U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

USDA-DOE Agrivoltaics Workshop

Welcome!

We will begin shortly.

Agenda

Session	Time (ET)	Title
Session 1: Introduction from Agencies (45 mins)	12:00 – 12:05	Welcome!
	12:05 – 12:15	Introduction from DOE Leadership
	12:15 – 12:30	USDA Climate-Smart Agriculture and Forestry Strategy
	12:30 – 12:45	DOE Agrivoltaics Portfolio
12:45 – 12:50, Break!		
Session 2: New and Ongoing Research Projects (1 hr, 50 mins)	12:50 – 1:30	New DOE Research Project: InSPIRE 3
	1:30 – 2:10	New USDA Research Project: UIUC Agrivoltaics
	2:10 – 2:40	Panel: DOE Research Project Updates
2:40 – 2:50, Break!		
Session 3: Industry Perspectives (1 hr, 10 mins)	2:50 – 3:20	Panel: Industry Perspectives
	3:20 – 3:25	Introduction to Breakout Sessions
	3:25 – 3:55	Parallel Breakout Sessions
	3:55 – 4:00	Farewell

Welcome from DOE Solar Office

Garrett Nilsen

Acting Director, Solar Energy Technologies Office

Office of Energy Efficiency and Renewable Energy

Department of Energy

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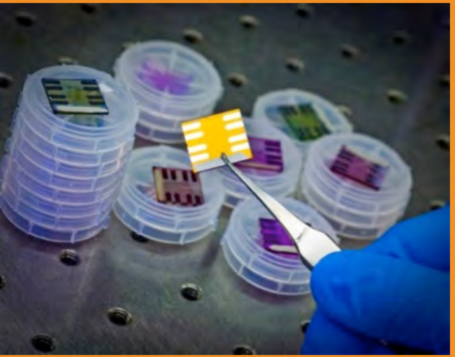
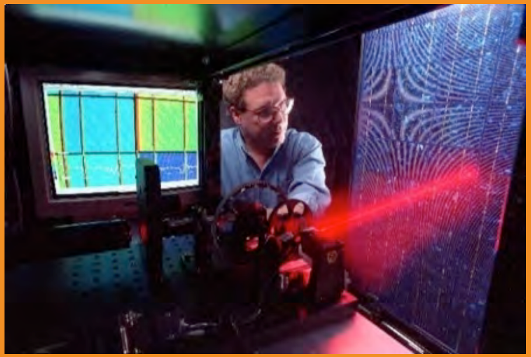



Welcome from SETO

Garrett Nilsen, Acting Director
Solar Energy Technologies Office

energy.gov/solar-office

January 10, 2022

Solar Energy Technologies Office (SETO) Overview

MISSION

We accelerate the **advancement** and **deployment of solar technology** in support of an **equitable** transition to a **decarbonized energy system by 2050**, starting with a decarbonized power sector by 2035.

WHAT WE DO

Advance solar technology and drive soft cost reduction to make solar **affordable** and **accessible** for all Americans

Enable solar to **support grid reliability** and pair with storage to provide new options for **community resilience**

Support **job growth**, **manufacturing**, and the **circular economy** in a wide range of applications

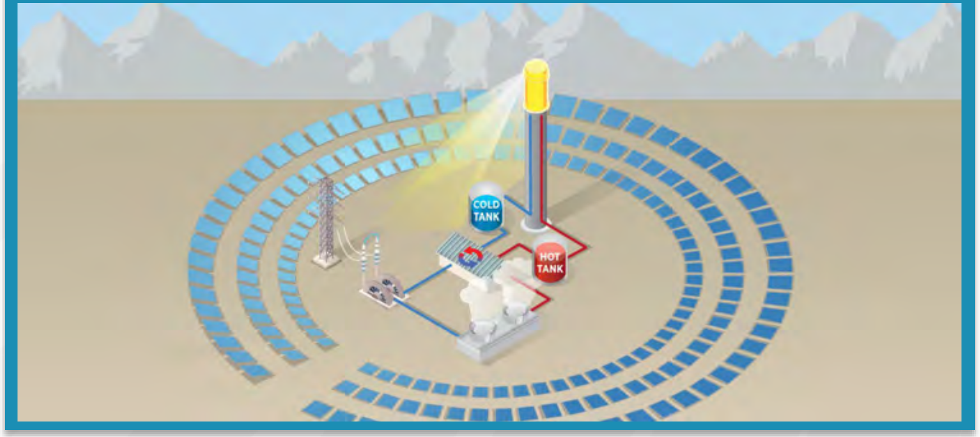
Driving Toward Administration Decarbonization Goals

- **Reduce hardware and soft costs** of solar electricity **for all Americans** to enable an affordable carbon-free power sector by 2035.
- Enable inverter-based technologies to provide essential grid services and black start capabilities while demonstrating the **reliable, resilient and secure operation of a 100% clean energy grid**.
- **Accelerate solar deployment and associated job growth** by opening new markets, reducing regulatory barriers, providing workforce training, and growing U.S. manufacturing.
- **Center energy justice** by reducing environmental impacts, removing barriers to equitable solar access, and supporting a diverse and inclusive workforce.
- **Support a decarbonized industrial sector** with advanced concentrating solar-thermal technologies and develop affordable renewable fuels produced by solar energy.

SETO Research Areas

PHOTOVOLTAICS

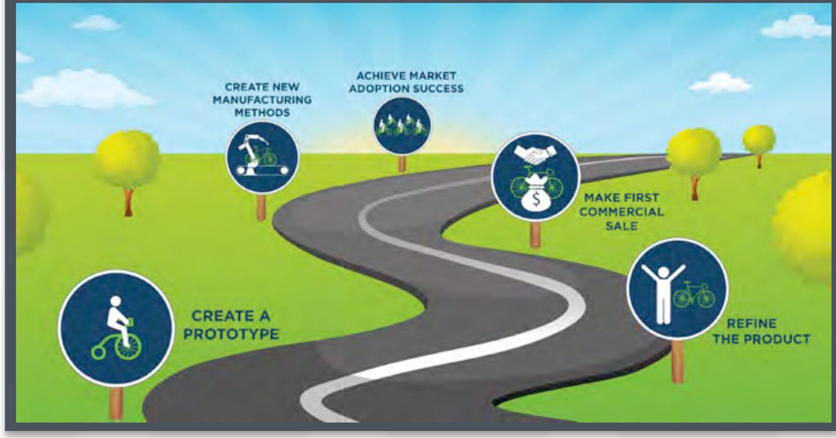
CONCENTRATING SOLAR-THERMAL POWER



BALANCE OF SYSTEMS/ SOFT COST REDUCTION

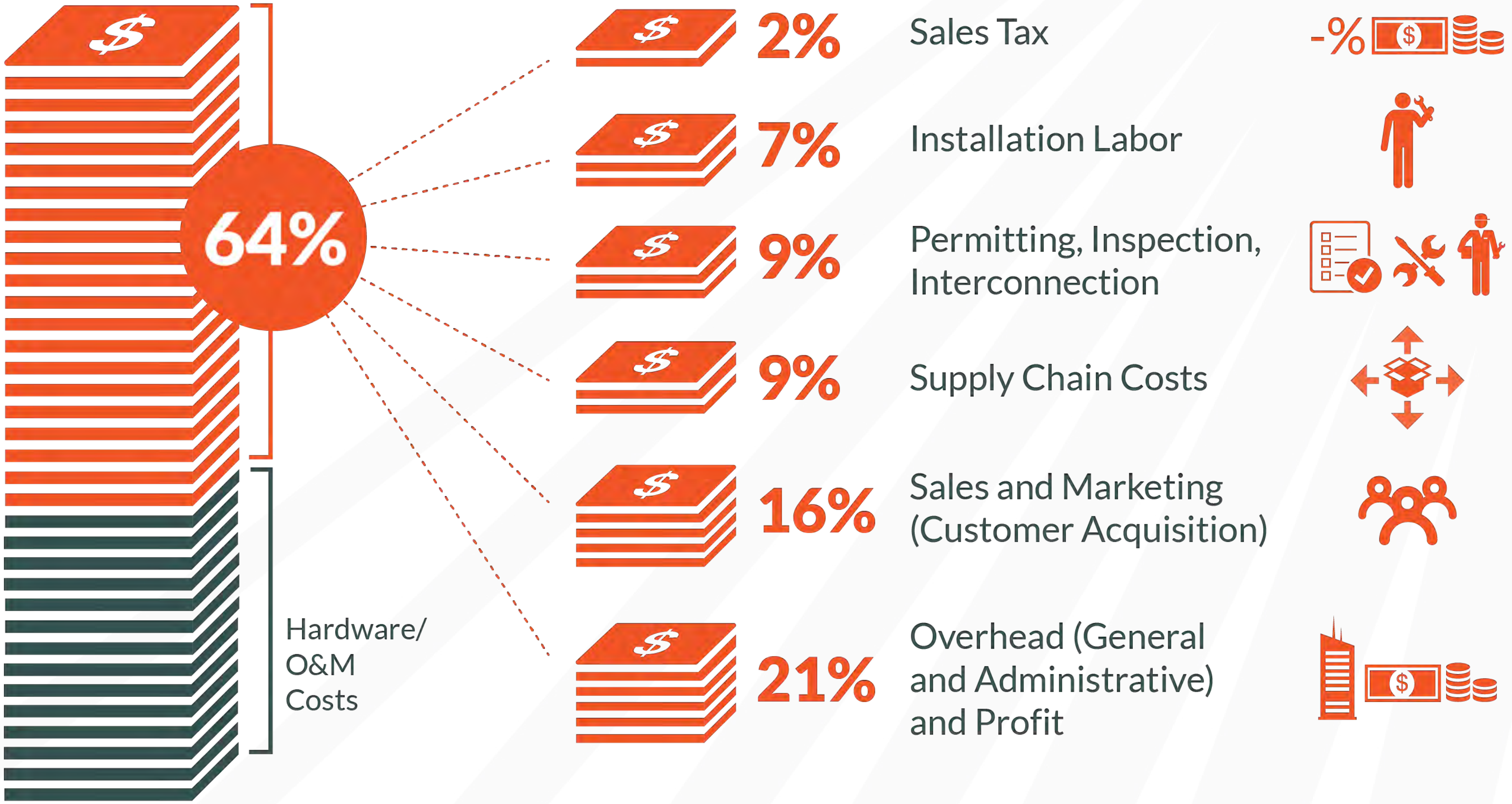
SYSTEMS INTEGRATION

MANUFACTURING AND COMPETITIVENESS



Balance of Systems (Soft Costs)

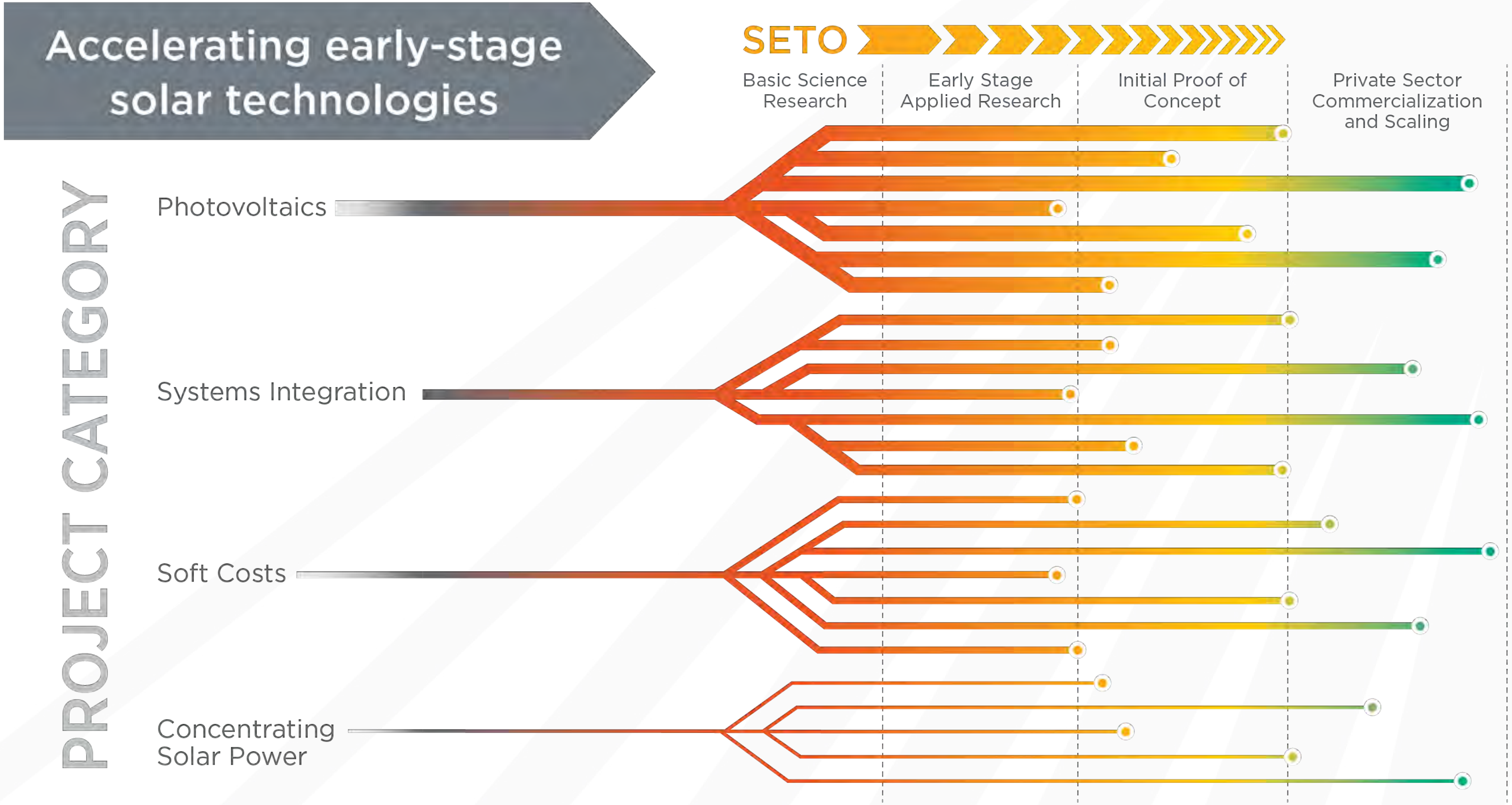
Michele Boyd, Program Manager



Source: National Renewable Energy Laboratory "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020 ."

Manufacturing and Competitiveness

Markus Beck, Program Manager



SETO Newsletter – Stay in Touch

The SETO newsletter highlights the key activities, events, funding opportunities, and publications that the solar program has funded.

SIGN UP NOW:
energy.gov/solar-newsletter

Climate-Smart Agriculture and Forestry

William Hohenstein

Director, Office of Energy and Environmental Policy

Office of the Chief Economist

USDA

USDA's Climate-Smart Agriculture and Forestry Strategy – Opportunities for Agrivoltaics

William Hohenstein

United States Department of Agriculture

Office of the Chief Economist

Office of Energy and Environmental Policy

Tackling the Climate Crisis at Home and Abroad

On January 27, 2021, President Biden signed Executive Order 14008 *Tackling the Climate Crisis at Home and Abroad*

- **USDA** was tasked with delivering a report with recommendations for a **climate-smart agricultural and forestry (CSAF) strategy.**
- What is **Climate Smart Agriculture**?
  - sustainably **increasing agricultural productivity** and incomes;
  - **adapting and building resilience**; and
  - reducing and/or removing **greenhouse gas emissions**

Mitigation recommendations for a Climate-Smart Agriculture and Forestry Strategy

A successful Climate-Smart Agriculture and Forestry (CSAF) Strategy will rely on a multi-pronged approach.

The 7 elements of this strategy are:

1. Quantify, track and report the benefits of CSAF activities
2. Ensure that the strategy that works for all farmers, ranchers, forest landowners, and communities
3. Leverage existing USDA conservation programs
4. Strengthen education, training, and technical assistance
5. Support new and better markets for agriculture and forestry products generated through CSAF practices
6. Develop a forest and wildfire resilience strategy
7. Improve research and innovation

USDA

USDA's Action Plan for Climate **Adaptation & Resilience**

Climate change poses a threat to:

- **Agricultural Productivity**
- **Water Quantity & Quality**
- **Vulnerable Communities**
- **Resilience to Extreme Weather Events**
- **Infrastructure and Public Lands**

USDA's Cross-Cutting Adaptation Actions

1. **Invest in soil and forest health** to build resilience to climate change across landscapes
2. **Increase climate outreach and education** to promote climate-smart adaptation strategies
3. **Broaden access and availability of climate data** at regional and local scales
4. **Increase support for research and development** of climate-smart practices and technologies to inform planning, decision-making
5. **Leverage the USDA Regional Climate Hubs** to deliver adaptation science, technology, and tools

Coalition for **Sustainable Productivity Growth (SPG)** for Food Security and Resource Conservation

The **SPG Coalition** aims to **accelerate the transition to more sustainable food systems** through productivity growth that optimizes the three dimension of sustainable development:

- **Social**
- **Economic**
- **Environmental**

Possible actions of Coalition members include:

1. Link productivity growth goals with resource conservation and climate goals
2. Link conservation and climate goals with productivity goals
3. Advance, implement, and promote Climate-Smart Agriculture and Forestry
4. Join or otherwise participate in the Agriculture Innovation Mission for Climate
5. Advance progress in growing the nutritional productivity of agriculture
6. Advance progress in conceptualizing and measuring sustainable productivity growth across objectives.

