



ASTRO: Facilitating Advancements in Low-Impact Solar Research, Deployment, and Dissemination

Rob Davis¹ and Jordan Macknick²

1 Connexus Energy

2 National Renewable Energy Laboratory

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List of Acronyms

ASTRO	Agriculture and Solar Together: Research Opportunities
CBRE	Coldwell Banker Richard Ellis
CCA	Community Choice Aggregation
DOE	U.S. Department of Energy
EPRI	Electric Power Research Institute
InSPIRE	Innovative Solar Practices Integrated with Rural Economies and Ecosystems
NGOs	nongovernmental organizations
NIPSCO	Northern Indiana Public Service Company
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
PV	photovoltaic
RFP	Request for Proposals
SARE	Sustainable Agriculture Research and Education
SETO	Solar Energy Technologies Office
STRIPs	Science-Based Trials of Rowcrops Integrated with Prairie
USDA	U.S. Department of Agriculture

Executive Summary

The U.S. Department of Energy’s (DOE’s) Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) project evaluates cost-reduction opportunities and assesses the environmental compatibility of solar energy technologies through low environmental impact designs and approaches.

To achieve the project’s aim, DOE brings together researchers from the National Renewable Energy Laboratory (NREL), Argonne National Laboratory, universities, local governments, agricultural and environmental groups, and solar industry partners to conduct field-based research complemented by foundational analytical studies.

The Agriculture and Solar Together: Research Opportunities (ASTRO) advisory group members come from across the United States and represent leading solar industry partners, state agencies, vegetation management companies, and other organizations focused on research, food and agriculture, and the environment. The ASTRO group is a complementary combination of organizations that creates positive feedback loops, sparking and solidifying new connections; accelerate the dissemination of information; and magnify the impact of the InSPIRE project and associated low-impact solar research initiatives.

ASTRO’s work was successful in accelerating the spread of information, increasing research investments from the public and private sectors, and catalyzing additional agrivoltaic project development by industry. Factors contributing to success included:

- The diversity of stakeholder expertise
- A commitment to sharing new design philosophies
- Targeting research that responds to concerns and needs across sectors
- Developing new collaborative ideas across institutions
- Accelerating the progress of research through early feedback from experts.

Tens to hundreds of billions of dollars will be invested in solar energy development in the United States during the next three years (2022–2024) of InSPIRE. Continued acceleration in development may contribute to anti-solar sentiment and local permitting restrictions, bans, and moratoriums that could “drive soft costs to infinity,” as noted in a Solar Energy Technologies Office (SETO) Lab Review (Nilsen 2020). InSPIRE research will document and quantify co-benefits that could broaden support for solar arrays in many configurations. Initial public opinion

“The quarterly ASTRO meetings have served as incredibly helpful prompts and reminders for people working in solar, farming, and conservation to design with more sustainable landscape management practices.”

Dr. Marla Spivak
University of Minnesota

“The ASTRO working group activities offer access to valuable, high-quality information and practice sharing among a diverse stakeholder network that promotes innovation, research, and business process improvements toward sustainable solar energy.”

Marcus Krembs
Enel North America

research indicates that support for solar photovoltaic (PV) technologies can increase when the system design incorporates agriculture. Therefore, continued use and improvement of solar designs and management practices—both for distribution-scale and transmission-scale projects—are critical to continuing to build community support for accelerated solar deployment.

In its discussions and feedback, ASTRO will address this rapid deployment of solar technologies along with other emerging questions related to scaling up agrivoltaic systems, identifying social perspectives and barriers that affect agrivoltaic systems, and developing advanced tools to support improved decision-making regarding agrivoltaic investments.



Figure ES-1. Connexus Energy solar array in Minnesota planted with pollinator-friendly groundcover

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1 Introduction

The U.S. Department of Energy's (DOE's) Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) project evaluates cost-reduction opportunities and assesses the environmental compatibility of solar energy technologies through low environmental impact designs and approaches (Figure 1). The InSPIRE project began in 2015 as an exploration of potential connections between the solar and agricultural industries.

To achieve the project's aim, DOE brings together researchers from the National Renewable Energy Laboratory (NREL), Argonne National Laboratory, universities, local governments, environmental groups, and solar industry partners to conduct field-based research that is complemented by foundational analytical studies.

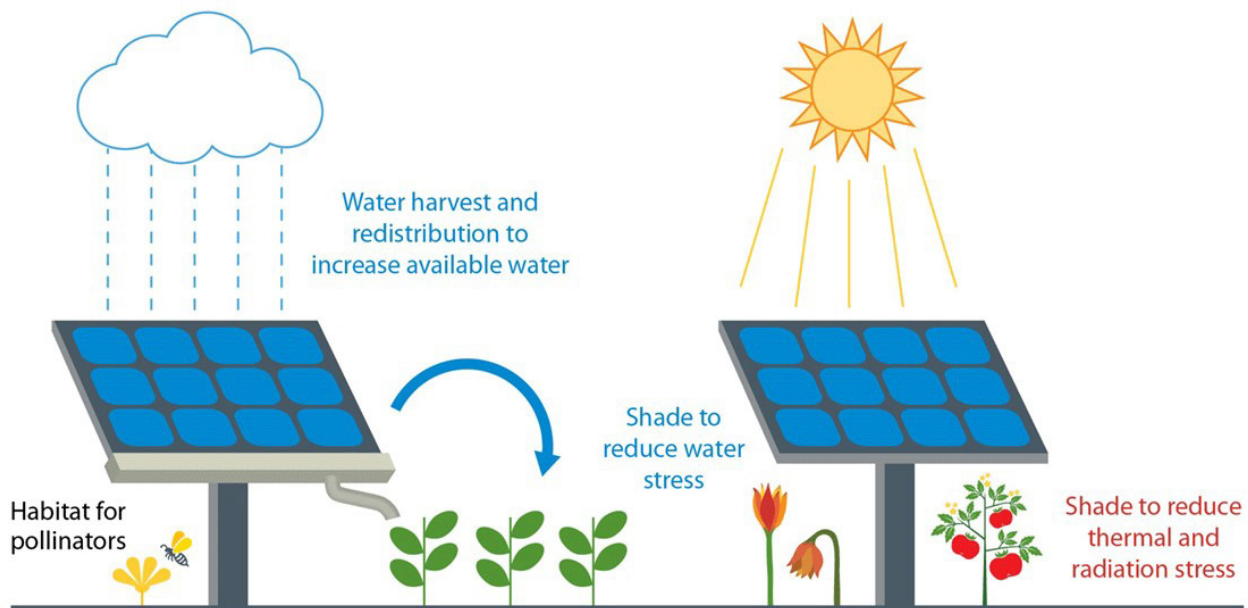


Figure 1. InSPIRE field-based research objectives.

