INDOOR SOILLESS FARMING:

PHASE II: Moving from theory to action

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Indoor soilless farming, a subset of Controlled Environment Agriculture (CEA), aims to reduce many of the more harmful effects of conventional field farming, including decreasing pressures on land, biodiversity, natural habitat, and climate. However, these indoor farms often have large energy footprints, are still figuring out the best way to support local communities and need support to share experiences and move the industry forward.

In our Phase I Innovation Analysis, WWF conducted a life cycle analysis of current systems, analyzed the future of indoor soilless farming, determined the optimal conditions for indoor farms to thrive, and conducted research on stranded assets,[1] markets, and partnerships available in the St. Louis, Missouri region.

In Phase II, WWF has used that research as a springboard for action. Phase II activities included:

- forming the St. Louis Controlled Environment Agriculture (STLCEA) Coalition;
- analyzing innovative energy systems utilizing various stranded assets;
- exploring potential partnerships;
- soliciting and evaluating proposals from indoor farms interested in building and running a pilot indoor farm;
- choosing an indoor farm partner to bring an integrated system to the St. Louis region;
- exploring the feasibility of a Center of Excellence (CoE) on indoor farming in the St. Louis region; and
- kicking off the CoE's initial projects and developing a long-term vision.

The STLCEA Coalition, a group of more than 70 members, selected AeroFarms, a leading vertical farming company with global headquarters in New Jersey and primarily growing leafy greens, to partner in the St. Louis region. AeroFarms has large indoor vertical farms in existence and underway both in the US and internationally. They also have small indoor vertical farms geared towards community development and support. AeroFarms is planning their next commercial indoor vertical farm, around 150,000 square feet, in the greater St Louis region, making this new farm one of the largest indoor vertical farms in the world once a site is chosen and the farm developed. It will grow several million pounds of produce annually.

In addition to the commercial farm, the Coalition is working with AeroFarms to explore bringing community indoor vertical farms to the St. Louis region. These would be designed to fit inside a school classroom, community building, or similar set-up. The goal would be to place the majority of these farms in schools to be integrated into the curriculum.

Additional partnerships to address social and environmental goals and create more circular systems were analyzed and could be added in the future. This included looking at a variety of integrations with stranded assets and use of renewable energy systems. Even if they don't make sense in the St. Louis region or for this project, these options may be relevant or useful for other indoor soilless farms or other regions of the world.

The Coalition has also made strides in founding a Center of Excellence in St. Louis. This includes exploring some individual projects to move key ideas forward while, in parallel, working towards establishing a physical Center of Excellence. One early project has focused on expanding technical and business support. To help move this goal forward, the Danforth Plant Science Center—through its partnership with the Wells Fargo Foundation and the National Renewable Energy Lab (NREL), the virtual IN2 incubator—focused their 2021 call for research projects on start-ups on indoor agriculture.

[1] Large infrastructure investments such as power plants and postal hubs that have depreciated in value but will continue to function and be used in at least a limited capacity for 10-50 years as well as byproducts of industry such as brownfields

Meanwhile, The Yield Lab Institute has been leading efforts to establish a permanent Center of Excellence in modern agriculture production in St. Louis, building on the city's deep plant science expertise and innovation. They are partnering with the University of Missouri St Louis (UMSL), the University of Missouri Extension, and the University of Missouri System to host the Center and partner with faculty expertise while also engaging other potential partners in the formation of the Center.

This process has brought successes and hurdles. Building a Coalition has made these efforts possible. Various levels of participation have allowed people to invest more or less time, but all have some skin in the game. The enthusiasm of the Coalition has brought significant progress on all fronts and it is extremely exciting to all involved to see this effort culminate in a large, innovative vertical farm in the St. Louis region, a series of community farms, and a CoE to build on St. Louis' plant science expertise. However, the STLCEA also struggled at times to explain what it brings to the table and where its limitations lie. There was also an unexpected hurdle as the entire project necessarily went remote, but that has ultimately led to wider participation than might otherwise have been possible.

The efforts of the Coalition will not overcome all limitations of indoor soilless agriculture. It still often comes with a large energy footprint and significant labor costs. It often isn't profitable to date to grow fruiting crops in vertical systems, and it may never make sense to grow commodity crops. Its products also come with a currently high price point, making it hard to address food inequality. However, indoor soilless farming also vastly decreases water use (and therefore energy linked to moving and treating water), eliminates soil erosion, often eliminates pesticide use, lowers food loss and waste, secures supply chains, addresses food safety, and can bring food to places that couldn't otherwise produce their own food. WWF believes that indoor farms will be one part of the solution to change the footprint of how we grow and consume food. A viable indoor vertical farm and CoE efforts in the St. Louis region will help to address these challenges, explore innovative paths forward, and provide learnings to spur further efforts and options worldwide.

BACKGROUND

Food production is the largest human impact on the planet. Habitat conversion, greenhouse gas (GHG) emissions, soil degradation, agrochemical runoff, and inefficient water use associated with current food production systems threaten the environment. World Wildlife Fund (WWF) envisions a more distributed and resilient food system in which some food is produced at scale closer to consumers, with more efficient use of inputs, less waste, and a lower carbon footprint.

Soilless indoor farming is generating excitement as a growing niche industry that aims to reduce many of the more harmful effects of conventional farming. At scale, this method of farming could decrease pressures on land, biodiversity, native habitats, and climate. However, the industry also faces hurdles that prevent it from moving beyond its current specialization in high-end leafy greens. Farms face difficulties related to energy and labor and need support to share experiences and move the industry forward.

In Phase I of its Indoor Soilless Farming project, WWF conducted a life cycle analysis of current systems, analyzed the future of indoor and vertical farming, determined the optimal conditions for farms to thrive, and conducted research on stranded assets, markets, and partnerships available in the St. Louis, Missouri region.

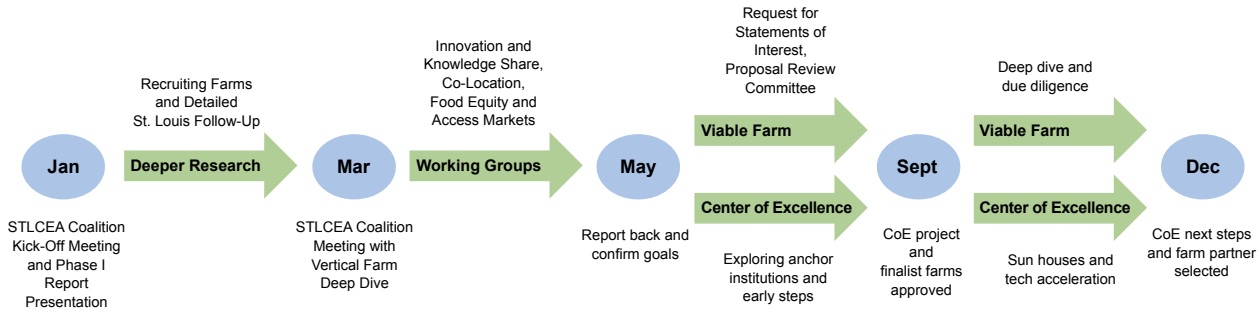
In Phase II, WWF has used that research as a springboard for action. Throughout 2020, WWF helped form the St. Louis Controlled Environment Agriculture (STLCEA) Coalition, completed due diligence on a variety of innovative energy systems utilizing various stranded assets, explored a multitude of partnerships, put out a request for statements of interest, narrowed to one finalist farm partner, and explored the feasibility of a Center of Excellence (CoE) on indoor farming in St. Louis. Since then, the team has moved forward in its goals to bring an innovative, commercial indoor vertical farm to the greater St. Louis region, is exploring the potential to bring community indoor vertical farms to the St. Louis region to integrate with public schools, and has assisted the new CoE in a few early steps that have set it firmly on a pathway to success. The end goal of these initiatives is to boost the CEA industry through shared learnings and to build a system that can be replicated worldwide, providing a new option for growing food more sustainably.

BRINGING AN INTEGRATED VIABLE FARM TO ST. LOUIS

The St. Louis region was chosen as a key partner for indoor farming. It has a metropolitan statistical area (MSA) with 2.8 million people and very hot summers and cold winters, which limit the growing season and therefore provides an opening for local food that can be grown year-round. It also possesses myriad stranded assets (former limestone mines, thermal power plants with excess capacity, underutilized USPS distribution hubs, etc.) and potential partners (strong universities, community finance trusts and foundations, regional grocery chains, and more), as well as unrivaled relevant science expertise with more than 1,000 PhDs working in plant science[2] (one of the highest concentrations in the world) and more than 14,500 agtech and bioscience jobs.[3] At the same time, it faces many of the same struggles facing other cities in the midwestern US and around the world. Its population is in decline, it is struggling with obesity and chronic health conditions, lower-skilled jobs that pay a living wage are disappearing, racial and gender inequity remain rampant, and existing assets are sitting stranded or underutilized. As the world moves beyond COVID-19, many more changes may face cities as people change where they work, how they work, where they eat and socialize, and even where they live. St. Louis represents an excellent opportunity to explore innovative ways to tackle hurdles facing indoor farming, bring healthy food to an urban population year-round, and utilize existing assets. WWF hopes that the lessons learned through this project can be shared widely, encouraging innovation and replication in cities and countries across the world.

PROCESS

WWF has been a catalyst and convener, but this project has been informed and driven by local input and expertise. In January 2020, WWF and The Yield Lab Institute, a local partner, kicked off Phase II with a meeting of the STLCEA Coalition, a group of more than 70 members including local stakeholders, economic development groups, venture capitalists, banks, plant science experts, academics, universities, hospitals, groceries, major restaurant chains, community groups, indoor soilless farms, industry partners, and other potential partner organizations. A full list of Coalition members is in Appendix I. WWF presented the Phase I Innovation Analysis as a springboard for next steps and the Coalition engaged in active discussion over the best opportunities and assets in the St. Louis region. By the end of the meeting, there was a list of additional partners to engage and avenues for deeper research and the group had decided to explore two goals: bringing a viable innovative indoor farm to the St. Louis region and building on St. Louis' plant science expertise to engage in innovation and/or knowledge sharing. On the viable indoor farm side, there was also a decision to specifically focus on vertical farms rather than greenhouses. Members agreed that there was less to add to greenhouse knowledge since there is already expertise and best practices in the space, and that the St. Louis region, with its humid climate which makes evaporative cooling difficult, would not be the best candidate for greenhouses.



An overview of STLCEA convenings in Phase II

[2] St. Louis Evonomic Development Partnership, 2020

[3] AllianceSTL using BLS 2019 data

These decisions set the stage and structure for the remainder of Phase II. The STLCEA Coalition continued to meet every two to three months with additional research, partner outreach, and small working groups leading the way between the larger meetings. The working groups provided a chance to engage in more depth on key areas of interest while also building local support and leadership as each group was led or co-led by a Coalition member in St. Louis. The full Coalition meetings, meanwhile, provided a chance for reflection and group decisions on direction and strategic priorities.

After the first STLCEA Coalition meeting in January, WWF completed deep dives with and recruited numerous indoor vertical farms to explore a potential innovative indoor vertical farm in the St. Louis region and the possibility of knowledge sharing between farms. These insights and conversations fueled a deeper analysis at the March meeting when four working groups were established to further probe top priorities: Innovation and Knowledge Sharing, Co-Location and Economic Development, Food Equity and Access, and Markets. After these groups presented at the May meeting, the Coalition decided to combine the groups further and focus on two parallel tracks: bringing a viable indoor vertical farm to the St. Louis region that tackled social and environmental goals and developing a Center of Excellence for controlled environment agriculture in St. Louis (see Center of Excellence.)

In late summer and fall, the working groups shifted from exploration to implementation. The viable indoor vertical farm group began to solicit individual farm proposals, created a Proposal Review Committee (PRC), and eventually narrowed the respondents to three finalist farms which were presented at the September STLCEA Coalition meeting. (Further details on farm selection are in Viable Farm Development and Design – Identifying Partner Farm(s).) Deeper dives and due diligence were led by the PRC throughout the fall, culminating in a final December STLCEA Coalition meeting to hear updates and approve the selected farm partner and the plans for social and environmental goals in the St. Louis region.

VIABLE FARM DEVELOPMENT AND DESIGN

WWF has worked in close contact with numerous St. Louis partners, local stakeholders, indoor vertical farms, and associated industry companies throughout the development and design process. Distributed leadership and early buy-in has been essential for building support, advancing the project, and finding innovative solutions that work for the St. Louis region.

Identifying Partner Farm(s)

Early on in Phase II, the STLCEA Coalition decided to focus on working with established indoor vertical farm partners. The Coalition's goals were to increase the environmental sustainability of indoor vertical farms, especially around the energy footprint, benefit the St. Louis region, and bring a viable indoor vertical farm to the St. Louis region that could move beyond growing leafy greens and herbs. Members agreed that working with an existing partner to build something new in the St. Louis region would be a smoother and faster process than creating or attracting a new start-up.