USDA

US Dairy Net Zero Initiative:
An Example of CSA Principles and Agrivoltaics

On-farm Benefits

Feed production & practice changes:

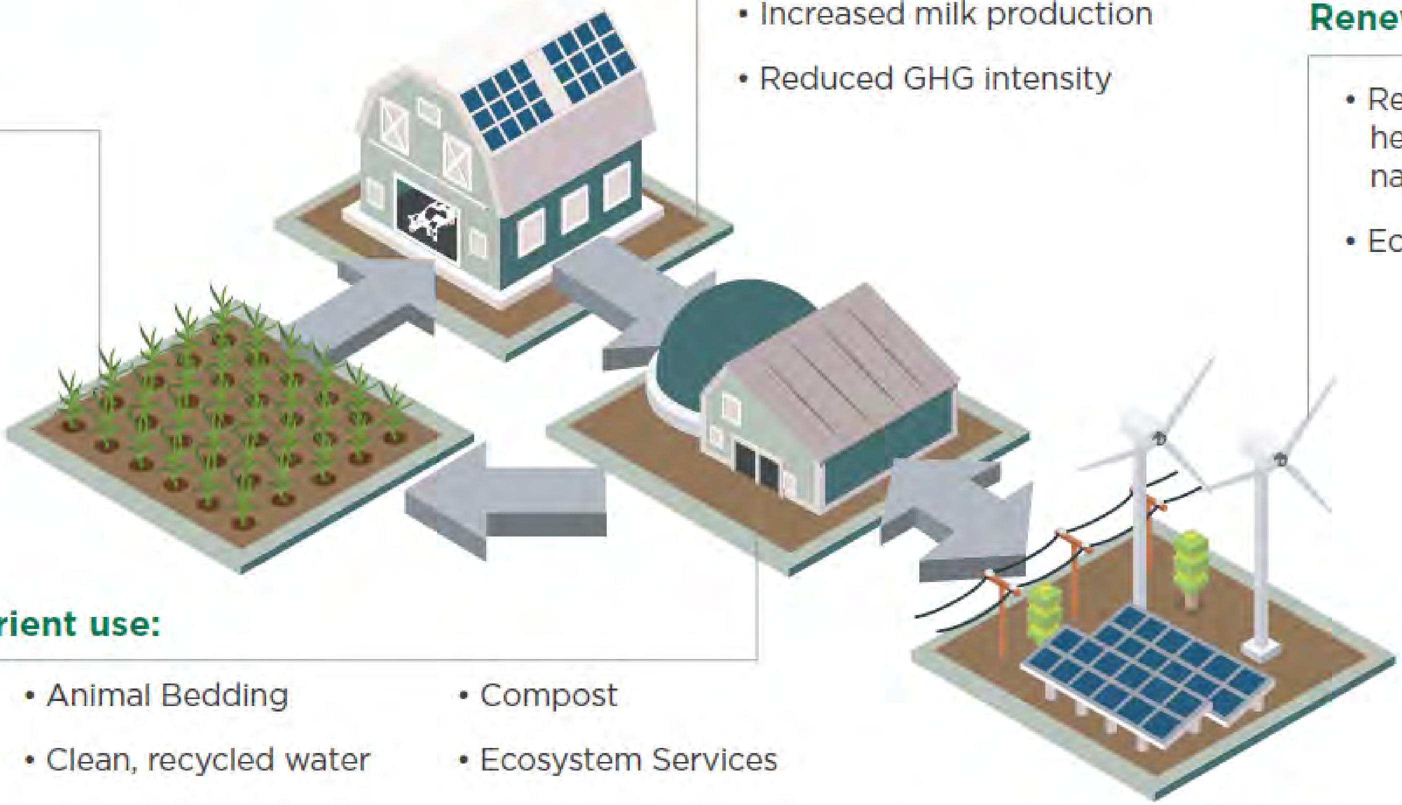
- Healthy soils
- Water resistant soils
- Improved nutrient and carbon cycling
- Enhanced air and water quality
- Ecosystem services

Cow care & efficiency:

- Healthier cows
- Increased milk production
- Reduced GHG intensity

Renewable energy:

- Renewable electricity, heat, vehicle fuel and natural gas
- Ecosystem services



Manure handling & nutrient use:

- Transportable, high-quality fertilizers
- Animal Bedding
- Clean, recycled water
- Compost
- Ecosystem Services

Visuals do not represent all possible practices, technologies or benefits. Each farm can voluntarily contribute to net zero efforts based on their individual operation

NET ZERO INITIATIVE

Opportunitiess for USDA/DOE Cooperation on Agrivoltaics

- USDA Climate Hubs
  - Provides a reliable source of climate-smart information, outreach, and extension
- Rural Development
  - RD provides loans and loan guarantees for rural coop generation, transmission, and distribution
- NRCS Conservation Programs
  - NRCS Administers an array of conservation programs and can address on-farm energy production in the context of conservation planning
- NEW: USDA Climate Smart Agriculture Partnership Initiative
  - Will focus on the production of "climate-smart" commodities

Introduction to DOE Agrivoltaics Portfolio

Michele Boyd

Program Manager, Strategic Analysis and Institutional Support

Solar Energy Technologies Office

Office of Energy Efficiency and Renewable Energy

Department of Energy

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SETO Agrivoltaics Research

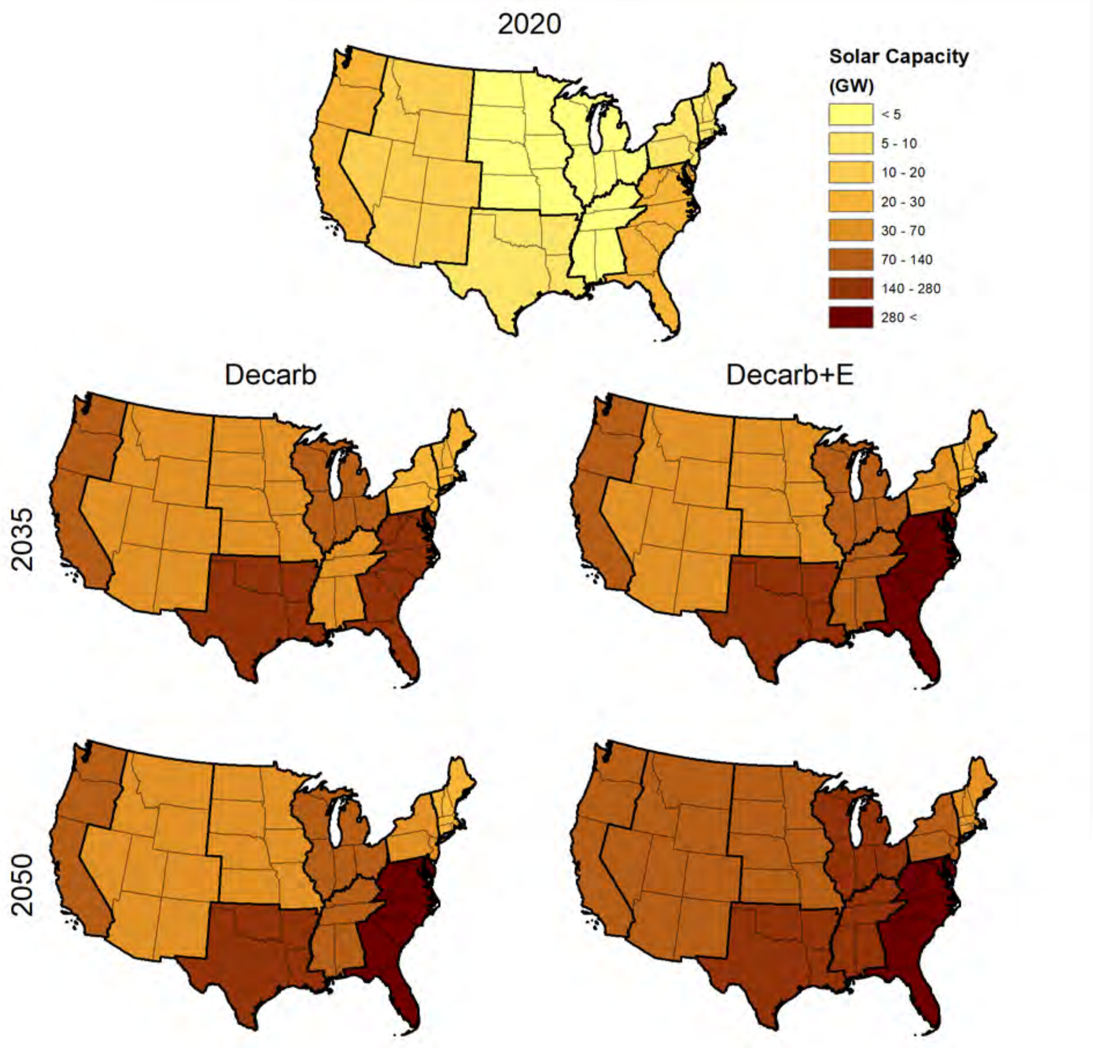
Michele Boyd, Program Manager
Solar Energy Technologies Office

energy.gov/solar-office

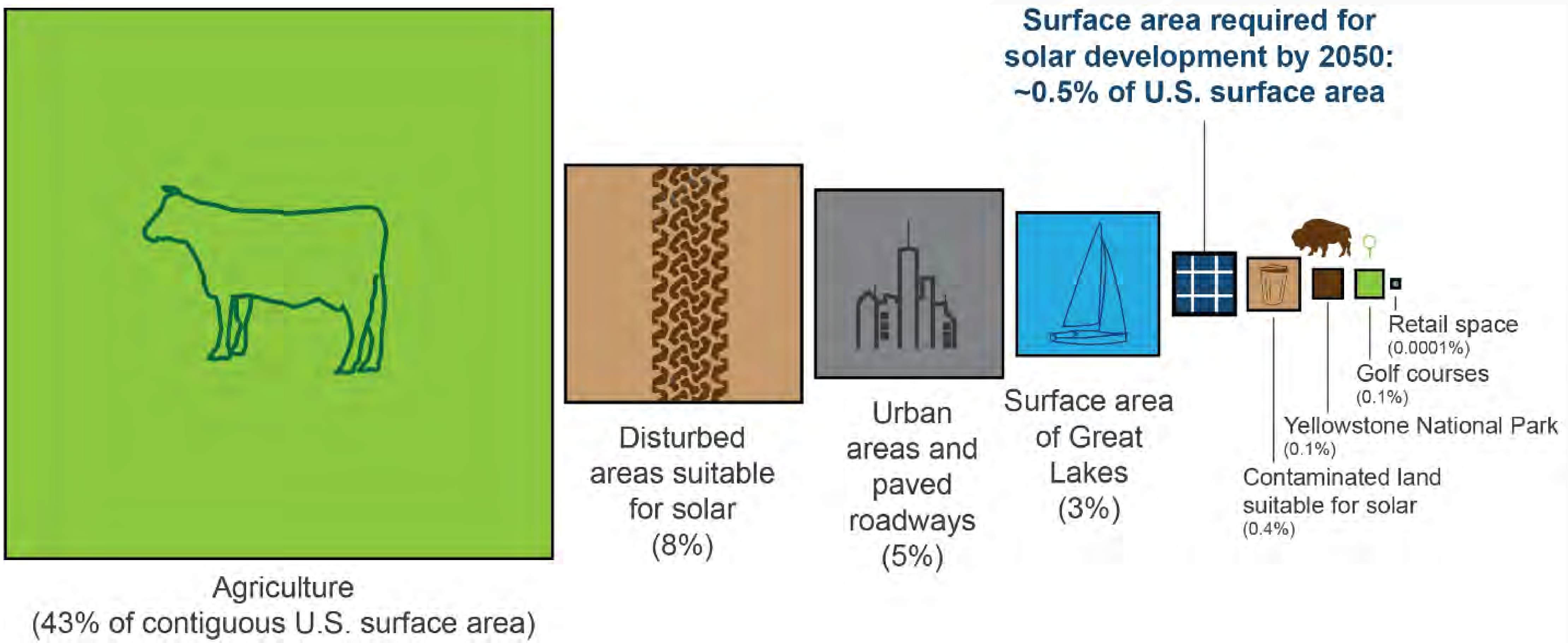
January 10, 2022

Solar Futures Study

- Released in September 2021
- Charts pathways to providing 45% of U.S. electricity through solar by 2050 (3% in 2020)
- Achieves 95% decarbonization by 2035
- *Every* Census region has more solar in 2035 than the highest regions do today
- Lots of capacity deployed in Georgia, Florida, Texas

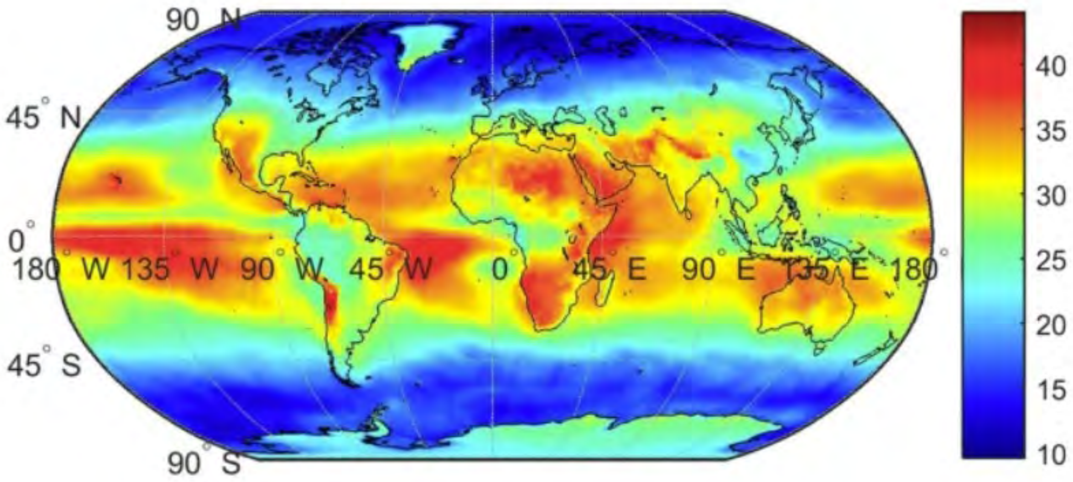


Solar Futures Study: Land-Use



Ground-mounted solar is projected to require about **5.7 million acres** by 2035 (0.3%), increasing to as much as **10 million acres** in 2050 (0.5%)

Agricultural Lands and Solar Development



Solar PV Power Potential is Greatest Over Croplands

Elnaz H. Adeh, Stephen P. Good, M. Calaf & Chad W. Higgins

Scientific Reports **9**, Article number: 11442 (2019) | Cite this article

Farm profitability remains a challenge

American Bankers Association and the Federal Agricultural Mortgage Corporation release results of joint survey.

When farmland is converted to solar energy production, it can lead to local concerns about impacts on agricultural land

Agrivoltaics = Agriculture + Photovoltaics

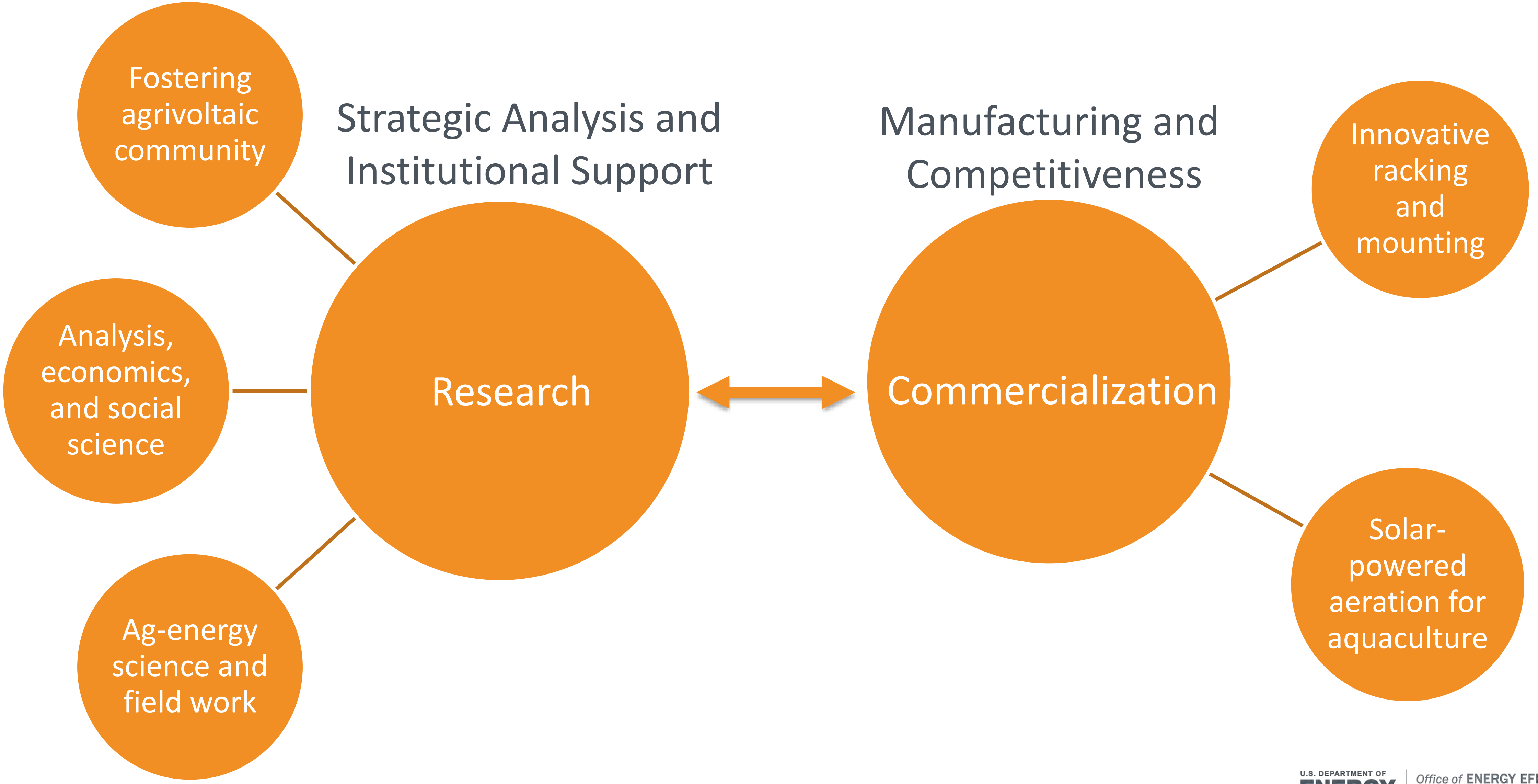
Can solar be combined on the same land with agriculture to the benefit of both agriculture and solar energy?

