U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

# Nexus of Energy, Water, and Agriculture, Research: Office of Energy Efficiency and Renewable Energy

January 2023

## Disclaimer

# List of Acronyms

| | |
|---|---|
| AMO | Advanced Manufacturing Office |
| AMMTO | Advanced Materials and Manufacturing Technologies Office |
| ARS | United States Department of Agriculture's Agricultural Research Service |
| BTO | Building Technologies Office |
| BETO | Bioenergy Technologies Office |
| BOR | United States Bureau of Reclamation |
| CESMII | Clean Energy Smart Manufacturing Innovation Institute |
| CHP | combined heat and power |
| $CO_2$ | Carbon Dioxide |
| DOE | United States Department of Energy |
| DOI | United States Department of Interior |
| EERE | Office of Energy Efficiency and Renewable Energy |
| EPA | United States Environmental Protection Agency |
| GHG | greenhouse gas |
| GTO | Geothermal Technologies Office |
| IEDO | Industrial Efficiency and Decarbonization Office |
| IAC | industrial assessment center |
| INL | Idaho National Laboratory |
| IWG | interagency working group |
| kW | kilowatt |
| LED | light-emitting diode |
| MOU | memorandum of understanding |
| NAWI | National Alliance for Water Innovation |
| NEWS | Nexus of Energy and Water for Sustainability |
| NNCO | National Nanotechnology Coordination Office |
| PNNL | Pacific Northwest National Laboratory |
| PV | photovoltaic |
| PCM | phase change material |

| | |
|---|---|
| R&D | Research and Development |
| RD&D | Research Development and Demonstration |
| RDO | Lighting Research and Development Opportunities |
| SETO | Solar Energy Technologies office |
| TAP | Technical Assistance Partnership |
| TW | Terawatt |
| RAPID | Rapid Advanced in Process Intensification Deployment Institute |
| USDA | United States Department of Agriculture |
| WATR | Water Treatment Interagency Working Group |
| WPTO | Water Power Technologies Office |
| WRAP | National Water Reuse Action Plan |
| WSC | interagency water subcabinet |

# Executive Summary

The Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) engages in research, development, and demonstration (RD&D) activities in the nexus of energy, water, and agriculture. This report focuses primarily on Energy-Water RD&D activities related to the agricultural sector that EERE and DOE's National Laboratories are coordinating with United States Department of Agriculture (USDA). Additionally, it addresses technology applications or assistance that could potentially be applied to agricultural needs.

EERE and USDA collaborate while maintaining their individual missions to accelerate RD&D in the Energy-Water Nexus. Both organizations engage with one another to ensure knowledge sharing, support programmatic alignment on strategic priorities, leverage national laboratory and research facility capabilities, and minimize duplication of efforts. This report discusses ongoing formal and informal collaboration between DOE and USDA through participation in engagement mechanisms, such as:

- A Memorandum of Understanding (MOU) between DOE and USDA focuses on cooperation and coordination on improving energy development in rural America. Other MOUs are under consideration that focus on activities at the nexus of energy, water, and agriculture.
- The Biomass Research and Development (BR&D) Board, which coordinates bioenergy Research and Development (R&D) across Federal agencies and with the White House.
- The Nexus of Energy and Water for Sustainability (NEWS) RD&D activities, based upon Section 1010 of the Energy Act of 2020 have been initiated through an Interagency Coordination Committee.
- The Interagency Water Subcabinet, formalized in October 2020, maintains high-level Federal coordination on energy-water nexus activities. The National Water Reuse Action Plan (WRAP) was launched in February 2020 by the Environmental Protection Agency (EPA) to build communities' capacity to pursue water reuse practices through collaboration across federal, state, tribal, local, and water sector partners. USDA and DOE are both active members of the Water Reuse Interagency Working Group.
- The Department of Interior's (DOI) Bureau of Reclamation (BOR), which organizes the Water Treatment Interagency Working Group (WATR) that holds an Annual Research Coordination Meeting supporting cross-agency knowledge sharing, national water strategy development and implementation.
- The National Nanotechnology Coordination Office (NNCO), which leads monthly meetings of Federal agencies to coordinate on nanotechnology RD&D for water treatment.

Additionally, individual EERE technology offices whose portfolios complement USDA programs collaborate directly with USDA on RD&D roadmaps, funding opportunities,

workshops, program development, and subject matter expertise in Energy-Water Nexus and other programmatic areas of mutual interest. Several example current programs and projects include:

- The National Alliance for Water Innovation (NAWI), also known as the Energy-Water Desalination Hub, which included representatives from USDA on its roadmap development for agriculture water/wastewater RD&D needs.
- Water/Wastewater Resource Recovery research, which addresses the removal and valorization of various contaminants from water, including agricultural wastewater, to generate other products.
- Irrigation Modernization tools, which are being developed to conserve water and energy for irrigation districts and farmers.
- Integrated Water Resilience program, which studies risk in rural agricultural communities at the intersection of water supply, irrigation, and energy.
- Solar Thermal Desalination to augment freshwater availability through distributed modular systems that include rural communities.

This report focuses primarily on Energy-Water RD&D activities directly related to the agricultural sector. Additional opportunities are currently being explored to leverage other EERE programs for potential USDA applications. Also, opportunities could be explored with other offices within DOE, including the Office of Science's Biological and Environmental Research , which invests in fundamental research in biotechnological approaches such as genome sequencing, proteomics, metabolomics, structural biology, high-resolution imaging and characterization, and integration of information into computational models that can be iteratively tested and validated to advance a predictive understanding of plant and microbial systems.

DOE and USDA have a strong basis for collaboration on Energy-Water Nexus activities to advance mutual interests, such as understanding impacts of climate change on water availability and quality for agriculture and energy; modernizing and decarbonizing irrigation systems; recovering crop nutrients and renewable natural gas from agricultural wastewater for energy and other products; direct energy production from sources like agrivoltaics and distributed wind; and promoting energy, water, and agricultural equity across all communities. More direct engagement between DOE and USDA at all levels, from technology managers and office directors to the Assistant Secretary and even up to the Interagency Water Subcabinet, would further accelerate these efforts and identify others for potential collaboration. The DOE National Laboratories also bring world-leading technical expertise to these efforts. At the same time, USDA has extensive subject matter expertise, research infrastructure, financing programs designed for deployment, and local channels to reach farmers, foresters, and rural communities across the U.S. and understanding the needs of those and other stakeholders.

# Table of Contents

# Introduction

DOE and USDA have a history of collaboration at the nexus of energy, water, and agriculture.[1] This interagency RD&D collaboration improves our national and community-level water and food security, improves water resiliency and water quality in our watersheds, reduces the energy and water intensity of the agricultural industry, and provides local economic development opportunities. Particularly, this RD&D offers rural America new economic markets that can provide USDA stakeholders with profitable and sustainable options without interfering with traditional agricultural production.[2] For example, oilseed crops can be double cropped with more conventional crops, providing additional income to the farmer as well as achieving benefits around weed and runoff reduction. Perennial bioenergy feedstocks, such as switchgrass, can be regionally adapted and complement existing land uses, thereby reducing farmer risk through diversification. As described in the report, DOE is currently leveraging the RD&D at its sites and national laboratories to benefit the agricultural industry. Additionally, DOE and USDA collaborate with other Federal agencies through various convening bodies, such as the Biomass Research and Development Board, the Water Treatment Interagency Working Group, and the Nexus of Energy and Water for Sustainability RD&D Office, as well as specific agency-led coordination efforts.