InSPIRE Objectives

The InSPIRE project provides foundational, unbiased data related to solar and environmental synergies and tradeoffs through four core research areas:

- Deployment of solar projects on agricultural lands for mutual benefit
- Long-term ecosystem impact assessments
- Low-impact site preparation practices for ground-mounted solar projects
- Economic evaluation of coupled solar and agricultural systems.

InSPIRE Research Approach

To address these research objectives, the InSPIRE project combines innovative, field-based research with complementary analytical studies. This dual approach provides foundational data to the scientific community while also synthesizing information for landowners, agricultural entities, the solar industry, researchers, and state decision makers. The InSPIRE team utilizes consistent, peer-reviewed methods across all research field plots to ensure comparability, in the

hopes of accelerating research advancements across similar types of sites. Specifically, the InSPIRE team analyzes the ecological and economic implications of:

- Native vegetation growth underneath and around ground-mounted solar installations
- Agricultural crop performance underneath traditional and innovative solar configurations
- Low-impact solar development approaches on soil quality, carbon storage, stormwater management, microclimate conditions, and solar efficiencies
- Pollinator-friendly solar for beneficial insects and improved local agricultural yields
- Economic tradeoffs of various solar development approaches.



Figure 2. Developers and stakeholders tour a solar site planted with regionally native vegetation.

Origins of ASTRO

In 2018, InSPIRE initiated an advisory group to provide feedback on research methods and directions to ensure that the research was targeting the highest-priority needs across sectors using the best available research methods. Other fields, such as urban development and healthcare, have created toolkits to help organizations work with advisory boards (Arnos et al. 2021) and have documented how boards can positively contribute to the rigor and relevance of research (Cronley 2021). The project team recognized the acceleration in both the pace of solar development as well as interest in exploring novel approaches that included synergies with ecosystems and agriculture. Driven by these growing needs, it was essential for the project team to have direct, frequent interactions with leading solar and environmental organizations across sectors. In order to ensure that the solar industry’s long-term investments were successful financially, environmentally, and agriculturally, responsive research was needed.

Members of InSPIRE’s Agriculture and Solar Together: Research Opportunities (ASTRO) advisory group come from across the United States and represent leading solar industry partners, state agencies, vegetation management companies, and other organizations focused on research, food and agriculture, and the environment. With diverse skill sets and areas of expertise, the ASTRO group members form a complementary combination of organizations that create positive feedback loops, sparking and solidifying new connections; accelerate the dissemination of information; and magnify the impact of the InSPIRE project and associated low-impact solar research initiatives.

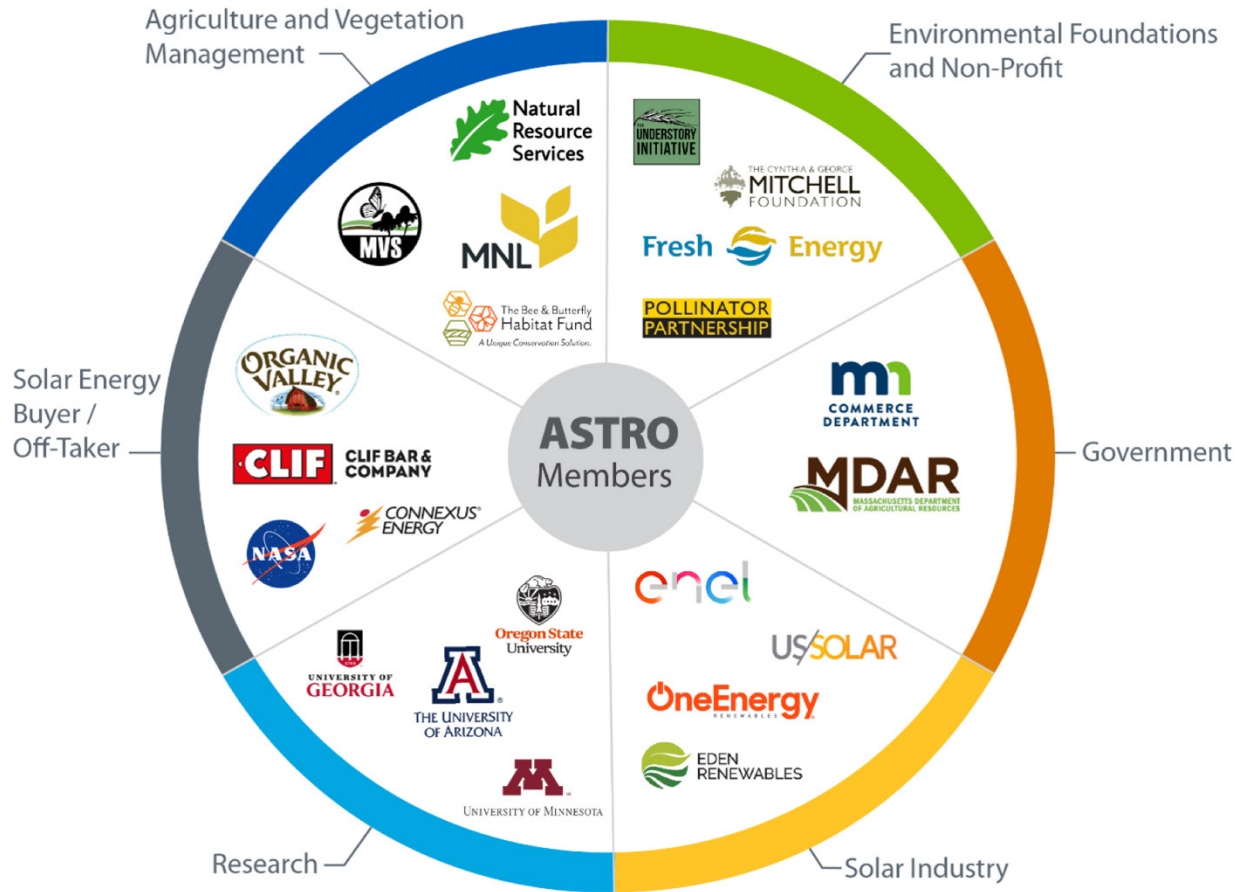


Figure 3. Subset of ASTRO member organizations.

2 ASTRO Background

A key challenge identified in InSPIRE’s first three years was that research insights in one area of the United States may not be applicable to all other areas, given the significant regional differences in soils, climates, crops, local markets, and agricultural knowledge and practices. To facilitate region-specific studies on solar and agriculture with consistent and comparable approaches—along with effective dissemination of information—InSPIRE principal investigators (PIs) and stakeholders wanted the new ASTRO advisory group to create a distributed research network with solar and agricultural experts across the United States. The ASTRO group started with our research project partners, located across 11 states, and expanded organically based on the capacities and needs of stakeholders and emerging trends in solar and agrivoltaics. In particular, this meant focusing on areas where clean energy and non-energy (community and agricultural) interests at the local and state level, particularly in rural areas, were increasingly in conflict. The growing abundance of places where there was emerging research interest by academic, industry, and state partners also contributed to interest in ASTRO. This work leveraged existing decentralized networks that were undertaking similar activities for agricultural practices (e.g., public land grant universities and their extension programs), combining this agricultural network with solar energy expertise and complementary nongovernmental organizations (NGOs).

