturing facilities could yield substantial energy savings and lower greenhouse gas emissions. With supportive policy and smart engineering, colocating high-tech greenhouses and data centers – possibly within a CHP-powered Farm Park (see ‘Optimal Design Conditions’ section) – the supply-demand mismatch can be solved, energy utilization optimized, operating costs reduced, more jobs created, and a resilient local economy launched.

APPENDIX B

References

Appendix B References

AmericanHort. (2022). Greenhouse & Nursery Labor Survey - preliminary findings on labor shortages and employment practices.

Bakker, Y. (2023). *Achieving Flow Synergy in Data Centers with a Residential and Greenhouse Program*. Delft University of Technology.

Blair, D. (2013, October 23). The Syracuse Green Data Center: Driving Energy Savings & System Reliability. Data Center Knowledge.

Bureau of Labor Statistics. (2020-2023). Occupational Employment Statistics for crop/greenhouse laborers and supervisors.

Cáceres, C. R., Törnroth, S., Vesterlund, M., Johansson, A., & Sandberg, M. (2022). Data-Center Farming: Exploring the Potential of Industrial Symbiosis in a Subarctic Region. *Sustainability*, 14, 2774. https://doi.org/10.3390/su14052774

Chen, X., Bai, J., Fu, L., Lei, Y., Zhang, D., Zhang, Z., Luo, Q., Gong, S., & Shen, B. (2024). Complementary waste heat utilization from data center to ecological farm: A technical, economic and environmental perspective. *Journal of Cleaner Production*, 435, 140495. https://doi.org/10.1016/j.jclepro.2023.140495

Du, Z., Li, Q., Yang, Y., & Zhang, L. (2024). Research on waste heat utilization potential of data centers for agricultural greenhouse heating. *Journal of Physics: Conference Series*, 2835(1), 012076. https://doi.org/10.1088/1742-6596/2835/1/012076

Eddy, R. (2024, December 13). Taming the greenhouse environment. *Produce Grower*. https://www.producegrower.com/article/taming-the-greenhouse-environment/

Elarga, H., Kauko, H., Birgen, C., & Sannan, S. (2023). Reuse of the surplus heat from data centers through different end users. *SINTEF Report 2023:00503*.

Falk, S., Asgari, N., Pearce, J. M., & van Wynsberghe, A. (2025). The potential of data center waste heat recovery for greenhouse food production in the U.S.: Ramifications for sustainable AI [Preprint]. *SSRN*. https://dx.doi.org/10.2139/ssrn.5170348

Google DeepMind. (2016, July 20). DeepMind AI reduces Google data centre cooling bill by 40% [Blog post]. https://deepmind.google/discover/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-by-40/

Hall, C., et al. (2023). H-2A Workers in Ornamental Horticulture. UF/IFAS Extension.

Industry trade publications. (Various dates). Greenhouse Grower, Greenhouse Management, Urban Ag News - reporting on labor challenges, wage pressures, and workforce statistics.

International Energy Agency. (2023). *Data centres and data transmission networks* (Tracking Clean Energy Progress 2023). IEA. https://www.iea.org/reports/data-centres-and-data-transmission-networks

Joint Legislative Audit and Review Commission. (2024). *Data centers in Virginia* (Report No. 598). Commonwealth of Virginia, JLARC. https://jlarc.virginia.gov/pdfs/reports/Rpt598.pdf

Judge, P. (2022, October 11). EcoDataCenter to reuse heat in fish farms and greenhouses. *DataCenterDynamics*. https://www.datacenterdynamics.com/en/news/ecodatacenter-to-reuse-heat-in-fish-farms-and-greenhouses/

Ljungqvist, H. M., Mattsson, L., Risberg, M., & Vesterlund, M. (2021). Data center heated greenhouses, a matter for enhanced food self-sufficiency in sub-arctic regions. *Energy*, 215, 119169. https://doi.org/10.1016/j.energy.2020.119169

Lü, X., Lu, T., & Zhang, Q. (2024). Optimizing Data Center Waste Heat Reuse: Case Studies and Environmental Implications. In P. Droege & L. Quint (Eds.), *Proceedings of the International Renewable Energy Storage and Systems Conference, IRES 2023* (pp. 65-71). Atlantis Highlights in Engineering, No. 32. https://doi.org/10.2991/978-94-6463-455-6_8

Oklahoma State University Extension. (n.d.). *Greenhouse carbon dioxide supplementation*. OSU Extension. https://extension.okstate.edu/fact-sheets/greenhouse-carbon-dioxide-supplementation.html

Ott, B., & Radgen, P. (2024). *Technology overview for waste heat utilisation from data centres*. University of Stuttgart, Stuttgart.