EERE[3] and USDA[4] collaborate, while maintaining their individual missions to accelerate knowledge sharing, support programmatic alignment on strategic priorities, leverage national laboratory and research facility capabilities, and minimize duplication of efforts. Formal and informal mechanisms for collaboration are discussed in this report. Within EERE, the Advanced Manufacturing Office (AMO) [now the Advanced Materials and Technologies Office (AMMTO and the Industrial Efficiency and Decarbonization Office (IEDO)], Bioenergy Technologies Office (BETO), Building Technologies Office (BTO), Geothermal Technologies Office (GTO), Solar Energy Technologies Office (SETO), and Water Power Technologies Office (WPTO) conduct RD&D, perform modeling and analysis, and provide technical assistance that is of potential interest to USDA stakeholders.

Energy, water, and agriculture nexus related RD&D includes waterpower, water quality, water treatment, desalination, water conveyance, bioenergy, lighting, material science, soil science, water and energy efficiency for industrial processes, solar energy and agriculture co-location, and geothermal direct use and heat pumps. EERE's investments in water and wastewater RD&D are highlighted in this report, such as those in the NAWI program that can make nontraditional water sources like seawater, brackish groundwater, and wastewater available for use (including

[1] https://www.energy.gov/articles/usda-doe-release-national-biofuels-action-plan
[2] https://biomassboard.gov/brd-initiative
[3] https://www.energy.gov/eere/about-office-energy-efficiency-and-renewable-energy
[4] https://www.usda.gov/our-agency/about-usda/mission-areas

in the agricultural sector) to address growing competition for water resources across the U.S. caused by climate change. Additionally, RD&D in wastewater resource recovery (i.e., recovery of fertilizers, biopower/biofuels, and water reuse) is also discussed. EERE has recently identified an additional priority area to modernize and decarbonize our irrigation systems such that they are integrated with renewable energy and improve water and energy efficiency.

Controlled environment agriculture aims to achieve optimal growth conditions of crops by optimizing resources such as water, energy, and space to increase crop yield and can be leveraged to benefit food insecure communities. When appropriate, technologies that could potentially be applied to controlled environment agriculture are identified, though controlled environment farming is currently not a primary focus within EERE's RD&D portfolios. EERE's RD&D on water and energy efficiency for industrial processes, materials science, lighting systems, solar energy, and advanced soils could be leveraged for use in greenhouses and four-season production platforms.

# DOE and USDA Interagency Collaboration Platforms

Several formal interagency RD&D collaboration platforms exist at the nexus of energy, water, and agriculture and serve as coordination points between DOE and USDA, as well as other agencies with equities in energy, water, and agriculture. A summary description of each is provided in the following sections.

## DOE and USDA Memorandum of Understanding

In October 2019, DOE and USDA leadership signed a memorandum of understanding (MOU) to promote rural energy and the development of technologies that will support rural and agricultural communities and domestic manufacturing.[5] The MOU was based on requirements from the 2018 Farm Bill and includes offices across DOE and USDA. EERE, the Office of Fossil Energy and Carbon Management, Office of Electricity, and Office of Cybersecurity, Energy Security, and Emergency Response all participate in interagency working groups convened by DOE and USDA that focus on five major areas: (1) Develop and expand energy- and manufacturing-related businesses, industries and technologies in rural America; (2) Encourage investments in new or improved rural energy infrastructure; (3) Enhance capital access for energy-related businesses and industries in rural America; (4) Support rural community investments that anticipate growth associated with rural energy investment and development; and (5) Encourage, support and invest in cyber security initiatives and grid improvement.

EERE technical offices, including AMMTO, IEDO, BETO, SETO, WPTO, and Wind Energy Technologies Office participate in the MOU discussions. They have been meeting with USDA counterparts at USDA's Rural Development, Office of Chief Scientist, National Institute of Food

[5] https://www.energy.gov/articles/doe-and-usda-join-forces-increase-energy-technology-development-and-deployment-rural

and Agriculture, and others to consider opportunities for coordination and collaboration on research priorities to advance affordable and reliable clean energy in rural areas. To date, the MOU has helped to increase communication between the two agencies, and DOE continues to explore opportunities to work with USDA employees and grant programs and provide technical assistance where possible.

Given the interest in the energy, water, agriculture nexus, DOE and USDA are working on a new or expanded MOU to include these areas of collaboration and opportunities to leverage DOE's national laboratories, USDA's Agricultural Research Service (ARS), The National Institute for Food and Agriculture, and Forest Service. This could be a potential additional area of collaboration in an expanded MOU between DOE and USDA as EERE is prioritizing decarbonization of industry, agriculture, and other sectors.

## The Biomass Research and Development Board

The BR&D Board[6] is a formal interagency collaborative composed of Federal agencies and the White House, co-chaired by the USDA and DOE. The BR&D Board coordinates biobased fuels, products, and power research and development activities across Federal agencies and aims to maximize the benefits of Federal programs and bring coherence to Federal strategic planning. In addition to DOE and USDA, the BR&D Board includes members from the U.S. Departments of Interior, Transportation, and Defense; the U.S. Environmental Protection Agency; the National Science Foundation; and the Office of Science and Technology Policy.

The BR&D Board recently released *The Bioeconomy Initiative: Implementation Framework*,[7] which serves as a guiding document for the BR&D Board member agencies "to increase government accountability and efficiency, maximize interagency coordination on bioeconomy research and other activities, and accelerate innovative and sustainable technologies that harness the nation's bioenergy resources to enhance U.S. security, economic growth, job creation, and environmental quality."

Since 2008 the BR&D Board has charged several interagency working groups (IWGs) to enhance information sharing and program coordination for specific components of the biofuel supply chain. These groups implement annual work plans to expand the sustainable use of the nation's abundant bioenergy resources for biofuels, bioproducts, and biopower. The IWGs and their focuses are as follows: Algae; Analysis; Feedstock Genetic Improvement; Feedstock Logistics; Feedstock Production Management; Conversion; Transportation, Distribution, and End Use; Sustainable Aviation Fuels; and Sustainable Bioeconomy.

[6] https://biomassboard.gov/

[7] https://biomassboard.gov/sites/default/files/pdfs/Bioeconomy_Initiative_Implementation_Framework_FINAL.pdf

## Nexus of Energy and Water Sustainability RD&D Office

In Section 1010 of the Energy Act of 2020, Congress directed the DOE and the DOI to establish NEWS and lead an Interagency RD&D Coordination Committee. The membership of the Interagency RD&D Coordination Committee is determined by the co-chairs and includes EPA, USDA, Army Corps of Engineers, the National Science Foundation, Navy, and the Department of Homeland Security. The Interagency RD&D Coordination Committee is directed to develop, within one year, an interagency plan on energy-water nexus RD&D activities, priorities, and objectives. DOE is also directed to integrate specific considerations into DOE's energy RD&D programs and projects including advancing RD&D for energy and energy efficiency technologies that meet the following objectives:

- minimizing freshwater withdrawal and consumption;
- increasing water use efficiency; and
- utilizing nontraditional water sources.