- Agriculture is defined as crops, livestock and/or pollinator habitat
- Potential benefits for farmers:
  - Provide diversified revenue
  - Reduce irrigation water needs
  - Improve crop yield, especially in dry areas
  - Improve resistance to extreme weather, such as droughts
- Potential benefits for solar industry:
  - Reduce land-use competition
  - Improve panel performance
  - Lower solar O&M costs

State of Agrivoltaics in the U.S.

- **Pollinator Habitat**
  - 150+ solar facilities with pollinator habitat in the US
  - 14 states have guidelines for seed mixes and management practices
- **Grazing**
  - Eastern U.S. has over 4,000 acres of solar sites maintained with sheep
  - Some cattle grazing is done under solar arrays
- **Crop Sites Across the US**
  - Massachusetts: 3 (+4 planned in 2022)
  - Colorado: 1
  - Maine: 1 pilot

SETO Research and Commercialization Activities in Agrivoltaics



InSPIRE

- Meeting Solar Cost and Deployment Targets through Innovative Solar Practices Integrated with Rural Economies and Ecosystems (**InSPIRE**)
- Led by the National Renewable Energy Laboratory, more presentation later today
- Three rounds of InSPIRE:
  - 1.0: FY16-FY18 ($1.2M)
  - 2.0: FY19-FY21 ($1.9M)
  - 3.0: FY22-FY24 ($3.7M)

FY20 FOA Topic: *Solar and Agriculture: System Design, Value Frameworks and Impacts Analysis*

Summary

- Build upon and expand ongoing SETO projects related to the co-location of solar and agriculture by developing technology, evaluating practices to date, and conducting research and analysis that enable farmers, ranchers, and other agricultural enterprises to quantify and realize value from solar technologies while maintaining availability of land for agricultural purposes.
- Goal: To facilitate and expand the co-location of solar and agricultural activities where it is beneficial to both industries and to the local community.

Areas of Interest

Applications may address one or more of these areas:

- System design and technology development
- New frameworks for integrating solar and agriculture
- Research on ecological and performance impacts of co-location

Funding: $7 million total (4 awards)

Project Duration: 3 years per award

Small Business Innovation Research Portfolio

- Solar racking/mounting design optimized for co-location:
  - Blue Rock Solutions – suspended solar racking
  - FarmAfield Labs – solar integration with livestock feeding structures
  - Rute Foundation Systems – cable stayed solar racking
  - Soliculture – solar racking/mounting for greenhouse integration
  - Taka Solar Corporation – tube-based photovoltaic system
  - Tectonicus Constructs – irrigation canal spanning solar racking
  - TrackerSled – modular solar trackers for rural application

- Solar powered aeration systems with aquaculture applications:
  - Dissigno International
  - Epsilon Innovation Group
  - FarmAfield Labs
  - Floating Island International
  - Hawaii Fish Company

SBIR · STTR America's Seed Fund™ POWERED BY SBA

Future Agrivoltaic Research Needs

- **Economic valuations** and tradeoffs at multiple scales for different agricultural approaches
- **Farmer perspectives** and factors that affect adoption rates for different agricultural approaches and regions
- Comprehensive assessment **environmental and ecological impacts** of co-located projects
- **Animal welfare** and nutrition studies
- **Public perception** of agrivoltaics projects
- Tracking existing and future agrivoltaic projects and **lessons learned**

Break!
12:45 – 12:50

InSPIRE Project at NREL

Jordan Macknick

Lead Energy-Water-Land Analyst

National Renewable Energy Laboratory

NREL
Transforming ENERGY

InSPIRE Project Overview

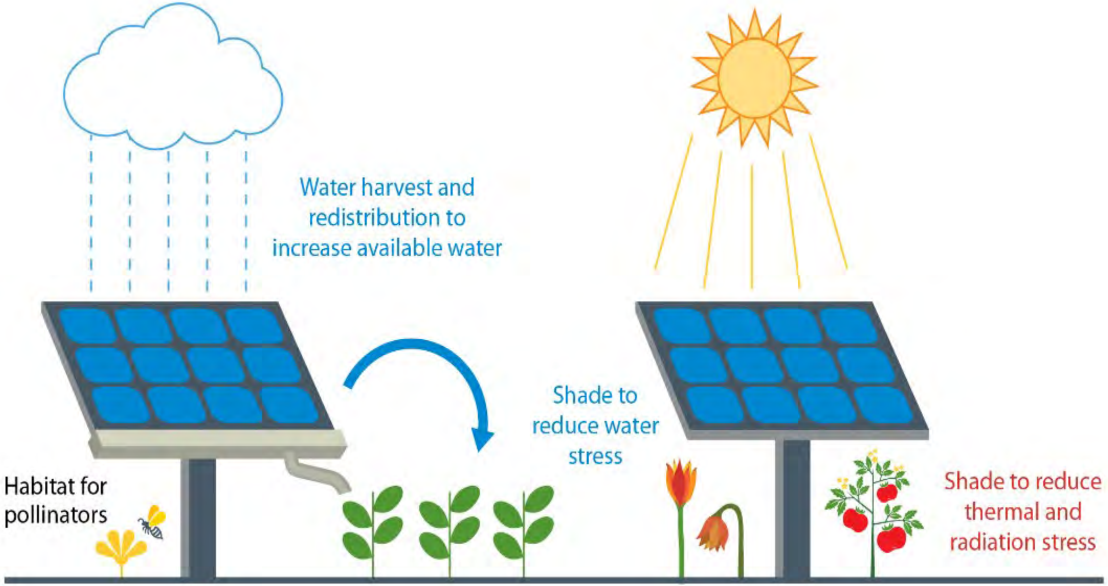
Jordan Macknick

USDA-DOE Interagency Workshop on Agrivoltaics 2022

January 10, 2022

InSPIRE provides foundational data on the interaction of solar and agriculture to enable improved decision-making that leads to mutual benefits for energy and food systems

DOE InSPIRE Research



Field-based research:

(1) Economic viability of solar-agriculture co-location configurations
(2) Increasing agricultural yields in arid environments
(3) Energy, water, and food security in remote, off-grid areas
(4) Pollinator habitat and ecological services

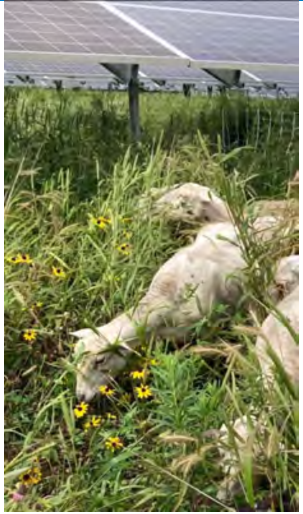
Analytical research:

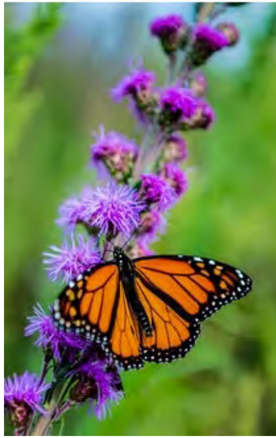
(1) Satellite imagery analysis of current land groundcover practices
(2) Cost-benefit analysis of O&M ground cover practices
(3) Quantification of ecological services of groundcover options

https://openei.org/wiki/InSPIRE

NREL National Renewable Energy Laboratory; Oregon State University; The University of Arizona; University of Massachusetts Amherst; Argonne National Laboratory; Temple University; Hyperion Systems; Cornell University; Colorado State University; PineGate Renewables; Regenerate Integrated Systems for People and Place; Fresh Energy; MNL; enel Green Power

InSPIRE Agrivoltaic Research Sites





Photos courtesy of Rob Davis, Fresh Energy; Werner Slocum, Dennis Schroeder, NREL

InSPIRE Project Sites

Overview of Field Research Activities at InSPIRE Agrivoltaic Sites

Vegetation Monitoring

Beneficial Insect Populations

Detailed Instrumentation

Soil Carbon

Temperature Probe

Relative Humidity Probe

Rain Gauge

Datalogger

Soil Heat Flux Plate

Wind Anemometer

Soil Thermocouple

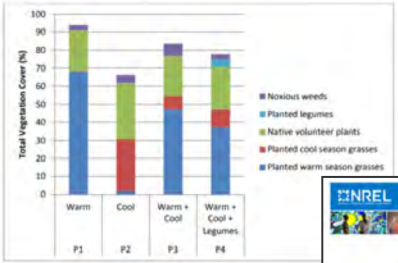
Pyranometer

Soil Moisture Reflectometer

PV Panel Thermocouple

Armstrong et al., 2016

Standard Protocols for Vegetation Evaluation



Beatty, B., Macknick, J., McCall, J., Braus, G., and Buckner, D. 2017. *Vegetation Performance under a Solar PV Installation.* NREL/TP-1900-66218. National Renewable Energy Laboratory, Golden.
http://www.nrel.gov/docs/fy17osti/66218.pdf

ASTRO Advisory Group

Research and Outreach Advisory Group

Quarterly Zoom calls since Jan 2019

Feedback on research directions and study designs

Development of new InSPIRE research sites and activities

Coordinated outreach activities

Community leading to new collaborations

Partial list of ASTRO Members

Unique Features of InSPIRE Research

- ASTRO advisory group
- Coordination with other US agrivoltaics projects
- Multiple agricultural activities
    - Crops, grazing, pollinator/ecosystem services, controlled environment
- Geographic coverage
- Different solar configurations
- Long-term research projects
- Mission

Kelsey Horowitz, Vignesh Ramasamy, Jordan Macknick and Robert Margolis. 2020. *Capital Costs for Multi-Land Use Photovoltaic Installations*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77811

Agricultural Crop Publications and Focus

- Tradeoffs in crop yields
- Irrigation water requirements
- Microclimate conditions
- Shading modeling
- Crop production in off-grid areas

Ecosystem Services Publications and Focus

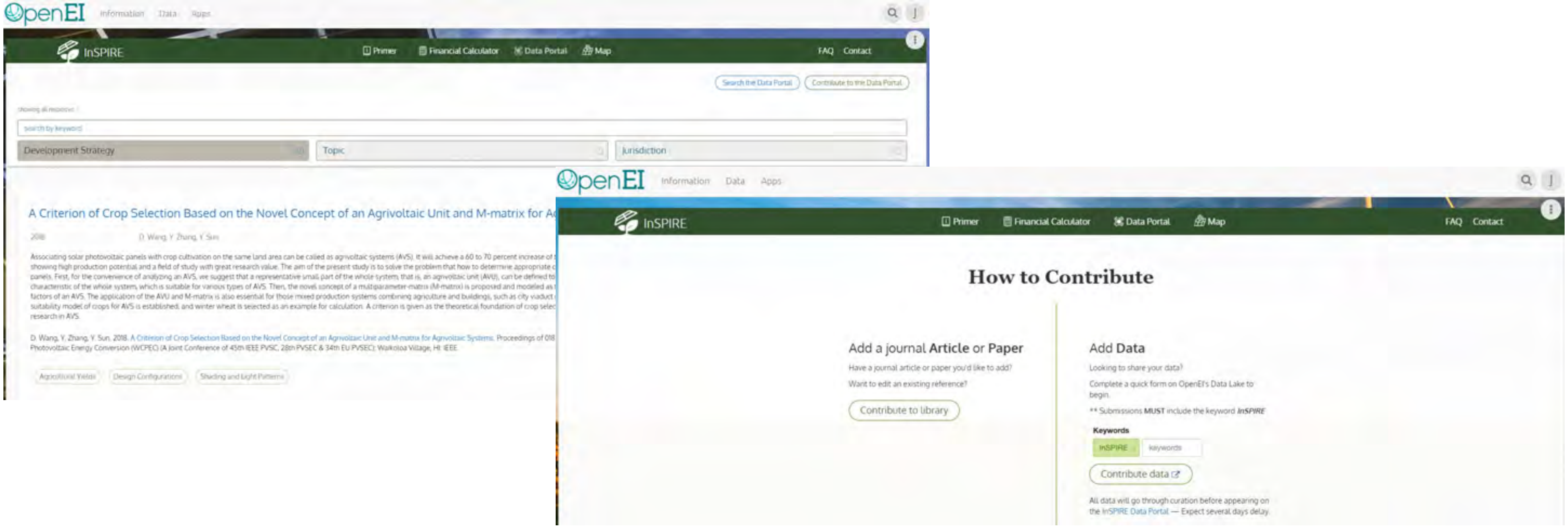
- Beneficial insect populations
- Potential impact of beneficial insects at solar sites on agricultural yields
- Approaches to revegetation of utility-scale solar projects
- Impacts of vegetation on soil and nutrient characteristics
- Impacts of vegetation on PV output

General Agrivoltaic Publications and Focus

- Capital cost impacts of Agrivoltaic configurations
- O&M cost impacts of different groundcovers
- Current groundcover of utility-scale PV projects
- Lessons learned from Agrivoltaic research projects
- Compatibility of agricultural activities with solar

InSPIRE Data Portal

The InSPIRE data portal (https://openei.org/wiki/InSPIRE/Data_Portal) serves as the starting point for hosting and contributing relevant agrivoltaic research data



InSPIRE Agrivoltaics Financial Calculator

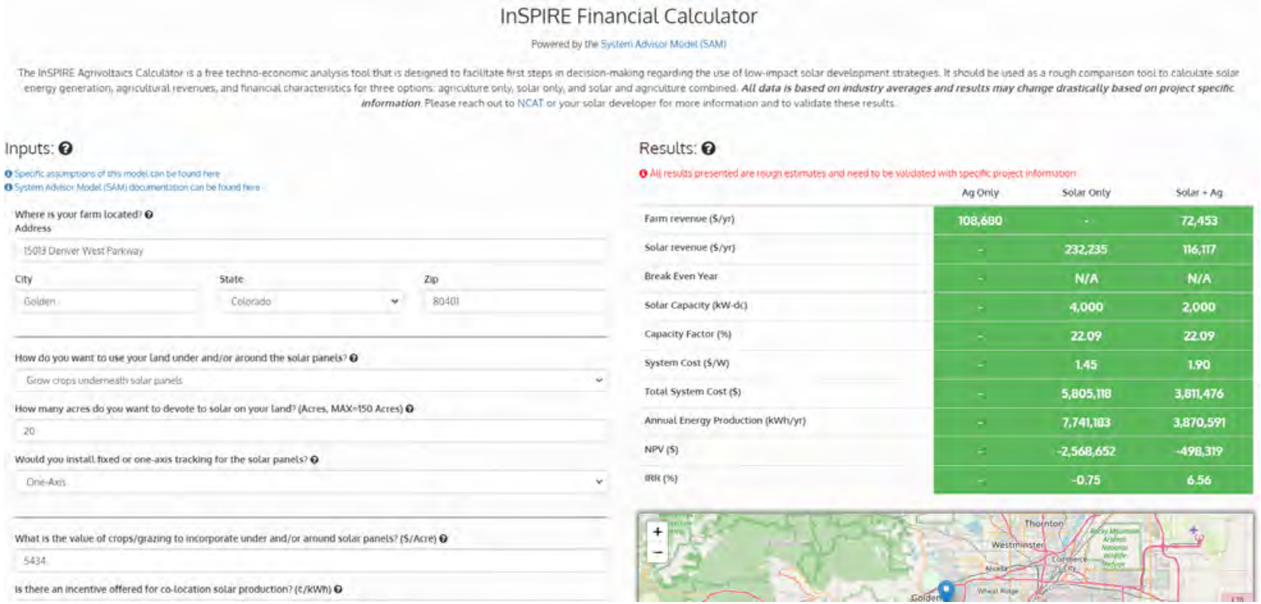
The InSPIRE financial calculator (https://openei.org/wiki/InSPIRE/Financial_Calculator) serves as the starting point for calculating economic viability of agrivoltaic projects

Adapts available tools (e.g., System Advisor Model [SAM]) plus latest data (e.g., capital cost and O&M studies) for easy-to-use, online co-location techno-economic assessment tool

Public-facing tool is customized for farmer use, but can also provide developers with validation and verification tools

User answers set questions that feed inputs into SAM API that calculate performance and economic metrics

Additional capabilities and customization available in non-public-facing version



Capital Cost Factors for Agrivoltaics

- Capital Cost Considerations
  - Module type and equipment
  - Panel height
  - Racking/Tracking system
  - Land acquisition costs
  - Installation labor costs
  - Site preparation costs
  - Risks