Sandberg, M., Risberg, M., Ljung, A.-L., Varagnolo, D., Xiong, S., & Nilsson, M. (2017). A Modelling Methodology for Assessing Use of Datacenter Waste Heat in Greenhouses. Luleå University of Technology & Swedish University of Agricultural Sciences. Retrieved from https://icoest2017.org/papers/greenhouse-waste-heat.pdf

Seaton, I. (2020, May 27). Data Center Heat Energy Re-Use Part 3a: Hot Water Cooling. *Upsite Technologies Blog*.

Siddik, M. A. B., Shehabi, A., & Marston, L. (2021). The environmental footprint of data centers in the United States. *Environmental Research Letters*, 16(6), 064017.

USDA Economic Research Service. (n.d.). Farm Labor statistics and analyses.

USDA NASS. (2019). Census of Horticultural Specialties - industry size and labor expense insights.U.S. Environmental Protection Agency. (2024). CHP policies and incentives. *U.S. EPA Combined Heat and Power (CHP) Partnership*. https://www.epa.gov/chp/chp-policies-and-incentives

Vogels, W. (2024, March). District heating: Using data centers to heat communities. *All Things Distributed (Amazon Web Services)*. https://www.allthingsdistributed.com/2024/03/district-heating-using-data-centers-to-heat-communities.html

Yuan, X., Liang, Y., Hu, X., Xu, Y., Chen, Y., & Kosonen, R. (2023). Waste heat recoveries in data centers: A review. *Renewable and Sustainable Energy Reviews*, 188, 113777. https://doi.org/10.1016/j.rser.2023.113777

APPENDIX C

Agriport A7 Case Study

Agriport A7 case study

A Scalable Model for High-Tech Agricultural Clusters

Agriport A7 is a leading example of how strategic infrastructure planning, public-private collaboration, and innovation in controlled environment agriculture (CEA) can transform regional economies. Located in the Netherlands, this 2,500-hectare agribusiness hub integrates state-of-the-art greenhouses, data centers, colocated energy assets, and advanced logistics infrastructure to support year-round food production and global export.

By aligning growers, utilities, data centers, and logistics firms within a centralized development, Agriport A7 has created a replicable model for high-efficiency agricultural clusters. Its success demonstrates how thoughtful colocation of energy, water, and waste systems can drive economic development, reduce environmental impact, and enhance food security.

This case study explores the key features, partnerships, and planning strategies behind Agriport A7's development—and offers insights for adapting its model to other regions seeking to scale resilient agricultural systems.

RESOURCE INNOVATION INSTITUTE

Agriport A7

OVERVIEW

Middenmeer, Netherlands

Strategic Siting

- **Highway Access**: Directly along the A7
- **Distance to Amsterdam**: ~30 miles via the A7
- **Nearest Airport**: Amsterdam Schiphol Airport. ~40 miles via the A7
- **Nearby Ports**: Port of Amsterdam. ~30 miles via the A7

Climate Zone

	Region 3, Southern Virginia Zone 4A (Mixed, Humid)	Wieringermeer region of North Holland, NL Climate Zone 5A (Cool, Humid)
Winter	Mild	Cold
Summer	Hot & Humid	Warm & Humid
Moisture	High	High
HVAC Focus	Balanced (Heat/Cool)	Heating-focused

Source: ANSI/ASHRAE Addendum a to ANSI/ASHRAE Standard 169-2020 Climatic Data for Building Design Standards

SIZE & CAPACITY

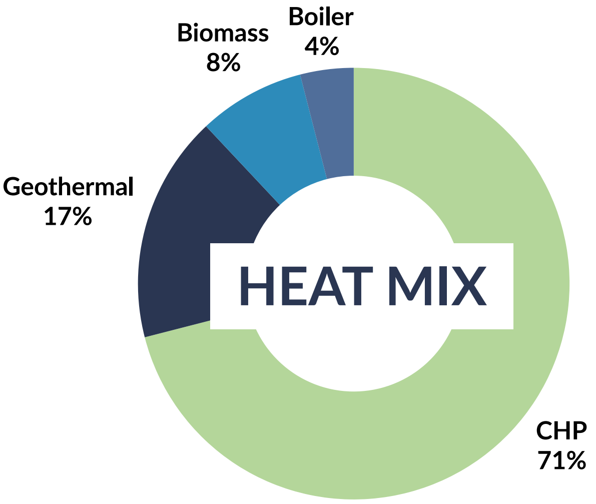
GREENHOUSE

1,557 Acres
(630 Hectares)