## National Water Reuse Action Plan

The EPA facilitates the development and implementation of the Water Reuse Action Plan (WRAP), which identifies collaborative actions across the water sector and Federal Government to drive progress on reuse for a more resilient water future.[8] Since February 2020, WRAP interagency collaborators, including DOE and USDA, completed 324 implementation milestones. Implementation milestone examples include:

- Implementation and management of the NAWI Energy-Water research hub at DOE.[9]
- DOE hosted a virtual two-day summit on the Future of Water Infrastructure and Innovation and issued a report summarizing proceedings.[10]
- USDA support for water reuse in agriculture resulting in a $15 million investment to help support the adoption of innovative conservation approaches on agricultural lands.

In 2022, EPA formally launched the Water Reuse Interagency Working Group, as directed under the Bipartisan Infrastructure Law. DOE and USDA continue interagency coordination on actions, tools, and resources to advance water reuse as part of this workgroup.

## Water Treatment Interagency Working Group

The DOI's Bureau of Reclamation organizes the WATR Annual Research Coordination Meeting Committee, which includes USDA, EPA, DOE, Department Of Defense, U.S. Geological Survey, National Oceanic and Atmospheric Administration, Centers for Disease Control and Prevention, and the National Science Foundation.[11] Key focus areas that are of interest to DOE

[8] https://www.epa.gov/waterreuse/water-reuse-action-plan
[9] https://www.epa.gov/sites/default/files/2021-04/documents/wrap-update-on-collaborative-progress.pdf
[10] https://www.energy.gov/eere/amo/articles/future-water-infrastructure-and-innovation-summit
[11] https://obamawhitehouse.archives.gov/sites/default/files/pcast_drinking_water_final_executive_summary_final.pdf, page ES-11

and USDA include water availability and quality, the water-energy-food nexus, water/wastewater treatment, and a portal for water-related data. The annual meeting goals include:

- Research Knowledge Sharing, Collaboration & Coordination: Research presentations are a key part of this annual meeting, providing information on the latest Federal water treatment research and allowing for interactive discussions on future research.
- Supporting National Strategies: Numerous WATR participating agencies have been working on national water strategies and implementation in support of the 2016 Water Infrastructure Improvements for the Nation Act. The annual meeting is an opportunity for agencies to discuss their ongoing efforts.
- Focus Areas: Technical Focus Area subcommittees are the heart of WATR knowledge sharing, collaboration, and coordination activities. WATR helps facilitate the forming of subcommittees aligned with agency member coordination needs. Current subcommittees include water quality, innovative technologies, water reuse for indirect/direct and agricultural uses, energy efficiency, cost reduction, environmental impacts, modeling, and smart water systems.

## National Nanotechnology Coordination Office

The NNCO is the coordination office for Federal agencies working in the emerging field of nanotechnology across several application areas such as water.[12] The NNCO acts as the primary point of contact for information on nanotechnology and leads regular meetings of Federal agencies coordinating specifically on nanotechnology for water treatment. DOE's interest is specific to desalination, water/wastewater cleanup, and use of nontraditional water resources. USDA is focused on security/availability of both surface and groundwater resources, nutrient challenges, precision agriculture, and nontraditional water use.

## The Interagency Water Subcabinet

The Interagency Water Subcabinet (WSC) was formalized in October 2020 by Executive Order 13956[13] to maintain high-level Federal coordination among various agencies including USDA and DOE on topics related to water, including energy, water, and agriculture activities. The Water Subcabinet is co-led by DOI and EPA, and includes members from USDA, DOE, U.S. Army Corps of Engineers, and the Department of Commerce. It can be a powerful convener of Federal agencies necessary for collaboration on future water infrastructure investments. As an example, through engagement from DOE as part of the WSC, a new MOU for Federal Hydropower among the DOE, the Bureau of Reclamation, and the Army Corps of Engineers was accelerated due to enhanced collaboration from the WSC.[14] The purpose of the MOU is to facilitate enhanced collaboration and coordination on technology RD&D as well as to identify

[12] https://www.nano.gov/nsiwater
[13] https://www.federalregister.gov/documents/2020/10/16/2020-23116/modernizing-americas-water-resource-management-and-water-infrastructure?msclkid=69b9a83cb9e511ecad094344c055fbcf
[14] https://www.energy.gov/sites/default/files/2020/08/f77/hydro-MOU-2020-signed.pdf

and potentially engage in mutually beneficial research projects that support individual Agency core missions. The MOU establishes topic areas to help position Federal hydropower to meet the nation's need for reliable and affordable renewable hydropower. Additional MOUs among WSC agencies, especially with USDA, could further improve collaboration.

EERE and USDA have a unique role in understanding the inextricable relationship among energy, water, and agriculture. As such, EERE and USDA continue to participate to share this focus and help steer the execution of the Federal Government's investments, especially in the areas of desalination, water/wastewater resource recovery and reuse, hydropower, and irrigation modernization.

# Energy, Water, and Agriculture Nexus Research Collaborations

EERE's technology offices including AMMTO, IEDO, BETO, BTO, GTO, SETO, and WPTO collaborate with USDA in areas of common interest including water (desalination, water treatment, hydropower, and irrigation), bioenergy, lighting, materials science, soil science, water and energy efficiency for industrial processes, the co-location of solar and agriculture, and geothermal direct use and heat pumps. EERE's technology offices often collaborate informally on program planning, exchange of technical expertise, and dissemination of technical results with other agencies. Sharing information and facilitating connections between researchers are high-impact, low-cost ways to further the goals of both Departments. A compilation of these collaborations that have a specific focus on energy, water, and agriculture is provided below and is a starting point for a potential interdepartmental agreement between DOE and USDA that connects research at the National Laboratories, the Agricultural Research Service, and the Forest Service.

## Advanced Manufacturing Research Collaborations

### Desalination Hub

The National Alliance for Water Innovation (NAWI) is DOE's Energy-Water Desalination Hub. NAWI's primary focus is on early-stage research and development (R&D) for energy-efficient and cost-competitive desalination technologies from non-freshwater sources across the United States.[15] NAWI is a public-private partnership led by DOE's Lawrence Berkeley National Laboratory in collaboration with National Renewable Energy Laboratory, and Oak Ridge National Laboratory with over 230 member organizations across the water treatment community.

The NAWI team develops technologies that treat seawater, brackish ground water, wastewater, and produced waters for fit-for-purpose use in municipal, industrial, agricultural, utility, and resource extraction (i.e., oil & gas, mining). NAWI's goal is to enable the manufacture of energy-efficient desalination technologies in the United States at a lower cost with the same (or

[15] https://www.nawihub.org/

higher) water quality and reduced environmental impact for 90% of nontraditional water sources within the next 10 years.

Since it was established in February 2020, NAWI has actively engaged USDA and other agencies to participate in developing five end-user "PRIMA" research roadmaps (i.e., Power, Resource Extraction, Industry, Manufacturing, and Agriculture) to define the RD&D priorities. USDA was an active participant in developing the roadmap for agriculture. All five PRIMA roadmaps were published on May 4, 2021.[16] Additionally, NAWI has released multiple requests for proposals in areas that align with the water treatment needs for the agricultural sector identified in the PRIMA roadmaps.

**Water/Wastewater Resource Recovery**

AMO, now IEDO, is leading RD&D and technical assistance programs to demonstrate advanced water resource recovery schemes. Wastewater from municipalities, industry, agriculture, utilities, and resource extraction (i.e., oil and gas, mining) is a potential source of thermal, chemical, and hydraulic energy—and can contain up to five times more energy than what is necessary to treat it. With the right technology, it is possible to convert or separate wastewater into renewable power (biopower/biofuels), along with chemicals, fertilizers, critical materials, and reusable water – ultimately decarbonizing our water/wastewater treatment processes and creating net zero or net positive facilities. These approaches can also benefit remote, rural, or Native communities that do not have access to large scale water infrastructure or reliable water resources. IEDO has been recently coordinating with USDA representatives on recent funding awards. There were sixteen projects for $27.5 million that were selected including a project with energy-water-agriculture focus on swine waste that was awarded to Kansas State University. In addition, several projects associated with anerobic digester water challenges were also selected. IEDO will continue to work with USDA on future topics for research.