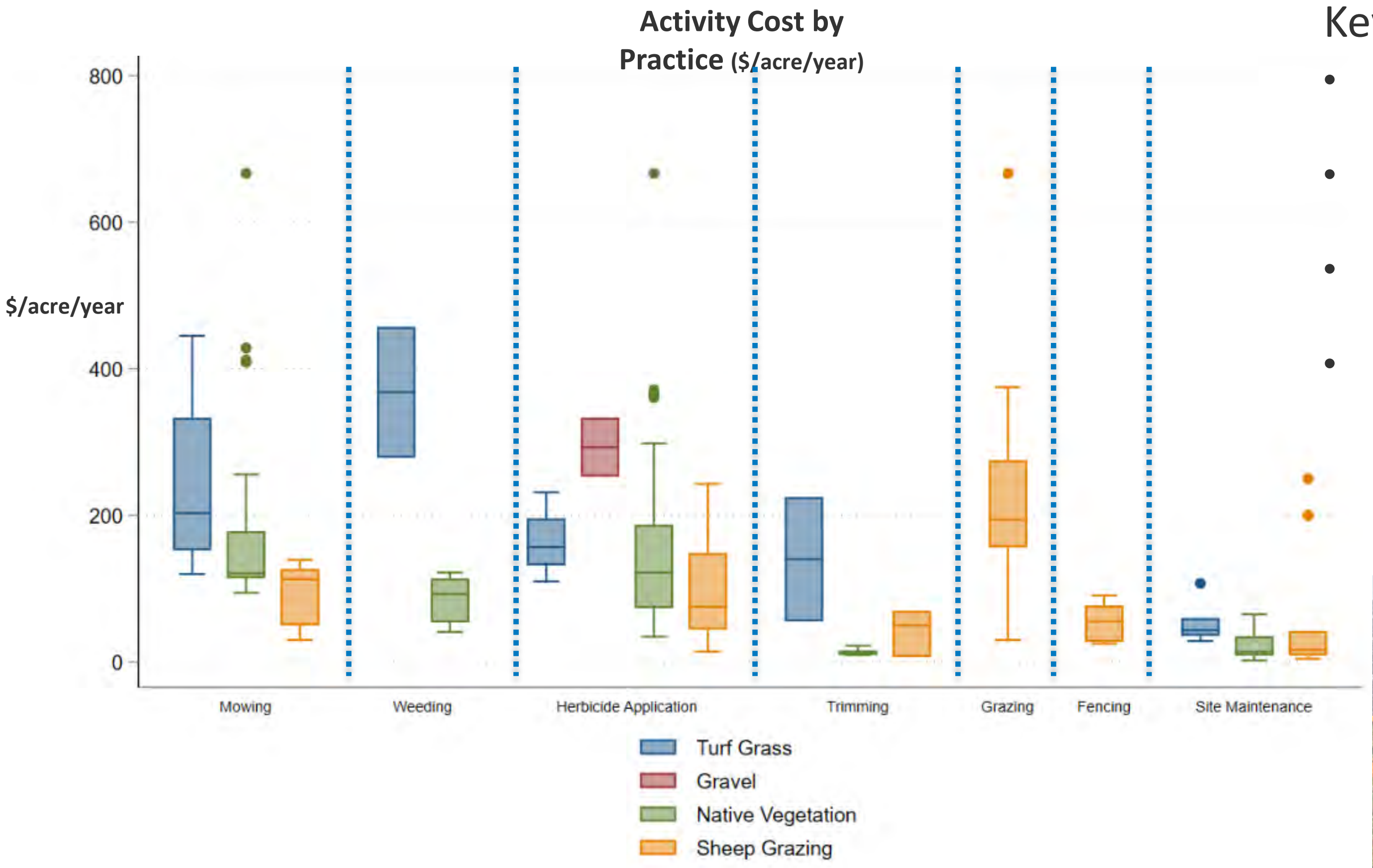
Figure 3. PV installed system costs for each dual-use scenario with benchmark assumptions for a PV system with 500 kW rated power

Costs are based on a simple average of modeled costs in Oregon, Arizona, Michigan, Massachusetts, New York, Connecticut, California, and Illinois—states that currently have one or more types of dual-use PV systems installed.

Results are for 500-kW systems. Results can vary at lower and higher installed capacities

Kelsey Horowitz, Vignesh Ramasamy, Jordan Macknick and Robert Margolis. 2020. *Capital Costs for Multi-Land Use Photovoltaic Installations*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77811

PV O&M Cost Analysis for Low-Impact Solar



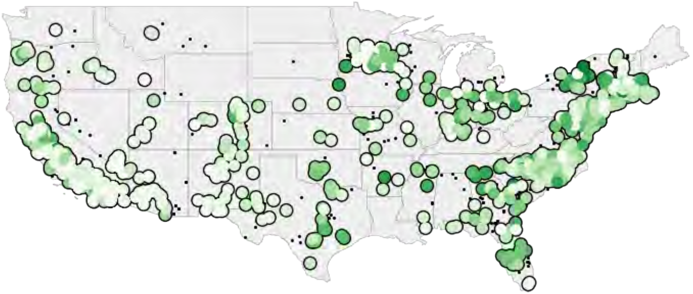
Preliminary Results—Do Not Cite! (Burton et al., *forthcoming)*

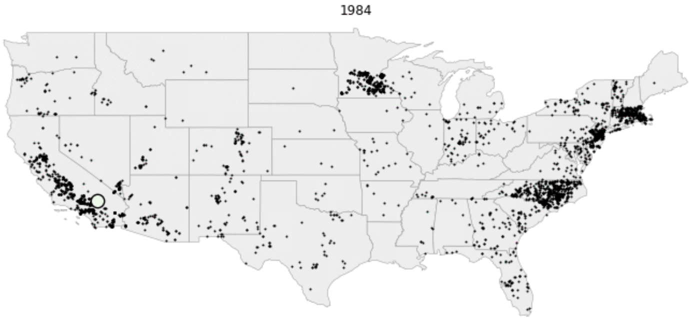
Key Preliminary Findings

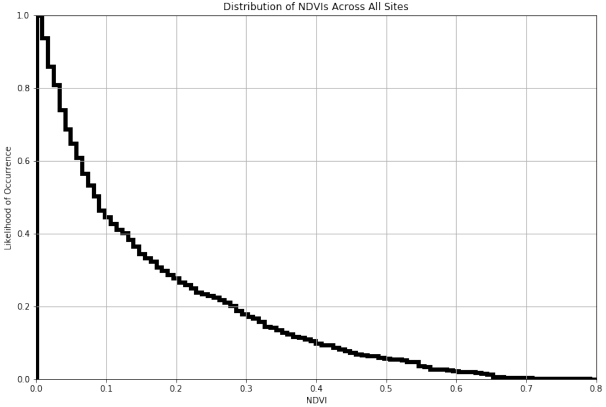
- Survey of >100 different PV sites across multiple years
- Specific activities needed can vary from site to site
- Costs can change each year due to vegetation evolution
- O&M costs are being combined with capital cost and other factors in a financial calculator that will be available soon!: https://openei.org/wiki/InSPIRE

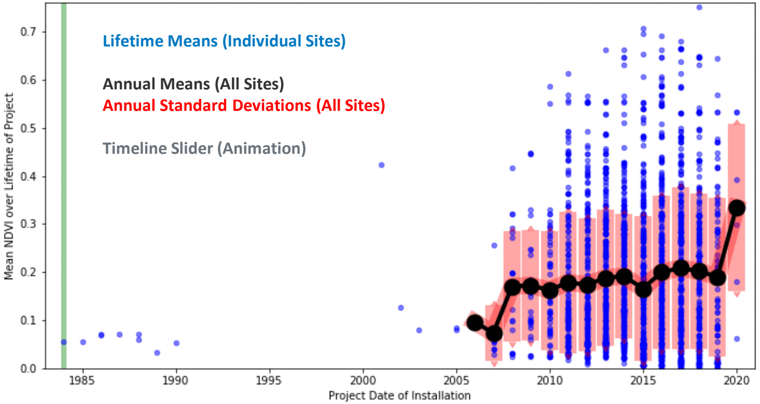
Evolution of Utility-Scale Solar Project Groundcover

Time Series and Geographic Trends of Vegetation (NDVI)



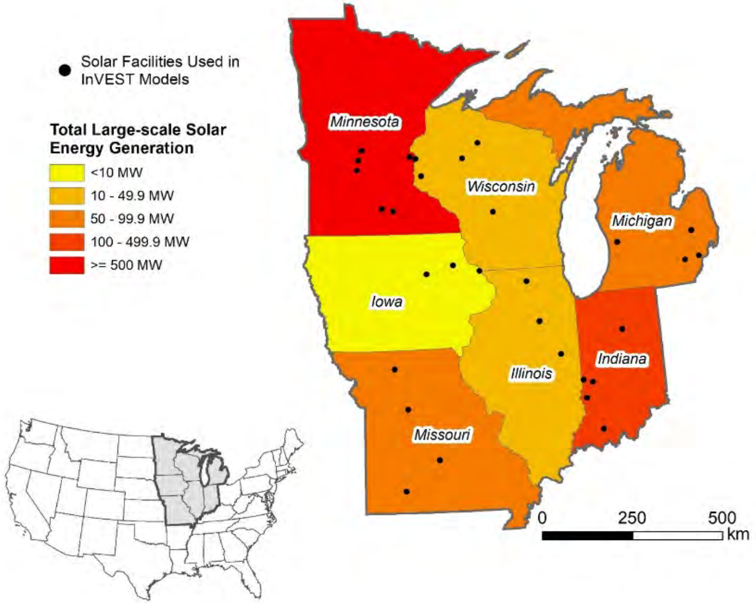


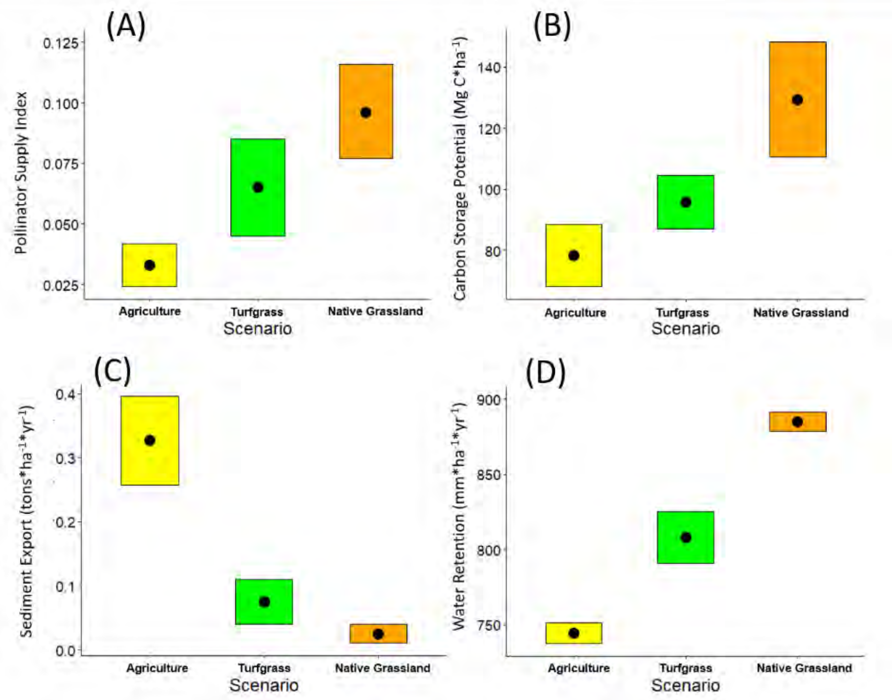




Ecosystem Services of Pollinator-friendly Solar

Ecosystem Service tradeoffs associated with solar land use scenarios modeled from 30 sites



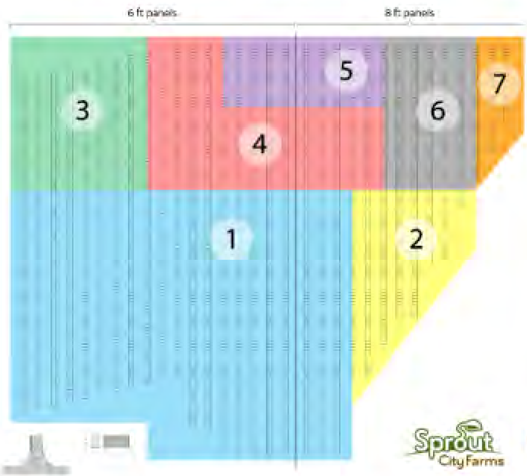


[Ecosystem Services](#)

Modeling the Ecosystem Services of Native Vegetation Management Practices at Solar Energy Facilities in the Midwestern United States *(2020)*

Leroy J. Walston, Yudi Li, Heidi M. Hartmann, Jordan Macknick, Aaron Hanson, Chris Nootenboom, Eric Lonsdorf, Jessica Hellmann

Jack's Solar Garden Overview of Partners



1. Sprout City Farms: Production Farm
2. NREL: Pollinator Habitat
3. CSU: Ecosystem Services
4. University of Arizona: Agricultural Test Plot
5. CSU: Water Management Test Plot
6. NREL: Grassland and Nutrient Cycling
7. CALC: Educational Area

Pictures from Jack's Solar Garden in 2021

InSPIRE Lessons Learned

Three primary categories:

1. Agrivoltaic Installations

2. Research Projects at Agrivoltaic Installations

3. Partnerships

52 individual insights

8 crosscutting themes

ASTRO Outreach Outcomes

Accelerate Information Dissemination

- Educational content on low-impact and agriculturally compatible PV solar designs and management practices was widely shared:
  - More than 30 hours of webinars reaching a total of more than 3,310 people
  - More than 36 hours of in-person events in 12 states attended by 1,780 people
- More than 45 separate original media stories during the period of InSPIRE 2.0 including a 2021 *Associated Press* story about InSPIRE that was syndicated to more than 230 media outlets with a reach generating more than 150 million media impressions.

News Articles on InSPIRE Research

Beneath Solar Panels, the Seeds of Opportunity Sprout

Low-Impact Development of Solar Installations Could Be Win-Win-Win for Food, Water, and Renewable Energy

https://www.nrel.gov/news/features/2019/beneath-solar-panels-the-seeds-of-opportunity-sprout.html

The Future of Agriculture Combined With Renewable Energy Finds Success at Jack's Solar Garden

Sept. 10, 2021

https://www.nrel.gov/news/program/2021/future-of-agriculture-combined-with-renewable-energy-finds-success-at-jacks-solar-garden.html

Giving Kids the Building Blocks To Envision a Solar Future

As Part of the InSPIRE Project, NREL Senior Analyst Helped Dream Up a Creative Way To Educate about Energy, Water, and Food

March 26, 2021

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

InSPIRE has published its research in Nature family journals, Applied Energy, Environmental Science & Technology, Frontiers in Environmental Science, etc. and has been featured in news stories by the Associated Press, Discover Magazine, Scientific American, Huffington Post, WIRED, E&E News, Grist, Utility Dive, NPR, etc.

InSPIRE III Scope 2022-2024

InSPIRE 3 Research Objectives

This project will facilitate better understanding of the mutual benefits and tradeoffs of solar and agriculture by providing foundational data and analysis to stakeholders in the agricultural and solar industry sectors.

This project will facilitate the replication and scaling-up of agrivoltaics research, evaluate agrivoltaic designs, fill key knowledge gaps related to agrivoltaic opportunities, and develop foundational data and resources to support future research in agrivoltaics across the globe.

