Controlled Environment Agriculture: A Case in Agricultural Transformation

2024 AAAS Annual Meeting; Lightning Talk

Abigail Boyd, Ph.D.

CEA Background

Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy, 13(1), 13–26. https://doi.org/10.1080/15487733.2017.1394054

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Engler, N., & Krarti, M. (2021). Review of energy efficiency in controlled environment agriculture. Renewable and Sustainable Energy Reviews, 141, 110786. https://doi.org/10.1016/j.rser.2021.110786

Gómez, C., Currey, C. J., Dickson, R. W., Kim, H.-J., Hernández, R., Sabeh, N. C., Raudales, R. E., Brumfield, R. G., Laury-Shaw, A., Wilke, A. K., Lopez, R. G., & Burnett, S. E. (2019). Controlled Environment Food Production for Urban Agriculture. HortScience, 54(9), 1448–1458. https://doi.org/10.21273/HORTSCI14073-19

Goodman, W., & Minner, J. (2019). Will the urban agricultural revolution be vertical and soilless? A case study of controlled environment agriculture in New York City. Land Use Policy, 83, 160–173. https://doi.org/10.1016/j.landusepol.2018.12.038

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Mitchell, C. A. (2022). History of Controlled Environment Horticulture: Indoor Farming and Its Key Technologies. HortScience, 57(2), 247–256. https://doi.org/10.21273/HORTSCI16159-21

Oh, S., & Lu, C. (2023). Vertical farming—Smart urban agriculture for enhancing resilience and sustainability in food security. The Journal of Horticultural Science and Biotechnology, 98(2), 133–140. https://doi.org/10.1080/14620316.2022.2141666

Shamshiri, R. R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., Ahmad, D., & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. 1-22. https://doi.org/10.25165/j.ijabe.20181101.3210

van Delden, S. H., SharathKumar, M., Butturini, M., Graamans, L. J. A., Heuvelink, E., Kacira, M., Kaiser, E., Klamer, R. S., Klerkx, L., Kootstra, G., Loeber, A., Schouten, R. E., Stanghellini, C., van Ieperen, W., Verdonk, J. C., Vialet-Chabrand, S., Woltering, E. J., van de Zedde, R., Zhang, Y., & Marcelis, L. F. M. (2021). Current status and future challenges in implementing and upscaling vertical farming systems. Nature Food, 2(12), Article 12. https://doi.org/10.1038/s43016-021-00402-w

Industry Challenges

Baraniuk, C. (2023, July 17). Lean times hit the vertical farming business. BBC News. https://www.bbc.com/news/business-66173872

Broadbent, J. (2023, June 28). How vertical farms are weathering the climate of closure. Just Food. https://www.just-food.com/features/how-vertical-farms-are-weathering-the-climate-of-closure/

Marston, J. (2023, February 28). How not to fail in vertical farming: 'Be on guard for hubris.' AFN. https://agfundernews.com/how-not-to-fail-in-vertical-farming-be-on-guard-for-hubris-say-indoor-ag-con-speakers

Southey, F. (2023, July 27). As vertical farms topple, can tech sow sustainability into controlled environment agriculture? Foodnavigator.Com. https://www.foodnavigator.com/Article/2023/07/27/As-vertical-farms-topple-can-tech-sow-sustainability-into-controlled-environment-agriculture

Tasgal, P. (2023, December 7). Is controlled environment agriculture investable today? AgFunderNews. https://agfundernews.com/is-controlled-environment-agriculture-investable-today

Walling, M., & LaFleur, K. (2023, October 22). Lots of indoor farms are shutting down as businesses struggle. https://www.myjournalcourier.com/news/article/modern-farmer-vertical-farming-18399974.php

Federal Agency Resources

USDA

Federal Advisory Committee for Urban Agriculture and Innovative Production. (2023). USDA. https://www.usda.gov/partnerships/federal-advisory-committee-urban-ag

- Advise the Secretary of Agriculture on the development of policies and outreach relating to urban, indoor, and other emerging agricultural production practices; identify any barriers to urban agriculture
- Connect producers to resources such as the USDA Urban Agriculture Toolkit, loan programs, and more.

Research and Science. (2023). U.S. Department of Agriculture. https://www.usda.gov/topics/research-and-science

- Summarizes USDA research including recent research strategy for 2023-2026 and Agriculture Advanced Research and Development Authority (AgARDA) implementation strategy.

Urban Agriculture. (2023). Retrieved June 1, 2023, from https://www.usda.gov/topics/urban

- Connects urban growers to resources such as grants, programs, services, and information.