With the goal of attracting the right farm partner through a mutual choosing process, a Viable Indoor Vertical Farm Working Group was created over summer 2020. It included St. Louis economic development groups, venture capitalists, indoor vertical farm consultants and partner companies, energy companies, groceries, academics, and more. The group put together a process and released a confidential solicitation as a Request for Statements of Interest (see Appendix II.) The Request was distributed to all Coalition members to share with their networks, sent to all indoor vertical farms that had participated at any step of the project, and shared with industry partners and pushed through their outreach and communication channels. The working group solicited farmer questions and shared them with all interested parties (see Appendix II) and held two webinars for interested farms to learn more. A total of 18 indoor vertical farms participated in one or both webinars and nine indoor vertical farms submitted Statements of Interest.

A Proposal Review Committee (PRC) was put together to read submissions and select finalist farms. The PRC included Julia Kurnik, Director of Innovation Startups, WWF; Gene Giacomelli, Professor Biosystems Engineering and Founding Director CEA Center, University of Arizona; Dennis Lower, President, Innovation Community Strategies; Michael Rose, Partner, The Mixing Bowl/Better Food Ventures; Mike Tipton, VP Produce, Schnucks; and Cara Weber, then Director, Greater St. Louis, Inc. PRC members read and evaluated proposals individually, using an evaluation matrix created by the group (see Appendix III.) Individual PRC rankings were combined and shared with the group. After robust discussion, additional questions were asked of shortlisted farms and the PRC confirmed its choice of three finalist farms.

A maximum of 300 points was possible across the matrix and the nine submitted farms received 138-247 points. The three finalist farms all had operational indoor vertical farms in the US, had national and international operations or international prospect pipelines, had farms ranging from 1,000 square feet to 70,000 square feet, had previously demonstrated community engagement, and were technologically innovative. They were all open to STL partner discussions and presented scalable options ranging from less than 10,000 square feet to up to 150,000 square feet with costs from $2M to $60M.

Throughout the fall, the PRC engaged in deep discussions with all three finalist farms while also completing due diligence on potential energy options, integration with stranded assets, site options, potential markets, funding, and social benefits to the St. Louis region. This deep dive also served as a mutual choosing process. While the Coalition wanted to ensure the selection of the best partner with the St. Louis region, it also had to convince the right partner that the St. Louis region was the best next step for the farm and that there was value in working with the Coalition. This period allowed for more in-depth discussions, the beginning of specific plans, and a longer process to get to know one another. A final indoor vertical farm, AeroFarms, was chosen in December 2020 by the PRC, presented for approval, and approved at the final STLCEA Coalition meeting. AeroFarms and the PRC then engaged in a deep dive throughout 2021 and 2022 to explore site options in and around the St. Louis region, on both the Illinois and Missouri sides, formalize partnerships, focus on energy and social priorities, put together a financial package, and identify customers. This process is likely to culminate in a chosen site and groundbreaking in 2023 with further details available at that time.

Energy Options and Stranded Assets

One of the primary goals of the project was to address the energy footprint, and the associated environmental impacts, of indoor vertical farms. Energy use is largely driven by the heavy use of grow lights. Across the industry, the average direct energy use of the lights is often quite high. Indirectly, these lights lead to significant HVAC costs. Even with efficient LED lights, when so many lights are packed in a closed space, there is a lot of excess heat and farms end up air conditioning even in winter even in cold climates. *(See Phase I Innovation Analysis.)*

However, it is not just the total energy footprint that matters but the source of the energy. In its Phase I Analysis, before working with any farm partners, WWF conducted a life cycle analysis comparing a hypothetical vertical farm placed in St. Louis to conventional farms in California, where most lettuce is grown today. The analysis revealed that the overall environmental and health impact of conventionally grown lettuce produced and shipped from California to St. Louis was lower than lettuce grown in an indoor vertical farm in St. Louis. However, when the hypothetical indoor vertical farm was powered by solar energy, that calculation changed. Many of the detrimental environmental impacts came from the source of the energy rather than the actual energy use. California has a much cleaner energy grid (23% coal, 30% natural gas, 46% renewable) compared to St. Louis (32% coal, 35% natural gas, 31% renewable.) WWF evaluated several options for reducing and greening the energy supply to vertical farms by integrating with existing stranded or underutilized assets.

To complete our analysis, WWF modeled two hypothetical indoor vertical farms – one small and one large – to use as industry averages. After surveying the landscape of indoor vertical farms today, the two models were set at a typical large farm, with a footprint of 100,000-150,000 square feet and using a roughly constant 5-7 MW of energy and a typical small farm, with a footprint of 5,000-10,000 square feet and using a roughly constant 75-125 kW of energy.

River Cooling

Electric services company Ameren is on track to close their Meramec coal power plant by the end of 2022. The facility currently uses the Mississippi River to cool the power plant and there are no plans for that existing infrastructure after the plant shuts down. While it would need to be retrofitted, it is possible that the existing infrastructure could be repurposed to cool a vertical farm. Additional water tubing would need to be added around the farm and use conductive metal to allow the cold to reach the containers. Humidity, which is carefully calibrated in vertical farms, would also have to be considered. A full cost and energy analysis would need to take place, in partnership with Ameren, but the stretch of the Mississippi River located along the state of Missouri does meet minimum temperature requirements (~10˚ C) needed to cool a farm from September to May on average.[4]

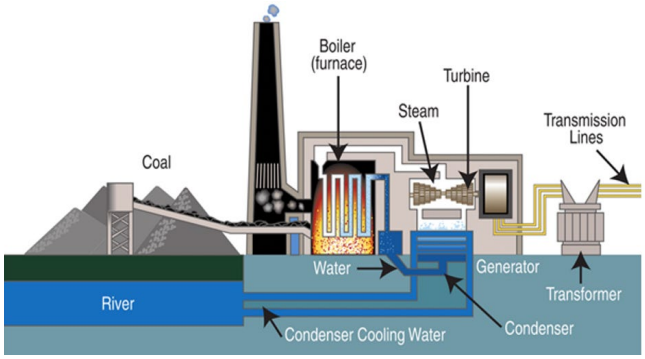


Diagram of a coal-fired power plant using a river cooling system. Source: Tennessee Valley Authority

However, right now, this is not a politically feasible solution. The Meramec power plant is surrounded by fly ash ponds. Ameren is currently determining the best options moving forward for this space and cannot commit to anything that involves bringing outside people onto the site. Progress should continue to be monitored and discussed if the situation changes and other power plants that utilize river cooling systems might be better suited to this type of repurposing.

Underwater Turbines

Underwater turbines are essentially windmills located on the floor of an ocean or river. Instead of wind, the propellers are spun by the underwater current and are attached to a gear box, generating electricity. Despite their simplistic nature, this a relatively new and untested technology. It is possible that a farm could be located near underwater turbines and receive power directly from them.

LCOE for various unit arrays ($/kWh)[5]				
	1-unit	10-unit	50-unit	100-unit
RM1 (tidal)	1.99	0.40	0.20	0.17
RM2 (river)	2.67	0.78	0.42	0.35
RM4 (ocean)	0.67	0.24	0.15	0.48

Levelized cost of energy for different types of river underwater turbines

The Mississippi River does (just) meet the minimum requirements needed for water turbines. It has an average velocity of 0.54 m/s, slightly above the 0.5 m/s requirement. It also has a depth of around 3 meters. This is above the 0.5 m minimum and, importantly, would allow turbines to be located low enough not to affect boats traveling above. However, in these minimal conditions, 1,600-6,000 turbines would be needed to power a large vertical farm completely by water turbine, covering 1-3 acres, and a small vertical farm would need 39-145 turbines. While the riverbed footprint wouldn't be overly large, wind turbines would be far more expensive than sourcing power from the St. Louis grid. The least expensive river turbine is about five times the cost of grid electricity (using the levelized cost of electricity, or LCOE, which represents the sum of financing, building, and operating a power plant over the total electricity generated throughout a plant's lifetime.) The lifetime and durability of these turbines also hasn't been tested and could lead to significant additional costs in the future.

Since they are so new, it is possible this technology becomes cheaper and more accessible in the future. Partnerships with a local university could be explored to run a pilot in the St. Louis region to assess the feasibility of implementing underwater turbines in the Mississippi River. This would provide a better understanding of the cost, environmental impact, including on fish that migrate up and down the river, and regulatory hurdles that may face a large-scale project while providing important insights into what type of sites are best suited for this nascent technology.

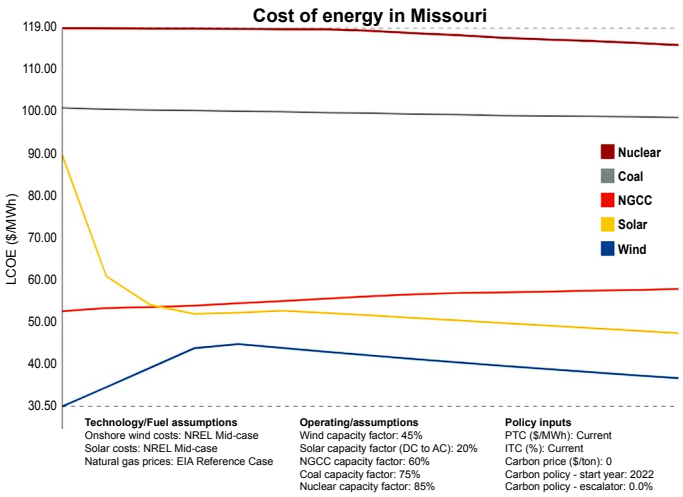
[4] Tang, Chunling et al. *"Water Temperature Changes in the Mississippi River Basin."* EPA

[5] Neary, Vincent Sinclair et al. "*Levelized Cost of Energy for Marine Energy Conversion Technologies.*" USDOE: Aug 1, 2016.

Solar Panels

Many indoor farms have tried experimenting with solar panels. Since they are completely enclosed, solar panels can be located on the roof of farms, harnessing the power of the sun while retaining tight control of the system within. They are also becoming increasingly affordable and can often be cheaper in the long run than coal or natural gas. However, the land needed for solar panels to power a farm continues to have a far larger footprint than the actual farm and the LCOE does not capture political difficulties or consider what already exists.

To fully power a large vertical farm in MO, which averages around five hours of sun per day, would require more than eight acres of solar panels.[6] This compares to an approximately 100,000 - 150,000 square foot farm in our model or perhaps 2-5 acres depending on needs for additional refrigeration, parking, and administration. This could be feasible in areas outside of cities or more rural locations but is limiting if trying to co-locate a farm with other buildings or in urban areas.



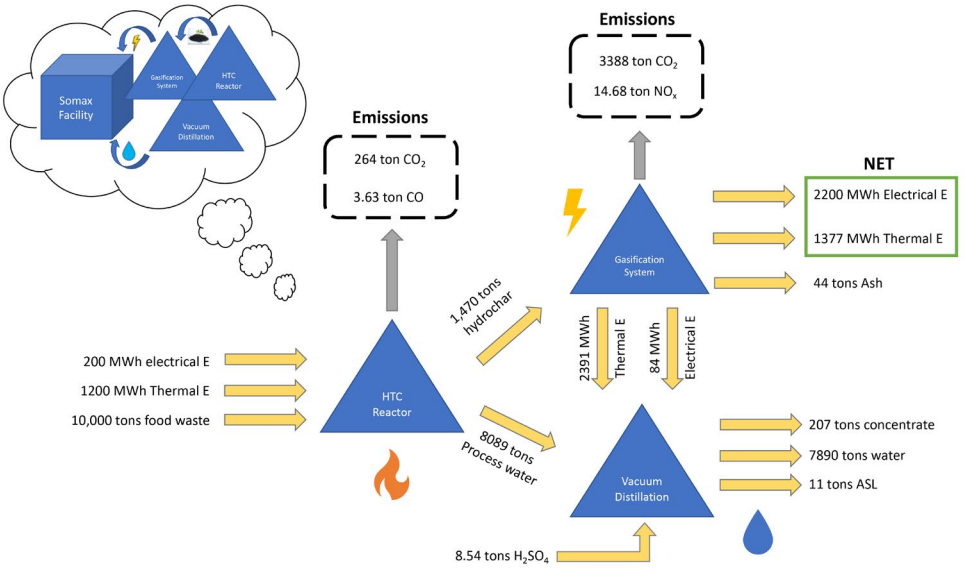
Cost of Building Power Plants in Your State. Source: National Resource Defense Council. https://www.nrdc.org/cost-building-power-plants-your-state

To fully power a small vertical farm in MO is far more feasible, needing just a portion of an acre of solar panels. For a co-located small farm, this is very doable. For example, perhaps a small farm could locate next to a grocery distribution center with panels on top of that relatively large building or next to a school, with some portion of the farm available for educational purposes, and solar panels on the school.