“Because of the committee and the quality and influence of its experts, we are taking dual-use solar designs considerably more seriously than if we had not been involved.”

Gavin Meinschein
DSD Renewables

“Participating in quarterly calls as a member of this community allows us to immediately contact just the right expert when we have suitable projects for specific agrivoltaic methods.”

Eric Udelhofen
OneEnergy Renewables

2.1 ASTRO Original Composition

The first ASTRO meeting was held on January 3, 2019, with 30 founding members. The members included experienced engineers, scientists, practitioners, and leaders from national laboratories, universities, solar development and management, and agriculture and conservation (Figure 4). Appendix B lists the affiliations of the founding members.

Figure

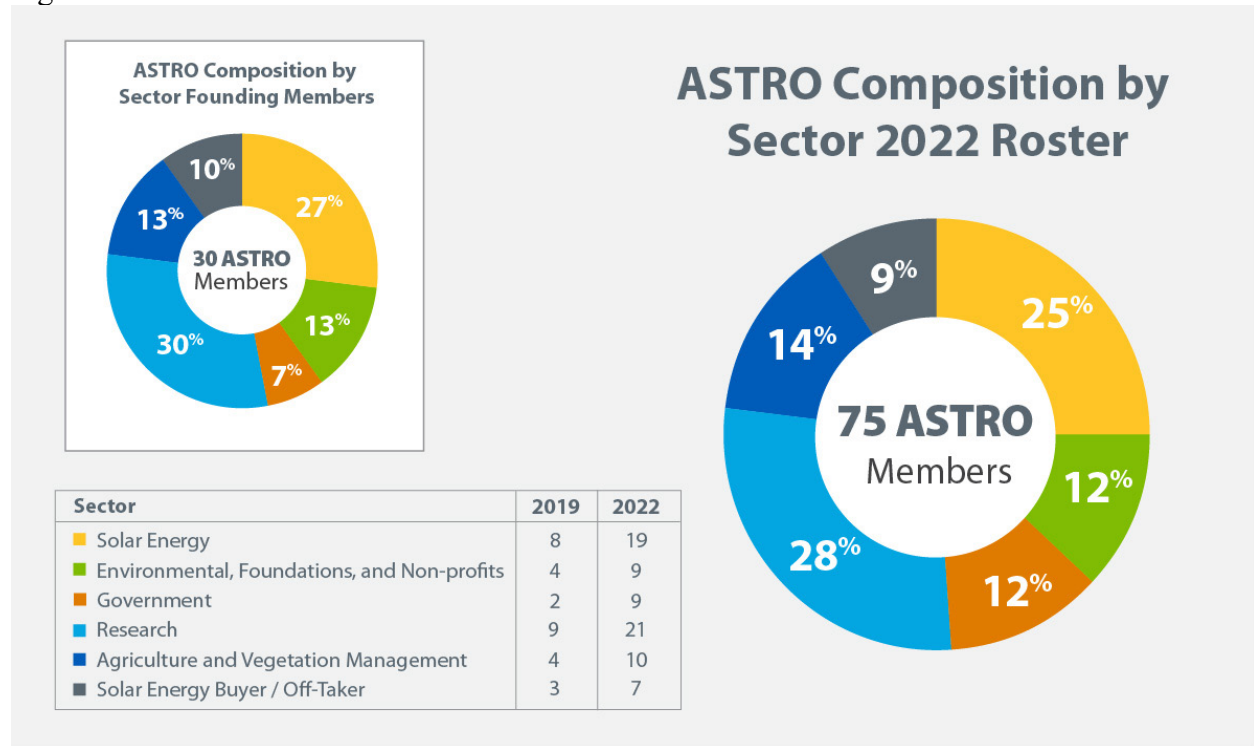


Figure 4. Composition of the ASTRO group by member organization sector in the original January 2019 group (left) and the 2022 roster (right).

2.2 Current ASTRO Composition and Growth

From 2018 to 2021, ASTRO grew from 30 to 99 members across 75 institutions, representing 30 states (Figure 5), while preserving a diverse balance of interests and experience.

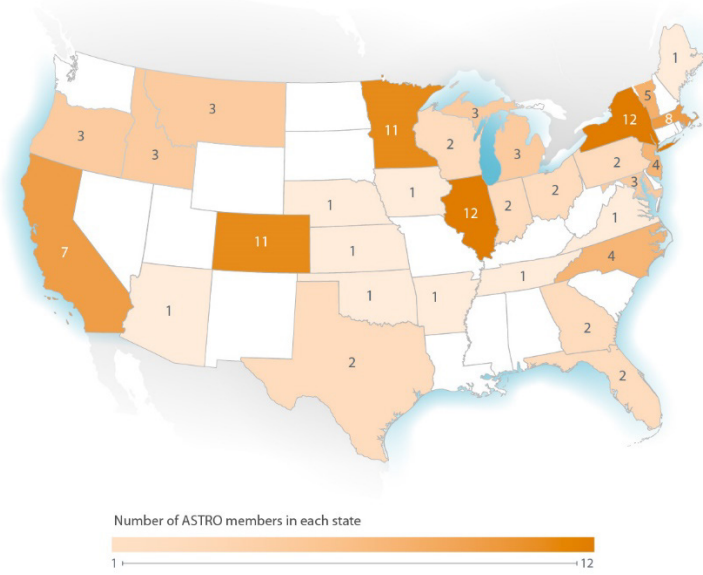


Figure 5. Map of ASTRO member locations.

ASTRO membership grew as a result of increased outreach and awareness by the solar, academic, agricultural, and environmental communities involved in the InSPIRE project. Membership also grew as a result of the increasing interest among the nation’s leading practitioners and researchers in emerging agrivoltaic approaches. As new organizations learned about agrivoltaic opportunities and saw value in presenting their views—while also listening to others who had implemented novel systems—their desire to become regular members of the ASTRO community grew. Quarterly virtual meetings (which became necessary with the onset of the COVID-19 pandemic) consistently drew more than half of the ASTRO members, with the rest able to view the recorded presentations and dialogue (Figure 6).

The diversity of ASTRO members’ professional roles and organizational interests remained a top focus, both in terms of maintaining engagement and attention and in steadily growing ASTRO membership. Proactive outreach to organizations doing relevant and compelling work (in industry, academia, advocacy, and government) was also done, which helped preserve the overall balance of the group over time.