- Comprised of seven separate companies
- Average farm size is 146 acres (59 hectares)
- Farm size range from 32-343 acres (13-139 hectares)

Energy Mix

- Electric mix 99% CHP *(40% in 2020 sold back to grid)*
- Remaining 1% was geothermal



DATA CENTER

185 Acres
(75 Hectares)

BUSINESS PARK

99 Acres
(40 Hectares)

SIZE & CAPACITY

Relevant Rules & Regulations

Environmental Regulation (OVNH2020, article 6.1.5a and 6.2.2.6a)

- ***Nationwide***: Ban on data centers larger than 10 hectares and 70 MVA in municipal zoning plans
- ***Province of Noord-Holland***
    - Spatial requirements for data centers:
        - Gross floor area of 2,000 m^2 and electric connection capacity of more than 5 MVA in the three cluster municipalities.
    - Requires data centers to conduct waste heat economic analysis, governs at the permit level.
    - Publishes Guideline for Sustainable Establishment Requirements for Datacenters in Noord-Holland
    - Provides technical assistance via funded position, Energy Transition Director / Expert Datacenter Heat

Source: Guideline for Sustainable Establishment Requirements for Datacenters in Noord-Holland

SUSTAINABILITY STRATEGIES

[Source: ECW Energy (2023)]

Energy

Geothermal	Primary heat source year-round. Three plants on site.
CHP	Over 50 CHP units with a capacity of over 200 MWe.
Solar	A total of 4.5 MWe of solar (2 MWe on rooftops and 2.5 MWe on water)
Biomass	Biomass (woodchips, primarily sourced from pruning waste) is used to supplement during peak periods of cold temperatures and to produce electricity to power the geothermal pumps.
Heat Storage	High temperature storage both above and below ground to "save up" for winter. This is a new technology in partnership with the Dutch research institute, TNO.

CO2 Production & Utilization

Purchased liquid CO2:

Partnered with Renewi, a liquid CO2 producer located in Amsterdam, to supply the greenhouses with supplemental CO2.

The CO2 is produced at a large-scale fermentation plant.

Produced CO2:

Utilizing CO2 produced from the CHP units

Water

Rainwater Capture	Used for both GH and DC. Unclear whether drinking water is used during the drier months. Water is stored in the above and underground reservoirs.
Recycling Water	Irrigation systems within greenhouses recycle the water, reporting water productivity of 4 L/Kg of tomato.
Data Center	In summer months, stored water is used to cool Data Centers.

REGULATIONS & POLICIES

Guideline for Sustainable Establishment Requirements for Datacenters in Noord-Holland

Energy, water, and sustainability requirements: Dynamic List of Establishment Requirements for Datacenters.

Building and operating a data center involves a complex set of dynamic requirements related to energy, water, and overall sustainability. These requirements are driven by factors like increasing data demand, environmental regulations, and growing public concern about the environmental impact of data centers.

Recognized Energy Efficiency Measures List (EML)

Energy saving measures with a payback period of 5 years or less. The EML consists of 3 parts: Buildings, Facilities, and Processes. The EML can be used to meet the energy-saving obligation. Measures apply to glasshouse horticulture and data centers.

WORKFORCE

GREENHOUSE

2,400 full-time horticultural workers (as of 2020)

DATA CENTER

1,500 – 2,000 estimated full-time employees as data centers reach capacity

BUSINESS PARK

5,000-7,000 full-time employees within 35 companies

Estimated 10,000 employees

Onsite housing for migrant workers

APPENDIX D

Estimated Tax Revenue

APPENDIX D

ESTIMATED TAX REVENUE BY OPERATION TYPE

County	FARMLAND Estimated Tax ($/acre)	GREENHOUSE Estimated Tax ($/acre)	DATA CENTER Estimated Tax ($/acre)	Source
Amelia	$4.84	$8.79	$520	Amelia County Assessment Info
Cumberland	$2.81	$2.81	$780	Cumberland County Brochure
Henry	$1.65	$2.34	$605	Henry County Real Estate
Nottoway	$6.04	$6.55	$765	Nottoway County Brochure
Pittsylvania	$3.72	$3.72	$527	Pittsylvania County Land Use
Prince Edward	$2.09	$2.40	$459	Prince Edward County Brochure
Averages	$3.53/acre	$4.44/acre	$609/acre	