



Trends, Insights, and Future Prospects for Production in Controlled Environment Agriculture and Agrivoltaics Systems

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What Is the Issue?

Public and private investments in alternative food production systems, such as controlled environment agriculture (CEA) and agrivoltaics (AV), have increased in recent years. CEA consists of crop production systems in greenhouses or other structures that use horticultural and engineering techniques beyond conventional soil-based outdoor production. These systems may increase yields, improve access to local foods, provide year-round food access, and/or improve nutritional outcomes relative to traditional large-scale outdoor farming. Additionally, CEA may provide climate change adaptation benefits by reducing the risk of crop failure in more extreme weather relative to traditional outdoor systems. AV is the colocation of solar panels and agricultural production. AV is designed to provide the climate change mitigation benefits of traditional large-scale solar developments while reducing land use competition with agricultural production. Though these systems face technological and economic challenges, the systems are part of a long history of technological advancement in the U.S. agricultural sector. While the systems are unlikely to displace more conventional and larger scale production in the near future, they may increase the supply of locally grown food for some communities and generate climate change benefits, including renewable energy.



What Did the Study Find?

Traditional greenhouses are an established production system. However, innovations in how crops are produced, including hydroponics and vertical agriculture, have led to growth in production and investment in the public and private sectors. AV systems are an emerging technology without a well-established commercial presence, but there is growing public and private investment in research and development. The main findings include:

- The amount of specialty crop production with CEA systems is small compared to outdoor production, but the number of individual CEA operations more than doubled to nearly 3,000 between 2009 and 2019.
- The quantity of crop production increased by 56 percent over that same period, from 502 million pounds to 786 million pounds.

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- The aggregate sales value for CEA crops rose from \$296 million in 1998 to \$769 million in 2014 (in inflation-adjusted terms) but declined to \$626 million in 2019 due to declines in the sales value of the dominant CEA crops (particularly tomatoes). This number is likely partly due to increased competition from imports, putting downward pressure on the value of sales per unit.
- Additionally, new technologies were used to produce a large share of total CEA production, with more than 60 percent of tomatoes, cucumbers, and lettuce grown using hydroponics in 2019.
- Recent U.S. Department of Agriculture (USDA) funding to support research and commercialization of CEA systems has increased substantially, including the awarding of contracts and grants exceeding \$50 million since 2022 through USDA's Office of Urban and Innovative Agriculture, Agricultural Research Service, and National Institute of Food and Agriculture.
- As of 2021, most of the approximately 300 AV sites were solar farms planted with pollinator-friendly vegetative cover. Roughly 35 sites combined solar panels with vegetation that were grazed by sheep, and a few were co-located with specialty crop production, including blueberries.
- Research sites evaluating a variety of other AV systems with specialty crop and/or livestock production have been established, including several projects funded by the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Solar Energy Technologies Office (DOE-SETO), which has been funding AV research since 2015. This funding included \$7 million for AV research awarded in November 2020 for the colocation of pollinator-friendly vegetation, specialty crop production, and livestock grazing with solar panels.

How Was the Study Conducted?

This report uses data from the 2017 USDA Census of Agriculture (COA) and Censuses of Horticultural Specialties (CHS). Specifically, to analyze the market for CEA, the authors used the protected culture statistics from the CHS in 1998, 2009, 2014, and 2019.* For historical information, the authors used Horticultural Specialties Reports from the COA, which is typically conducted every 5 years for the period 1890–1994. For general information on the market for specialty crops, the authors used data from the USDA's National Agricultural Statistics Service (NASS) COA and Vegetable Annual Summary Reports for 1998–2019. Also included is information from the U.S. Department of Energy's list of funded solar research projects and extensive literature reviews.

* The authors included 1998 in the Census of Horticultural Specialties (CHS) years instead of 1997. USDA refers to it as the 1997 CHS, but the data were collected for the 1998 calendar year.