The program of quarterly ASTRO meetings has been a central component of the group’s success and increase in membership. A curated selection of material and presentations that were directly applicable to people’s professional responsibilities and interests, paired with programming that was adjacent to these responsibilities and interests, resulted in consistent and positive feedback.

“I want to commend the ASTRO Advisory Committee for organizing such a talented group of people to continually share solar design concepts and approaches. I am consistently impressed and appreciative of the quality and diversity of presenters on the planned ASTRO meeting calls.”

Gerry Palano
Massachusetts Department of
Agricultural Resources

“I always walk away from ASTRO meetings excited about the growing scientific understanding of how solar PV + habitat can help restore biodiversity to millions of acres of land.”

Elysa Hammond
Clif Bar & Company



Figure 6. Subset of ASTRO members on a quarterly virtual meeting.

2.3 ASTRO Member Activities

Throughout the InSPIRE 2.0 research years, ASTRO members contributed to the InSPIRE project in three primary ways: (1) participated in regular quarterly meetings, (2) peer review of InSPIRE research design plans and research papers, and (3) outreach to the broader scientific and industry communities on InSPIRE research and related topics (Figure 7).

The regular ASTRO quarterly meetings were designed to share information about the most recent research, policy, and industry investment activities related to agrivoltaics. This information sharing also facilitated new partnerships, cross-sectoral research ideas, and insights into other members’ successes and lessons learned. The meetings were virtual, 90-minute calls with 3–5 short presentations from ASTRO members and/or invited guest speakers. A full list of ASTRO presentations and speakers is included in Appendix B; presentation topics and speakers have included:

- Introduction to regenerative energy (Michael Baute, Silicon Ranch)
- Dryland cropping with multiple potato varieties (Amy Garrett, Oregon State University)
- Evapotranspiration from basic, pepper, and tomato crops (Greg Barron-Gafford, University of Arizona)
- Native and naturalized seed mixtures (Pete Berthelsen, Bee and Butterfly Habitat Fund)
- Beneficial insects and conservation biocontrol (John Losey, Cornell University)
- Solar-based beekeeping (Dustin Vanasse, Bare Honey).

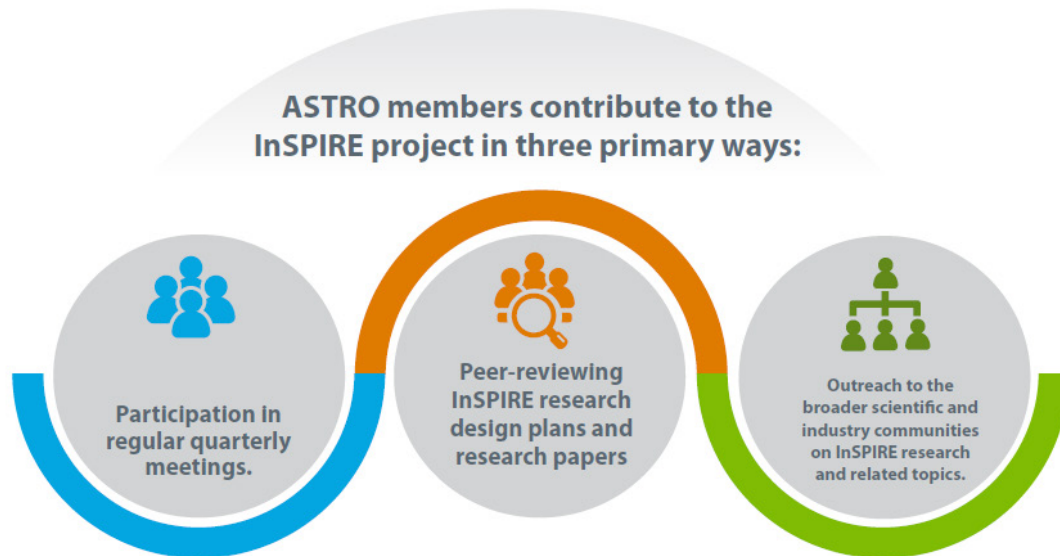


Figure 7. Overview of ASTRO member activities.

Peer review of research plans and research articles is another essential feature of ASTRO. By participating in the peer review process, ASTRO helped ensure that the InSPIRE project conducts research that meets the needs of stakeholders while also following best research practices—in a field where, at times, there are no established methods. Each InSPIRE field project has its methods reviewed by members of ASTRO, including updating field research methods each year as needed. This type of feedback encouraged sharing among researchers and practitioners regarding methods and research outcomes, and can lead to greater consistency and comparability across field sites.

The third key feature of ASTRO is outreach to the broader community. ASTRO members served as a primary gateway for disseminating information about agrivoltaics and the InSPIRE project. The diversity of members by geography, sector, institution type, and existing networks helped accelerate outreach activities and connections to other relevant stakeholders beyond InSPIRE’s traditional research network. ASTRO members conducted proactive engagement with potential new collaborators, researchers, energy buyers, and other stakeholders. Many of ASTRO’s new members were brought on as a result of existing members discussing the value of the advisory group with their community.

3 ASTRO Outcomes and Broader Impacts

The research and shared insights that resulted from ASTRO's work have helped accelerate the spread of information; increase research investments from the private sector, academia, and national philanthropic institutions; and catalyze additional agrivoltaic project development by industry. Highlights of ASTRO’s accomplishments related to information dissemination, research investments, industry deployment, and other relevant outcomes are described below.

3.1 Accelerating the Dissemination of Information

ASTRO activities produced educational content, including webinars and in-person events, as well as sparking interest by a wide range of national and regional, trade and mainstream media.

- Educational content on low-impact and agriculturally compatible PV solar designs and management practices was widely shared:
 - Separate from the ASTRO quarterly calls, more than 30 hours of educational webinars reached a total of more than 3,310 people.
 - More than 36 hours of in-person events in 12 states were attended by 1,780 people.
- More than 45 original media stories during the period of the grant focused on a InSPIRE project site, quoted an ASTRO member, or utilized information from an ASTRO member. Media coverage included a 2021 *Associated Press* story about InSPIRE that was syndicated to more than 230 media outlets nationwide, generating more than 150 million media impressions.

3.2 Increasing Investment in Research

Ongoing research for InSPIRE, in combination with regular ASTRO meetings, has contributed to an increased interest in (and awareness of) state-funded and locally funded agrivoltaic research initiatives. These initiatives involve partners that met or became more familiar with one another's work through ASTRO. Since 2019, ASTRO members have played a role in more than \$12,500,000 of agrivoltaics research.

One such effort involved a group of ASTRO members and other researchers in Illinois. The team collaborated on a successful grant proposal to the U.S. Department of Agriculture's (USDA's) National Institute of Food and Agriculture Sustainable Agriculture Systems program. The USDA's \$10-million, 4-year research grant to the University of Illinois Urbana-Champaign to study agrivoltaics included NREL, the University of Arizona, Colorado State University, and the University of Illinois Chicago.