InSPIRE Project Evolution and Trajectory

InSPIRE 1 (2016-2018)

Assessing feasibility and potential of Agrivoltaics

Initial field research

InSPIRE 2 (2019-2021)

Developing best practices

Establishing long-term research sites

Facilitating growth in Agrivoltaics

InSPIRE 3 (2022-2024)

Supporting national Agrivoltaics efforts

Continuing engagement and innovative long-term research

Innovative Solar Practices Integrated with Rural Economies and Ecosystems

InSPIRE Scope Overview

Engagement, Coordination, and Outreach

- ASTRO network
- Interagency coordination
- Host international conference

Innovative and Long-term Field Research

- Crop production
- Ecosystem services
- Bi-facial system analyses
- Sheep grazing
- Soil quality monitoring

Foundational Research Services for Agrivoltaics

- Agrivoltaic project tracking
- Research Protocols
- Research Roadmap
- InSPIRE data portal and website
- Economic analysis of scaling-up agrivoltaics

InSPIRE 3 Engagement Activities

1. **Maintain ASTRO Network Engagement and Facilitate "Seed" Research Projects**

2. **Host and Organize International Agrivoltaics Conference**

3. **Support Inter-Agency and Cross-Jurisdictional Collaboration**

InSPIRE 3 Foundational Research Services

1. Track Agrivoltaics Projects

2. Maintain and Update InSPIRE Data Portal and Website

3. Publish Standardized Research Protocols and Research Roadmap

4. Analyze Economics of Scaling of Agrivoltaics

InSPIRE 3 Field Research

1. Agrivoltaic Crop Production and Irrigation Tradeoffs

2. Ecosystem Services at Long-Term and New Research Sites

3. Bifacial PV Agrivoltaics Groundcover

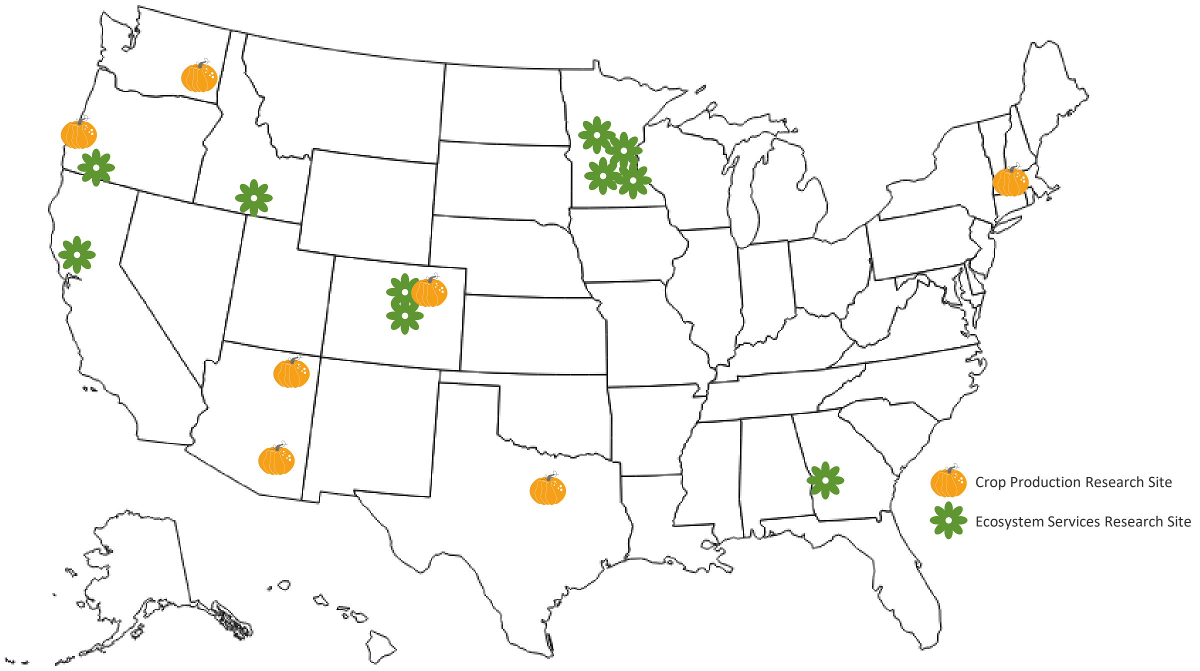
4. Sheep Grazing Evaluation Standards and Guidelines

5. Soil Quality at Solar and Agrivoltaic Sites

InSPIRE 3 Field Research Site Locations

- 10 ecosystem services and pollinator habitat research sites

- 7 crop production research sites



InSPIRE 3 Crop Research Detail

InSPIRE 3 Crop Production Field Research Sites

Site Name	State	Crops Grown	Research Focus	Status as of Fall 2021
University of Arizona Biosphere 2	AZ	Tomatoes, peppers, carrots, herbs, lavender, kale, chard, spinach, and bok choy.	Farming in arid regions; irrigation trials	Existing agrivoltaic research site with instrumentation.
Lily Solar	TX	Dryland cotton, tomatoes, peppers, herbs	Dryland farming; farming in arid regions; irrigation trials	Existing operational solar site. Will need to modify groundcover and install some instrumentation.
Jack's Solar Garden	CO	Tomatoes, peppers, carrots, eggplant, leafy greens, green beans, herbs	Farming in arid regions; irrigation trials; alternative solar panel heights	Existing agrivoltaic research site with instrumentation.
Oregon State	OR	Potatoes, tomatoes, leafy greens	Dryland farming; hugelkultur	Existing agrivoltaic research site. Will add additional instrumentation.
Colville Tribe	WA	Ancient foods/plants	Subsistence farming; medicinal plants; ancient foods	Existing agriculture operation. Solar installation will occur summer/fall 2021. Instrumentation in spring 2022.
Navajo Nation	AZ	Ancient foods/plants	Subsistence farming; medicinal plants; ancient foods	Existing agriculture operation. Solar installation will occur summer/fall 2021. Instrumentation in spring 2022.
University of Massachusetts	MA	Peppers, greens, herbs	Alternative solar panel configurations	Existing agrivoltaic research site. Will add additional instrumentation.

- ***Implement alternative PV operation and crop management designs***
- ***Conduct detailed data collection of crop yields, microclimates, PV output, and water consumption***
- ***Improve crop response modeling by extending field research results to other crops and regions***
- ***Develop recommendations for agrivoltaic crops for different regions and configurations for subset of InSPIRE research areas***

InSPIRE 3 Ecosystem Services Research Details

- ***Conduct percent cover analyses at solar-pollinator sites to support comparison of seed mixes/vegetation establishment in various regions of the U.S***
- ***Conduct observational pollinator analyses at solar-pollinator sites to support estimates of changes in diversity and abundance of pollinators***
- ***Quantify crop benefits near solar-pollinator sites***
- ***Monitor wildlife at solar-pollinator sites***
- ***Evaluate water retention and carbon sequestration** at **solar-pollinator sites***

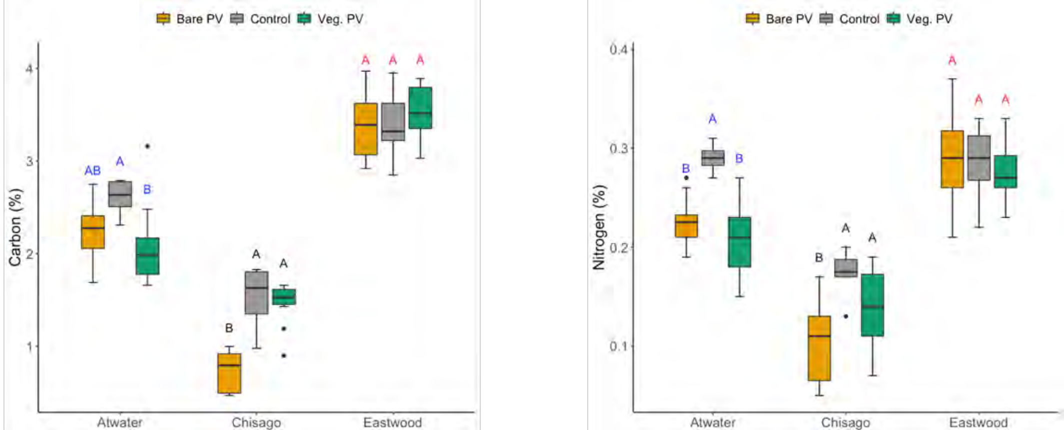
InSPIRE 3 Ecosystem Services Research Sites

Site Name (Solar Partner)	State	Size	Pollinator Planting Date/Seed Mix/Area	Ecosystem Services Research Planned
Carter Site	GA	1.3 MW	2019	Percent Cover, Pollinator (Observational)
Clif	ID	2 MW	2019	Percent Cover
Atwater (Enel)	Atwater MN	5 MW	June 2018	Percent Cover, Pollinator (Observational), Agricultural
Chisago (Enel)	Chisago MN	5 MW	June 2018	Percent Cover
Eastwood (Enel)	Mankato MN	5 MW	June 2018	Percent Cover, Pollinator (Observational), Agricultural, Passive Wildlife Recorders and Motion-triggered cameras
Connexus (Engie, So-Core)	Ramsey MN	3.4 MW	Oct 2018	Percent Cover, Pollinator (Observational), Agricultural, Passive Wildlife Recorders and Motion-triggered cameras, Soil and Water Studies
Jack's Solar Garden	CO	1.1 MW	June 2021	Percent Cover, Soil and Water Studies
NREL STM	CO	200 kW	Spring 2022	Percent Cover, Soil and Water Studies
Eagle Point (Pine Gate Renewables)	OR	9.9 MW	2018	Percent Cover
UC Davis	CA	16.3 MW	2021	Percent Cover, Pollinator (Observational), Passive Wildlife Recorders and Motion-triggered cameras, Soil and Water Studies

USDA Collaboration Opportunities

1. Long-term soil quality data collection
2. Conference co-hosting
3. Workshop participation
4. Research priorities and roadmap

SOIL CARBON AND NITROGEN



Research Needs

Controlled Environment Agrivoltaic Research Needs

- Evaluation of crop res configurations
  - Tunable waveleng
  - Variations in shadi
- Economic tradeoff an
- Electricity utilization c
- Field trials in different

31

Agrivoltaic Grazing Research Needs

- More detailed economic trade returns for agricultural and sol
- Sector-level extrapolation of in
- Stocking rate and density varia
- Vegetation and groundcover st
- More complete accounting of s to accommodate different spe
- Regional-, terrain-, and species
- Life cycle comparison of emissi other vegetation management
- Animal welfare and nutrition st
- Specific research on cattle graz

28

Pollinator-Friendly Solar Research Needs

- Seed mix and groundcover growth studies across different regions and solar configurations
- Seed mix variations and optimiz
- Detailed cost tradeoffs of solar c heights) and ecological and ecor
- More comprehensive assessmen regions and configurations
- Beneficial insect habitat and po
- Impact of beneficial insect habit
- Large-scale solar impacts and tr
- Stormwater runoff studies acros
- Carbon and soil nutrient monito

25

Agrivoltaic Crop Production Research Needs

- Evaluation of crop responses by:
  - Solar configuration
  - Solar materials used (light/shading/wavelengths)
  - Irrigation methods
  - Region
- Expansion of crop types considered
- Economic analysis of tradeoffs by region for different solar configurations and crop management approaches
- Improvement in crop models to account for partial shade and altered microclimate and soil regimes
- Nutrient content
- Examination of feasibility of large-scale field crops

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Thank you!

InSPIRE website: https://openei.org/wiki/InSPIRE

Jordan.Macknick@nrel.gov

303-275-382

SCAPES Project at UIUC

Madhu Khanna

Professor

University of Illinois Urbana-Champaign

Greg Barron-Gafford

Professor

University of Arizona

SCAPES

Sustainably Co-locating Agricultural and Photovoltaic Electricity Systems

Designing Agrivoltaics for Sustainably Intensifying Food and Energy Production

Madhu Khanna and Greg Barron-Gafford

January 10, 2022

Funded by

USDA National Institute of Food and Agriculture

iSEE Institute for Sustainability, Energy, and Environment

Meet the SCAPES Leadership

- Project Director: Madhu Khanna
- Research Thrust: Greg Barron Gafford

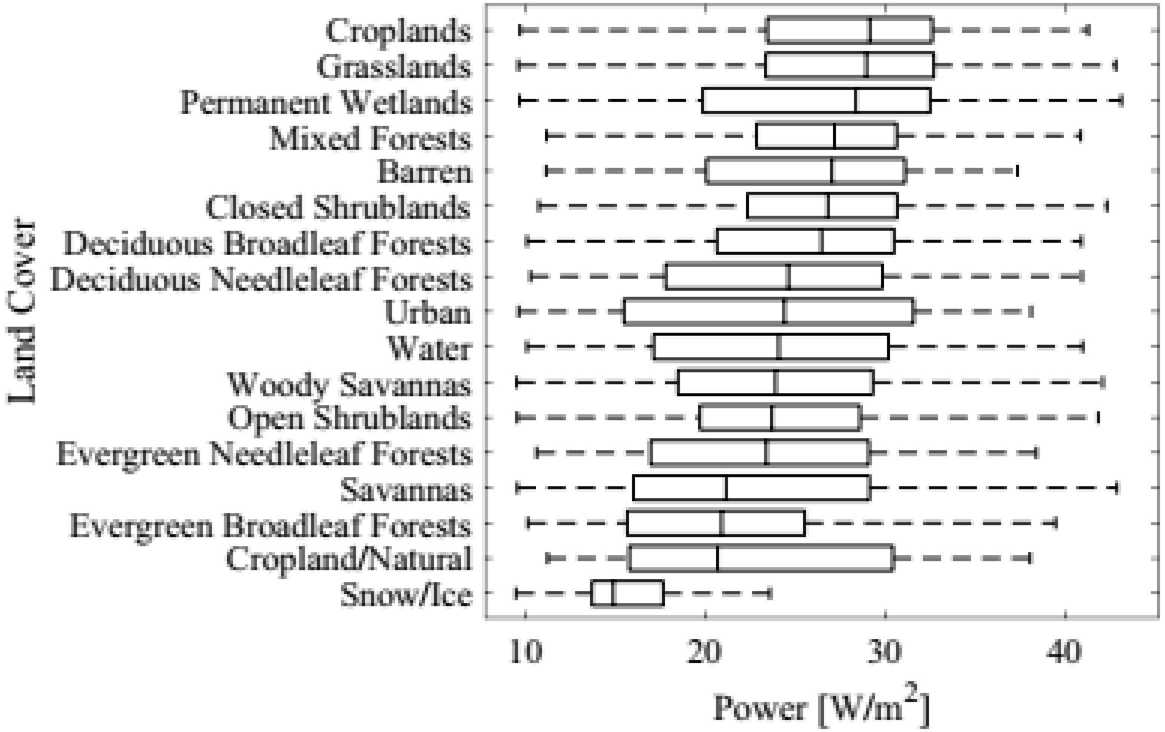
  - Crop Physiology: Carl Bernacchi
  - Solar Panel Optimization: Nenad Miljkovic
  - Modeling SCAPES Impacts at Landscape Scale on Climate and Markets: Kaiyu Guan
- Extension: Dennis Bowman

  - Stakeholder Working Groups
    - Farmers and solar energy developers
- Education: H. Chad Lane

  - Educational app
  - K-12: Camps
  - Science Museums
  - Grad and undergrad course modules

The Problem

Solar PV potential is greatest over cropland

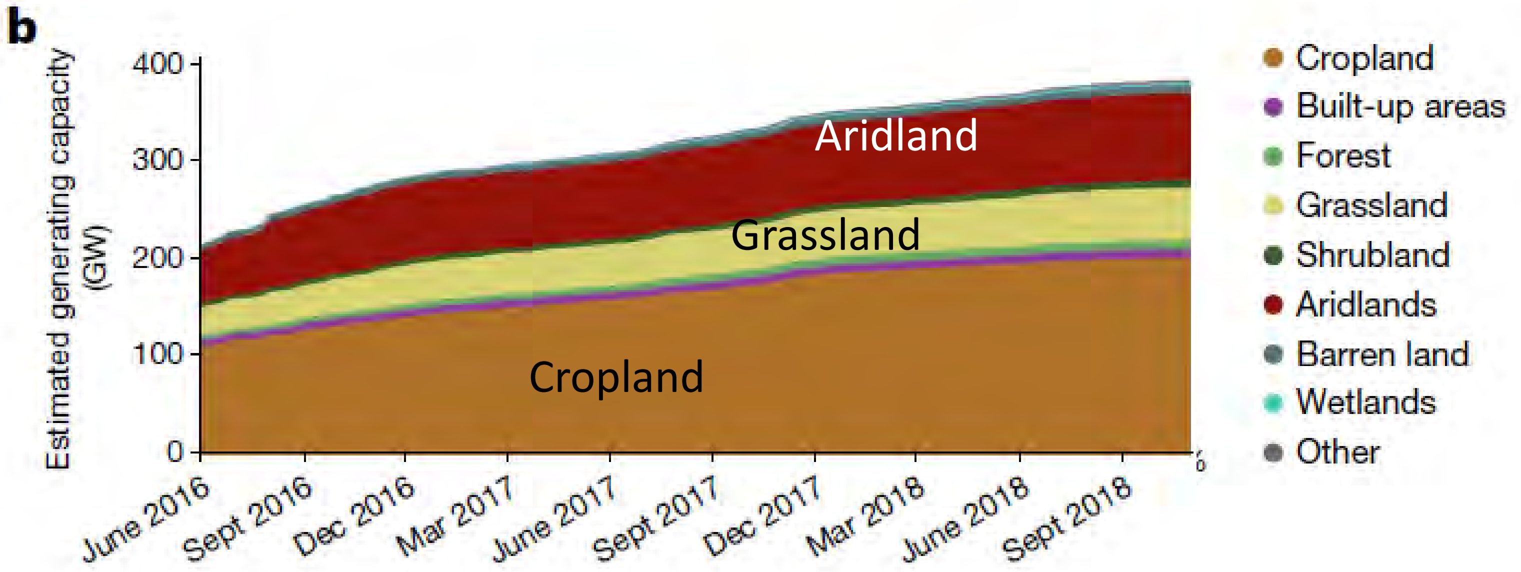


Solar PV Potential Ranked by Land Classification

Adeh, Elnaz H., Stephen P. Good, M. Calaf, and Chad W. Higgins. Solar PV Power Potential Is Greatest Over Croplands.
Scientific Reports 9, no. 1: 11442. https://doi.org/10.1038/s41598-019-47803-3.