**Water Resource Recovery Prize**

AMO, now IEDO, launched the Water Resource Recovery Prize to accelerate the transition from conventional wastewater treatment to a model of resource recovery from municipal wastewater. Multidisciplinary teams competed in this two-phased competition, that offered cash prizes for cutting-edge water treatment technology system configurations and business plans for small to midsize plants that could help lower the ultimate cost of treatment by extracting additional value from wastewater, which could include agricultural run-off.

## Water Power Research Collaborations

**Irrigation Modernization**

WPTO, USDA, and BOR share a common interest in modernizing irrigation water infrastructure that can help to unlock community benefits including increased revenue for farmers, conserved water to improve intentional management, enhanced water quality, and increased renewable

[16] https://www.nawihub.org/roadmaps

energy development such as small in-conduit hydropower. One of the core investments is often converting canals to pressurized pipes, which increases on-site energy generation potential, gives farmers more control over on-farm irrigation practices, and reduces water loss from irrigation systems operations. Irrigation modernization is an important contributor to decarbonizing agriculture because it reduces energy demand from pumping, improves ability to adopt and enhance smart agriculture practices, and can also support generation of clean energy to charge electrified farm equipment or power other rural electric loads.

WPTO has specifically been working with USDA, and with industry partners like the Farmers Conservation Alliance (a non-profit that helps irrigation districts navigate modernization), to engage national laboratory technical modeling capabilities on advancing these topics.[17] As an example, WPTO identified the cost, technical expertise, and time for irrigation districts to develop modernization plans as a key barrier. Based on this, Idaho National Laboratory (INL) and Pacific Northwest National Laboratory (PNNL) are leading development of IrrigationViz, a tool that helps farmers, districts, and communities design and debate scenarios involving capital improvements to their system.[18] IrrigationViz performs cost-benefit analysis based on local conditions and compares results of multiple scenarios, helping communities to analytically consider various alternatives. As part of the program, WPTO and USDA counterparts have stood up a working group on irrigation that is developing a preliminary framework for a joint demonstration and deployment program.

**Integrated Water Power Resilience**

WPTO's Integrated Water Power Resilience project studies resilience frameworks based on cascading risks in rural communities where water supply, irrigation, and power are inextricably linked. PNNL and INL are leveraging much of the work DOE has conducted on resilience to understand and quantify the resilience implications and opportunities for integrated water-power systems. As part of this project, INL developed a model and performed a case study with an irrigation district that obtains both water and power from a BOR reservoir and associated hydropower facility. Researchers have been collaborating directly with USDA scientists on this work, which is focused on identifying barriers to resilience. They are developing frameworks and tools, supporting coordination, and planning future research and development to turn barriers into opportunities for mutual resilience of the power and water sectors.

**Sustainable Aquaculture**

WPTO and AMO cofunded a recently completed project at the PNNL that addresses kelp harvesting for various needs in coastal Alaska. These needs include renewable energy, food, fuels, and other products that could provide economic benefits to disadvantaged coastal communities. It is widely viewed that Alaska will have a thriving kelp industry within the next 5

[17] https://inl.gov/article/circulatory-systems-of-the-american-west/
[18] https://irrigationviz.pnnl.gov/?msclkid=3e2b4137b9eb11ecbd21ffa594ec2a9b

to 10 years[19] that has the potential to not only lead the United States in kelp production for food (initially), but also become a significant leader in world kelp production with additional nonfood products, including fertilizers, biochemical and food additives, as well as minerals and metals. In addition, the project provides another view of how the Alaska kelp industry could capitalize on the use of fish waste, existing fish processing facilities, and marine renewable concepts to provide additional value and benefit for energy and other products for coastal Southwest Alaska communities. While additional study is needed, Alaska stakeholder communities in the Southwest Alaska Municipal Conference region, and others, could derive significant economic benefits from such a symbiotic relationship.

WPTO has been engaged with the National Oceanic and Atmospheric Administration on sustainable aquaculture and fisheries power needs, including environmental monitoring for aquaculture. This also includes understanding environmental monitoring of macroalgae production, which has the potential to serve as a natural source of carbon dioxide removal.

### Waves to Water Prize R&D

WPTO's marine energy program funds targeted efforts to advance the design of wave energy desalination systems for applications ranging from disaster relief or aquaculture to small-scale community applications as part of the Powering the Blue Economy™ initiative,[20] which includes interests within USDA's aquaculture program. Recently, the program announced the winners of a 5-stage Waves to Water prize to accelerate the development of small, modular, wave-powered desalination systems, end-user focused assessments with communities on functional requirements for small scale systems.[21] Building from this investment, WPTO plans to further develop full-scale desalination technologies from incubation to deployment, focused on remote and coastal communities that could potentially support aquaculture as well as disaster relief applications. Critical to WPTO's long-term effort will be informing the design of systems by integrating end-user needs, customer discovery, co-design principles, and/or community-centered design in the process of technology development. The program expects to see scalable solutions that are fit-for-purpose and effective.

## Solar Energy Research Collaborations

### Solar Thermal Desalination R&D

SETO is funding RD&D and prizes to develop solar thermal desalination technologies to address the challenge of expanding the availability of fresh water for residential, industrial, and agricultural use. This is an opportunity to augment existing freshwater resources in rural agricultural communities through distributed modular systems for water availability. This can be achieved by decarbonizing the treatment of challenging saline water using solar-thermal energy,

[19] https://www.adfg.alaska.gov/Static/fishing/pdfs/mariculture/ak_mariculture_devplan_06-29-18.pdf
[20] https://www.energy.gov/sites/prod/files/2019/03/f61/73355.pdf
[21] https://www.energy.gov/eere/articles/doe-announces-winners-wave-energy-powered-desalination-prize-competition?msclkid=fa68f790b9ec11eca4e0c8168eb928d3

with minimal electricity and conventional energy resources. In 2018, SETO awarded $21 million to 14 projects focused on reducing the cost of solar thermal desalination technologies.[22] Projects are focused on reducing the cost of collecting, storing, and delivering solar heat, improving the efficiency of thermal desalination technologies, and integrating these technologies to cost-effectively treat high-salinity brines that cannot be treated by conventional desalination technologies.

To accelerate the development of realistic demonstrations and exploration of business cases for this technology, SETO launched the $10 million Solar Desalination Prize in April 2020. The Solar Desal Prize is a four-contest program designed to accelerate the commercial development of thermal desalination systems powered by low-cost solar-thermal energy. The Solar Desalination Prize gives innovators a pathway from initial concept to a field-tested system that provides clean, accessible water that can include agricultural use. Based on the overwhelming interest and number of submissions, in April 2021 SETO launched a second round of the prize, with an additional $5 million.

# Opportunities to Leverage Energy Efficiency and Renewable Energy Programs for Agricultural Applications

There are several opportunity areas within EERE that can benefit food insecure communities and the agriculture industry, including industrial processes at AMMTO and IEDO, Lighting and Materials development at BTO, bioenergy and soil science at BETO, solar energy at SETO, and geothermal resources at GTO. These areas include RD&D or technical assistance efforts partially focused on aspects of energy, water, and agriculture and are summarized below.