In another project, the state of New Jersey, noting early agrivoltaic field work in Massachusetts, dedicated \$2 million in funding to Rutgers University to develop regionally appropriate pilot agrivoltaic research projects. Rutgers had previously presented to ASTRO on their ambitions for the (then-anticipated) funding, and ASTRO members provided feedback on the team's project plans.

In yet another effort, the state of Colorado adopted a law that included \$150,000 of dedicated funding for research into agrivoltaic designs and approaches. The governor had a ceremonial signing of the bill at an InSPIRE research partner site, Jack's Solar Garden.

In New York, Cypress Creek Renewables committed \$100,000 over three years for a research partnership with Cornell University. The developer was introduced to the Cornell research team, including assistant professor Scott McArt, through ASTRO. Later, the New York State Energy Research and Development Authority (NYSERDA) awarded an additional \$198,000 to the

American Solar Grazing Association and Cornell University for research on agricultural enterprises related to solar.

In Oregon, the State Department of Agriculture awarded the first-ever Conservation Innovation Grant—to researchers who are also ASTRO members.



Figure 8. Scientist checks stormwater and soil moisture sensors on an InSPIRE project site.

Numerous grants were awarded in Minnesota in connection with ASTRO efforts, including the following:

- The University of Minnesota and the Natural Capital Project received a grant from electric cooperative Connexus Energy for research into ecosystem services and pollinator-friendly solar, following a connection through ASTRO.
- An ASTRO member received a \$50,000 research grant from the Minnesota Department of Agriculture for research that is complementary to the work happening at Cornell University. The grant recipients met through ASTRO.
- Solar grazers developing a commercial wool product received a USDA SARE (Sustainable Agriculture Research and Education) grant. The grant recipient was encouraged to seek this funding by another ASTRO member.
- Monarch Joint Venture received a grant from electric utility Ottertail Power and independent power producer Enel to document wildlife responses to pollinator-friendly ground cover at four solar arrays. NREL and other ASTRO members provided the utility with best practices information about solar ground cover.

In Georgia, Friends of President Carter received a generous donation of perennial wildflower seeds from Ernst Conservation Seeds to use on the president’s 2-MW solar array. ASTRO members, including the University of Georgia, the University of Minnesota, and NREL, are working together to study the site for biodiversity as well as improved stormwater management.



Figure 9. Stakeholders visit Carter Solar in Georgia prior to re-seeding the site with a native seed mix.

Finally, in Florida, after presenting to ASTRO, an ecologist and educator at the Disney Corporation made a business case to internal management that resulted in the creation of a research intern position to study pollinator-friendly ground cover under and around solar.

3.3 Industry Deployment of Low-Impact and Agrivoltaic Projects

In private-sector development, there has been a surge of investment across the country in PV projects that incorporate dual uses and co-benefits for agriculture and ecosystems. All of the partners listed below have participated in ASTRO meetings and have developed new partnerships as a result.

Solar and Crops

- In Colorado, Jack’s Solar Garden (1.2 MW) is partnering with Sprout City Farms and NREL to grow a diverse array of crops. ASTRO members connected the organizations and have multiple research studies at the site.
- In Maine, BlueWave Solar is pairing solar with blueberry crops on a 4.2-MW project. BlueWave staff have had regular engagement with ASTRO research and development members.
- In Massachusetts, developers—including Pine Gate Renewables, an ASTRO member—are pursuing elevated solar (1–5 MW) above cranberry bogs.
- In Minnesota, ASTRO member OneEnergy Renewables is partnering with Featherstone Farms for a 1–3-MW solar array with a diversity of crops near MiEnergy Electric Cooperative’s headquarters. In addition, SunShare Solar is working with Ames

“My colleagues and I are incredibly grateful to the Department of Energy for funding this work at the National Renewable Energy Lab. Every ASTRO meeting teaches us something new, collaboration happens, and collectively we are developing solutions in PV solar landscape design and management.”

Colleen Hollinger
Natural Resource Services

Farm and Tangletown Gardens on raised bed vegetable crops in the rows of a solar array, using advice from multiple ASTRO members. Finally, ASTRO member Connexus Energy is working with Prairie Restorations for the nation's first solar project to include commercial seed production and harvesting.

Solar Grazing

- ASTRO member Silicon Ranch and its partner, White Oak Pastures/Will Harris, are rotationally grazing several thousand head of sheep on solar projects in Georgia, Tennessee, and Missouri (>100 MW).
- ASTRO member Enel Green Power is having Minnesota Native Landscapes graze more than 1,000 head of sheep around the 100-MW Aurora Solar project.
- Nexamp is working with ASTRO member American Solar Grazing Association to have sheep graze several 2–5-MW projects in New York.

Solar Beekeeping

- In several midwestern states, Bare Honey is managing honeybee hives on several pollinator-friendly solar farms. They have created a national marketing relationship with ASTRO member Clif Family Winery (founders of Clif Bar), resulting in Clif Family Solar Grown honey winning a series of national awards.
- In Vermont and New York, Bee the Change is working with ASTRO members Encore Renewables and Greenbacker Capital to tend both honeybee hives and vegetation on their solar farms.
- Old Sol Apiaries in Oregon has more than 40 hives outside the fence of a 10-MW InSPIRE project site built and operated by ASTRO member Pine Gate Renewables.

In addition to the rapidly growing number of projects that use agrivoltaic designs, a variety of energy buyers are implementing procurement policies that favor dual-use solar. For example, mechanisms encouraging pollinator-friendly ground cover on solar have been utilized by private industry, including the following:

- In California, MCE Clean Energy is including pollinator-friendly ground cover requirements in its future solar Request for Proposals (RFPs) process. The core RFP language was drafted by Ben Foster of Fosterra LLC. (a previous SETO grant recipient) thanks to a grant provided by ASTRO member Clif Bar & Company. ASTRO member Fresh Energy facilitated the connection between Clif Bar, Foster, and MCE.



Figure 10. Executives from conservation nonprofit Pheasants Forever and other stakeholders visit an Enel Green Power site in the InSPIRE study.

