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9-ERDD-01 and â€œIndoor Ag and Advanced Wastewaterâ€“ request for information

Area A: Advanced energy efficiency and load shifting in indoor farms
Indoor farm is defined here as a facility for growing crops under controlled environment twenty-four hours a day, seven days a week â€“ lighting, nutrients, water delivery and heating/cooling. Unlike a greenhouse, indoor farm uses artificial lighting as a primary source of light. Indoor farms include vertical farms.
The following will help us align our future solicitations with needs of disadvantaged communities:
a. Can indoor farms help solve some problems, such as food security, in low income or disadvantaged communities? What are the barriers that should be addressed to better address these problems?
Comment: Yes, the indoor farm has the potential to address food security in low-income and disadvantaged communities. For example, the shipping container type of small indoor farming system could ensure food security in small remote communities where fresh vegetables are costly. This farming system could also provide a year-round supply of fresh foods to the people living in extreme climate zones where field crop production is not feasible most of the time.
However, most indoor farming projects are mostly focused on growing vegetables near the cities due to market demand. Most indoor farming systems are mainly focused on short time cash crops due to high capital and operation costs. The healthy market demand for the produce grown in the indoor farm is essential for economic sustainability. The following are the major barriers that need to address for ensuring food security for low income and disadvantaged communities by adaptation of indoor farming:
1. Investigate the potential of growing the types of fruits and vegetables in demand among these group of people.
2. Most of the indoor farming system is highly sophisticated, so these systems' adaptation could be challenging for the remotely disadvantaged communities. More research programs need to be implemented to develop indoor farming technologies to minimize capital and operation costs by adapting local resources. Also, training and education programs are required among these groups of people about indoor farming systems' potential to ensure their food security.
b. What technological advancements in indoor farms are needed to improve the availability of affordable fresh produce in LI/DAC communities and provide additional benefits-like jobs?
Comment: A high capital and operation costs in indoor farms cause higher product prices, so the LI/DAC communities can't afford it. Therefore, technological improvements, such as the small-scale indoor farming system's design using locally available resources, are required to reduce capital costs. The energy costs are the main operational costs for indoor farms, so the energy-efficient cooling and lighting systems

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   Comment: Yes, the indoor farm has the potential to address food security in low-income and disadvantaged communities. For example, the shipping container type of small indoor farming system could ensure food security in small remote communities where fresh vegetables are costly. This farming system could also provide a year-round supply of fresh foods to the people living in extreme climate zones where field crop production is not feasible most of the time.

   However, most indoor farming projects are mostly focused on growing vegetables near the cities due to market demand. Most indoor farming systems are mainly focused on short time cash crops due to high capital and operation costs. The healthy market demand for the produce grown in the indoor farm is essential for economic sustainability. The following are the major barriers that need to address for ensuring food security for low income and disadvantaged communities by adaptation of indoor farming:

   1. Investigate the potential of growing the types of fruits and vegetables in demand among these group of people.

   2. Most of the indoor farming system is highly sophisticated, so these systems' adaptation could be challenging for the remotely disadvantaged communities. More research programs need to be implemented to develop indoor farming technologies to minimize capital and operation costs by adapting local resources. Also, training and education programs are required among these groups of people about indoor farming systems' potential to ensure their food security.

b. **What technological advancements in indoor farms are needed to improve the availability of affordable fresh produce in LI/DAC communities and provide additional benefits-like jobs?**

   Comment: **A** high capital and operation costs in indoor farms cause higher product prices, so the LI/DAC communities can't afford it. Therefore, technological improvements, such as the small-scale indoor farming system's design using locally available resources, are required to reduce capital costs. The energy costs are the main operational costs for indoor farms, so the energy-efficient cooling and lighting systems are essential to reduce operating costs.