## Advanced Manufacturing Office (now the Advanced Materials & Technologies Office and the Industrial Efficiency and Decarbonization Office) – RD&D and Technical Assistance

**Better Plants Program**

The Industrial Efficiency and Decarbonization Office's (IEDO's) Better Plants program is an initiative designed to strengthen U.S. manufacturing competitiveness by driving leadership in energy innovation. Through Better Plants, DOE partners with industry leaders to make U.S. manufacturing plants and water and wastewater treatment centers more energy efficient through robust technical assistance and facilitating the sharing of successful best practices. Through Better Plants, partners, including food processors, voluntarily set a specific goal, typically to reduce energy intensity by 25% over a 10-year period across all their U.S. operations.

[22] https://www.energy.gov/articles/department-energy-announces-21-million-advance-solar-desalination-technologies

As a no-cost, voluntary program, Better Plants attracts partners from all different sectors, including many companies associated with food processing. Examples of these partners include Campbell Soup, Agropur, Southwest Cheese, and J.R. Simplot. Partners join Better Plants for a variety of reasons, including national recognition, peer to peer networking and solutions sharing, and technical assistance and resources. Despite the variety of sectors in the program, partners recognize many shared challenges in industrial systems and relish the opportunity to learn from other companies' successful strategies. IEDO works to provide Better Plants partners with helpful tools and resources to overcome barriers and identify opportunities to save energy. Through Better Plants, partners receive support from Technical Account Managers who help facilities develop energy management plans, identify energy-saving opportunities, and track energy performance metrics. In addition to technical guidance, Better Plants partners have access to free tools and software, on-site In-Plant Trainings on various energy savings topics, access to technical assistance programs, and more. To raise USDA's awareness of the Better Plants program and other resources, IEDO is collaborating directly with USDA to extend Better Plants benefits to USDA's stakeholders under the DOE-USDA MOU.[23]

**Industrial Assessment Centers**

DOE's Industrial Assessment Centers (IACs) have traditionally worked with small and medium-sized U.S. manufacturers to reduce their energy use and improve their productivity and competitiveness. Additionally, IACs are now offering up to 50 assessments per year at no cost to industrial or municipal water and wastewater plants. Located at premier engineering universities, there are 24 IACs across the country that train faculty and engineering students to assess energy use, process performance, and waste and water flows at local plants. Under the direction of experienced professors, IAC engineering students analyze energy use of equipment including pumps, motors, compressed air, lighting, process heat, steam and combined heat and power (CHP) systems. The final IAC report provides plants with energy-saving and productivity improvement recommendations including cost estimates and projected payback periods

**Combined Heat and Power Agricultural Applications**

CHP is an energy efficiency and resiliency technology option for the agricultural and food processing sectors. Of the over 4,700 CHP systems in the United States, there are 233 CHP in the agriculture sector and 234 CHP systems in the food processing sector that are in the DOE CHP database.[24] Food processing plants have a diverse range of power and thermal needs ranging from large systems at grain or meat processing centers to smaller systems at local breweries or bakeries. CHP systems are well-suited to meet these needs.

CHP systems allow for the efficient production of electricity and thermal energy from a single source. Compared to the overall efficiency of a conventional generation system with separate

[23] https://www.usda.gov/media/press-releases/2019/10/24/usda-and-doe-join-forces-increase-energy-technology-development-and

[24] https://betterbuildingssolutioncenter.energy.gov/chp/solutions-at-a-glance/us-doe-chp-installation-database

heat and utility power, CHP applications are typically around 25% more efficient, and offer improved reliability and resiliency for end user operations. The increased efficiency and enhanced resilience of CHP systems offer significant financial savings opportunities and economic benefits to a variety of facility and application types. In addition to energy cost savings, CHP systems can lead to facility expansions and increased end-user revenue and productivity, job creation, and economic benefits for surrounding communities. For example, the Clover Hill Dairy, located in Campbellsport, Wisconsin began operation of an anaerobic digester to assist in the treatment of animal waste in which the recovered biogas is utilized to fuel a 300-kilowatt (kW) CHP system.[25] Due to the success of the initial CHP system and expansion of the dairy farm from 1,250 to 2,000 cattle, the farm doubled the size of its digester vessel and then expanded its CHP system with an additional 180-kW system. The excess electricity is sold to the local electric utility, and the waste heat recovered from the system is used to heat the farm's digester, milk house, and parlor. At the Forest Glen Oak Dairy in Dayton Oregon, the dairy waste-to-energy operation was viewed as an important step in upgrading the farm's sustainability and in optimally managing its resources.[26] Collecting and processing the dairy wastes helps protect water quality in local watersheds, while combustion of the biogas naturally produced in many waste decomposition processes keeps methane —a potent greenhouse gas—from entering the atmosphere. The nutrient-rich digester product liquid is used on-site as a fertilizer to grow feed for the cows, and the process also produces an inert fiber through composting for use as clean bedding material for the dairy cows. Excess fiber is sold to nearby vineyards to be used as mulch around the base of grapevines.

While CHP may offer promise, those systems that utilize biogas from anaerobic digestion, present several key challenges in rural and agricultural settings. Often in agricultural settings, the quantities of waste are much smaller than those found in urban settings, and by extension biogas, that are present create economic challenges. Traditional anaerobic digestion systems are capitally intensive and rely on economies of scale. It is not always possible to overcome this scale challenge as the aggregation of waste from multiple sources (e.g., in co-op arrangements) can be cost-prohibitive.

BETO, specifically for several years, has invested in technologies that can improve the economics of anaerobic digestion by exploring ways to increase the yield of biogas from a given volume of waste or design new digester configurations that can reduce the capital footprint. There are also sustainability challenges and barriers to these systems. Air and water quality impacts must be considered at distributed scales to prevent deleterious impacts to health and quality of life on neighboring communities and watersheds. DOE has collaborated with USDA, EPA, and other agencies to ensure that novel approaches identify and can prove that they mitigate key environmental and social sustainability indicators. Lastly, it is important to

[25] https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/CHP_Economic_Success_Stories_0.pdf

[26] https://chptap.ornl.gov/profile/80/ForestGlenOaksDairy-Project_Profile.pdf

acknowledge that digester and CHP systems will not always meet the needs of all agricultural settings. Ultimate feasibility and success of these projects is dictated by local and hyper-local factors. These include but are not limited to quantity of waste, proximity to natural gas pipelines/interconnections, demand for electricity and heat, and access to financing, capital, and incentives.

An emerging U.S. market utilizing CHP technologies is greenhouses. Greenhouses require light, heat, and $CO_2$ for plant production. In additional to CHP providing on-site power generation, the greenhouse can use the thermal heat provided from the system for climate control and the $CO_2$ for plant growth.

IEDO is conducting research and development on combined heat and power technologies to improve their efficiency and cost-effectiveness. IEDO also provides CHP technical assistance to rural communities and food processing facilities through CHP Technical Assistance Partnerships (TAPs). IEDO's 10 regional CHP TAPs help stakeholders and end users understand policies, technologies, and other opportunities about combined heat and power. Their aim is to make facilities including agriculture and food processing facilities around the United States more resilient, energy efficient, and sustainable.