- In Minnesota, Xcel Energy, one of the nation’s largest electric utilities, included ground cover requirements in its latest solar RFP, resulting in an announcement for a 480-MW solar project with pollinator-friendly ground cover. ASTRO member Fresh Energy worked closely with Xcel Energy leadership to further refine and expand the RFP language (first created for MCE) and publicly recognized Xcel’s commitment in front of key audiences—a large regional symposium of pollinator advocates and the nation’s largest gathering of pheasant hunters and conservationists.
- In Indiana, the Northern Indiana Public Service Company (NIPSCO) included pollinator-friendly ground cover requirements in its 2021 solar RFP. ASTRO member Fresh Energy introduced NIPSCO to the expertise of the Bee and Butterfly Habitat Fund, which built confidence and trust in the approach. A firestorm of opposition to large-scale solar from several Indiana counties prompted researchers from Purdue University and other stakeholders to contact ASTRO members for additional information about best-practice solar designs that benefit pollinator-dependent agriculture.
- Large corporations Clif Bar & Company, Bank of America, Iron Mountain, and CBRE are including pollinator-friendly ground cover requirements in their solar RFPs or encouraging their suppliers to request pollinator-friendly solar. ASTRO member Fresh Energy was contacted by Clif Bar for assistance on a planned pollinator-friendly solar array at the company’s newest bakery. Through conference presentations and networking, Clif Bar and Fresh Energy worked with other organizations, including providing a presentation to several hundred sustainability and energy professionals hosted by

GreenBiz. Walmart Corporation installed pollinator-friendly ground cover¹ at a solar array adjacent to one of its distribution centers in South Carolina and encourages its fresh fruit suppliers to establish pollinator habitat on at least 3% of their land,² including pollinator-friendly solar.

- Aveda, the natural beauty brand, and Giant, the multinational grocery retailer, included pollinator-friendly ground cover requirements in each of their 1-MW headquarter solar projects. ASTRO member Fresh Energy connected both organizations to skilled practitioners, who were ultimately selected to seed and manage the ground cover.

3.4 Additional Beneficial Research and Outreach Outcomes

The ASTRO network is prompting participants to secure new funding and develop new collaborations that will accelerate analysis and identification of best practices.

In one such partnership, ASTRO members that had previously collaborated provided inspiration and input into the creation of the world’s first LEGO kit for a solar farm.³ The PDF instructions⁴ for the LEGO set include direct links to InSPIRE research. In a separate effort, other ASTRO members that had previously collaborated provided case studies and feedback for the creation of a chapter on low-impact and pollinator-friendly solar⁵ in a new book from Princeton Architectural Press. And in another collaboration, ASTRO members produced an educational display which cites InSPIRE research at the nation’s largest State Fair, held annually in Minnesota.



Figure 11. Educational materials use InSPIRE research to engage new audiences.

¹ <https://corporate.walmart.com/newsroom/2021/04/13/restoring-pollinator-habitats-is-key-to-feeding-the-future>

² <https://corporate.walmart.com/policies#walmart-u-s-pollinator-health-position>

³ <https://www.nrel.gov/news/program/2021/giving-kids-the-building-blocks-to-envision-a-solar-future.html>

⁴ <https://drive.google.com/file/d/1X2ceG6V8c5y-j5bIHFTjnxjyNWLqNZX/view>

⁵ https://issuu.com/papress/docs/goodenergy_robDavis1

ASTRO members that had not previously worked together have also developed new collaborations. In one such partnership, members took existing knowledge from 2018 (bird mortality can happen with PV solar in the southwestern United States) and explored questions and published research⁶ related to other wildlife, specifically pollinators. In other new collaborations, ASTRO members secured funding and collaborated to publish research⁷ related more broadly to ecosystem services, and collaborated to highlight and publish research⁸ on the numerous different PV solar designs and the ways they might interact with nature.

4 ASTRO Moving Forward

In three years, ASTRO has evolved in ways that reflect both the overall growth of the solar industry and the regional, national, and international interest in solar PV designs that provide co-benefits and drive down solar soft costs. Anti-solar sentiment has been noted in a previous SETO Peer Review as a contributing factor that can “drive soft costs to infinity” (Nilsen 2020). Insights from research on other forms of development including cellular towers and natural gas development (Smith 2015; Wilke 2020) may hold insights for development of PV solar. For example, in addition to documenting and quantifying co-benefits, initial public opinion research (Pascaris 2021) indicates that support for PV solar can increase when a system design incorporates agriculture.

Importantly, through the InSPIRE/ASTRO research and network, diverse PV solar designs are emerging that give energy buyers, local and state planners and regulators, and industry a growing number of feasible options and pathways to continue to support accelerated solar deployment.

Looking forward, continuing to engage and work with agricultural partners—including all other DOE-funded projects in the agrivoltaics space—will be beneficial, as will strengthening and expanding ASTRO participation to involve more university energy and agriculture extension educators. During the past three years of InSPIRE, extension educators individually reported benefiting from hearing about the diversity of quality, low-impact, and agrivoltaic projects advancing nationwide.

During the next three years (2022–2024) of InSPIRE, tens to hundreds of billions of dollars will be invested in solar energy development in the United States—investments complemented by public resources in the form of the Federal Solar Investment Tax Credit and various state policies. Continued use and improvement of solar designs and management practices—both for distribution-scale and transmission-scale projects—is critical to continuing to build community support for accelerated solar deployment. In its discussions and feedback, ASTRO will address this rapid deployment of solar technologies along with other emerging questions related to scaling up agrivoltaic systems, identifying social perspectives and barriers that affect agrivoltaic

⁶ <https://doi.org/10.1021/acs.est.8b00020>

⁷ <https://doi.org/10.1016/j.ecoser.2020.101227>

⁸ <https://doi.org/10.1038/s41893-019-0309-z>

systems, and developing advanced tools that could support improved decision-making regarding agrivoltaic investments.

Complementing this work related to industry trends, ASTRO is also implementing a competitive seed research grant initiative that will help emerging researchers and students take on innovative projects where they can get direct funding and guidance from the ASTRO community. The ASTRO seed grants are small financial grants that will catalyze and support novel agrivoltaics research according to the following three pillars:

- 1) Providing opportunities to emerging, first-time, and junior researchers, including undergraduate, graduate, and advanced high school students (who may play a supporting role on projects). Combining PV solar with other uses and functions creates opportunities to benefit people from a diverse set of backgrounds and skillsets. Seed grants target applicants from under-resourced and/or historically marginalized communities.
- 2) Addressing timely issues that require a response with research that can be completed and reported on within 6–9 months. Projects need not require full-time effort (e.g., summer internship) and may also be completed in conjunction with unrelated studies or work.
- 3) Studying approaches and outputs that will advance the field of agrivoltaic research and deployment.

“ASTRO meetings have been incredibly useful in my role as a university extension educator. Farmers, community leaders, and others rely on extension to disseminate best practices and share applicable research and case studies. With ASTRO, we have access to a national view and network of partners exploring topics directly relevant to the interests of the communities served by Michigan State University.”

Charles Gould
Michigan State University

The ASTRO seed grants will provide a mechanism to help train the next generation of agrivoltaic scholars, while simultaneously advancing research that benefits the stakeholders that comprise ASTRO. ASTRO will continue to evolve and respond to critical needs across sectors, ensuring that InSPIRE research and other associated research efforts provide the most value to the community.