   Besides food security, the commercial-scale indoor farm could create a significant job market for disadvantaged communities. This sector needs workers to manage planting, cultivation, monitoring, harvesting, and research and development.

c. **How could disadvantaged communities and private companies develop mutually beneficial partnerships? For instance, could it be viable for a private company that develops a technology platform for indoor farming to provide it at a discount to local communities? In exchange, these communities would train workforce for the platform and participate in testing new crops and technologies?**

   Comment: As the indoor farm has the potential of creating new jobs in the communities. Therefore, the private company could target the people from disadvantaged communities and trained them to adapt to their workforce. Also, the company could provide a discounted rate for their employee. However, government and agencies need to encourage the private company for this kind of partnership by implementing the industry's beneficial program.

The following will help us target our specific research:

a. **What is the typical breakdown of electric and natural gas use in indoor farms? How important is reducing energy costs relative to other costs?**

   Comment: The breakdown of electrical and natural gas use in indoor farms depends on the local municipality's utility price. The electricity would be the major costs for indoor farming as essential lighting is completely provided artificially. The artificial lighting and dehumidification system could consume about 80% of total electricity consumption in indoor agriculture (Graamans et al., 2018). The remaining electricity could be used for cooling and other control systems such as irrigation. The natural gas is mostly used to heat the controlled volume under heating mode and could be used to supply the CO_2 through the combustion of natural gas. However, a significant amount of heating needs in an indoor farming facility could be supplemented from artificial lighting. Therefore, the breakdown of electricity and natural gas could be largely different case by case. In general, the use of natural gas is very minimal as compared to electricity consumption.

The high capital costs and operation costs are the major challenges facing the indoor farming industry. The figure below shows a typical breakdown of optional costs in an indoor farming system. The reduction of energy costs is a relatively more feasible option to make indoor production systems sustainable. The energy cost in indoor farms could be 15%-40% of the total production costs. The potential of reducing the energy costs per unit produce could be 20%-40% smoothly, but the theoretical possibility could be 50%-80% (Kozai, 2018).

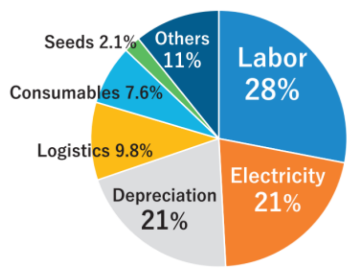

Fig: Typical production costs in an indoor farming system for lettuce production in Japan (Ijichi, 2019).

b. What systems of indoor farms have technical potential for improvements in energy efficiency over the currently available best-in-class equipment? What is preventing growers from deploying these improvements?

Comment: The following are systems that have the potential for improvements in terms of energy efficiency:

1. Renewable energy-based cooling and lighting systems instead of mechanical cooling systems and grid electrical load.

2. Energy-efficient dehumidification system as compared to mechanical dehumidification.

3. Energy-efficient lighting system for other cash crops besides leafy vegetables.

4. Control systems: automated control systems through integration of fault detection and diagnosis tool to the control program.

The followings are the major barriers for growers to implement the improved systems:

1. A significant knowledge gaps about the potential of improved systems to minimize the operational costs in indoor farming. Most of these existing technologies are adapted from residential and commercial buildings.

2. High capital costs for most improved technologies to improve the production facilities' energy efficiency.

3. Low profit is the barrier for growers to take the challenges of large-scale investment.

c. **Is there an interest and feasibility of shifting the electrical load to be flexible to the electric grid, such as increasing electricity use when renewable energy is plentiful and decreasing when renewable energy is not available?**

Comment: As most of the electricity use in indoor farms used for lighting, and the optimum photoperiod of plants could differ depending on the crops. The required photoperiod could range between 14-24 hours, so the shifting of electrical load could be interesting to maximize the use of renewable energy for the production facilities' HVAC system. Also, the optimum set-point temperature during the dark period could reduce 35-40˚F, so the heating and cooling load could also be shifted depending on the utility supplier's pricing policy. A couple of research studies have been conducted to study the energy-saving potential from shifting the greenhouses' thermal environment parameter. The shifting electrical load could be an interesting research topic for indoor farm as no research (to my best knowledge) has been conducted on shifting the load based on renewable energy sources' availability.

d. **Is there interest in developing, designing and operating zero carbon indoor farms? If so, are there examples of zero carbon indoor farms?**

Comment: The indoor farm has the potential for making these production facilities net-zero carbon (NZC) by designing energy-efficient buildings and produce on-site energy from renewable energy. Also, the indoor farm needs to supply additional CO_2 for optimum production in controlled environment settings. However, the concept of net-zero carbon is the next step, as there are significant knowledge gaps to make this industry as net-zero energy (NZE), which is the first step towards the goal for NZC. In recent, a small number of indoor farming industries are trying to design their farm as net-zero energy. The following are the two indoor farms that have been designed based on the concept of NZE.