**Manufacturing Institutes and Agriculture**

The AMMTO and IEDO support six Manufacturing USA Innovation Institutes, which are multi-year funded consortia that work with many industry partners in specific technical areas. Two of these institutes, the Clean Energy Smart Manufacturing Innovation Institute (CESMII) and the Rapid Advancement in Process Intensification Deployment (RAPID) manufacturing institute have both funded projects related to agriculture. Smart Manufacturing is the information-driven, event-driven, efficient, and collaborative orchestration of business, physical, and digital processes within plants and factories, and across the entire value chain, which includes agriculture and food processing. CESMII has funded a project with Tyson Foods and ThinkIQ to create smart-manufacturing profiles to optimize yield and material utilization on poultry processing equipment, enabling decisions based on real-time constraints in material flows, operations, and energy consumption in a protein-based food processing environment.[27] This project will demonstrate increased operational efficiencies that could be extended to other food processing and energy-intensive industries.

RAPID is focused on enabling the development of breakthrough process intensification and modular technologies to boost energy productivity and energy efficiency through manufacturing processes in industries such oil and gas, pulp and paper, food processing and various domestic chemical manufacturers. The institute address common barriers that include high capital costs, complexity of intensified modular systems, insufficient design tools and data, lack of standardized protocols, and limited understanding of these technologies by industry. RAPID

[27] https://www.cesmii.org/operational-efficiencies-traceability-improvement-initiative/

recently awarded a project in New York to Cornell University that addresses the growing problem of treatment and disposal of dairy and food wastes. With the right combination of process technologies, these wastes can become a resource for energy and nutrient recovery.[28]

## Building Technologies Office RD&D and Technical Assistance

### Lighting for Agriculture Applications

Lighting, particularly Light Emitting Diode (LED) technology, has significant potential to reduce energy consumption for plant and animal controlled-environment food production. LED technology may improve the effectiveness of production environments by increasing yield, reducing the use of water, and reducing the use of pharmaceuticals and chemicals in the production environment. These LED results as well as others are documented in the executive summary of a DOE Lighting R&D Program report, Energy Savings for Lighting in Horticultural Applications,[29] which shows that lighting for indoor horticulture—which is comprised of buildings with non-stacked indoor farming, vertical farming, and greenhouses with supplemental lighting—used 5940 gigawatt hours of energy (equivalent to 61.5 trillion British thermal units) of source energy consumption using report assumptions) in 2017. If LED use were feasible for the entire sector, the energy used could be reduced by 40%. Additionally, for animal product production, the use of LED technology can improve the health of animals.

The most recent version of DOE's Lighting Research and Development Opportunities (RDO) report,[30] includes a section on lighting agricultural applications, which describes the current state of lighting science as it applies to horticulture and animal agriculture. LED lighting may improve the efficiency of horticulture and controlled-environment operations, which could be further improved through additional research and development. In controlled environment agriculture, plants are the primary receivers of the visible or infrared light emitted from a fixture, and plants have multiple receptors with unique response spectra. Such receptors affect plant growth and development, and light from these fixtures can be tuned to overlap with the spectral response of different receptors.

BTO and USDA have held several meetings to coordinate efforts among ARS, the USDA Office of Chief Scientist, and DOE-supported scientists on RDO. Several specific R&D directions have emerged from those discussions that are aligned with BTO Lighting R&D goals and benefit USDA. Historical and projected LED horticultural efficacy levels can be derived from LED performance projections. As with other LED projections in the RDO report,[31] the efficacy levels can be increased by running the LEDs at a reduced current density, and they can be decreased by increasing the current density. BTO has identified that research into deep red (with an emission wavelength around 660 nanometers) and far red/infrared sources (700-800 nanometers) have

[28] https://www.aiche.org/rapid/projects/integrated-systems-model-sustainably-managing-dairy-and-food-wastes
[29] https://www.energy.gov/sites/default/files/2017/12/f46/ssl_horticulture_dec2017.pdf
[30] https://www.energy.gov/eere/ssl/downloads/2019-lighting-rd-opportunities, page 91
[31] https://www.energy.gov/sites/default/files/2019/02/f59/edit.ssl_rd-opportunities_jan2019..pdf

particularly high potential for seed germination and vegetative growth. While neither the RDO nor other DOE documents have identified specific future targets for photosynthetic or luminous efficacy at these wavelengths, such targets may be considered as part of the BTO's future strategy development.

As more detailed understanding of plants' light needs emerges, more specific plant response spectra may be discovered, and light fixtures can be engineered to optimize plant response. Just as illumination for humans must accommodate multiple functions of light, indoor horticultural lighting must be suitable for multiple plant responses. While not necessary for plant growth, it can be helpful to include visible wavelengths that allow close inspection of plants by humans for nutritional deficiencies, pathogens, or other problems that can be detected visually. It is expected that relevant DOE funding opportunities will balance potential for efficiency gains against the multiple functions that lighting must serve, both for general and specific applications.

**Materials Science for Thermal Storage**

An opportunity area that can be leveraged by the agriculture industry from material science is thermal energy storage research that is led by BTO. BTO focuses on improving the cost and performance of thermal energy storage materials and optimizing systems performance through research and development.

Traditional greenhouses often have poor insulation and inefficient heating and cooling systems that increase energy consumption and operating costs. In such poorly insulated greenhouses, thermal mass can be integrated into the walls and floors to store solar heat during the day for later release during the night.[32] This enables a more stable thermal environment, preventing plant damage, prolonging the planting season when no auxiliary heating systems are used, and enhancing overall greenhouse productivity.

Many forms of thermal mass can be utilized for greenhouses (as well as other buildings), including cement, brick, or barrels of water. More recently, phase change materials (PCMs) are being utilized as an effective means of adding thermal mass to greenhouses. PCMs are materials that typically change from a solid to a liquid and vice versa when absorbing and releasing heat. There are several types of PCMs, such as paraffins, fatty acids, and salt hydrates. PCMs are particularly effective for passive temperature control when there are large diurnal temperature swings (i.e., larger variations between outside day and night temperatures). Salt hydrates are especially promising, because they are typically nontoxic and nonflammable, have a higher energy density, and thus require less space than other classes of PCMs and other forms of thermal mass. PCMs can be readily added to new and existing greenhouses alike. While salt hydrates seem particularly promising for their low-cost and large energy density potential, several hurdles still need to be overcome, including cycling and lifetime issues.

[32] https://www.energy.gov/eere/buildings/thermal-energy-storage

BTO is working on research and development to tackle these material challenges and improve the efficiency, utilization, lifetime, and cost of thermal energy storage. Once these materials and products are optimized with long lifetimes, greenhouse designs of the future will be able to maximize the use of solar heat for year-round heating and reduce cooling demands due to overheating during the summer months, thereby reducing overall greenhouse energy operating costs and enhancing overall greenhouse productivity.

## Bioenergy Technologies – RD&D and Technical Assistance

**Bioenergy and Soil Science**

EERE's research in bioenergy necessitates a collaborative relationship with USDA. This is predominately done through BETO, whose mission is to develop industrially relevant, transformative, and revolutionary bioenergy technologies to enable economically and environmentally sustainable, domestically produced biofuels, bioproducts, and biopower.