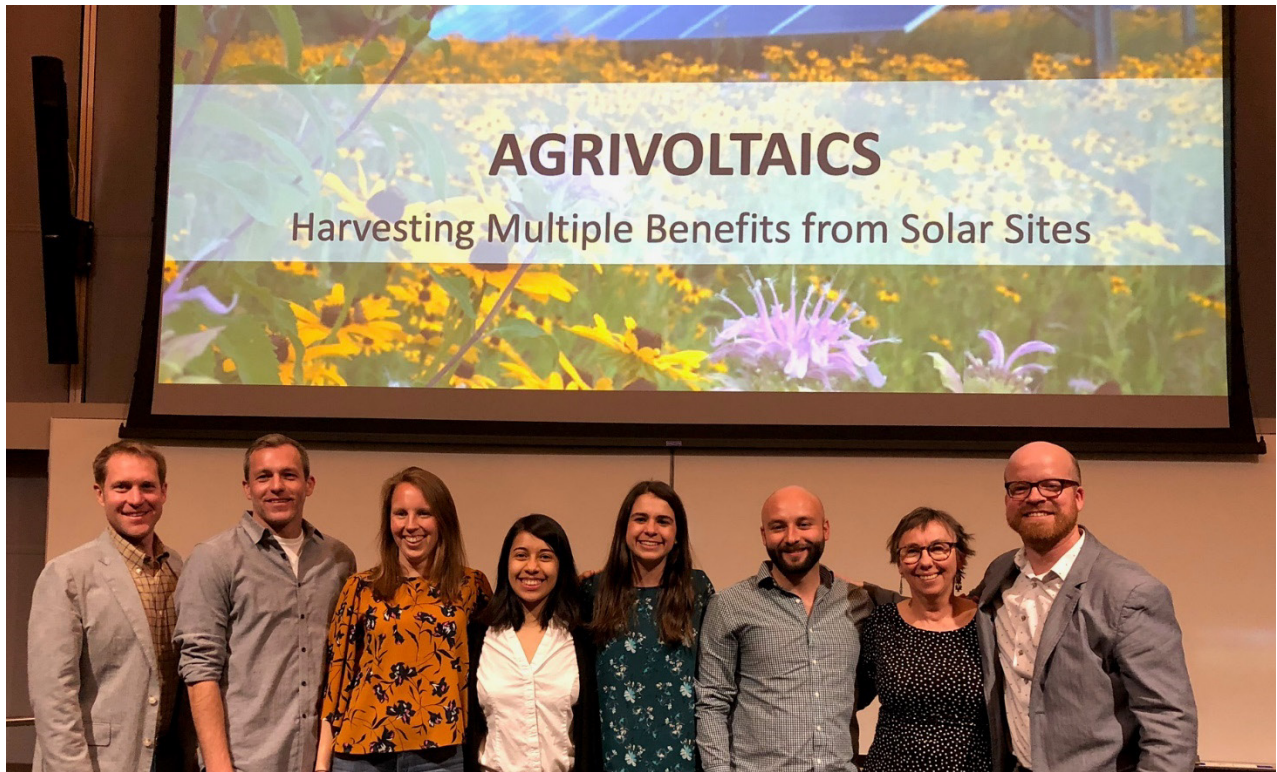


Figure 12. Graduate students research agrivoltaics and produce an event to share insights.

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Appendix A. Appendix A. Testimonials From Participants

“For most of the last decade there has been an ‘all hands on deck’ call for more acres of plants that provide nectar and pollen to sustain pollinator populations. The quarterly ASTRO meetings have served as incredibly helpful prompts and reminders for people working in solar, farming, and conservation to design with more sustainable landscape management practices.”

— Marla Spivak, University of Minnesota

“The ASTRO group connected researchers to a network of landscape and agricultural experts as well as solar developers, that allows us to pursue novel research quickly and collaboratively. The ASTRO group remains a high-value network for our continued research and outreach efforts.”

— Steven Grodsky, Cornell University

“Enel Green Power is leading the transition to a decarbonized society and is innovating toward a new era of sustainable energy. The ASTRO working group activities offer access to valuable, high-quality information and practice sharing among a diverse stakeholder network that promotes innovation, research, and business process improvements toward sustainable solar energy. As an organization, Enel Green Power is committed to sustainable, and increasingly circular, energy systems design, construction, and operations, while continuously seeking to improve practices that enable solar growth in rural communities and accelerate toward an inclusive energy transition.”

— Marcus Krembs, Enel Green Power

“My colleagues and I are incredibly grateful to the Department of Energy for funding this work at the National Renewable Energy Lab. Every ASTRO meeting teaches us something new, collaboration happens and collectively we are developing solutions in PV solar landscape design and management.”

— Colleen Hollinger, Natural Resource Services

“I want to commend the ASTRO Advisory Committee for organizing such a talented group of people to continually share solar design concepts and approaches. I am consistently impressed and appreciative of the quality and diversity of presenters on the planned ASTRO meeting calls. The organizers demonstrate a great instinct for balancing information about a wide variety of relevant solar design topics. No doubt, in every meeting I learn something new or find new connections.”

— Gerry Palano, Massachusetts Department of Agricultural Resources

“OneEnergy Renewables is grateful for the connections, research, and best practices that we have learned about through the ASTRO advisory committee. Participating in quarterly calls as a member of this community allows us to immediately contact just the right expert when we have suitable projects for specific agrivoltaic methods.”

— Eric Udelhofen, OneEnergy Renewables

“I always walk away from ASTRO meetings excited about the growing scientific understanding of how solar PV + habitat can help restore biodiversity to millions of acres of land. I’m equally inspired by my ASTRO colleagues—sharing their expertise from engineering to entomology from universities, nonprofits, businesses, and government agencies across the country.”

— Elysa Hammond, Clif Bar & Company

“Participating in the ASTRO advisory committee has been a significant benefit to engaging my company with thinking about dual-use solar practices. Because of the committee and the quality and influence of its experts, we are taking dual-use solar designs considerably more seriously than if we had not been involved.”

— Gavin Meinschein, DSD Renewables

“ASTRO meetings have been incredibly useful in my role as a university extension educator. Farmers, community leaders, and others rely on extension to disseminate best practices and share applicable research and case studies. With ASTRO, we have access to a national view and network of partners exploring topics directly relevant to the interests of the communities served by Michigan State University.”