1. A four-story (93,500 ft^2) red brick warehouse is now set to become a major net-zero vertical farm where the operation is fueled from food waste. The zero-energy facility relies on the on-site combined heating and power (CHP) system that contains a large anaerobic digester that converts food waste into biogas to power, heat and cools the building.

2. The University of Toronto is designing a net-zero vertical farm in their Scarborough campus. The proposed vertical farm would be a state-of-the-art building that will create training and research opportunities in various fields, including waste management, clean energy, sustainable building design, water conservation and urban agriculture. The project focuses on installing the acres of solar panels needed to convert sunlight into electricity to make the artificial sunlight.

e. What technological research and demonstration activities are necessary to make indoor farming a cost-effective option?

Comment: The following technological research and demonstration activities are essential to make indoor farming a cost-effective option:

- Research to develop low-cost technologies for small-scale community based indoor farm for disadvantaged communities.
- **The zero-energy concept for indoor farming**: The following research programs are needed to make the indoor farming system net-zero energy:
    - ➢ Study potential energy savings from energy-efficient building design to minimize the HVAC costs in indoor farms.
    - ➢ Renewable energy-based design of the cooling and lighting system for indoor farms.
    - ➢ Study the potential of energy production from the waste biomass in indoor farms and other feasible renewable sources.
    - ➢ Automated on-going commissioning of indoor farm to minimize the energy waste in the indoor farming system.

- **Study the potential of growing a wide variety of crops**: Indoor farming is still mainly focused on growing leafy vegetables. Research programs are needed to study the potential of an improved lighting system to grow other fruits and demanding vegetables besides the leafy vegetables.
- **Retrofitting existing structures for indoor farming:** The use of existing structures such as abandoned warehouses could potentially reduce the capital costs. Strong research programs are needed to study the potential of using abandoned structures or using brown-field space for indoor farming.
- **Educational program:** The social resistance, where masses of people have the wrong perception about the alteration of traditional farming, is the natural way to grow food. More education programs are needed to ensure the consumer about the quality and nutritional value of crops grown in the indoor farming system. The removal of the wrong perception would help to minimize the barriers for a broader market.

f. **What are some crops that could be cost-effectively grown using indoor farms beyond "traditional" leafy greens, cannabis and tomatoes? What are current and future prospects of using controlled environments to grow high-value crops with fine-tuned taste and aroma like coffee, for instance?**

Comment: The high costs of producing crops indoors are factors to grow the crops that can be produced in weeks; the longer the growing period, the greater the electricity cost for HVAC systems. However, indoor farming systems have the potential of growing different types of crops beyond the leafy greens. The following could be the example for different types of crops that could be grown in indoor farming settings:

Small root vegetables: Turnip, radish, carrot, water chestnuts, mushroom.

Medicinal and condiment: Panax ginseng, angelica acutiloba, onion, hot chili, wasabi.

Fruits: Strawberry, raspberry, blackberry, blueberry, and grape.

Fodder production for animal feed: wheat, barley.

A high cash crop like coffee could be grown in indoor farming facilities, but the operating costs would be the major challenge as the harvesting period is relatively longer as well as the quality and people perception could be challenging. However, aromatic plants like mint, chamomile, rosemary, and parsley, could be grown, which is popular in tea industry.

g. Please recommend some past or current indoor farming projects and related publications, proceedings, or reports that you believe would assist us in properly targeting a future solicitation.