The Problem

Potential for Conflict Between Food and Solar Energy Production



Time Series of New Solar Installations by Land Cover

Kruitwagen et al., 2021

Agrivoltaics: simultaneously producing food and energy from solar panels on the same area

Agrivoltaics:

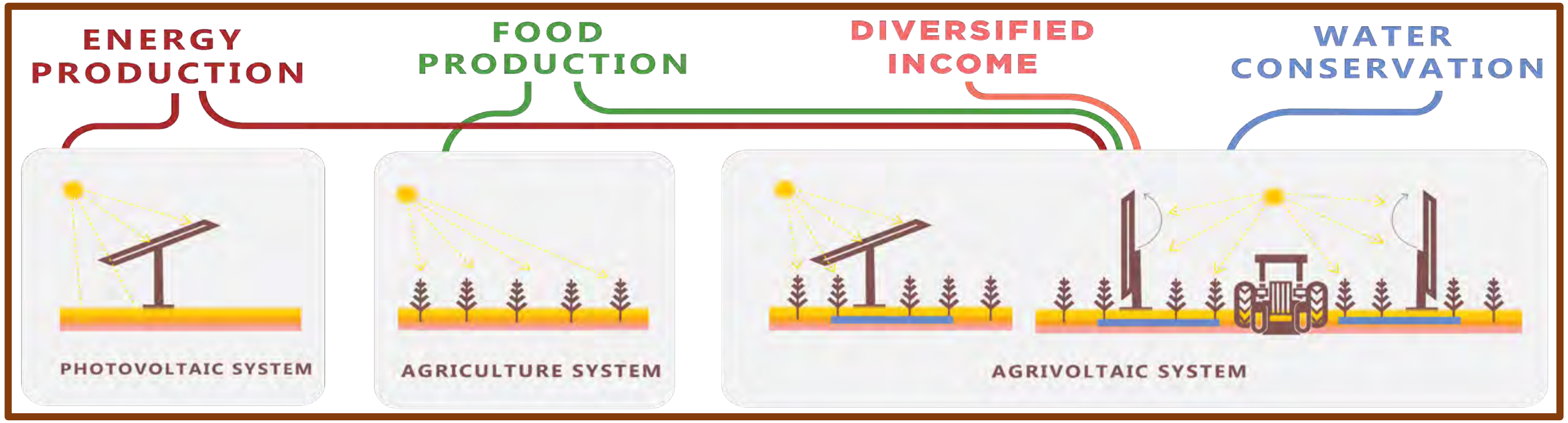
- the solution to increasing concerns over solar energy's land demands
- Increasing the productivity of land
- Making agriculture climate-smart
- Creating multi-functional landscapes

Sources: https://www.businessinsider.com; Adeh et al., 2019; Dept. of Energy, 2020

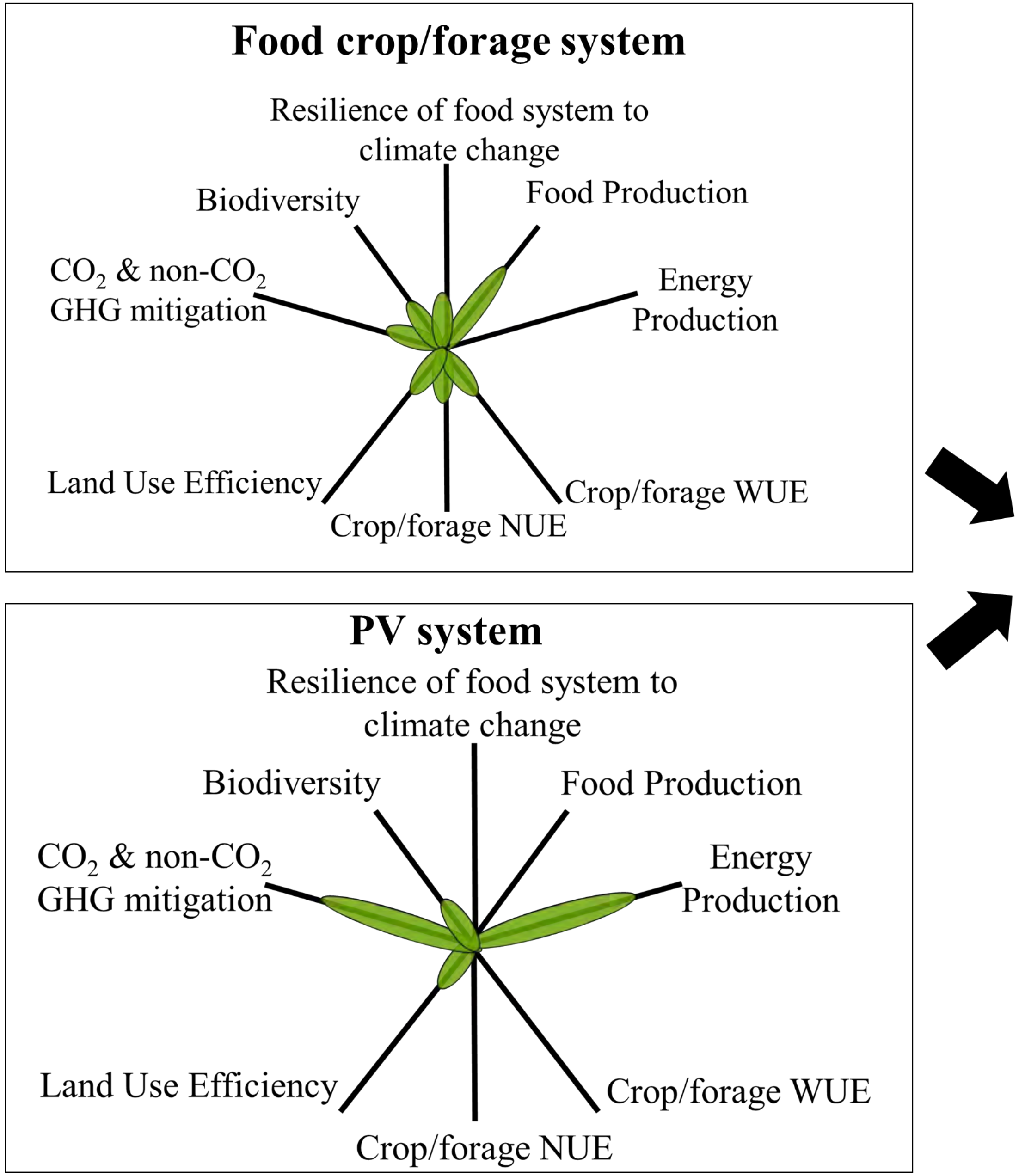
AV provide mutual benefits across the food–energy–water nexus

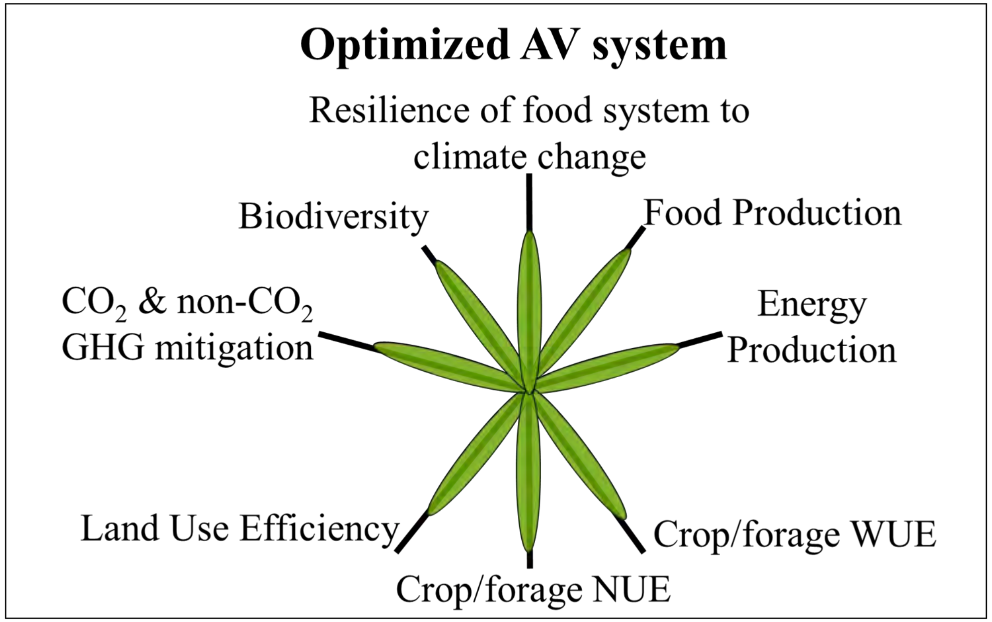
Enable the use of land for crop production and solar energy generation to

- increase combined (food and electricity) productivity of land,
- Increase/maintain crop yield
- Conserve soil moisture
- Increase adaptation to a changing climate
- diversify and increase farm profitability
  - with diverse crops (row crops, forage, and specialty crops)
  - across a range of biophysical environments.
    - Corn Belt
    - Great Plains
    - South West



Potential agronomic, ecological and environmental benefits of AV





Adapted from **Gomez-Casanovas N** et al (2021), STOTEN, 799, doi.org/10.1016/j.scitotenv.2021.149466

- Land Equivalent Ratio (LER):
- (*Y crop AV/Y monocrop) + (Y electricity AV/Y electricity PV*), where *Y* is yield

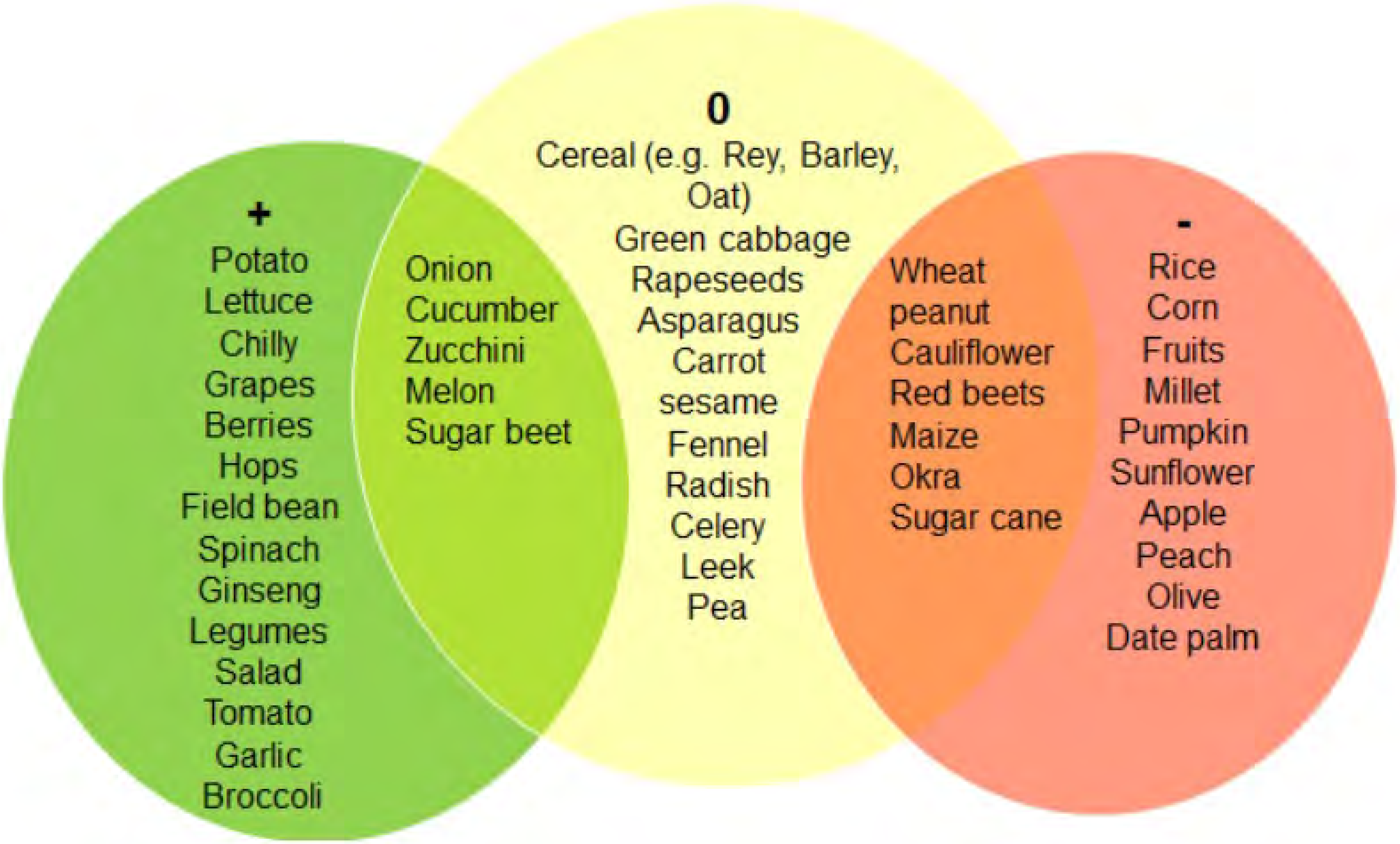
- Land Evapo-transpiration Ratio (LETR): ET per unit land

- Dollar Land Ratio (DLR): Returns per unit land

What do we know so far?

Author /year	Context	Methods	Impacts evaluated
Dupraz et al. (2011)	Combining PV and crops for optimising land use	Simulation models Land equivalent ratio	A 35%-73% ↑ of land productivity
Dinesh & Pearce (2016)	Potential of AV systems, U.S.	A coupled simulation model for crop and PV	30% ↑ in economic value. ↑ PV power of 40-70 GW from lettuce production
Malu et al. (2017)	AV potential on grape farms in India	Techno-economic analysis	↑ economic value BCR>15
Valle et al. (2017)	Total productivity of land by combining PV and crops, U.S	Field trials	↑ crop biomass ↑ PV energy ↑ land productivity
Sekiyama & Nagashima (2019)	Solar sharing for food and clean energy production	Field experiments	↑ corn yield by 5% in low density PV panels
Moreda et al. (2021)	Profitability of AV system in Spain	Benefit-cost analysis	Internal rate of return (IRR) ≈3.8%-5.6%
Zheng et al. (2021)	Economic benefits of AV systems, China	Field experiments with econ. analysis	Average LER ≈1.64 Benefit/cost ratio ≈5.14

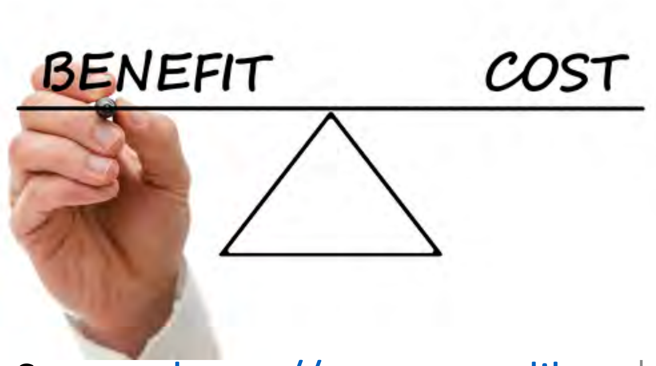
Crop suitability for AV



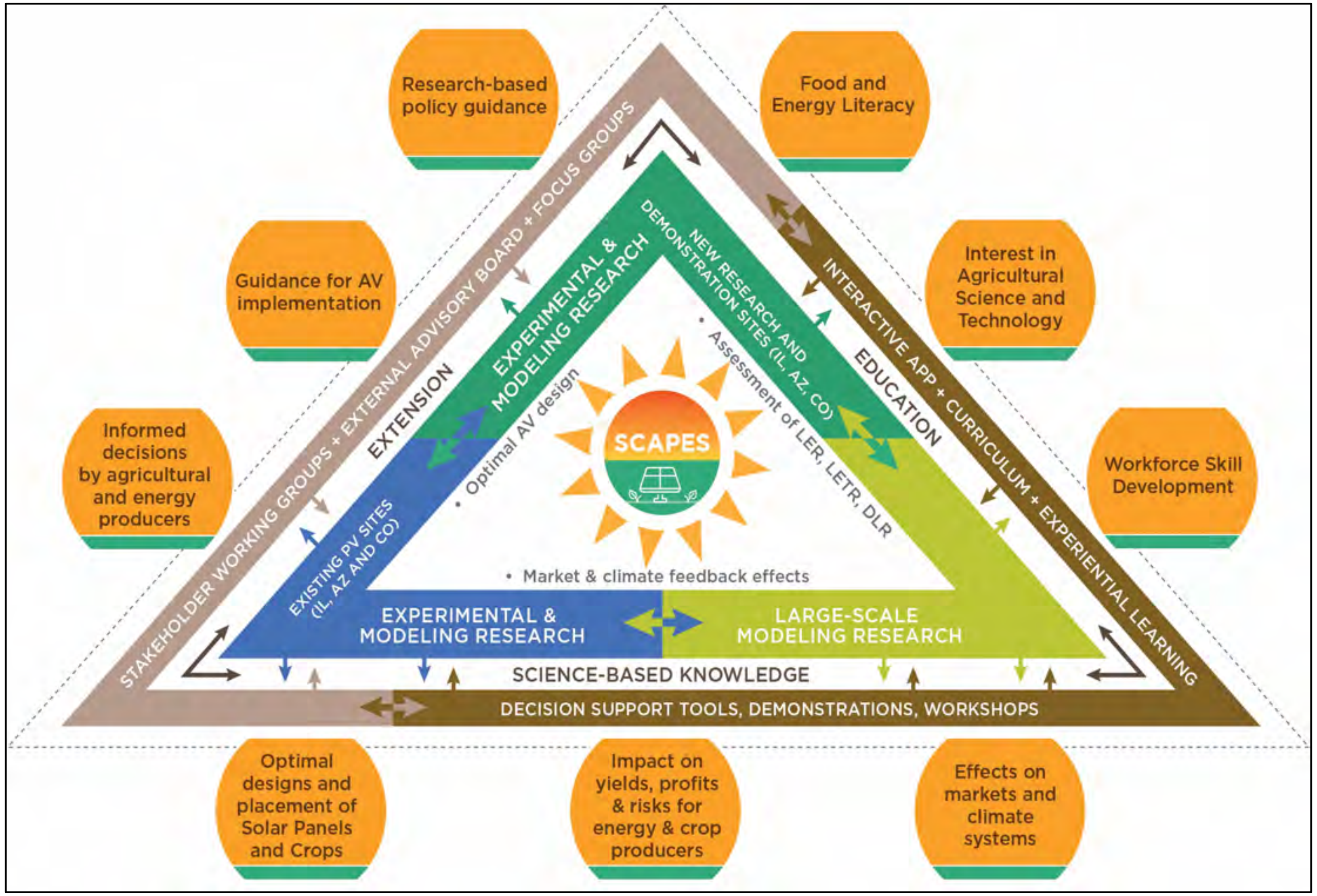
Neupane Bhandari, et al. Economic Feasibility of Agrivoltaic Systems in Food-Energy Nexus Context. *Agronomy* 11, no. 10: 1906.