Urban, Indoor, and Emerging Agriculture. (2022). National Institute of Food and Agriculture. http://www.nifa.usda.gov/grants/funding-opportunities/urban-indoor-emerging-agriculture

- Research funding opportunity totaling roughly $9,400,000 with awards of $50,000 to $1,000,000 available for research entities across government, academia, industry, and the non-profit sector.

USDA ARS. (2023). https://www.ars.usda.gov/

- USDA's chief scientific in-house research agency
- Multiple active projects on CEA across ARS locations

USDA Climate Hubs. (2022). https://www.climatehubs.usda.gov/

- Regional hubs across USDA agencies, led by ARS and Forest Service to deliver science-based, region-specific information and technologies to agricultural producers to make climate-informed decisions.

USDA ERS. (2023). https://www.ers.usda.gov/

- Provides statistical information on food, nutrition, agriculture, and markets and conducts economic research to inform public and private decision making

NASA

Hall, L. (2021). NASA Research Launches a New Generation of Indoor Farming. NASA. http://www.nasa.gov/directorates/spacetech/spinoff/NASA_Research_Launches_a_New_Generation_of_Indoor_Farming

- Outlines contribution of NASA research to indoor farming

High-Efficiency LEDs Grow Crops, Stimulate Alertness. (2018). NASA Spinoff. Retrieved June 20, 2023, from https://spinoff.nasa.gov/Spinoff2018/cg_7.html

- Summarizes tech transfer of NASA LEDs in crop growth

Lighting in a Bottle. (2022). NASA Spinoff. Retrieved June 20, 2023, from https://spinoff.nasa.gov/lighting-in-a-bottle

- Summarizes tech transfer of NASA LEDs in crop growth

NASA Technology Transfer Program. (2023). https://technology.nasa.gov/

- Promotes translation of NASA intellectual property to broadly benefit society

DOE

ARPA-E. (2023). https://arpa-e.energy.gov/

- Supports high-potential, high-impact research too early for private sector investment with funding and technical assistance.

EERE eXCHANGE: Funding Opportunity Exchange. (2023). Retrieved March 23, 2023, from https://eere-exchange.energy.gov/Default.aspx#FoaIdb19eb829-1258-42ec-871c-2439c1f51460

- Funding opportunities for specific research topics; May 2023 featured CEA Accelerator to "demonstrate the energy, water, and decarbonization benefits that can be achieved through efficient operation of CEA."

Office of Energy Efficiency & Renewable Energy. (2023). Energy.Gov. https://www.energy.gov/eere/office-energy-efficiency-renewable-energy

- Advances research and development for cross-sector decarbonization, including agriculture (specifically energy and water use).
- Houses numerous technology offices related to energy efficiency and sustainability

FDA

Nutrition, C. for F. S. and A. (2022). FDA Issues Report Highlighting Salmonella Outbreak in Packaged Leafy Greens Produced in a Controlled Environment Agriculture Operation. FDA. https://www.fda.gov/food/cfsan-constituent-updates/fda-issues-report-highlighting-salmonella-outbreak-packaged-leafy-greens-produced-controlled

- Recent report on foodborne illness outbreak traced to CEA operation (believed to be FDA's first investigation on a CEA operation), contains food safety recommendations for CEA operations and calls for additional collaboration and research

Office of Regulatory Affairs. (2023). Recalls, Market Withdrawals, & Safety Alerts. FDA; FDA. https://www.fda.gov/safety/recalls-market-withdrawals-safety-alerts

- Reports on foodborne illness outbreaks and product recalls

NIH

ARPA-H. (2023). National Institutes of Health (NIH). https://www.nih.gov/arpa-h

- Supports high impact biomedical and health research

Grants & Funding. (2023). National Institutes of Health (NIH). https://www.nih.gov/grants-funding

- Numerous funding opportunities in nutrition, food security, and environmental health

NIH Intramural Research Program. (2023). https://irp.nih.gov/

- Internal NIH research program for integrated/synergistic biomedical research

Nutrition, Health, and Your Environment. (2023). National Institute of Environmental Health Sciences. Retrieved June 21, 2023, from https://www.niehs.nih.gov/health/topics/nutrition/index.cfm

- National Institute of Environmental Health Sciences provides information about the relationship between nutrition and environment, including health and nutrition disparities in urban areas and near schools
- NIEHS also houses intramural research related to nutrition, health, environment, agriculture, etc.