Comment: Followings are the list of some current and current projects related to indoor farming:

1. Urban Agriculture Assessment and Recommendations: Connecting Urban Farmers with Broderick/Bryte Community to Improve Community Food Access, Nutrition Education, and Economic Development (Centre for land-based learning)
2. Optimizing Indoor Agriculture for Leafy Green Production- University of Arizona and Michigan State University.
3. Light Use Efficiency in Vertical Farms- Wageningen University, The Netherland.
4. Exploring the Contribution of Vertical Farming to Sustainable Intensification from the Point of View of the Innovator and the Farmer- University of Leeds, UK
5. Room for Growth: Princeton's Vertical Farming Project Harvests Knowledge for a Budding Industry.

The followings are the list of publications, reports and books related to indoor farming:

Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(2), 24.

R Shamshiri, R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., ... & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture.

Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. *Agricultural Systems*, *160*, 31-43.

Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, *13*(1), 13-26.

Pennisi, G., Sanyé-Mengual, E., Orsini, F., Crepaldi, A., Nicola, S., Ochoa, J., ... & Gianquinto, G. (2019). Modelling Environmental Burdens of Indoor-Grown

Vegetables and Herbs as Affected by Red and Blue LED Lighting. *Sustainability*, *11*(15), 4063.

Report: Designing an Economically Feasible Vertical Farm – A combined European Endeavor for Sustainable Urban Agriculture. Link: https://www.researchgate.net/publication/321427717_Vertical_Farm_20_Designing_an_Economically_Feasible_Vertical_Farm_-_A_combined_European_Endeavor_for_Sustainable_Urban_Agriculture

Report: Agriculture and Food Research Initiative Competitive Grants Program: Link:https://nifa.usda.gov/sites/default/files/rfa/FY-2018-AFRI-Foundational-RFA.pdf

Report: INDOOR SOILLES FARMING: PHASE I: Examining the industry and impacts of controlled environment agriculture. Link: https://c402277.ssl.cf1.rackcdn.com/publications/1340/files/original/WWW_SoilessAg_Phase1_Final_Report_Full_051320.pdf?1589416541

Report: Exploring the contribution of vertical farming to sustainable intensification from the point of view of the innovator and the farmer. Link: https://www.see.leeds.ac.uk/fileadmin/Documents/research/sri/workingpapers/SRIPs-117.pdf

Book: Kozai, T. (2018). Smart Plant Factory.

The following will help us establish performance metrics for energy efficiency research on indoor farming:

a. The following metrics could be used to describe effectiveness of advanced indoor farm operations when comparing potential technologies for deployment:
   - Annual energy use and water consumption per square foot of indoor farm
   - Annual energy use and water consumption per pound produced
   - Net annual cost of production per pound produced

b. Are there any additional metrics that should be taken into the consideration?

Comment: The lighting is the primary demand of energy use in the indoor farming system. The plants consumed about 1-2% of total electrical energy consumed from the lighting system, and the remaining 98–99% of the electrical energy that is not absorbed by plants is converted to heat energy into the culture room need to be removed by airconditioners to the outside area or could be used for heating during the wintertime (Kozai, 2018). So, the **light use efficiency (LUE)** could be another metrics for energy efficiency research in indoor farms. Also, the **CO_2 use efficiency (CUE)** could another important metric related to energy use because CO_2 supply costs are significant in a completely closed controlled environment setting.

Resource use efficiency (RUE) is another metric that is very common for evaluating indoor farming facilities. RUE includes all different resources such as electricity (energy), water, CO_2, fertilizer, seed, human, and space.

c. **What are quality sources of information for energy intensity of existing indoor farms and potential for improvements in the near-term future?**

   Comment: I have listed several report, articles, and books which could provide quality information about energy intensity of indoor farms. Also, some existing industry like Aer Farm in New York, Plenty in California, could be quality sources for information about indoor farming.

References:

Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. *Agricultural Systems*, *160*, 31-43.

Ijichi H (2018) NAPA research report: chapter 3 plant factory business – current status and perspectives of plant factory business. Nomura Agri-planning Consult (in Jpn), 58–80.

Kozai, T. (2018). Smart Plant Factory.