However, the costs can also be higher than they originally appear. Solar energy costs have dropped significantly in recent years. In Missouri, the LCOE of a new solar plant is around $50 per MWh – cheaper than coal (slightly more than $100/MWh) and natural gas (around $60/MWh). However, this is comparing building a new solar plant today to building a new coal plant today. Since coal plants already exist and have extra capacity, building a solar plant would require significant upfront investment that isn't necessary for energy already from the grid. Since Missouri's grid doesn't need a large injection of new energy sources, it also means that energy generated by a solar plant would either lead to a glut on the grid or force an existing plant to be retired far earlier than planned, leading to shut down costs and the environmental remediation that must accompany that process.

Finally, the politics of building fields of solar panels may not always be feasible. Missouri is a regulated energy state. They will not purchase energy or allow energy on to the grid that is not produced by Ameren. A farm could try to go "off-grid" but then risks losing some guarantee of security by being on the grid. Ameren does offer a Neighborhood Solar Program. This is a program for all non-residential Ameren Missouri electric customers with space for solar panels. If a customer has up to an acre of space for solar panels in an area that will bring community benefit (e.g., in a low-income community, alongside a school, etc.) then Ameren will build and operate solar panels on that site. However, this is capped at an acre. In Missouri, this translates to around 850 kwh of energy per day. This is helpful but only a small fraction of the energy needed by a large vertical farm – though it could be very useful to a small vertical farm. Illinois is an unregulated state and would allow for easier solar panel installation, but the same LCOE comparison limitations would remain. This option would likely only be feasible if a third-party, such as Ameren or a private solar facility, was already investing in a solar farm and covering the upfront costs but looking for a long-term offtake agreement with a large energy user, such as a vertical farm.

[6] Missouri Department of Natural Resources: Division of Energy.



A model of a 10,000 ton HTC process. Source: Armstrong, Philip Marshall. "Integrated Life Cycle Assessment for a Closed Loop Organic Food Waste to Energy System." Villanova University: May 2019 and updated by SoMax

Food Waste to Energy

There is a lot of innovation happening around waste to energy systems. SoMax BioEnergy, an energy company using organic waste, has developed hydrothermal carbonization (HTC) systems that can create energy from a wide variety of waste products, including heterogenous food waste. This means they are not limited to just food that is compostable or useful in other sources, but can take a mix of proteins, prepared foods, carbohydrates, fresh produce, and more. Byproducts from brewing beer and wine (e.g., grape marc) would also be very useful fuel. SoMax is also able to create energy from human waste or manure.

While SoMax BioEnergy's technology is new, there are no actual untested technologies in the process. HTC coal production is well-researched and tested and the burning closely matches that of coal burning but with a low environmental impact. HTC systems take in the waste products and create hydrochar, which can then be gasified to create energy. The process also creates a few byproducts and emissions: carbon dioxide, ash, thermal energy, distilled water, and liquid nitrogen fertilizer. All of these can potentially be repurposed. The carbon emissions are relatively low and could be recycled back into a co-located farm – as can the liquid nitrogen fertilizer. The ash is useful as an absorbent in cement manufacturing or construction work. The distilled water can be used for a large variety of applications and if the hydrochar is gasified solely for thermal energy, temperatures come out as 1500˚F air and could be used for industrial purposes – or to create beer.

The upfront costs are significant but this waste to energy system is likely to be a profitable enterprise or to save costs if owned by the city, county, or state. It could also break even in just five years for a large indoor vertical farm, though wouldn't necessarily make sense for a small indoor vertical farm.

To fully power a large vertical farm in our model, a 15-16 container facility, including a gasifier, would be needed. This would cost an estimated $50 million in upfront capital. It would also need a large amount of space. The needed gasifier and gensets would be roughly 35,000 square feet. However, it could be financially enticing.

While the upfront costs are high, a facility could not only sell its energy (if it were not legally connected to the farm) but could also charge tipping fees to collect waste (which are already being paid by companies) and/or sell associated byproducts such as nitrogen fertilizer created by the HTC process. Assuming 238,000 tons of wet food waste with a $30/ton tipping fee, the facility could make $7.1M annually. Meanwhile, in our model, a large vertical farm will spend an estimated $4-5M annually on energy at an eight-cent commercial rate in St. Louis. If there were a joint venture for free energy or a partner farm owned the facility, it could break even in five years and then continue to enjoy free energy and income from tipping fees. Alternatively, the city or another government entity could fund SoMax, achieve savings on waste fees while significantly reducing landfill emissions, and sell electricity to the farm at a low rate.

Type of Waste Fuel	Tons of Waste Needed to Power a Large Vertical Farm Annually
Beer byproduct	247,596
Heterogeneous food waste	237,838
Human waste	270,803

There are the potentials for other synergies and different trade-offs depending on the type of waste used. Carbohydrates, such as spent brewery and distillery grains or bakery waste, provide the highest energy density hydrochar. Breweries and distilleries usually sell spent grains as animal feed, but many are now over producing what can be used in that manner, leading to additional waste streams that end up in landfills. Co-locating with a brewery means the thermal heat could be used by the brewery while the spent grains could be used by the energy facility. Heterogenous food waste is slightly less efficient than all carbohydrates but could reduce the wasted food that ends up in landfills – a significant source of methane gas, a gas that is far more potent than carbon dioxide. While it is best to avoid wasted food in the first place, all waste will never be eliminated, and this provides a productive way to make use of it. With around a pound of food wasted per person each day in the United States,[7] a population of just 1.3M is needed to fully power a large vertical farm using a SoMax facility. This is smaller than the St. Louis MSA. There could also be partnerships with area wastewater treatment plants or animal farms to produce energy from human and/or animal waste. It is the least efficient method to produce HTC energy, and there wouldn't be close to enough people in the St. Louis region to power an HTC facility solely from human waste, but it would be making use of a waste product available in every country and region in the world – and one that is rarely repurposed.

At this point, powering a small vertical farm wouldn't be financially feasible. It would need just a quarter of a container, erasing all economies of scale and leaving a lot of excess capacity which would monumentally shift a small vertical farm's business model. While a small vertical farm could purchase energy in an offtake agreement from such a facility, building one for this purpose likely wouldn't make sense at this time, or at least without other partners involved.

Underground Facilities

The energy use of vertical farms comes from two sources: direct lighting and cooling the farms that are heated by the heavy use of grow lights. It is currently estimated that energy for operations is $0.04 per kg of saleable lettuce grown in California and shipped to Chicago compared to $0.89 per kg of saleable lettuce grown in a vertical farm in Chicago and sold locally.[8] This also comes with a significant environmental footprint in addition to a large financial cost. LEDs will continue to improve but are unlikely to negate the problem of excess heat. However, a farm could be located underground to enjoy cooler temperatures year-round and less of a need to cool its facility.

The St. Louis region has a plethora of caves that were explored early in the project but were ultimately determined to make poor options for an indoor vertical farm. Caves are naturally occurring so not only are they often small, but they have uneven walls and floors. Many do not provide easy access from the ground. While they might be appropriate as they are now for small-scale farms or for growing mushrooms, significant investment and work would be needed to make the caves habitable for commercial-sized indoor farms, even when looking at our small farm model.

However, mines offer a viable option. Unlike caves, people manufacture mines, so they are already better suited for industry. They are much larger, often provide easy access, and usually have flat floors and walls. Mines are also ubiquitous, with perhaps half a million abandoned mines in the US alone,[9] and often shed jobs as they close so repurposing them would bring economic development benefits. The St. Louis area has already seen two mines repurposed for commercial use, Bussen Underground and Rock City, but there are also many abandoned mines around the two states that could also be explored in the future.

[7] Milman, Oliver. *"American waste 150,000 tons of food each day – equal to a pound per person."* The Guardian: April 18, 2018.

[8] Nicholson, Charles F. et al. *"An Economic and Environmental Comparison of Conventional and Controlled Environment Agriculture (CEA) Supply Chains for Leaf Lettuce to US Cities."* From Food Supply Chains in Cities. Springer International Publishing: 2020.

[9] Bale, Rachael. *"The problem with America's abandoned mines."* Reveal: Oct 21, 2014.

Steam Loop Integration

St. Louis, like many cities around the world, has a historic steam loop underground. These were often built decades ago and consist of a network of underground pipes carrying steam underneath downtown St. Louis. In just the US, there are more than 700 similar systems, often referred to as "district energy."[10] Steam loops can bring significant environmental efficiencies through re-using waste heat and providing low-energy heat options – and now potentially cooling options, as well.

An indoor vertical farm could integrate into an existing steam loop, making use of closed-loop steam cooling and thermal sources which bring significant energy efficiencies.[11] It's also possible that in a closed-loop system like these ones, an indoor vertical farm could then recycle its own waste heat back into the steam loop or even make use of CO2 released by the power plant back into its own facility to improve plant yield. Heat and CO2 capture and re-use are both explored further below.

Co-Location Options

Co-locating could provide several synergies, including options for utilizing waste heat and carbon dioxide emissions. Indoor vertical farms often spend significant HVAC costs on air conditioning to remove excess heat from the farms. While there are options for avoiding these costs, such as by locating underground, there are also possibilities to utilize the heat. In our model, even a small indoor vertical farm could produce enough heat to fully heat a 60,000 – 100,000 square foot building. A large indoor vertical farm, however, would potentially heat a much larger building(s) of over one million square feet. While this would not lower the energy footprint of the farm, it would lower the overall energy footprint of the entire partnership. It could also be monetarily beneficial to both parties. The farm could sell the heat at a price point lower than what the building would otherwise pay to heat itself but also provide income to the farm from what would otherwise be a waste product. In this model, the heat produced by a large vertical St. Louis farm would be worth $893,520 annually if sold at average St. Louis rates and the heat produced by a small vertical farm would be worth $8,870 annually. The cost to put in the piping infrastructure needed to repurpose the heat ranges from $270,202 if located 1 km away to $4,053,027 up to 15 km away (the maximum distance before it becomes impractical.) Even at this long distance, breakeven would occur by year five for a large vertical farm. Co-locating less than 1 km away would lower costs even beyond the $270,202. However, the costs of the piping are fixed so the break-even for a small vertical farm at just 1 km would take more than 30 years and likely wouldn't make sense.

Heating a co-located building would only be useful in the St. Louis region for about six months of the year. Heat would still be vented and wasted the remaining six months. It is worth considering if there are other entities that could use a year-round source of heat. It would not be hot enough to produce energy in a CHP plant (if transferred as air it would be 70-85˚F and if as water from water-cooled LEDs it would be roughly 140˚F) but could provide heat for a variety of lower temperature needs.

Indoor vertical farms could also provide an opportunity to sustainably recycle carbon dioxide emissions. If CO2 could be captured, indoor vertical farms could use the CO2 to boost growth of their plants and recycle it back into oxygen. St. Louis has several breweries. During the fermentation process, carbon dioxide is produced. Currently, that CO2 is largely vented as an emission, but could be captured and productively used in farms. Not only would this decrease emissions, but it would boost yield in farms, thereby lowering the energy footprint per pound of produce (assuming it is not solely replacing purchased carbon dioxide pumped into farms.) By increasing the CO2 concentration in the grow zones by 200-300%, growth rate would increase by 180-200%. There are limits on how much CO2 can be in a farm to ensure worker safety, but it could be pumped in overnight and may become less of a concern as more farm operations are automated.

[10] Nunez, Christina. "*How Hidden Labyrinths Under Cities Are Becoming Clean Energy Powerhouses*." National Geographic: Feb 5, 2016.

[11] Soares, Claire. "*Ch 10: Performance, Performance Testing, and Performance Optimization*." Gas Turbines (Second Edition), ScienceDirect: 2015, p. 533-636.

Higher yields would lead to increased revenues. Assuming just a 40% increase in CO2, which would be safe for humans, there would be an 85% increase in yield. In our model, we assumed the large vertical farm would sell two to three million pounds of lettuce annually and a small farm would sell around 50,000 pounds of lettuce annually. Since most indoor vertical farms sell organic mixed greens at a high price point, this could mean millions in additional revenue for a large farm and several hundred thousand in additional revenue for a small farm. Since carbon dioxide capture systems used in breweries cost an estimate $500,000, this would likely make sense. However, some breweries use their own surplus CO2 and may not have extra to sell. Additionally, the cost of the excess CO2 is just $40,896 annually. CO2 could also be captured from coal-fired power plants, but it would need to be scrubbed before being repurposed, leading to higher costs.

Co-location options could also potentially be stacked with other energy savings. For example, SoMax Bioenergy, discussed above, produces a small amount of carbon dioxide emissions. SoMax could co-locate with a farm to power it, but then the farm could also use the emissions, closing the loop, using an otherwise harmful waste product, and decreasing the joint environmental impact. Alternatively, if a farm were co-located with a brewery and SoMax, SoMax could use the waste products from the brewery and sell energy to the farm and/or brewery while the farm could take wasted carbon dioxide emissions from both the brewery and SoMax.