While BETO is concerned with the entire supply chain related to the production of cost-effective bioenergy, having specifications to reduce the cost, improve the quality, and increase the quantity of sustainable renewable and reusable carbon-based feedstocks is a primary need. BETO's Feedstock Logistics R&D includes production, as well as research into harvesting, collection, storage, transportation, and preprocess of the feedstocks. This research is done in collaboration with USDA, as USDA-ARS also has a wide portfolio of research related to many aspects of feedstock production, including feedstock breeding. Information is shared between the relevant programs at USDA through the BR&D Board Feedstock Logistics and Feedstock Production & Management Interagency Working Group, which meets regularly through the year. BETO (and other parts of DOE) participated in a working group on the best design for USDA's Rural Energy Pilot Program as well as supported review of proposals.

USDA and DOE coordinate on common issues associated with developing the Bioeconomy, specifically associated with the "industrial Bioeconomy" to displace petroleum and reduce greenhouse gas (GHG) emissions. As described earlier, the BR&D Board was established to coordinate the efforts across agencies with the goal of deploying technologies that maximize the use of biomass as a resource for fuels and products. The effort is co-chaired by DOE and USDA with additional agencies involved. The Operations Committee representing the various agencies involved meets twice a month and additionally coordinates through topical working groups to share data and develop strategies to leverage each agencies' capabilities. Recently, DOE, USDA, and the US Department of Transportation approved a Memorandum of Understanding on the Sustainable Aviation Fuel Grand Challenge.

Recently, BETO has leveraged work within its R&D portfolio and interagency relationships to focus on biogenic carbon drawdown, maximized specifically through sustainable agricultural and forestry land management. This encompasses several pillars of R&D, including landscape design modeling and analysis, carbon flux sensors and tools, and R&D on GHG reduction technologies

in the agricultural and forestry sectors. Landscape design models can be optimized for maximum carbon sequestration, renewable carbon utilization, and/or lowering carbon intensity through various bioenergy technological scenarios. These scenarios may use perennial crop production, agroforestry, forest management, bioenergy with carbon capture and storage, biochar, and other strategies, which, in addition to reducing carbon emissions in the atmosphere, could provide diversified revenue sources for farmers and landowners, including their carbon credit systems. These models support analyses of the most environmentally sustainable and beneficial scenarios utilizing bioenergy technologies for carbon drawdown. BETO supports carbon flux sensor and tool development to advance verifiable quantification of the rate and permanence of particular land management practices and bioenergy technologies by leveraging work from Advanced Research Projects Agency - Energy and DOE Office of Science. Finally, BETO supports further technological development to reduce greenhouse gas emissions overall, such as through advancing resource and energy recovery from rural waste.

BETO's Algae Program collaborates with the USDA via the Biomass R&D Board Algae Working Group on topics including health and safety permitting requirements for bringing algae food to market, in coordination with research and industry stakeholders, as a pathway to lower the costs of algae cultivation for bioenergy and bioproducts. For example, BETO and USDA are jointly funding a project led by Los Alamos National Laboratory that is investigating the impacts of using agricultural wastes such as corn stover to boost the productivity and biochemical composition of microalgae grown for food, feed, and fuels.[33]

Additionally, algae research is a potential R&D area that can be leveraged for controlled environment farming. Algae can be grown to produce fuel, food, food components, feed, and soil amendments and can efficiently produce high quality proteins, carbohydrates, and oils while minimizing land and water use versus traditional row crops. Algae is grown domestically today in both open ponds, greenhouses, and closed "photobioreactors" for commercial-scale specialty food and feed ingredients, as well as nutritional supplements such as omega-3 fatty acids. BETO funds R&D on algae that includes projects to scale up algae in greenhouses under natural light and with $CO_2$ supplementation, as well as many lab-scale projects that involve building advanced lighting systems to study algae growth.[34]

Furthermore, the potential for bioenergy crops to improve soil quality, reverse environmental degradation, and provide ecosystem services is an important area of research. For example, research developed in the agricultural sector could potentially be translated to controlled environment farming. Bioenergy crops have the potential to reverse environmental degradation and provide ecosystem services, including the improvement of soil quality when produced or

[33] https://www.lanl.gov/museum/news/newsletter/2018/08/algae-fuel.php
[34] https://www.energy.gov/sites/default/files/2021-11/beto-algae-solutions-web-oct-2021.pdf

harvested with this aim in mind. Switchgrass and miscanthus can improve water quality, reduce nutrient runoff (e.g., nitrogen, phosphorous), improve water absorption in soils, reduce soil loss (from wind and water erosion), improve overall soil health and quality, increase carbon sequestration relative to row crops, and help with flood mitigation. Switchgrass can be placed in marginal land, riparian buffers, saturated buffers, prairie strips, utility rights-of-way, and dedicated farms. Maintenance irrigation is not required, although it may be needed during establishment. Prairie grass mixtures are another category, with ecosystem services like those of switchgrass. In particular, the strategic planting of prairie strips can deliver multiple ecosystem services compared to the adjacent corn-soybean croplands. The diversity of native prairie grasses may increase soil microbe diversity and thereby enhance ecosystem function.

In addition, short rotation woody crops are useful in poorly draining soil, require low nutrient input, and have little need for herbicides/pesticides. They have the potential to sequester metals and carbon and to increase soil nitrogen retention. Plantations may be in riparian buffers or dedicated fields. They can provide riverbank stabilization and windbreaks, and they can improve soil fertility over time.

Overall, bioenergy crops and the various scenarios in which they are deployed have the potential to sequester carbon biologically (e.g., perennial roots) and technologically (e.g., biochar production, carbon storage in long-lived forest products), improve soil quality, and provide other ecosystem services, all while providing income diversification and displacing petroleum-derived fuels and products with sustainable biofuels and bioproducts (e.g., Sustainable Aviation Fuels).

**Billion Ton Study**

BETO and the DOE National Labs are currently drafting an update to the Billion Ton Report, anticipated for publication in FY23 or FY24. This iteration of the Billion Ton Report is the fourth in a series of Energy Department national assessments that have calculated the potential supply of biomass in the United States. Previous reports have concluded that the United States has the future potential to produce at least one billion dry tons of biomass resources (composed of agricultural, forestry, waste, and algal materials) on an annual basis without adversely affecting the environment. This amount of biomass could be used to produce enough biofuel, biopower, and bioproducts to displace approximately 30% of 2005 U.S. petroleum consumption and would not negatively affect the production of food or other agricultural products. USDA contributes subject matter expertise and forest resource models to ensure maximum accuracy and relevancy.

## Solar Energy R&D and Technical Assistance

**Agriculture and Solar Energy Co-Location (Agrivoltaics)**

Photovoltaic solar generation currently provides 3% of the U.S. electricity supply. According to DOE's Solar Futures Study, solar could account for as much as 40% of the nation's electricity

supply by 2035 and 45% by 2050.[35] To reach these levels, a total of 1 Terawatt (TW) of solar capacity will need to be deployed by 2035 and 1.6 TW will be needed by 2050.[36] Ground-mounted solar will require about 5.7 million acres, or 0.3% of the U.S. contiguous land area in 2035, and about 10 million acres, or 0.5% of U.S. contiguous land area in 2050.[37] While this is a small fraction of US land area, growth in ground-mounted solar can create local land-use competition, particularly in areas where solar facilities are displacing agricultural land.