Existing CEA Collaborations

2024 Joint CEA Workshop. (n.d.). Retrieved January 29, 2024, from https://sites.google.com/view/cea2024jointworkshop/home

Altland, J., Apul, D., Harbick, K., Ling, K., Lipscomb, G., & Stokes-Draut, J. (2021). Multi-agency Collaboration Addressing Challenges in Controlled Environment Agriculture (p. 36) [Workshop Report]. University of Toledo. https://www.utoledo.edu/research/rsp/pdfs/cea-workshop-report.pdf

Controlled Environment Indoor and Vertical Food Production Coordinated Research Conference (p. 83). (2019). [Conference Report]. University of Arizona. https://ceac.arizona.edu/sites/default/files/2023-09/USDA%20NIFA%20AzCEA%20FINAL%20Report%20Indoor%20Agriculture%20Conference_Full%20Report.pdf

Research and Development Potentials in Indoor Agriculture and Sustainable Urban Ecosystems (p. 20). (2018). [Workshop Report]. U. S. Department of Agriculture, Office of the Chief Scientist. https://www.usda.gov/sites/default/files/documents/indoor-agriculture-workshop-report.pdf

Workshop on Advancing Controlled Environment Agriculture on Land and in Space in the Next 20 Years. (2023). https://www.utoledo.edu/research/advancing-controlled-environment-agriculture/
Workshop on advancing controlled environment agriculture on land and in space in the next 20 years
Toledo, OH; June 27-29, 2023

Research and development potentials in indoor agriculture and sustainable urban ecosystems
Washington, D.C.; June 27-28, 2018

Federal Collaboration Mechanisms

U.S. Global Change Research Program. (2024). GlobalChange.Gov. Retrieved January 29, 2024, from http://www.globalchange.gov/

- Interagency Crosscutting Group on Climate Change and Human Health: https://www.globalchange.gov/our-work/interagency-groups/cchhg
    - CCHHG Climate Change, Food Systems, and Nutrition Security Workstream: https://www.globalchange.gov/content/cchhg-climate-change-food-systems-and-nutrition-security-workstream

Research Transformation

Boyd, A. P., Luo, Y., Kustas, W. P., Fukagawa, N. K., Mattoo, A. K., Crow, W. T., Pachepsky, Y., Kim, M. S., Lillehoj, H. S., Van Tassell, C. P., Zhang, H., Blomberg, L. A., Dubey, J. P., & Lunney, J. K. (2023). Cross-cutting concepts to transform agricultural research. Frontiers in Sustainable Food Systems, 7. https://www.frontiersin.org/articles/10.3389/fsufs.2023.1242665

Caron, P., Ferrero y de Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., Arnold, T., Astralaga, M., Beukeboom, M., Bickersteth, S., Bwalya, M., Caballero, P., Campbell, B. M., Divine, N., Fan, S., Frick, M., Friis, A., Gallagher, M., Halkin, J.-P., … Verburg, G. (2018). Food systems for sustainable development: Proposals for a profound four-part transformation. Agronomy for Sustainable Development, 38(4), 41. https://doi.org/10.1007/s13593-018-0519-1

Govaerts, B., Negra, C., Villa, T. C. C., Suarez, X. C., Espinosa, A. D., Fonteyne, S., Gardeazabal, A., Gonzalez, G., Singh, R. G., Kommerell, V., Kropff, W., Saavedra, V. L., Lopez, G. M., Odjo, S., Rojas, N. P., Ramirez-Villegas, J., Loon, J. V., Vega, D., Verhulst, N., … Kropff, M. (2021). One CGIAR and the Integrated Agri-food Systems Initiative: From short-termism to transformation of the world's food systems. PLOS ONE, 16(6), e0252832. https://doi.org/10.1371/journal.pone.0252832

Hölscher, K., Wittmayer, J. M., & Loorbach, D. (2018). Transition versus transformation: What's the difference? Environmental Innovation and Societal Transitions, 27, 1–3. https://doi.org/10.1016/j.eist.2017.10.007

Learn About Convergence Research. (2022). National Science Foundation. https://beta.nsf.gov/funding/learn/research-types/learn-about-convergence-research

Linnér, B.-O., & Wibeck, V. (2020). Conceptualising variations in societal transformations towards sustainability. Environmental Science & Policy, 106, 221–227. https://doi.org/10.1016/j.envsci.2020.01.007

National Research Council. (2014). Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond. The National Academies Press. https://doi.org/10.17226/18722

National Academies of Sciences, Engineering, and Medicine. (2022). Enhancing Coordination and Collaboration Across the Land-Grant System. The National Academies Press. https://doi.org/10.17226/26640

National Academies of Sciences, Engineering, and Medicine. (2019). Science Breakthroughs to Advance Food and Agricultural Research by 2030. The National Academies Press. https://doi.org/10.17226/25059