Partner Companies and Organizations

The STLCEA Coalition includes many strong potential partner companies, but a few have been most significant to date. On the market side, Schnucks has entered conversations with numerous indoor vertical farms before and is now going to test sourcing some hydroponic products from an Illinois farm, their first foray into vertical sourcing, as well purchase from AeroFarms' new indoor vertical farm in Virginia as its produce becomes available. They do, however, buy some products from hydroponic greenhouses. The grocery chain is intrigued by the possibility of partnering with and/or sourcing from an indoor vertical farm due to food safety and supply chain concerns. There have been myriad recalls of field-grown leafy greens, particularly romaine, in recent years. Meanwhile, supply chains have long been fragile, and COVID-19 highlighted how quickly disruptions can occur. Sourcing from a bio-secure local facility would be a big value add, but ultimately the financials need to work.

Currently, most vertical farms are selling at an organic price point. Retailers need to be able to meet their own margins while also offering a product of interest to consumers. Groceries, like Schnucks, believe that consumer education will be integral to any relationship and wants to see a strong investment on this front as part of any package. Consumers need to be educated on the benefits of vertical farming, including longer shelf life, higher nutrition, enhanced flavor profile, and lower environmental footprint, to seek the product and come back for more. This can and should be part of original marketing efforts by the entire STLCEA Coalition and, if the community farms initiative moves forward, could be a part of that process.

Panera, headquartered in St. Louis, is also interested in vertical farming but has never sourced from one. While there is no commitment to purchase, restaurant brands like Panera continue to show interest in locally and sustainably sourced produce. Panera debuted the "Cool Food Meals" certification from World Resources Institute in 2020 to label items with a lower carbon footprint and continues to engage with guests around more sustainable options. Even without the environmental benefits that can come from vertical farming, Panera is always looking for innovative ways to source fresh produce like herbs, such as cilantro and basil, and strawberries. Currently, the popular cafe chain brings in produce daily to regional hubs and then distributes them locally to individual cafes. This means there is a significant cost and environmental footprint – and perhaps room to explore other local year-round options. In addition, year-round production could enable them to feature fragile ingredients like strawberries on menu throughout the year rather than just the summer months.

However, unlike grocery stores, restaurants like Panera have limited pricing structures. They do not offer higher priced sandwiches with organic lettuce and herbs. Food safety is their top consideration and quality, supply chain resilience, and environmental footprint are all important, but ultimately options must be cost competitive to avoid pricing out current consumers.

On the energy side, Ameren, SoMax, and local waste companies provide possible synergies. Ameren can be a partner through its Neighborhood Solar Program, possible co-locations with thermal power plants to capture excess heat, and in exploring future renewable energy solutions. (See Energy Options and Stranded Assets.)

SoMax Bioenergy could also be a synergistic partner. The waste-to-energy company (see Energy Options and Stranded Assets) could simply sell energy to an indoor vertical farm but could also be further integrated. For example, if an indoor vertical farm co-located near a grocery distribution center, a SoMax facility could also co-locate. Not only could SoMax power the farm, which could immediately provide produce to the distribution center, but food waste could be sourced from the distribution center to create additional energy. While packaged bakery waste (e.g., sliced loaves of bread) would require additional equipment investments to unpackage, central facility waste would not be packaged in this way, smoothing the process even more. If a SoMax facility were located elsewhere, there would be potential partnership opportunities with waste companies already servicing the greater St. Louis area and with the city or county itself.

The St. Louis region also brings opportunities for plant science partnerships. NewLeaf Symbiotics has already expressed a strong interest in partnering with this project and the farm that comes to fruition. They work with Methylotrophic plant—associated beneficial microbes or M-trophs. These are naturally occurring microbes that have developed beneficial symbiotic relationships with plants. NewLeaf Symbiotics has built a knowledge base focusing on M-trophs that strengthen plants, increase root mass, improve plant growth, enhance nutrient uptake, and improve crop quality. To date, they have been largely focused on commodity crops but are now beginning to investigate using M-trophs on vegetables, herbs, and floriculture in CEA farms. They want to partner with the farm to test at scale whether their laboratory findings of two-digit percent yield enhancement, improved and synchronous germination, root development and architecture, and nutrient uptake and content hold true. These improvements would lower the energy footprint per pound of produce needed, bringing both an environmental and financial benefit.

Source: NewLeaf Symbiotics

The St. Louis region is also home to many breweries that produce CO2 through their fermentation process. Most of the time this CO2 is simply released as an emission. Instead, a co-located farm might be able to capture and recycle that CO2, using it to promote faster plant growth and therefore improved yields and lower energy footprint per pound produced. However, it is important to note that it may not be immediately feasible to grow hops in vertical farms so farms may not be able to supply the brewery unless it needs specialty beer ingredients. Hops reach heights of up to twenty-five feet so it would mean replacing many layers of plants with a single item, a large financial tradeoff.

Finally, there are opportunities to work with partner companies to offer social goals. There are many groups in the St. Louis region doing terrific work in food and agriculture. Good Life Growing, a social enterprise and farm seeking to combat urban decay and food insecurity, is one logical partner. They are already running micro farms around the city in low-income neighborhoods and have built a strong worker training program to equip workers with skills to eventually build and run their own farms. They also sell their produce to the local community. Good Life Growing expressed a strong interest in working together as a project moves forward.

Short- and Long-Term Metrics for Success

In the Request for Statements of Interest, the PRC codified key goals for bringing a vertical farm to St. Louis:

1. **Innovation Goals:**
   a. Willingness to pilot new technologies that emerge from Center of Excellence research
   b. Willingness to expand product type beyond leafy greens and herbs.
2. **Sustainability Goals:**
   a. Willingness to explore different energy solutions: co-location, co-generation, energy from organic waste, etc.
   b. Willingness to explore different innovations to decrease energy footprint.
   c. Willingness to explore use of stranded and underutilized assets.
   d. Willingness to explore smart use of water resources.
3. **Social Goals:**
   a. An ownership/equity model that will bring gains to the community.
   b. Nutrition/education component
   c. Locating in low-income area or brownfield
   d. Training and employment of local workforce
4. **Demonstration Goal:**
   a. Willingness to share broad lessons learned to serve as model for other farms and regions.

While nearly all farms that submitted statement of interest expressed a willingness and ability to tackle most or even all the goals, certain farms better demonstrated some than others in past work and innovation. Throughout due diligence in fall 2020, goals began to fall into short-, medium-, and long-term categories.

AeroFarms' large size means that it needs a significant energy draw and lowering that footprint is a top goal. While it cannot easily co-locate with many buildings to share excess heat or absorb carbon dioxide emissions, it is a top candidate for some of the other energy integration options. Additionally, due to its sheer size, any successful innovation would be worth sharing with the entire industry. While specific financial deals would not be shared, AeroFarms is dedicated to working with WWF to outline possible deals and partnerships and provide ongoing general learnings where possible.

Future Steps

Over the next few months, the team will continue to work with AeroFarms with the goal of a site announcement and groundbreaking in 2023. The Coalition is also continuing to explore the feasibility of bringing community indoor vertical farms, from AeroFarms, to area schools, groceries, and community buildings to support STEM and nutrition education.

Long-term, the STLCEA Coalition will continue to serve as a sounding board and partner for the indoor vertical farm, as needed. It is likely that various members would be customers, funders, and partners. Others may want to work with AeroFarms to continue to explore new options and share those learnings broadly. While the exact structure may evolve, AeroFarms and other applicant indoor farms saw a value in working with such an esteemed group, and the Coalition has led to several side projects and a lot of excitement. It is likely that continuing to keep the group updated and at least loosely affiliated with ongoing efforts will yield further benefits.

CENTER OF EXCELLENCE

While controlled environment agriculture is a quickly expanding industry attracting a lot of interest and capital, it remains a disparate industry. There are few generally recognized best practices and little knowledge sharing. Many farms are not only growing produce but also developing their own lighting, monitoring technology, automation, grow recipes, and more. This leads to duplication of efforts and steep and redundant learning curves. It also prevents the industry from achieving economies of scale. There is room for collaboration to advance common interests and move the entire industry forward. With its plant science expertise, St. Louis provides an excellent location and myriad potential partner companies to explore innovation and knowledge sharing and even develop a Center of Excellence with both physical and virtual capacities.

PROCESS AND EVOLUTION

At the first meeting of the St. Louis Controlled Environment Agriculture Coalition in January 2020, discussion centered around the strengths and opportunities present in St. Louis (see Bringing an Integrated Viable Farm to St. Louis – The Process.) The city is a global leader in agricultural innovation, agtech, and plant science. In addition to one of the highest concentrations of plant scientists in the world, from 2000-2015, St. Louis secured more utility patents in plant husbandry than any other United States metropolitan area.[12] The city continues to be a bioscience leader through its unique combination of corporate, academic, and entrepreneurial innovation and employers operating in this space. Bayer Crop Science is headquartered in the city and DuPont Protein Solutions, Nestlé Purina, Novus International, KWS SAAT, and Bunge are all in St. Louis as well. Key bioscience and agricultural start-ups are also quickly cementing St. Louis' entrepreneurial assets, including Benson Hill Systems, NewLeaf Symbiotics, Edison Agrosciences, Evogene, CoverCress, and more. Finally, St. Louis is home to many key academic and nonprofit institutions with an agriculture focus. The Donald Danforth Plant Science Center is the largest independent plant science research institution in the world and the Missouri Botanical Garden is the nation's oldest botanical garden in continuous operation. Many of these groups come together at 39 North, a 600-acre innovation district in St. Louis anchored by the Danforth Plant Science Center, Bayer Crop Science, the Yield Lab, and the Helix Incubator. While not focused on agriculture, the nearby Cortex Innovation Community also works to empower business owners and start-ups and catalyze economic development.

St. Louis is also home to Washington University, a national powerhouse in bioscience, the Genome Institute at Washington University, Saint Louis University with a new bioscience research center, and the University of Missouri – St. Louis (UMSL), home to the Whitney R. Harris World Ecology Center. Dr. Haitao Li, Professor at UMSL's College of Business, led a joint grant application between UMSL and the University of Missouri – Columbia to the Missouri Agricultural and Small Business Development Authority to study the economics and optimal design of Missouri's indoor agriculture supply chain. Additionally, the National Geospatial-Intelligence Agency broke ground last year on a new facility in North St. Louis. As the Coalition began to understand some of the hurdles facing the industry, interest began to coalesce around using St. Louis' assets to form a Center of Excellence for controlled environment agriculture, among other novel growing systems, to explore technological and plant science solutions.

While it is leading in plant science, St. Louis is facing many of the same hurdles facing other former industrial cities worldwide. Situated on the banks of the Mississippi and Missouri Rivers, it was once the gateway to the West and a hub for river commerce. The city's population grew rapidly throughout the 19th century, leading to a geographic expansion, streetcars, parks, and finally the St. Louis World's Fair, which cemented its international reputation. St. Louis always had a strong agricultural focus but also expanded to a variety of manufacturing industries and value-added products. Today the city remains an agriculture distribution hub for commodity crops with Cargill, Bunge, and myriad fertilizer and processor

[12] USPTO Calendar Year Patent Statistics.

companies located along the Mississippi River, but other facets have changed. The city began a slow but steady decline in population after 1950. Some of the largest companies were purchased and greatly reduced their local employment while others left. Social unrest, largely driven by racial disparities, decimated parts of downtown and sped up flight from the city. Today, the population continues to shrink, the poverty rate remains high (24% in the city itself[13]), racial unrest and divides remain, and St. Louis City is ranked as one of the most dangerous cities in the country, with a violent crime rate of 1,927 per 100,000 people in 2019.[14] Racial inequality also remains persistent with a 15% racial poverty gap between black and white Missouri families statewide (compared to a similar 13% nationally.)[15]

The STLCEA Coalition felt it was imperative to explore all those avenues, the hurdles and opportunities facing the city, and to determine if and how indoor soilless agriculture could integrate those learnings with an eye to using St. Louis as an example for other cities, regions, and countries. Working groups, all led by local partners and volunteers, were formed to examine innovation, knowledge sharing, and food access and equity and then to report back to the full Coalition. The working groups found that there was space for a Center of Excellence to tackle technological innovation and sharing of best practices but that next steps should focus on finding an anchor institution and a source of funding. The food access and equity group, meanwhile, highlighted the glaring food insecurity in the region (St. Louis city has a food insecurity rate of 23.3%[16]) and its racial roots (in households with children in the city of St. Louis, African American families are six times as likely to receive SNAP benefits.[17]) After robust discussion, Coalition members were eager to move ahead with a Center of Excellence but wanted to see it try to tackle not only technological innovation and knowledge sharing, but to engage in probing how indoor soilless farming could address inequality through education, jobs, and production of fresh, healthy produce.

[13] US Census QuickFacts: St. Louis, Missouri.

[14] CBS News: The most dangerous cities in America, ranked.

[15] US Census: American Community Survey.

[16] Glander, Grace. *Conference raises attention on Missouri's rate of food insecurity.* Missourian: Nov 11, 2019.

[17] City of St. Louis: Child Food Insecurity.

[18] "*The US vertical farming market is projected to reach values of around $3 billion by 2024.*" PRNewswire: Jan 22, 2019.