Co-locating agriculture and solar on the same land, often called "agrivoltaics," could reduce land-use conflicts, preserve America's farmland, and provide benefits to farmers including crop production, livestock grazing, and/or pollinator habitat beneath or between rows solar panels. Some of the potential benefits for farmers include providing a diversified revenue stream, reducing irrigation water needs by shading the plants, improving crop yield, especially in dry or hot areas, and improving crop resistance to extreme weather, such as droughts. Potential benefits for the solar industry include making siting of solar facilities easier, improving photovoltaic (PV) panel performance by cooling the panels, and lowering solar operation and maintenance costs. It is of critical importance to work directly with farmers and agricultural communities, as well as the solar industry, in the siting and design of co-located solar and agriculture to ensure that both sectors can benefit.

Solar co-located with pollinator habitat is becoming more common in the U.S. Fifteen states have guidelines for pollinator seed mixes and management practices at solar facilities.[38] Minnesota alone has 55 solar-pollinator sites.[39] Grazing sheep under solar panels is also becoming more widespread. Data on solar grazing is not currently collected, but the American Solar Grazing Association roughly estimates that about 12,000-15,000 acres of solar sites are maintained with sheep.[40] Cattle are grazed on under solar panels at a few commercial farms.[41] Commercial solar plus crops, which are not as common, can be found in Colorado,[42] Maine,[43] and Massachusetts.

SETO has been funding research on agrivoltaics since 2015. Through the National Renewable Energy Laboratory's Innovative Site Preparation and Impact Reductions on the Environment project, research is being carried out at 29 sites across the country, including at both universities and commercial solar facilities.[44] The project is researching questions such as the economic viability of agrivoltaics using a variety of crops and configurations; agricultural yields in arid

[35] https://www.energy.gov/sites/default/files/2021-09/Solar%20Futures%20Study.pdf
[36] Ibid.
[37] Ibid.
[38] https://fresh-energy.org/beeslovesolar/pollinator-friendly-solar-scorecards
[39] http://bwsr.state.mn.us/sites/default/files/2022-03/List%20of%20HFS%20Sites%203_3_2022.pdf
[40] https://solargrazing.org/
[41] https://solargrazing.org/wp-content/uploads/2019/06/On-Pasture-Co-location-of-solar-agriculture.pdf
[42] https://www.jackssolargarden.com/
[43] https://bluewave.energy/bw-resources/agrivoltaic-pilot-program-on-maine-blueberry-farm-set-to-provide-critical-dual-use-insights
[44] https://openei.org/wiki/InSPIRE

environments; and the impact on natural pollinator populations and nearby agriculture productivity. Research on growing crops under PV panels in the drylands in Arizona found up to a 3-fold increase in crop yield, depending on the crop type, a 50% reduction in irrigation requirements, and a 2% increase in solar panel performance.[45] Research on growing pollinator habitat under PV panels in Minnesota found 3 times more beneficial plant species, a 4-fold increase in pollinator insects, higher energy output from the PV panels, and less mowing required at the solar facilities, which can help lower operational and maintenance costs.[46]

In 2020, SETO expanded its agrivoltaic research portfolio through a funding opportunity,[47] selecting four projects totaling $7 million.[48] These projects are studying the agricultural, economic, and social impacts of co-location on farms in Massachusetts; pasture-based cattle grazing under solar panels in Georgia; and the agricultural, ecological, and economic impacts of pollinator habitats at large-scale solar sites in the Midwest. Another project has established an Agri-Solar Clearinghouse to provide information and technical assistance to farmers interested in agrivoltaics.[49]

In February 2021 and January 2022, SETO and USDA held interagency workshops on the topic of agrivoltaics. The goal of these workshops was to bring together relevant USDA and SETO staff to share their respective expertise and to identify areas for collaboration on research and outreach to stakeholders. The January 2022 workshop was attended by over 100 people, including SETO and USDA funded researchers. [50]

Agrivoltaics have the potential to address land use conflicts and benefit both the farming and solar industries, as well as local communities, but research is needed for agrivoltaics to scale. In addition, existing and future agrivoltaic projects need to be tracked and evaluated for lessons learned. Some of the remaining questions include the economic valuations and tradeoffs for farmers; the environmental and ecological impacts of agrivoltaics; animal welfare and nutrition impacts of solar grazing; and public perception of agrivoltaics projects.

## Geothermal Energy RD&D and Technical Assistance

### Geothermal Applications

Low-temperature geothermal energy is another technology supported by EERE that can be used in agricultural production including both direct use of geothermal fluids and geothermal heat pump applications. Currently, geothermal fluids are used directly in some agricultural

[45] https://doi.org/10.1038/s41893-019-0364-5
[46] Macknick, Jordan. "Multi-year impacts of pollinator-friendly planting at three utility-scale solar sites in Minnesota". Forthcoming.
[47] Funding Opportunity Announcement: Solar Energy Technologies Office Fiscal Year 2020 Funding Program, https://www.energy.gov/eere/solar/funding-opportunity-announcement-solar-energy-technologies-office-fiscal-year-2020
[48] SETO 2020 – Solar and Agriculture, https://www.energy.gov/eere/solar/seto-2020-solar-and-agriculture,
[49] https://www.agrisolarclearinghouse.org/
[50] https://www.agrisolarclearinghouse.org/usda-doe-seto-office-agrivoltaics-workshop/

production. GTO conducts analyses and develops communications that provide key data about the amount of low-temperature geothermal energy available that could be used for agricultural purposes including greenhouse heating, drying, and other food processing needs for thermal energy.[51]

# Conclusion

The RD&D, modeling and analysis, and technical assistance activities supported by EERE can be leveraged for the agricultural sector to lower emissions; provide pathways to decarbonization; increase water quality, security, and availability; support increased food production; and increase energy efficiency for farmers and rural communities. EERE has recently initiated efforts towards decarbonization of industry, agriculture, and other sectors. This RD&D is necessary to decarbonize the agricultural sector, address the impacts of climate change, and reduce the competition for water resources. At the same time, there must be consideration of the effects that climate variability may have on water supplies as well as quality for energy and fuel production. These objectives are not only important to DOE, but they are also important to USDA and other Federal agencies.

Although EERE predominantly supports research in energy efficiency and renewable energy, technologies like waterpower, bioenergy, lighting, material science, environmental control, soil science, water and energy efficiency for industrial processes, and geothermal heat can be applied to challenges in the energy, water, and agriculture nexus. Additionally, new partnerships between DOE and USDA Climate Hubs and extension network would be beneficial for bridging stakeholder needs to research and technical assistance for new technologies applied to USDA stakeholders

To facilitate the transfer of information and technologies across sectors, EERE will continue and expand collaborations with USDA by sharing technical expertise, supporting research at national laboratories, and participating in interagency working groups. The informal collaborations summarized in this report should be considered as a starting point. A potential next step is the expansion of the MOU between DOE and USDA to connect ongoing research at the National Laboratories with research at the Agricultural Research Service as well as many of the other USDA agencies to increase the collective impact of both agencies. The primary benefit to DOE is that the USDA can provide the agricultural technical needs, priorities, and requirements to inform DOE research project investments. A strong USDA/DOE collaboration focused on the nexus of energy, water, and agriculture could allow the USDA and the agricultural community to benefit from the collective technical expertise of DOE and the National Laboratory system and enable a well-defined integrated approach to solving real challenges related to the nexus of energy, water, and agriculture.

[51] https://www.energy.gov/eere/geothermal/low-temperature-coproduced-resources

U.S. DEPARTMENT OF ENERGY

*Office of* ENERGY EFFICIENCY & RENEWABLE ENERGY

**For more information, visit:**
energy.gov/eere/office-energy-efficiency-renewable-energy

DOE/EE-2767 • June 2022