Key knowledge gaps

- Comprehensive evidence of potential benefits of AV systems is lacking
- Limited understanding of the effects of AV on local microclimate, evapotranspiration rates, and the regional climate system
- Little work done to optimize AV design to maximize its potential
- Farmer willingness to adopt AV technology?



Source: https://www.econlib.org/



- Engage with stakeholder groups.
- Design AV systems optimized for location-specific crop productivity, resource needs, and electricity generation with research and demonstration sites at IL, CO and AZ.
- Establish high-impact experiential educational programs integrated with research and extension.

- Can AV enhance yields and the combined food and electricity productivity of land while conserving water, diversifying and increasing farm profitability across a range of biophysical environments?
    - Rainfed Midwest, dryland Great Plains and irrigated South-west
    - At research and demonstration sites
    - Under locally suited cropping systems and different AV configurations
    - Extrapolated to regional scales under spatially heterogeneous land quality, solar radiation and cropping environments
- Economic returns from agrivoltaics compared to conventional agriculture of stand-alone solar energy generation
- Examine potential feedback effects of large-scale AV adoption on the climate due to the albedo effect and on markets for food and electricity
- Determine willingness of farmers to adopt AV systems and land they would be willing to convert to AV using focus groups and survey instrument
    - Trade-offs they are willing to make between crop yield and electricity output

Plans for Extension and Education

- **Extension:**
  - Stakeholder Working Groups
    - Farmers and solar energy developers
    - Government agencies
    - Trade associations
  - External Advisory Board

Dennis Bowman

Chad Lane

- **Education:**
  - Educational app
  - K-12: Camps
  - Science Museums
  - Grad and undergrad courses

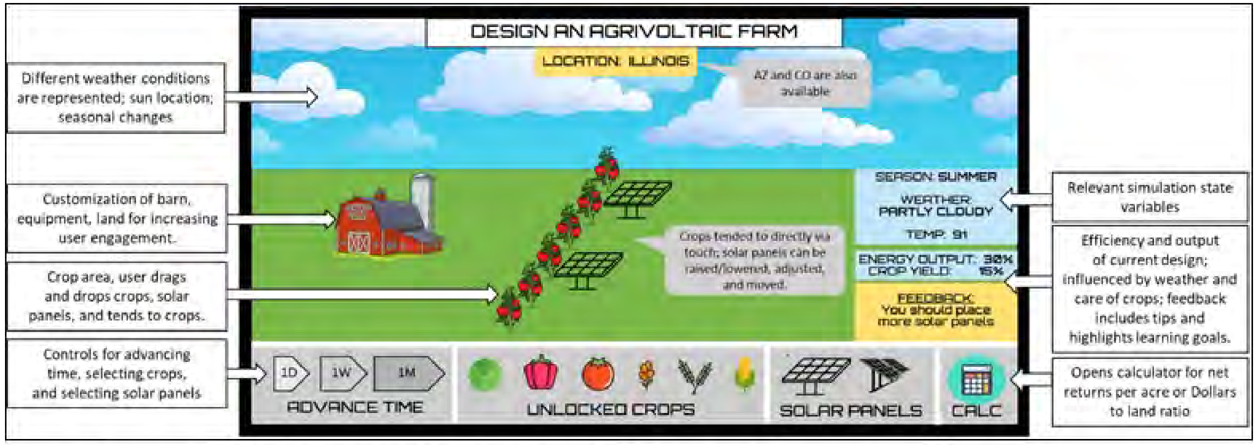


Figure 6: Mock-up of Educational AV Simulation App

- Crop physiology
- Solar panel optimization
- Landscape modeling
- Economics

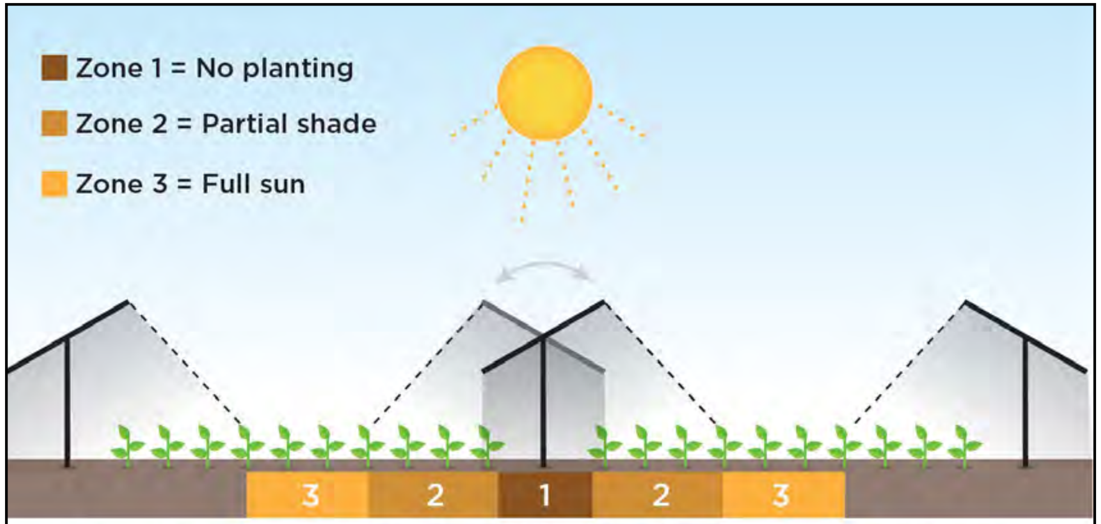


Figure 3: Zones of Shade and Light with Photovoltaic Panels

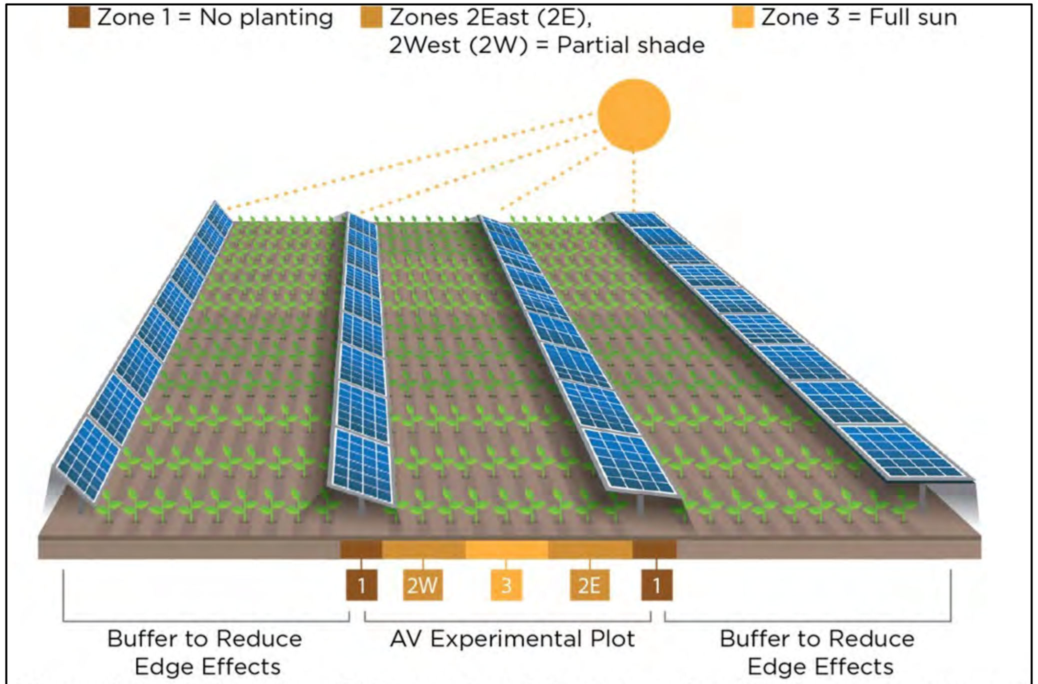
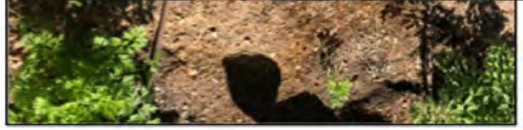


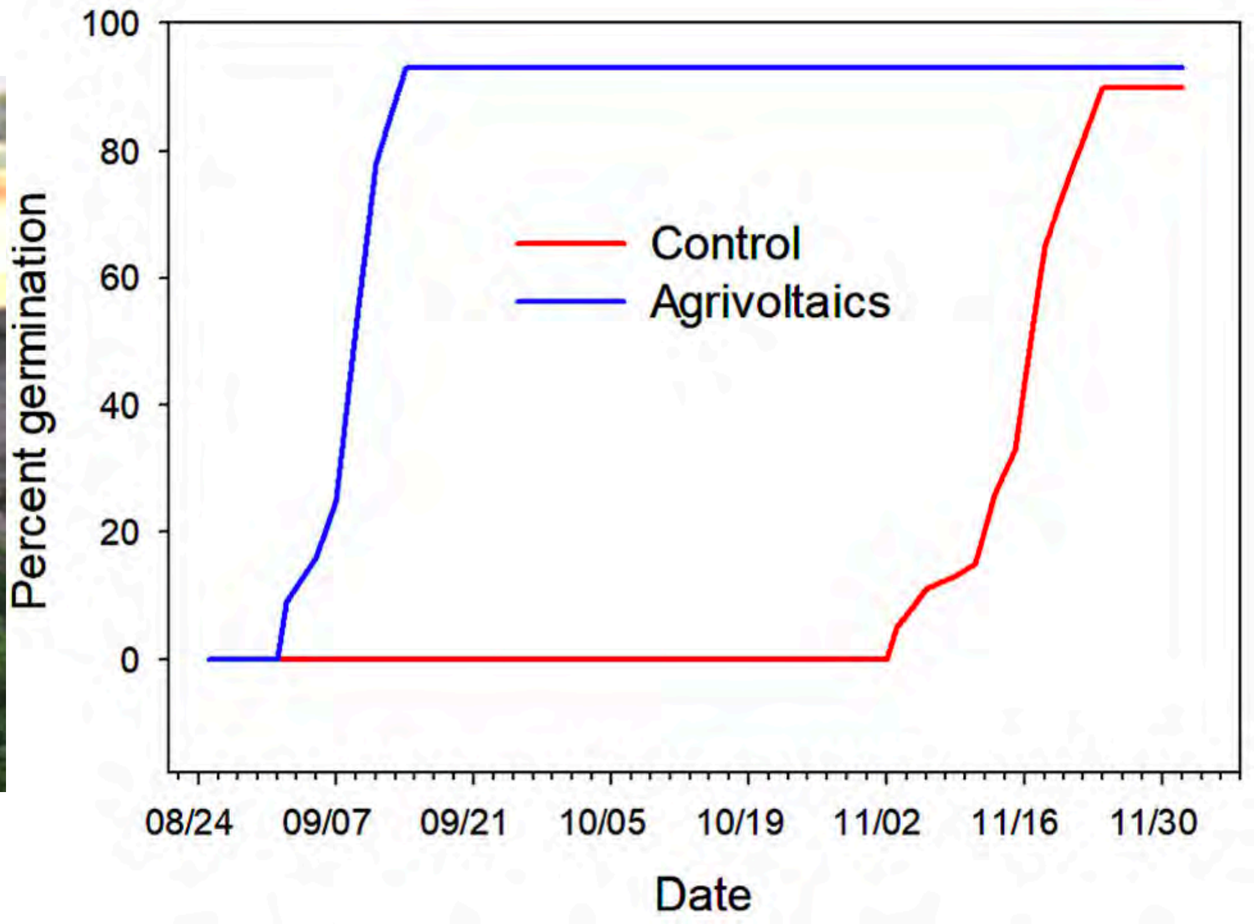
Figure 4: Depiction of an AV Research and Demonstration Site for measurements of individual crop plant responses, and yield, to the full range of environmental alterations caused by PV panels. Similar sites will be located in IL, CO and AZ.

Agrivoltaics can extend the growing season!

Agrivoltaics



* *Initiating* the growing season (changing the phenology)



Agrivoltaics can extend the growing season!

Agrivoltaics

Open-sun

* *Extending* the growing season (changing the phenology)

* Prevents freeze damage

Agrivoltaics can lead plants to alter the form and function!

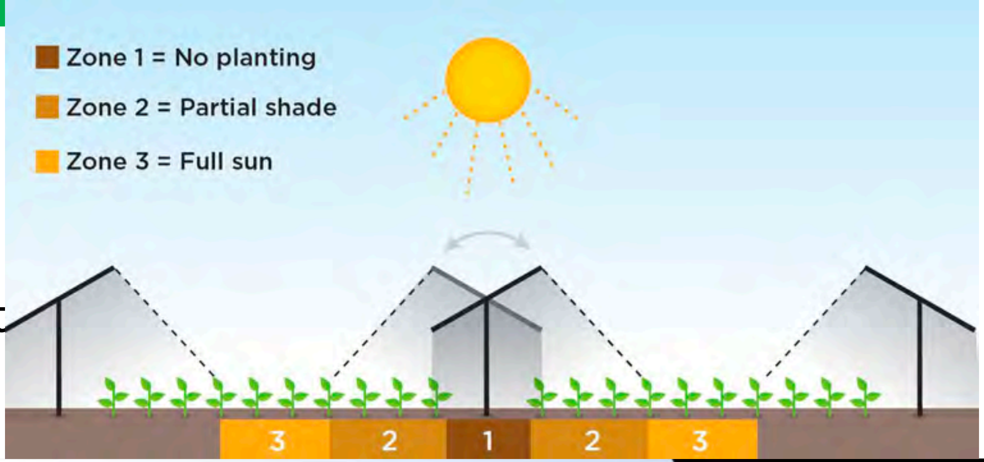
- Additional key research questions:
  - How does this impact quality and nutrition?
  - What other crop features might change in an agrivoltaic system?
  - How can we *alter* plant traits to be most beneficial for agrivoltaics?
  - How might we intentionally select plants and plant traits for the benefit of PV within an agrivoltaic system?

What questions come to mind when you hear that Agrivoltaics changes the microclimate so much we change seasonality, form and function**?**

- **Additional key research questions**:
  - How do all of these patterns vary geographically?
  - What other benefits in terms of ecosystem services come along?
  - How does this impacts economics on the ground?
    - *What does it mean to be able to produce outside of traditional growing seasons?*
  - What *new* opportunities now exist (higher value, higher nutrition, etc.)?
  - How can we bring nutrition and food production to communities to land that was previously non-arable or marginal?
  - How might agrivoltaics become a ‘climate-smart’ adaptation tool?

What questions come to mind as you watch this video?

- **We have found**: *We must account for spatio-temporal *patterns*.*
- **Early findings include diurnal patterns in**:
  - Plant function (photosynthesis and transpiration), which varies type
  - Plant water stress & needs for vegetation, which varies by plant
  - Moisture deposition from panels
  - ‘Value’ of solar energy capture by overhead solar panels



- **Additional key research questions**:
  - How do all of these patterns vary geographically?
  - How might bifacial patterns allow for increased light transmission and energy production?
  - How does seeing installations in action influence farmer, energy producers, or political decision-making?

Video credit:
Aaron Bugaj

What questions come to mind as you watch this video?

- How do patterns of benefits 'scale' and change across geographic space?
- What challenges or opportunities come with industry-scale ag or PV installations?
  - Facilitated opportunities with both industries
- How do operations of each industry impact the other & how does that change through time?
- How do patterns of benefits change through time – especially important as we see record and 'unprecedented' changes?