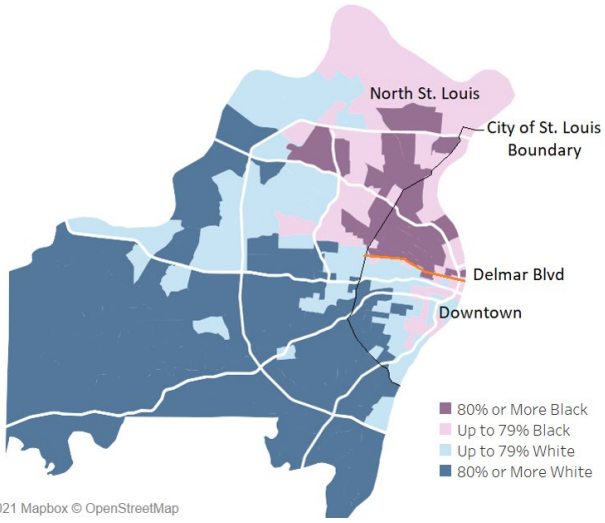
NEEDS AND OPPORTUNITIES

The STLCEA Coalition prioritized two areas of focus for a potential Center of Excellence: knowledge sharing/best practices and food equity and access. The Coalition was eager to support efforts on both avenues and/or to try to explore ways to connect the two together without leading to competing interests.

Disparate Industry and Technological Innovation

While controlled environment agriculture, and specifically high-tech soilless agriculture, is attracting significant venture capital money and scaling quickly, it also remains a highly fragmented industry. Even before COVID-19 became prevalent worldwide, the US vertical farming market was projected to be $3 billion by 2024, growing at a more than 24% CAGR from 2018 to 2024.[18] However, those numbers are across a vast number of technology providers and produce providers who are also sometimes one and the same. Many farms are developing their own sensors, automation, lighting, and data and automation while also concentrating on growing produce, yield, and grow recipes.

St. Louis provides an ideal testing ground. The Donald Danforth Plant Science Center has many state-of-the-art greenhouses that could be used as space for research to advance indoor technology. Its staff, as well as partnerships with University of Missouri, Washington University, St. Louis University, and Bayer Crop Science, could provide plant science and technical expertise for business support, commercialization, and scale while offering a space for elevating and sharing best practices. New technologies and integrations could also be tested in tandem with a new, innovative indoor vertical farm in the St. Louis region tackling social and environmental goals.

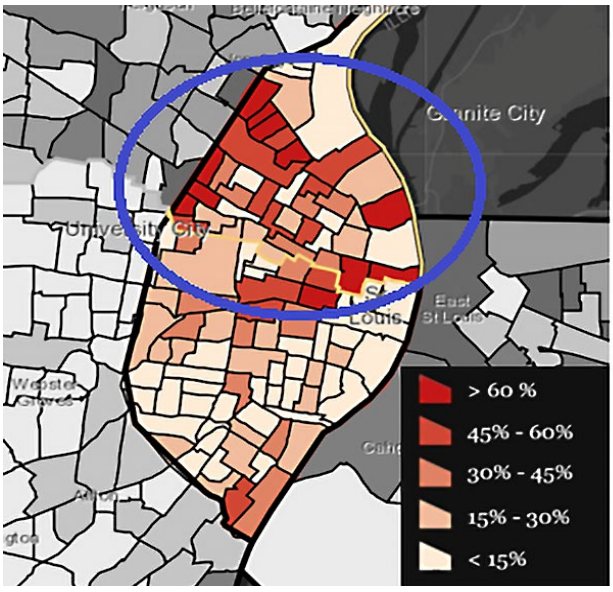


Inequity and Inequality

In St. Louis, the 'Delmar Divide' is well-known. South of Delmar Boulevard, neighborhoods are 70% white but just north of the street, neighborhoods are 98% black.[19] The divide is stark and holds true when examining poverty rates, health, educational opportunities, and more. There is also a severe lack of access to healthy, fresh, affordable foods. Just a single large grocery store remains north of Delmar Boulevard. Many residents are low-income and face a low level of food access within half a mile of their home, leading to heavy dependence on expensive corner stores that often lack healthy produce.

There are groups working to improve the situation. The St. Louis Food Bank and Operation Food Search work to provide a safety net for those most in need. The St. Louis MetroMarket sells fresh, affordable food grown in the region to food insecure communities by subsidizing sales with grants and corporate sponsors. Known and Grown locates and markets farmers who utilize good stewardship practices, with a focus on finding and supporting local minority farmers. Gateway Greening, an organization that trains urban growers and promotes local gardens, is shifting its headquarters to the Delmar Divine, a real estate initiative aiming to serve as a model for community development in north St. Louis. There are also non-food innovations happening in the region, including MADE, a modern makerspace on Delmar Boulevard, and the Craft Alliance, an art gallery featuring local artists and offering classes.

Percentage of population that is low-income and beyond ½ mile from a supermarket *(Source: Missouri Coalition for the Environment using data from Esri, HERE, NPS; Census Bureau; USDA)*



All these efforts are making a difference, but the area north of Delmar continues to grapple with intersectionality – many instances of inequality that exacerbate one another. Healthy food is at the heart of many of these problems. For example, infant mortality rates are much higher in north St. Louis than elsewhere in the city. Two zip codes have rates at 64.5 deaths per 1,000 live births and 28.8 deaths per 1,000 live births, with the lowest in north St. Louis at 9 deaths per 1,000 live births.[20] This is in comparison to 5.7 deaths per 1,000 live births nationally.[21] The second leading cause for infant mortality is pre-term birth and low birth weight, often caused by or exacerbated by marked nutrient deprivation of mothers during gestation and at the time of birth. Similarly, 73% of residents in north St. Louis are overweight or obese, compared to just 51% in downtown St. Louis.[22] Dr. Will Ross, Professor of Medicine, Washington University, says "access to fresh fruits and vegetables may be more important than me writing a prescription for antihypertensive blood pressure medication."[23]

Even the availability of food, however, would not necessarily be enough. Geographic access and affordability are major hurdles, but it also needs to be culturally relevant. Residents need to know how to cook the food, have the tools to do so, and the time to do so. They also need to know why that food may be more beneficial than other options. Barriers are known but immense and inter-connected.

The STLCEA Coalition debated, however, whether indoor soilless agriculture was the best way forward to tackle these issues. Indoor soilless agriculture remains expensive due to high energy and labor costs. Most major CEA farms sell directly to businesses, not immediately benefitting area residents. Technologies that allow farms to innovate and expand do not necessarily lead to more affordable or accessible food. And, the food that is most financially profitable, such as herbs, microgreens, and high-end spring mixes including baby arugula, baby spinach, and other similar varieties, may not be the most desired food and may lack the variety needed to provide for nutritional needs. The Coalition decided to focus immediately on education and integration with local schools while continuing to probe opportunities to address food insecurity in St. Louis through controlled environment agriculture.

[19] US Census: American Community Survey, 2012.

[20] "*Public Health: Understanding Our Needs*." The City of St. Louis Department of Health: Update 2016.

[21] CDC: Reproductive Health.

[22] "*Health Department Releases Report on Obesity in the City of St. Louis*." City of St. Louis: May 6, 2015.

[23] Interview by Collin Riggins. August 2020.

THE YIELD LAB INSTITUTE AND ACTIONS TO DATE

The Yield Lab Institute, a St. Louis non-profit think tank supporting agriculture and food technology and innovation, agreed to lead the Center of Excellence working group and probe possibilities around the STLCEA Coalition's parallel goals. The working group established a four-part vision for a future Center of Excellence (CoE):

- Physical space where CEA start-ups can test or pilot technologies and innovations.
- Virtual space to support knowledge sharing and best practices globally and to push out new ideas and innovations.
- Support to foster interactions between public and private sectors to accelerate innovations and bring them to market.
- Expertise and focus on using indoor agriculture to address food apartheid, access, and equity.

During this process, the Yield Lab Institute also agreed to take on early ownership of a CoE, including supporting efforts to offer technical and business support for indoor ag start-ups and leading efforts to establish a full-fledged, permanent Center of Excellence in the region, to be located on the campus of the University of Missouri – St. Louis (UMSL) in north St. Louis.

Technical and Business Support

The Donald Danforth Plant Science Center and the Yield Lab Institute are exploring a partnership to offer plant science, biology, business, and go-to-market expertise to indoor agriculture start-ups. The Danforth Center has an ongoing partnership with the Wells Fargo Innovation Incubator (IN2) and NREL to support tech innovation in sustainable agriculture. The IN2 program focused its 2021 funding awards to support collaborative research projects with start-ups in indoor agriculture. This research was supported by the Danforth Center's existing state-of-the-art greenhouses and growth chambers as well as plant biology expertise.

Additionally, the Yield Lab Institute and AgLaunch, a Memphis-based non-profit best known for partnering early stage agtech companies with members of its farmer network for field trials, explored a potential partnership with the Danforth Center to provide technical support. Start-ups and innovations developed would potentially be shared and tested in partnership with the viable commercial indoor farm coming to the St. Louis region.

Physical Center of Excellence

The Yield Lab Institute is working with the University of Missouri – St. Louis (UMSL) and the University of Missouri system to build and host a physical Center of Excellence. The Yield Lab Institute has led this effort with the support of Dennis Lower, Principal, Innovation Community Strategies, to tackle next steps and bring a CoE to fruition. Together, they have identified a consultant to complete a feasibility study and The Yield Lab Institute and UMSL are currently identifying and applying for grants and funding sources to help cover this cost. The consultant will be examining and informing on organizational structure, ongoing funding, and areas of focus. The Yield Lab Institute has also engaged a larger stakeholder group, including the Danforth Plant Science Center, to explore potential partnerships and involvement across the St. Louis region. The physical center will aid and accelerate efforts in workforce and business development and in research and development to improve the CEA industry, boost market adoption, and address food insecurity and inequity.

The Yield Lab Institute will also continue to explore ongoing partnership opportunities. In addition to groups already involved and discussed above, there are options to partner with St. Louis area school systems on curriculum integration and STEM education. Small systems could potentially be located on school land. Schools could also visit facilities and integrate lessons from the farms into science, health, and social science classes.

Finally, these projects and future efforts will continue to generate learnings. Since knowledge sharing remains a problem across the CEA industry, those learnings will be extremely useful and should be widely shared. This could be through a formal pay-to-play model or an open-source sharing of new information and insights. It is likely that both options would be utilized depending on the type of information. Technology sensitive data or aggregate data would be protected while best practices on achieving social goals and serving previously underserved communities could be widely and freely offered. There are many options to explore but far more should become clear in coming months.

BROADER LESSONS

The viable indoor vertical farm and the Center of Excellence are meant to serve as a springboard for future efforts - a demonstration of how an indoor vertical farm can integrate with a community while also addressing its energy footprint by utilizing stranded assets and unique partnerships. While this effort may be new and unique, the process and types of decisions considered will serve as lessons learned and innovative possibilities in other areas. Lessons will be updated and shared through the Center of Excellence and other avenues as these projects move forward.

ANALYSIS OF COALITION BUILDING AND STRATEGIES FOR USING ST. LOUIS REGION AS A SPRINGBOARD

The Coalition process that WWF put together for Phase II has been a success but also brings some limitations. The Coalition achieved great cohesion, strong buy-in and interest, and even, unexpectedly, increased enthusiasm and participation by moving to a remote format. However, it was also limited in achieving all its goals by needing to convey a nuanced message of what support was available without any hard promises or grants.

Outreach to members began during Phase I as research was conducted so that by the completion of Phase I, an initial Coalition had been formed. The group met for the first time at the start of Phase II and grew slightly in membership as additional potential partners or holes were identified.

Indoor farmers were not included in the initial kick-off meeting but did join for the second meeting and other subsequent ones. This decision gave the largely St. Louis focused group time to learn about the state of the industry through the report and then to discuss internal strengths, hurdles, and interests. There were other non-farm industry experts present to answer questions and provide insights. When indoor farmers were brought into the Coalition for the second meeting, Coalition members already possessed a baseline knowledge that allowed them to advance quickly in conversation with the indoor farmers and engage in more in-depth discussions.

While the STLCEA Coalition was fairly large, more than 70 members, (see Appendix I), the process allowed people to learn over time and take on leadership roles of interest, generating a lot of enthusiasm and support. There were options to only attend the large Coalition meetings (five throughout 2020), participate in working groups, lead working groups, and work on smaller projects that came up throughout the process. The inclusive process led to a stronger project, shared wisdom, and buy-in from all participants. Even though there were no requirements, participation and giving their time led to members having “skin in the game” that likely increased enthusiasm and passion for seeing the project come to fruition. Coalition members were also able to learn about possibilities and potential partners over an extended period, which paved the way for detailed conversations with finalist farms.