— Charles Gould, Michigan State University

Appendix B. Original Members of ASTRO

Universities/Research Organizations/Nonprofits (15)

- University of Minnesota, MacArthur Genius Award winning researcher and contributor to the nation’s first pollinator-friendly solar scorecard
- Michigan State University, blueberry ecologist, wild pollinator expert, and extension educator
- Wychwood Biodiversity, CEO and principal investigator of world’s first scientific study of pollinator-friendly solar
- University of Massachusetts-Amherst, pioneering researcher with first dual-use crops/PV system in the Northeast
- University of Arizona, pioneering researcher with first dual-use crops/PV system in the Southwest
- Cornell University, pioneering researcher with first pollinator-friendly and grazing PV system in the Northeast
- Oregon State University, pioneering researcher with first dual-use crops/PV system in the Northwest
- University of California-Davis, founder of the Wild Energy Lab
- University of Georgia, entomologist and extension educator working on President Carter’s solar array in Plains, Georgia
- Electric Power Research Institute (EPRI), practice lead for “Power in Pollinators” research initiative
- North Carolina Botanical Garden, executive director and pollinator habitat expert
- Colorado Butterfly Pavilion, executive director and pollinator habitat expert
- Bee and Butterfly Habitat Fund, CEO and national pollinator habitat seed mixture expert
- Fresh Energy, founding director of the Center for Pollinators in Energy
- Pollinator Partnership, executive director of national organization for pollinator habitat conservation.

Industry/Solar Developers (10)

- Clean Capital, CEO and former U.S. Chief Resilience Officer
- Enel, one of the world’s largest renewable energy developers and operators
- Engie, lead engineer of distributed solar systems for the world’s largest independent power producer
- Pine Gate Renewables, environmental lead for first pollinator-friendly solar sites in the Northwest
- U.S. Solar Corporation, development and policy leads for company with large development pipeline for Walmart Corporation
- Cypress Creek Renewables, New York development lead
- OneEnergy Renewables, development director of projects for Organic Valley and Clif Bar
- Eden Renewables, CEO of UK-based company that began building pollinator-friendly solar projects in 2014
- Understory Initiative, leading landscape consultant in the Northwest

- Prairie Restorations, leading landscape consultant in the Midwest.

Solar Energy Buyers (3)

- Organic Valley, renewable energy procurement manager of nation's largest co-op dairy
- Clif Bar & Company, senior vice president of environmental stewardship
- Connexus Energy, vice president of power generation for the Midwest's largest electric cooperative and owners of the nation's first pollinator-friendly solar project.

Government (2)

- Massachusetts Department of Agriculture
- Minnesota Department of Commerce.

Appendix C. Quarterly ASTRO Meetings 2019–2021

Date	Speakers and Topics	Archive link
Winter 2019	Lexie Hain of American Solar Grazing Association, Jake Marley of Hyperion Solutions, and Jorge Figueroa of Jorge Figueroa Environmental Solutions, LLC	
Summer 2019	Amy Garrett of Oregon State University, Greg Barron-Gafford of University of Arizona	
Fall 2019	Stephen Herbert of the University of Massachusetts, Heidi Hartmann and Lee Walston of Argonne National Laboratory	Recording
Winter 2020	<p>Jason Schmidt of the University of Georgia reports on successful seeding of President Carter's solar farm with John Buffington of SolAmerica</p> <p>Enel Green Power site report-out</p> <p>NREL's PV-SMaRT study (hydrology and stormwater)</p>	Recording
Spring 2020	<p>Zak Gezon of Disney discusses the research the organization is doing on the four acres of pollinator habitat outside their newest solar array</p> <p>Michael Baute of Silicon Ranch discusses the business'</p>	Recording

Date	Speakers and Topics	Archive link
	<p>grazing and regenerative agricultural practices</p> <p>Lexie Hain of American Solar Grazing Association and Lindsey White of Ernst Pollinator Services discuss "Fuzz & Buzz," a new suite of seed mixes and management practices intended to benefit sheep and bees</p> <p>Lee Walston of Argonne National Laboratory will discuss preliminary results of a new paper on ecosystem services and pollinator-friendly solar</p>	
Summer 2020	<p>Amy Garrett of Oregon State University discusses dryland cropping with potato varieties</p> <p>Chad Higgins of Oregon State University discusses grazing and vegetation performance</p> <p>Pete Berthelsen of the Bee and Butterfly Habitat Fund discusses native/naturalized and other seed mix insights and work with the United States Geological Survey</p> <p>Robin Ernst of Ernst Pollinator Service shares experience with plugs on two InSPIRE sites</p>	Recording

Date	Speakers and Topics	Archive link
	Dan Schibel of Aveda discusses pollinators in the energy procurement process	
Fall 2020	<p>Byron Kominik of Jack's Solar Farm</p> <p>Sujith Ravi of Temple University</p> <p>John Losey of Cornell University discusses ladybugs and beneficial insects</p> <p>Jake Janski of MN Native Landscapes discusses grazing</p> <p>Charles Gould discusses Michigan State University's new solar project</p>	Recording
Winter 2021	<p>Four 2021 DOE FOA awardees:</p> <p>Stephen Herbert of the University of Massachusetts discusses specialty crops under elevated, spaced panels</p> <p>Iris Caldwell of the University of Illinois discusses pollinator-friendly ground cover</p> <p>Michael Baute of Silicon Ranch discusses grazing cattle</p> <p>Stacie Peterson of the National Center for Appropriate Technology (NCAT)</p>	Recording

Date	Speakers and Topics	Archive link
	discusses the Agri-Solar Clearinghouse	
Spring 2021	<p>Maggie Graham of Oregon State University discusses her 4-month, 12-visit observational study of a pollinator-friendly 9.5-MW solar array</p> <p>Juliana Isaacs of Sol Systems discusses the company’s 12-MW bifacial solar with tracking panels at the University of Illinois</p> <p>Javier Damia Levy of Aztec Engineering discusses how higher torque-tube heights can result in reduced grading costs and less soil disturbance</p> <p>Abby Arnold of American Wind and Wildlife Institute discusses an upcoming solar symposium</p>	Recording
Summer 2021	<p>Max Trommsdorff of Fraunhofer Institute reports on AgriVoltaics 2021</p> <p>Kelly Rourke of Pollinator Partnership reports on their work with MCE Clean Energy (California-based electric service provider)</p> <p>Stephen Herbert of University of Massachusetts-Amherst</p> <p>Matthew O’Neal of Iowa State University talks about prairie strips (Iowa State Science-Based Trials of Rowcrops Integrated with</p>	Recording

Date	Speakers and Topics	Archive link
	<p>Prairie Strips[STRIPs] Project) and a recent article in <i>Entomology Today</i> with Adam Dolezal</p> <p>Agriculture extension educator David Specca of Rutgers University talks about the university’s agrivoltaics research, expecting to initially focus on nursery crops and vegetables</p> <p>Monarch Vegetation Services discusses its pollinator habitat project with Giant headquarters</p>	
Fall 2021	<p>Ebony Murrell of The Land Institute discusses co-location of silphium perennial crop and solar</p> <p>Alexis Pascaris of Michigan Technological University discusses agricultural producer attitudes and solar</p> <p>Alan Knapp of Colorado State University discusses low-growing arid grassland and solar</p>	Recording