Video credit: Aaron Bugaj

AmeriFlux

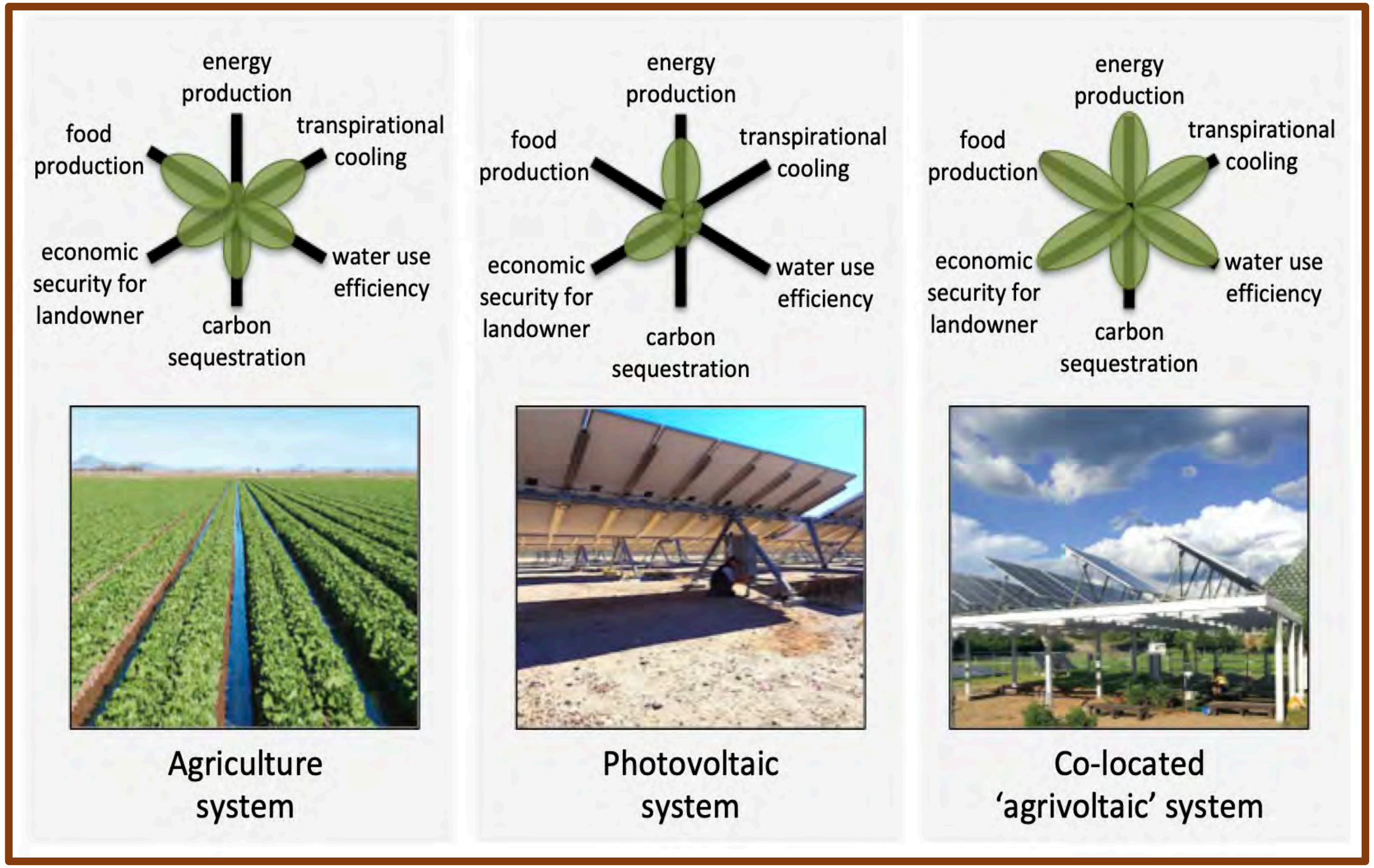
ltar Long-Term Agroecosystem Research

We need to continue to evolve our thinking to acknowledge that agrivoltaics is a ‘system’ of systems

We can optimize systems!

…but we have to acknowledge that we are making trade-offs and understand the drivers and levers and knobs

- Ag systems can be optimized for production or water or land conservation…
- PV systems can be optimized to meet regional demands…
- But truly ‘optimizing’ this system requires an understanding of goals and measures of costs and benefits



Thank you! Any questions?

- Project Director: Prof. Madhu Khanna
    - University of Illinois Urbana Champaign
    - Email: khanna1@illinois.edu

- Project website:

https://sustainability.illinois.edu/research/agrivoltaics-project/

Research Projects Panel

NCAT NATIONAL CENTER FOR APPROPRIATE TECHNOLOGY

University of Massachusetts Amherst

UIC UNIVERSITY OF ILLINOIS CHICAGO

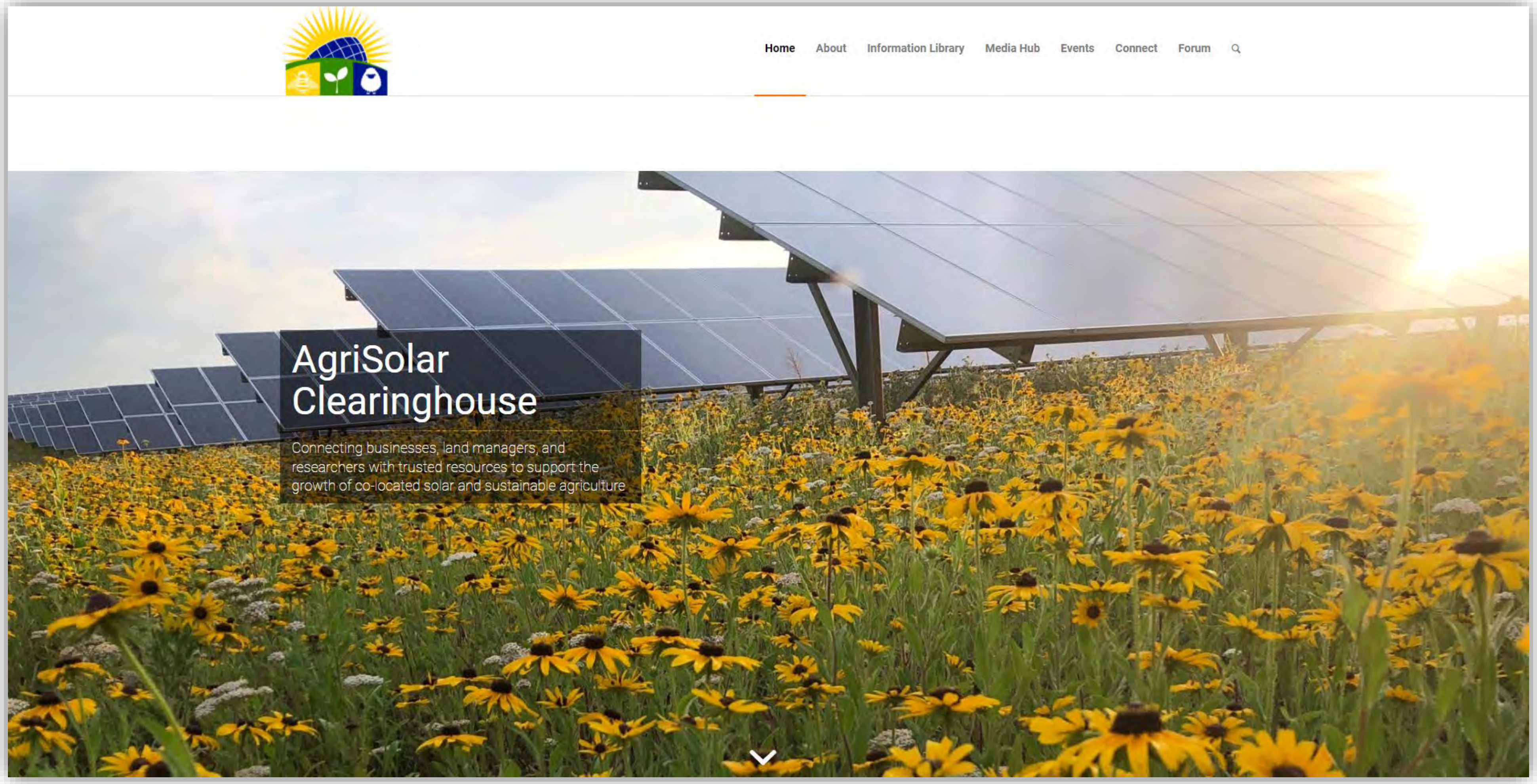
SILICON RANCH

NATIONAL CENTER FOR APPROPRIATE TECHNOLOGY

The AgriSolar Clearinghouse

Stacie Peterson, PhD, NCAT Energy Program Director

Welcome to the AgriSolar Clearinghouse



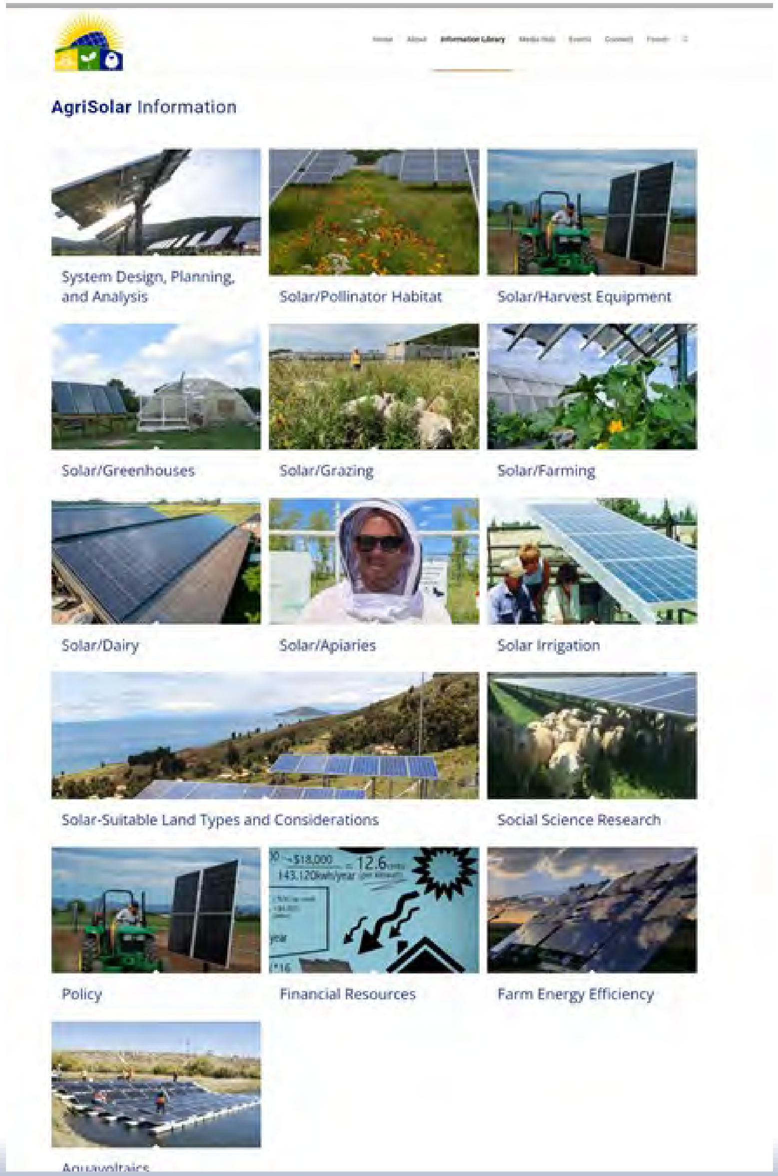
agrisolarclearinghouse.org | agrisolar@ncat.org | 866-723-8677

A DOE Solar Energy Technology Office-funded relationship-building, information-sharing network

AgriSolar Clearinghouse Features

- Central Hub
- User Forum
- Peer-to-peer network
- Technical Assistance
- Story-telling atlas
- Information Library

- Media hub
    - Publications
    - Podcasts
    - Videos
    - Webinars
    - News
    - Field Trips



Meet the AgriSolar **Partners**

Our 20 partners include the leading experts in AgriSolar in the country. They are here to provide cutting-edge research, technical assistance, facilitate relationships, and develop best practices media.

Robin Burton
Research Analyst | Markets & Policy Analyst; National Renewable Energy Laboratory

Diane Brandt
Oregon Policy Manager, Renewable Northwest

Rob Davis
Agrivoltaics and Science Communication Expert

Rebecca Efroymson
PhD, Distinguished Scientist, Environmental Sciences Division; Oak Ridge National Lab

Greg Barron-Gafford
PhD, Biogeographer

Ari Goldstein
Breezy Point Energy; CEO, Co-founder

Max Greene
Regulatory & Policy Director; Renewable Northwest

Amy Johnson
PhD, Conservation Ecologist and Program Director; Smithsonian's Virginia Working Landscapes

Heidi Kolbeck-Urlacher
Policy Associate, Center for Rural Affairs

Iara Lacher
PhD, Owner, Landscape Ecologist; Conservation Futures, LLC

Jordan Macknick
Lead Energy-Water-Land Analyst, National Renewable Energy Laboratory (NREL)

James McKinion
President/Founder, Helical Solar Solutions, LLC

Phal Mantha
Director of Agriculture and Sustainability; Ridge to Reefs

John Palm
Bozeman Green Build; Owner

Scott Sklar
Energy Director; George Washington University Environment & Energy Management

Seeta Sistla
PhD, Assistant Professor; CalPoly Corporation

Paul Sturm
Executive Director; Ridge to Reefs

Chris Terrell
CEO, Co-founder; Wexus Technologies

Andrew Valainis
Executive Director; Montana Renewable Energy

Lee Walston
Ecologist; Argonne National Laboratory

Meet the AgriSolar **Stakeholders**

Our stakeholder group serves as a review board for the Clearinghouse. It includes leading experts in solar grazing, pollinator habitat, farmland conservation, agrivoltaics, and rural affairs.

Peter S. Berthelsen

Partnership Director, Bee and Butterfly Habitat Fund

Andy Bingle

Education Director, Colorado Agrivoltaic Learning Center

Alex DePillis

Senior Agriculture Development Coordinator, Vermont Agency of Agriculture, Food, and Markets

Lexie Hain

Executive Director, American Solar Grazing Association

Chuck Hassebrook

Vice President for Project Development, Sandhills Energy

Emma Kampherbeek

MSc, Animal Sciences, Wageningen University & Research

David Murray

Solar Policy Director, American Clean Power Association

Alexis Pascaris

Founder, AgriSolar Consulting, LLC

Jesse Puckett

Senior Manager for Sustainability Projects, Enel North America

Kelly Rourke

Executive Director, Pollinator Partnership

Cody Smith

Community Resilience Coordinator, Environmental

Lucy Stolzenburg

Texas Solar Energy Society

Ethan Winter

Northeast Solar Specialist, American Farmland Trust

Questions?

Agrisolarclearinghouse.org

Impacts of Dual-Use Solar on Crop Productivity and the Agricultural Economy in Massachusetts and Beyond

UMass Amherst

Academic Partnerships with Commercial Solar Developers

Establishing research site trials within broader solar projects

6-8 site trials, across state regions

3 solar developers committed to support dual-use research

Breadth of crops (hay, row crops, cranberries) and grazing

Site trial and national data used to assess economic impacts on farm and agricultural economy

Project builds on UMass dual-use experiments at Research Farm and Cranberry Station

UMassAmherst

Center for Agriculture, Food, and the Environment

UMass and AFT to conduct research. State energy and agriculture agencies are policy partners.

DOER

Massachusetts Department of Energy Resources

College of Social & Behavioral Sciences

Resource Economics

American Farmland Trust

SAVING THE LAND THAT SUSTAINS US

MDAR

UMassAmherst | Clean Energy Extension

Research Site Trials

Solar Developer	Property Owner	Location (MA Town)	Commodity	PV Capacity (DC)	PV Technology
BlueWave Solar	Knowlton Family Trust	Grafton	Pumpkins, strawberries, greens	0.33 MW	Fixed-Tilt (SE facing) + Bi-Facial Panels
			Grazing	2.8 MW	
	Cabral Farms, Inc.	Dighton	Winter squash	3.9 MW	Single-Axis Tracker + Bi-Facial
Sun Bug	Reddy Fox Farm	Monson	Hay	250 kW	Fixed Tilt, Bi-Facial
Hyperion Systems	Czajkowski	Hadley	Vegetables	388 kW DC	Fixed Tilt, Post Driven Mounting
PineGate Renewables	Weston, Williams, Wainio	Carver	Cranberry	10 MW	Single-Axis Tracker; Battery Storage
	Perry, Shores, Wainio	Carver	Cranberry	3.5 MW	Single-Axis Tracker; Battery Storage
	Dunham, Correira	Plympton	Cranberry	6.2 MW	Single-Axis Tracker; Battery Storage






UMassAmherst | Clean Energy Extensi

Evaluation of Economic, Ecological, and Performance Impacts of Co-Located Pollinator Plantings at Large-Scale Solar Installations

- Project period: March 2021 – February 2025
- Objectives:
    - Research scalability and configuration of pollinator plantings at facilities >10 MW
    - Create comprehensive implementation guidance and decision tools for solar developers and policy-makers
    - Engage solar industry partners and share findings with broader industry stakeholders

Photo courtesy of Stantec / Evergy

UIC

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Argonne NATIONAL LABORATORY

Cardno

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Key Components

Field Research

- Six (6) Solar Facility Test Sites
- PV Performance Study
- Ecological Evaluation
- Capital and O+M Cost Study

Tool Development

- Large-Scale Pollinator Solar Implementation Manual
- Cost-Benefit Calculator
- Solar Site Seed Selection Tool
- Pollinator Solar Field Assessment Module

Outreach & Engagement

- Industry Advisory Group
- Technical Advisory Group
- Online hub through ROWHWG website

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Break!
2:40 – 2:50

Agrivoltaic Industry Perspectives

ASGA

BLUEWAVE

CONNEXUS® ENERGY
Your Community Energy Partner

Jack's SOLAR GARDEN

BLUEWAVE PROJECTS

Maine and Massachusetts

ROCKPORT BLUEBERRY PROJECT (VOLUNTARY)

- Standard fixed-tilt solar located on top of existing wild blueberry patch (bi-facials)
- Hosting crop trials over half site in partnership w/ local grower and UMaine
- Research impacts of construction on existing berries, growing conditions, yield
- Grower will manage crop trial for 5 years for prod. subsidy / equip. investment
- Interdisciplinary partnership will inform best practices on all sides

GRAFTON AGRIVOLTAIC PROJECT (REGULATORY)

- Two elevated fixed-tilt agrivoltaic canopies located on 5th generation farm
- Modified design allows for greater sunlight access and maneuverability
- Ground crops / crop trials + rotational grazing / soil carbon study + holistic study of farm
- Intermediary farm manager will oversee agricultural operation / compliance
- Farm infrastructure, operational subsidies provided for subtenant farmers
- Interdisciplinary partnership involves federal, state, university, NGO, private sectors



Jack's
SOLAR & GARDEN


Colorado
Agrivoltaic
LEARNING CENTER




Breakout Sessions

- You will be able to choose the session you attend
- Our industry and research experts will be in the breakout rooms to talk with you
- Ask questions, have a conversation, connect with others in the field!

- Session options:
  - Pollinators
  - Livestock and Grazing
  - Crops
  - Commercialization and Deployment

Thank you for joining!

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