There were also some unexpected benefits from moving to a virtual process. While the Coalition met in person in January 2020, COVID-19 forced all remaining meetings, and all working group meetings, to move to a fully virtual method. There were some growing pains. The March meeting, for example, was switched to remote just a week before the meeting took place. A two-day agenda had to be pared down to just a few hours. Long and large virtual meetings were relatively new so many people were still adjusting to new technologies and there were no best practices on length or encouraging participation. However, the switch did mean that indoor farmers were able to attend from across the world. Farmers participated from Hawaii to Japan, and most of the international farmers would not otherwise have participated in the meetings.

As virtual became the norm, it brought other benefits. Participation rates remained high and even increased. International participation continued to rise, and people felt more comfortable taking on leadership roles. There were fewer time constraints without needing to find locations and factor in travel time and costs. The Coalition was able to include working group leaders and participants from all over the US and internationally. If some participants had been able to meet in person and others only remotely, this might have created a two-tiered system with some people more invested than others. Since everyone was remote, not only did it increase participation, but no one was left out or unable to take on a more involved role due to their location.

It is difficult to know whether this will be a viable model, or the best model, moving forward. There will likely need to be decisions made at each location based on local expertise available, potential members, constraints, and more. However, perhaps at least some virtual component or making some smaller groups entirely virtual even if there is no medical need to do so could bring strong benefits.

However, while there were a lot of successes, there were also limitations in the makeup of the group. Ultimately, the Coalition included a lot of potential partners, allies, funders, and customers, but the Coalition was not offering anything concrete. Indoor farm proposals were solicited, and many indoor farms were still interested in participating, but others expressed that while useful, it was perhaps not enough of a value add to leapfrog this effort in front of their ongoing pipeline of projects. The Coalition struggled at times to convey the benefits it did bring to the table without overpromising and being clear on what it did not. In the future, it might be beneficial to discuss this early on and see if there is a way to secure any additional incentives up front to solidify the process.

RISKS AND HURDLES

Indoor soilless agriculture brings many benefits. It vastly decreases water use, does not erode soil, often does not require pesticide use, has the potential to reduce loss and waste, secures supply chains, addresses food safety, and can bring food to places that couldn't otherwise produce their own food. However, it is far from a panacea. It often comes with a large energy footprint and significant labor costs. Today, most indoor soilless farms produce mainly leafy greens and herbs. Profitability to grow fruiting crops in indoor vertical systems is still being evaluated, and it may never make sense to grow commodity crops. If these limitations remain, indoor soilless agriculture will be one part of addressing farming's large environmental footprint, but its limitations must be discussed to allow for proper planning and understanding of what is possible now, what is out of range, and what can be tackled in an innovative way to bring added benefits.

Addressing Food Inequality

Controlled environment agriculture can be expensive. Recent analysis estimates that lettuce grown in a local greenhouse is 158% to 163% higher cost than field lettuce grown in California and shipped to Chicago and New York City respectively while lettuce grown in a local indoor vertical setting would be 153% to 157% higher.[24] While the transportation costs are significantly lower or even negligible (which also brings cost savings through reduced food loss and waste), indoor vertical farms experience higher energy costs, and greenhouses experience higher land and building costs. Both types of CEA operations often have high staff costs since there are often more management and marketing positions since this is a new industry introducing itself and they are spread over a much smaller volume of produce than field grown crops.

[24] Nicholson, Charles F. et al. "*An Economic and Environmental Comparison of Conventional and Controlled Environment Agriculture (CEA) Supply Chains for Leaf Lettuce to US Cities.*" From *Food Supply Chains in Cities.* Springer International Publishing: 2020.

Total landed cost for delivery of 1 kg lettuce to wholesale produce markets in NYC and Chicago *(Source: Nicholson, Charles F. et al. An Economic and Environmental Comparison of Conventional and Controlled Environment Agriculture Supply Chains for Leaf Lettuce to US Cities.)*

Cost category	New York City wholesale market, Hunt's point			Chicago international produce market		
	Field	GH	PF	Field	GH	PF
	$/kg delivered saleable lettuce					
Production supplies	0.17	0.29	0.27	0.17	0.29	0.27
Labour and management	*0.09*	*4.31*	*4.31*	*0.09*	*4.31*	*4.31*
Packaging	0.98	0.76	0.76	0.98	0.76	0.76
Utilities other than water and energy	0.00	0.03	0.03	0.00	0.03	0.03
Miscellaneous	0.50	0.10	0.10	0.50	0.10	0.10
Water (direct production only, not evaporative cooling)	0.02	0.08	0.08	0.00	0.08	0.08
Energy for operations	*0.04*	*0.46*	*1.36*	*0.04*	*0.41*	*0.89*
Structure, equipment, land, growing and delivery equipment	*0.08*	*2.05*	*0.90*	*0.08*	*1.00*	*0.40*
Transportation from production to market (fuel)	*1.17*	*0.00*	*0.00*	*0.87*	*0.04*	*0.04*
Total landed cost	3.04	8.09	7.82	2.72	7.03	6.89

Source: Authors' own calculations

Note: *Field* indicates field-based production in Salinas Valley, California, *GH* indicates a CEA greenhouse located in the same metropolitan area as the wholesale market, and *PF* indicates a CEA Plant Factory located in the same metropolitan area as the wholesale market

Due to this higher cost, despite its other environmental benefits, many CEA indoor farms are not currently a viable option in the United States to directly address food insecurity. This higher cost means that produce is usually sold at an organic price point in grocery stores, out of range for low-income buyers. (See Regional Differences and Opportunities to explore how this calculus may change in other countries.) In the US, most CEA farms, though not all, also sell in the business-to-business (B2B) market, meaning they are not directly bringing food to areas lacking access to fresh produce.

However, indoor soilless agriculture may offer social benefits through educational partnerships and increasing awareness of how food is grown. Indoor farms can partner with schools at all levels to offer tours to spark interest and to integrate their work into curriculums. K-12 schools could use indoor farm visits and partnerships to spur lessons in STEM classes as well as health and nutrition. Indoor farm workers could visit the classroom and share samples and students could visit indoor farms to see plants growing at various stages. This hands-on approach could interest a broader swathe of students. Small indoor farms could even be built on school grounds so students could study them firsthand and literally enjoy the fruits of their labor. At a college and university level, indoor farms could offer opportunities for thesis projects and hands-on exploratory courses in addition to the same benefits offered at a K-12 level.

Indoor farms are already starting to do this. Freight Farms is partnering with Sodexo to put its container farms at schools across the country, though they will be focused first on production and only secondarily on education. Plenty is planning regular school visits and lectures in connection with its indoor vertical farm in Compton, CA. AeroFarms partnered with Jersey City, NJ to build ten community indoor vertical farms in senior centers, schools, public housing, and municipal buildings and is exploring a similar model in the St. Louis region. Meanwhile, Princeton University's Vertical Farming program helped build a hydroponic indoor vertical farm in a local elementary school's cafeteria and design STEM lessons connected to the farm. There is more to this than just science. It can also be about boosting long-term health. A study at a US high school found that five times as many students ate salad when they grew it themselves – though that large increase meant a still small 10%.[25] There is an opportunity to build on these findings and efforts to develop a larger, more integrated partnership.

Indoor farms could indirectly boost healthy eating habits by simply becoming part of the community. As of 2013, just 13.1% of American adults ate the recommended daily allotment of fruit and a paltry 8.9% met recommended vegetable intake.[26] Some of this is due to cost and access, but awareness and connection to fresh produce is another large barrier that local farms are well placed to circumvent.

[25] Wansink, Brian et al. "*A plant to plate pilot: a cold-climate high school garden increased vegetable selection but also waste.*" Acta Paediatrica: April 17, 2015.

[26] Lee-Kwan, Seung Hee et al. "*Disparities in State-Specific Adult Fruit and Vegetable Consumption – United States, 2015.*" CDC: November 17, 2017.

Several studies have clearly demonstrated that when low-income communities grow their own fruits and vegetables, they eat more of them. In San Jose, participants doubled their vegetable intake when provided with a city plot and in Denver community gardeners boosted their intake from four to six servings daily compared to non-gardeners.[27] Even the indoor urban CEA farms that are not community gardens and would not be able to offer those benefits easily, can still make farming more accessible. This can be done simply by locating in a community and letting residents see food growing. Those efforts can be boosted through tours, classes, and small demonstration indoor vertical farms located in easily accessible settings such as community centers, libraries, and religious buildings.

Finally, indoor vertical farms could offer specialty items that are not otherwise available. While cost will remain a concern for now, some people eat fewer fruits and vegetables than others due to lack of cultural familiarity and may continue to do so even if costs come down. When examining predominantly Latino and African American neighborhoods in Chicago, researchers found that while grocery stores were more likely to carry culturally specific items such as chayote in Latino neighborhoods and black-eyed peas in African American neighborhoods, "more stores…carried less than 50% of commonly consumed or culturally specific fruits and vegetables."[28] This was especially true of African American neighborhoods. This is likely an issue for immigrant groups as well, whose culturally specific foods may not even be able to grow at a commercial scale in North or Central America. Indoor vertical farms can address this gap by changing their environment to grow target foods in a hyper local environment. Crops that need entirely different conditions can grow in separate rooms, allowing for highly diverse indoor vertical farms that target even relatively small populations.

Job Creation and Workforce Development

Indoor soilless farms will create jobs, but there will be limitations. AeroFarms' Virginia indoor vertical farm recently advertised more than 100 positions. Gotham Greens' hydroponic greenhouse in Baltimore created 60 jobs. Plenty's newly announced Richmond, Virginia farm is expected to create 300 jobs. This makes a difference in a community. However, the number of jobs is still small compared to other industries. At its peak, Bethlehem Steel had 30,000 employees and supported an entire town. Indoor soilless farms will not be able to do the same.

While indoor soilless farms will not create the most jobs, they may, however, create jobs with transferrable skills. Unlike conventional field farming, working in a high-tech indoor farm is not simply about physical labor. While there is planting and harvesting, many of the most rote tasks are completed through automation. Workers at these indoor farms often end up learning several STEM skills on the job, including the basics of horticulture, technology, and infrastructure. These skills will be transferrable to other farm jobs and even other industries, allowing room for advancement. Many of the farms are also investing directly in workforce development for this purpose. Universities are also seeing this need. Cornell University recently received a grant from the USDA's National Institute of Food and Agriculture to design and implement new training programs for farmers working in greenhouses.[29] There is room to do more on this front.

While the number of jobs may not be huge, indoor farms can have an impact by choosing where to place those jobs. While a farm located in a low-income community may not address local food insecurity problems since they are often not selling directly to consumers (though some do offer community sales programs), it can employ people from the local

[27] Belluz, Julia. "*4 fixes for the astonishing lack of vegetables in the American diet.*" Vox: August 15, 2017.

[28] Grigsby-Toussaint, Diana S. "*Availability of commonly consumed and culturally specific fruits and vegetables in African-American and Latino neighborhoods.*" Journal of the Academy of Nutrition and Dietetics: August 27, 2012.

[29] Isaacson, Talia. "*In the News: Our Director Helps Provide CEA Training Opportunities*." Cornell Small Farms Program: July 9, 2020.

community. Farms can choose to locate in areas with high unemployment, hard to employ individuals, and/or low-income individuals. Targeted hiring campaigns can even be developed. Giving living wages and access to fresh produce for those who are hired could lead to a ripple effect as more people in the community are emotionally invested in the farm and helping to spread the word.

Finally, indoor farms also have the opportunity to move beyond just job creation and workforce development to offer wealth creation to minority communities. There can be purposeful intent to source minority-owned (or at least partially minority-owned) farms or innovative financing could be used to give ownership and equity stakes to minority workforces. For example, a community or foundation could make a debt investment that only repays the principle with all profits converting to equity for workers. This could directly translate to wealth creation and community support, while continuing to boost a growing business.

Transforming Farming's Footprint

Agriculture has a large environmental footprint. Food production may result in as much as 30% of total greenhouse gas emissions,[30] agriculture uses 70% of all freshwater used by humans,[31] and 38% of Earth's land is used for agriculture.[32] To meet future population demands, the world will need to produce 60-70% more food as we do now (or nearly twice as much if we don't reduce the food loss and waste rates) but without utilizing more land or resources. Indoor farming brings significant gains, including using a tiny fraction of the land needed for conventional agriculture, a tiny fraction of the water, and none of the soil. It also usually doesn't come with the impact of pesticide use, giving it an improved environmental and health footprint. However, even with the expansion of indoor and vertical farms to fruiting crops, which are often not yet profitable, these farms will likely be limited to specialty crops. To put that in perspective, in the United States, just over 10 million acres are used for farming fruits and vegetables out of a total 320 million acres of harvested cropland.[33] Some of the biggest crops include corn (90.8 million acres), soy (83.8 million acres), and wheat (38.8 million acres).[34]

To truly revolutionize the footprint of agriculture, commodity crop agriculture needs to be addressed, but these crops will not be grown in CEA farms without significant energy or technological advances. A recent study found that wheat yields could be increased 220 to 600 times if grown in a 10-layer indoor vertical farm with optimized temperatures, intense artificial light, high CO2 levels, and a maximum harvest index.[35] However, this was a predictive study under ideal situations that may not be replicable in reality. Additionally, even in these ideal situations, the theoretical maximum yield wheat farms lost money. The cost to return ratio was predicted at 46:1 with estimates that even with significant energy and lighting improvements, the best future cost to return ratio would be 6:1.[36] Countries could choose to invest in facilities for food security reasons, but they would not be commercially viable.

Indoor vertical farming can bring fresh fruits and vegetables to locations that couldn't otherwise grow them, improve the environmental footprint of specialty crops, and build resilient supply chains. All of these are important benefits. However, it is just one tool of many that will be needed to change the environmental footprint of agriculture.

[30] Fountain, Henry. "*Cutting Greenhouse Gases from Food Production is Urgent, Scientists Say.*" NYTimes: Nov 5, 2020.

[31] Khokhar, Tariq. "*Globally, 70% of Freshwater is Used for Agriculture.*" World Bank: March 22, 2017.

[32] *"Land use in agriculture by the numbers."* FAO: May 2020.

[33, 34] USDA: 2017 Agriculture Census.

[35, 36] *Asseng, Senthold et al. "Wheat yield potential in controlled-environment vertical farms." Proceedings of the National Academy of Sciences of the United States of America: July 27, 2020.*

REGIONAL DIFFERENCES AND OPPORTUNITIES

This project was focused on the St. Louis region. Opportunities and drawbacks were weighed in a local environment. This held true for farm location, energy options, social benefits, and more. While some of these lessons will be true more broadly, others may vary by city, region, and country.

Indoor soilless farms can bring food to places that cannot otherwise grow their own food. In the US, while indoor soilless farms can grow in low-income areas, they are often not able to offer prices that low-income residents can afford. (See Risks and Hurdles – Addressing Food Insecurity.) However, in places where fresh fruits and vegetables are more expensive this may change. For example, islands must import nearly all their food. Even for a nearby island, this holds true. Puerto Rico's supermarket items are 21% more expensive, on average, than in the United States.[37] In 2015, this meant iceberg lettuce in Puerto Rico was $1.96 a head compared to $1.41 in the mainland US.[38] However, many islands, Puerto Rico included, also face higher energy costs. Puerto Rico's current commercial energy rates are around 19 cents per kwh, compared to 11 cents per kwh on average in the mainland US.[39] The feasibility of offering lower cost foods will depend greatly on the energy rate and reliability or the possibility of alternative sources of energy. Island nations, such as Japan, are already investing heavily in indoor vertical farming for this reason.

Islands may also make water turbines and food waste-to-energy options more feasible. While the Mississippi River generally meets the minimum standards needed to host water turbines, they do best in areas of high velocity and either little traffic or a deep seabed to avoid interfering with boats. Inherently, this makes islands attractive. Ocean turbines are already more efficient, offering comparative rates of 15 cents per kilowatt hour (see Energy Options). This is already less expensive than standard energy rates on many islands. At 15 cents per kilowatt hour, water turbine generated energy is 22% less expensive than current commercial rates in Puerto Rico.[40]

Islands may also struggle with food waste. In the US, landfills can be located far away from urban areas but on islands land may be at a premium and waste may have to be shipped far away or end up discarded in the ocean. On islands, this can lead to "resource loss, damage to the marine and local environment and continuous nuisances created by littering, trucks and treatment facilities."[41] While it won't consume all waste, a waste-to-energy facility such as the one offered by SoMax Bioenergy could capture the food waste, creating energy while cutting down on the harmful effects of local landfills.

Different regions and countries may offer other additional energy opportunities that are not viable in the St. Louis region as well. For example, solar power remains out of reach as an option to power a large farm in the St. Louis region. (See Bringing an Integrated Viable Farm to St. Louis – Energy Options and Stranded Assets.) However, St. Louis only averages around five sunny hours per day. Yuma, Arizona and Phoenix, AZ are the two sunniest cities on the planet, averaging around 11 sunny hours per day.[42] However, since Yuma, AZ already grows significant amounts of leafy greens in greenhouses (though with soil) and is located near California, there may be little incentive to explore vertical farms.

The trade-offs may be different in the Middle East, which also boasts some of the sunniest cities on the planet. Aswan, Egypt is the third sunniest city on the planet but many cities in the Middle East boast ten or more sunny hours per day.[43] Many of those cities are also located in or near deserts. Middle Eastern countries often need to import most of their food and may not have access to fresh water needed for conventional agriculture. Readily available sunshine may already change the financial calculus, but even if not, some countries may weigh the trade-offs to indoor vertical farming differently. For example, if water is not available and food security is an issue, those benefits may make indoor vertical farming attractive even if energy to the farms needs to be subsidized.

[37, 38] Morales, Ed. *"Puerto Rico's soaring cost of living, from giant electric bills to $5 cornflakes."* The Guardian: July 12, 2015.
[39, 40] US Energy Information Administration, updated Nov 19, 2020.
[41] Camilleri-Fenech, Margaret et al. *"Where do islands put their waste?"* Elsevier: September 10, 2018.
[42, 43] Miller, Lisa. "*What Places on Earth Have the Most Hours of Sunlight?*" Seattle pi.

The usefulness of waste heat and capturing CO2 emissions will also vary by location. In the St. Louis region, waste heat to warm a building would only be useful for half of the year. In areas warmer than the St. Louis region the cost needed to capture and transfer the heat are likely not worthwhile whereas cooler climates could use the heat for a greater period of the year. There are farms and data centers already doing this in cooler areas, such as northern Europe and Canada. Carbon dioxide emissions will also depend on a region's local industry. Breweries, which not only release CO2 but offer food grade space that may even be shareable, are a great partner choice but not available everywhere. There is no shortage of CO2 emissions but the ability to capture them, the safety in co-locating, and other factors will need to be considered in determining other potential partners.

Ultimately, each country, city, and region will have its own priorities. Indoor vertical farming's cost and footprint will vary due to the cost of local land, energy, labor, and more. However, government interest and subsidies may have an even larger impact on the viability of local indoor vertical farming. It is possible that there is ultimately a patchwork of farming systems as each region emphasizes and searches for the solutions that most fit a unique environment.

APPENDIX 1: STLCEA COALITION MEMBERS

Note: All titles and affiliations were at the time of the STLCEA's work throughout 2020

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Matt Bauer
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Adam Bergman
Managing Director, EcoTech Capital

Andrew Blume
Owner, DBA Symphony Agtech and Board Member,
FarmTech Society

Connie Bowen
Director of Innovation/Investment, AgLaunch

Zack Boyers
Chairman and CEO,
US Bancorp Community Development Corporation

Richard Brion
Founder and CEO, Revolution Agriculture

Dan Broderick
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Doug Burris
Maui Greens

Leland Chamlin
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Matt Helms
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Tom Hillman
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Jess Karol
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Sean Lock
Partner, Roeslein Alternative Energy LLC

Dennis Lower
President, Innovation Community Strategies (formerly Cortex
President & CEO)

John McDonnell
Chairman, BioSTL

Brad McNamara
President and Co-Founder, Freight Farms

Marcia Mellitz
Consultant, Strategic Guidance

Paulina Murrath
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Frank Pica
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Michael Willis
Architect and Visiting Professor 2020, Washington University Sam Fox School of Visual Arts and Design

Tom Wiltrout
Board Member, Innovative Seed Solutions

APPENDIX II: REQUEST FOR STATEMENTS OF INTEREST

The St. Louis Controlled Environment Agriculture Coalition (STLCEA Coalition) is soliciting Statements of Interest from CEA companies to build, own, and/or operate one or more commercially viable indoor farms in St. Louis, Missouri, USA that will pilot research, technologies, and partnerships with existing entities as well as technologies generated by a newly formed St. Louis CEA Center of Excellence. It is the aspiration of the STLCEA Coalition that this project will tackle some of the challenges facing the industry in a commercially viable way, thereby significantly adding to and accelerating the replication of CEA best practices globally. The Coalition will assist the selected farm developer(s) to define the scope and requirements of the project(s) to be developed.

Background

Food production is the largest human impact on the planet. Habitat conversion, greenhouse gas (GHG) emissions, soil degradation, agrochemical runoff, and inefficient water use associated with current food production systems threaten the environment. World Wildlife Fund (WWF) envisions a food system that meets the needs of both people and nature, but to get there we must decrease the environmental impacts of food production through more efficient use of inputs, decreasing waste, reducing associated GHGs, and examining how to sustainably produce more food closer to consumers. Guided by these goals, WWF identified the indoor soilless farming industry as one potential solution to decrease the environmental impacts caused by our current food production model. However, to be an effective alternative there are hurdles that must be overcome, namely the large energy footprint required by CEA farms that result in limited financial profitability for crops other than leafy greens and herbs.

During Phase I of its Indoor Soilless Farming project, the Markets Institute research team completed an Innovation Analysis examining the industry today, conducting a life cycle analysis to compare systems, exploring the potential to leverage stranded and underutilized assets and unique partnerships, and finally building a robust coalition of stakeholders to launch a new farming system. Now in Phase II, the STLCEA Coalition has been actively working to establish a CEA Center of Excellence and to bring one or more indoor farm operations to the region that will utilize unique partnerships, existing assets, and innovative technologies to tackle some of the challenges facing the industry in a commercially viable way and stakeholder-driven approach.

St. Louis Assets and the STLCEA Coalition

St. Louis is a global leader in agricultural innovation, agtech, and plant science, including 600+ agtech and bioscience firms, more than 750 plant science PhDs (one of the highest concentrations in the world), and more than 18,000 agtech and bioscience jobs. From 2000-2015, St. Louis secured more utility patents in plant husbandry than any other United States metropolitan area. Today, the city remains a bioscience leader through its unique combination of corporate, academic, and entrepreneurial innovation and employers operating in this space. Bayer Crop Science is headquartered in the city and DuPont Protein Solutions, Nestle Purina, Novus International, KWS SAAT, and Bunge are all in St. Louis as well. Key bioscience and agriculture start-ups are also quickly cementing St. Louis' entrepreneurial assets, including Benson Hill Systems, NewLeaf Symbiotics, Edison Agrosciences, Evogene, and more. Finally, St. Louis is home to myriad key academic and nonprofit institutions with an agriculture focus. The Donald Danforth Plant Science Center is the largest independent plant research institute in the world and the Missouri Botanical Garden is the nation's oldest botanical garden in continuous operation. St. Louis is also home to Washington University, a national powerhouse in bioscience, the Genome Institute at Washington University, Saint Louis University with a new bioscience research center, and the University of Missouri – St. Louis, home to the Whitney R. Harris World Ecology Center.

St. Louis also enjoys a thriving food scene. In 2020, eight St. Louis-based chefs and restaurants were nominated as semifinalists for the prestigious James Beard Awards. Bon Appetit magazine rated two of St. Louis' restaurants, Nixta and Vicia, as their top 50 best new restaurants in 2017 and Food and Wine magazine put St. Louis as the fifth best place to eat in the entire country in 2019. St. Louis is also home to some major food companies. Panera Bread, known locally as the St. Louis Bread Company, is headquartered in the city and Anheuser-Busch, now ABInBev, calls the city home.

In addition to the above assets, any farm(s) chosen as a partner(s) through this process will have the full support of and access to the St. Louis Controlled Environment Agriculture Coalition. The STLCEA Coalition is a group of more than 70 members, including local stakeholders, economic development groups, VCs, banks, plant science experts, academics, universities, hospitals, groceries, major restaurant chains, community groups, indoor soilless farms, industry partners, and potential partner organizations seeking to add CEA innovation and farming to the Midwest's history of being a global agricultural leader.

Though not a formal entity, a full list of Coalition participants is included in Appendix A. The Coalition will work with a selected farm(s) to define the scope and requirements of the project(s), as well as assistance to bring the project(s) to fruition. Specific support and assets are listed in Project Goals and Support. The STLCEA will not directly own, run, or purchase from a farm, but will work with the selected farm(s) each step of the way to secure necessary support and developed needed partnerships to launch the enterprise. Please note, while several indoor soilless farmers have participated in the STLCEA Coalition to date and shared their expertise, they will be recused from the decision-making process to avoid any conflicts of interest.

Project Aspirational Goals and Support

1. Innovation Goals:

a. Willingness to pilot new technologies that emerge from Center of Excellence research

b. Willingness to expand product type beyond leafy greens and herbs

2. Sustainability Goals:

a. Willingness to explore different energy solutions: co-location, co-generation, energy from organic waste, etc.

b. Willingness to explore different innovations to decrease energy footprint

c. Willingness to explore use of stranded and underutilized assets

d. Willingness to explore smart use of water resources

3. Social Goals:

a. An ownership/equity model that will bring gains to the community

b. Nutrition/education component

c. Locating in low-income area or brownfield

d. Training and employment of local workforce

4. Demonstration Goal:

a. Willingness to share broad lessons learned to serve as model for other farms and regions

5. St. Louis Resources and Assets:

a. Incentives based on location

b. Access to plant science expertise including genomics

c. Community partners/farmer owner engagement

d. Community partner connections to partner on relevant aspirational goals

e. Collaborative sourcing of wholesale/retail customers

f. Investor and financing prospects

Timeline

7/16/20 – Request for Statements of Interest released

7/29/20 and 7/30/20 – Webinar on Request for Statements of Interest

8/14/20 – Statements of Interest due

9/14/20 – Top candidates selected, and in-depth conversations begin

12/1/20 – Farm(s) partner(s) selected

Webinar

We will hold two webinars, on July 29 at 10 AM CT and July 30 at 11 AM CT, to walk through the proposal, provide a little more background, and answer questions from interested parties. This session will be recorded and made available afterwards to anyone who was not able to attend. Additional questions may be submitted following the webinar, with the questions and answers distributed to all interested parties. Any proprietary information will be redacted prior to distribution. **If you are interested in attending the webinar, receiving the recording, or both, please email us to let us know you are an interested party *(see Contacts/Questions).*** Please let us know if you are interested but this date does not work so we can move the webinar as needed.

Proposal Requirements

1. Company description, history, and headquarters location
2. A list of operating CEA projects, including location, size, cost, and date put into service
3. Current CEA projects in development
4. Do you lease and/or manage any facilities?
5. Proposed agricultural products to be grown
6. Ideal farm size to be developed
7. General site requirements (not site specific at this time/the Coalition will work with the developer to finalize a site)
8. Desired customer(s)
9. Customer commitment requirements before commencing development
10. Ideal funding structure
11. Of the Aspirational Goals, which ones do you believe you can achieve?
12. Give examples of how you have worked with the community in locations where you have current CEA operations, including minority engagements
13. Explain why you would be a good fit for the St. Louis CEA initiative

Review Process and Confidentiality

This will be an iterative and interactive review process. A Proposal Review Committee (PRC), a small subcommittee of the STLCEA, will review all Statements of Interest with the intent of finding one or more partners who can work with the Coalition to tackle a number and variety of goals laid out above. In reviewing the submissions, the PRC will clarify with the submitting party any questions that arise in the review processes. The PRC will then create and present a shortlist to the full Coalition membership (minus the farms) for the Coalition's agreement to proceed to the next step. The PRC will then engage the shortlisted parties in deeper, one-on-one conversations. The objective of these deeper conversations is to develop detailed specifics on the proposed farm, such as location, size, cost, required financing structure, product type, customer(s), aspirational social goals, and any other distinguishing characteristics and requirements related to the owner/operator. Once the top candidate(s) have gone through this deep dive, a final recommendation(s) will be made to the Coalition for approval to implement the project.

Unless otherwise required by law, the PRC will protect the confidentiality of the nonpublic information submitted by participating farms during the review process for a period of three years. Full applications will only be reviewed by the PRC. If, as part of the review process, it is necessary for the PRC to share this information with other members of the STLCEA, it will do so under the terms of a non-disclosure agreement. The PRC will present the results of the solicitation to the Coalition using the following process:

- A summary of the steps taken by the PRC to solicit Statements of Interest
- A summary of the review and evaluation process
- The results of the solicitation and generalized presentation of respondent submissions in a matrix format (see Matrix categories below)
- To protect farms' proprietary materials while maintaining a transparent process, the Matrix will list companies as "Company A", "Company B", etc., and numeric data will be presented as ranges. This data will be shared on a PowerPoint slide through screen share during a Zoom meeting. The meeting will not be recorded, and the slide will not be provided to anyone outside of the PRC.
- A recommendation of the farm submissions will be presented based on the evaluative criteria in the previous section and additional information gathered during the review process.
- Once consensus is reached with the full Coalition, the PRC will then proceed to a deep dive with the top candidate(s) as noted above.
- When details are confirmed, the PRC will report back to the Coalition with its final recommendation(s) for approval; the name(s) of the recommended farm(s) will then be shared.
- Matrix:
  - Type of system proposed (e.g., hydroponics, aeroponics, etc. and greenhouse, vertical, etc)
  - Total CEA farms in operation and development:
    - 0
    - 1
    - 2-5
    - 6-10
    - >10
  - Size and number of existing farm operations:
    - <10K square feet #
    - 11K-50Ksquare feet #
    - 51K-99K square feet #
    - 100K+ square feet #
  - Proposed agricultural products to be grown
    - Leafy greens
    - Herbs
    - Fruiting crops
    - Other
  - Proposed farm size
    - <10K square feet
    - 11K-50K square feet
    - 51K-99K square feet
    - 100K+ square feet
  - Ideal funding structure
  - Desired customer(s) or other partner(s)
  - Top three aspirational goals on which the farm would like to focus with brief, oral description of proposed process to achieve these goals

Evaluation Criteria

1. Capability of the developer as evidenced by successful completion and operation of CEA projects.
2. Willingness to work with the Coalition to achieve as many of the Aspirational Goals as possible
3. Demonstrated engagement with the local communities where you have current CEA operations.

Contacts/Questions

Questions and Statements of Interest should be emailed to Julia Kurnik (Julia.kurnik@wwfus.org) and Dennis Lower (dlower49@gmail.com). **We encourage all farm developers who are potentially interested in submitting a Statement of Interest to email ASAP to register as an interested party.**

Communications and updates, including an invitation to the webinar (above) and a recording after it has taken place, will be sent to this list of interested parties. Additionally, all questions and answers emailed to Julia and Dennis will be aggregated and sent to the interested group on a regular basis.

STLCEA COALITION- BRINGING AN INDOOR FARM TO ST. LOUIS
Q&A — 7/31/20
QUESTIONS SUBMITTED IN WRITING & ASKED DURING THE WEBINARS

How is my privacy protected? Is there an NDA? UPDATED ANSWER

Yes. Please see more information on this process in the updated Request for Statements of Interest. To summarize, submitted proposals will only be reviewed by a small proposal review committee (PRC) made up of 5-7 people who will all sign an NDA prior to receiving any Statements of Interest. We will release the names of the PRC members by early this week as well as a copy of the NDA. In late September, after top candidates are chosen, the PRC will report on the process to the full Coalition, minus all farms, to give them insight into the process and why we are recommending a shortlist of finalists. However, only a matrix will be shared with them with all company names removed and presenting only ranges of information. The exact matrix and those details can be seen in the Request for Statements of Interest.

NEW QUESTION: How will the goal of knowledge sharing/demonstration be balanced with confidentiality?

Success for us is not only being able to bring a farm to fruition in St. Louis that tackles environmental and social goals in a financially profitable way, but the chance to share some of those lessons learned with the broader industry to encourage similar attempts in other locations. However, the types of lessons learned that we would share will be broad ones. We would not ask a farm to share any proprietary information around exact energy footprint, economics, new technology (if their own), etc. Instead, we would want to share high-level lessons. For example, this could include whether structuring a community equity participation through a land or cash contribution worked, or if partnering with a thermal power plant or food-to-waste energy company worked and sharing the challenges and benefits around such partnerships.

Is the expectation that you all will select one party who will then go on to fully fund, own, and operate a farm in St Louis?

We have currently left the process open as to whether it is one or more farms. We would not choose more than one farm if they would be competitors, but there is the possibility that, for example, there would be a small farm that wants to focus on restaurants and/or D2C and another large farm that wants to focus on grocers/ institutional customers. In that case, if they were not competitors, it's possible there would be an appetite for more than one farm. At this point, our goal is one farm, but we are open to more if it makes sense.

How will the farm be funded? Who will own the farm?

Our goal is for the farm to be a commercially viable enterprise. We want to see if utilizing these partnerships makes it financially viable as well as demonstrating environmental gains so that these partnerships can be duplicated elsewhere and make strides for the industry in a sustainable way. At this time, the Coalition does not have a committed source of funding, but we do have a variety of potential funders in the group, as can be seen in Appendix A. The Coalition includes banks, VCs, economic development groups who can help with incentives and grants, and city officials. While no entity has committed to funding since it depends on the project and farm partner, they are at the table because they are interested. Our goal as a Coalition is to help bring funding and customers in addition to partnerships addressing environmental and social concerns.

As to ownership, the Coalition would not own or run the farm. Most likely the farm would be owned by the entity who applied as well as possible investors. However, there are unique pieces being discussed such as, could the community be part of the ownership structure, perhaps through contributing the land or some other means? This would mean that if the farm is commercially successful, the community would financially participate in the upside. Or would a partner farm be interested in managing and running the farm for a non-profit or other owner with a revenue share? This might allow more of a social enterprise approach to accomplish some of the social or demonstration goals. These are just two ideas; we encourage you to think creatively with out-of-the -box ideas.

NEW QUESTION: Are green bonds being explored at all?

Yes. As with the rest of the funding process, this is still in an exploratory phase and final determination can only be made in conjunction with a farm and a proposal. However, we are actively exploring the possibility of using social impact or green bonds to fund some portion of this project/farm. This is being discussed with groups who have structured green and social impact bonds in the past.

Can you share the planned involvement and support from the city, energy companies, university, and financial institutions involved?

All these groups are participating in the Coalition, but it is a bit of a chicken and egg problem. They are all actively participating because they see a lot of regional benefit and interesting possibilities in this project. All are highly intrigued about being involved. However, it is hard to discuss specifics with them since it also depends on who the farm partner is, how big the farm is, who the customer is, what the footprint looks like, what energy and community partners are involved, etc. During the deeper conversations with shortlisted farms, the farms will get the opportunity to engage in depth with potential partners to discuss specifics around funding, energy, city support, etc.

How will WWF continue to be involved?

WWF would not own, manage, or run the farm. Currently, WWF's role is as a convener and catalyst. WWF would stay informally involved to see if this model and partnerships are working (e.g., do the partnerships lead to environmental or social benefit.) There would be no formal requirement, but if the farm were willing to share some data down the line, it is possible that WWF would ultimately be interested in updating the Life Cycle Analysis (LCA) completed in the Phase I Innovation Analysis. However, this is just one possibility of WWF's long-term involvement. This is not required, and all data would be owned by the farm. Even without an LCA, if this model appeared to be presenting strong gains either environmentally or socially, WWF would want to share the basic idea of this type of partnership and provide those lessons learned to other farms. This is the Demonstration Goal referred to in the Request for Statement of Interest.

Do the farms who have participated in the Coalition get priority?

No. All Statements of Interest will be considered equally. We want this to be a completely open and transparent process. All are welcome and encouraged to respond if this initiative aligns with their goals and makes sense. It is possible, however, that for the farms that have been involved to date, they may know more about the goals and how the Coalition reached this point, which may help them craft a more responsive proposal. To alleviate concerns on this front, any farm that is interested in the notes, slide decks, or even recordings for the meetings that happened virtually of the full Coalition is welcome to request this information and they will be provided.

NEW QUESTION: It seems you are looking for a proven/profitable strategy but also innovative/cutting edge ideas. If you had to choose just one, which would you choose?

Obviously, in an ideal world, we would choose both. We want a farm that is innovative but ultimately profitable, too. We will be looking for a proven partner who has an innovation track record and is willing to explore new and innovative ideas for this project. We do not necessarily expect that every idea will be advanced or work. We see value in learning both what works and what doesn't work, however, it is essential that the effort is a viable commercial enterprise. The Coalition will do everything it can to help advance both objectives.

NEW QUESTION: In what format would you like the proposals?

We are flexible on this. We do want an electronic submission, but whether that is a PDF, PPT, Word document, or something else is up to you – the quality of the content is most important to us. If you want to include videos or other materials, please simply provide a link or submit it as an attachment if not too large. We are happy to accept whatever format allows you to best communicate your company and vision for this project.

APPENDIX III: JUDGING MATRIX

STLCEA Farm Proposal Evaluation Form

NOTE: Financial capacity is not being evaluated until we shortlist the top 3 proposals

Farm Name:	0	1	2	3	4	5	Total
Evaluative Criteria							
1. Innovation:							
• Past demonstration of commitment to CEA technology innovation							
• In the proposal, articulated a willingness to explore new technologies and produce varieties							
2. Sustainability:							
• Past demonstration of commitment to energy and sustainability goals							
• In the past, have used stranded assets and partnerships to drive down energy footprint							
3. Social:							
• Past demonstration of commitment to social goals and community engagement							
• History of unique approaches and innovative ideas to accomplish social goals and make use of partnerships in this area							
• Indicated commitment to address social goals in STL							
4. Demonstration:							
• Commitment to sharing lessons to boost the industry							
5. Operational History:							
• Demonstrated experience of farm/developer in building and operating a viable commercial CEA farm scaled as follows: (1) 0-1 (2) 2-3 (3) 4-5 (4) 6-7 (5) 8+							
6. Partnership:							
• Willingness to work with the STLCEA Coalition and community to achieve aspirational goals							
7. Supplemental Consideration:							
• Quality and responsiveness to the request for Statements of Interest							
• Additional points based on belief that the farm would serve the best interests of the STLCEA initiative							
TOTALS							

Other Subjective Comments, If Any: