Agrivoltaics Overview of Opportunities

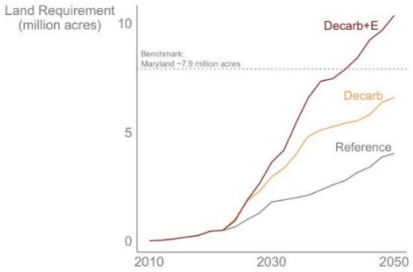
November 14, 2023

Jordan Macknick

NASEO Rural Energy Working Group Webinar: Agrivoltaics

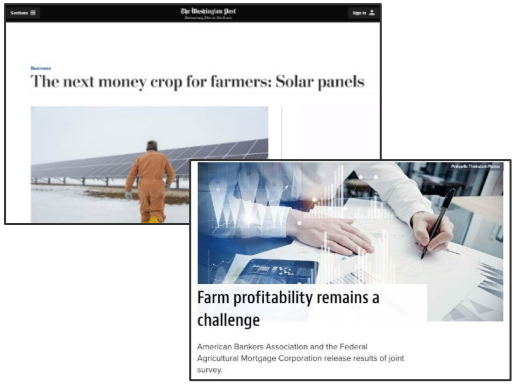
Agrivoltaics Motivation: Confluence of Solar and Land-Use

Rapid Expansion of Utility-Scale Solar



Solar Land Requirements:
2030: 2 - 4 million acres
2050: 4 - 10 million acres

Economics Benefits to Farmers for Hosting Solar Projects



Public Opposition to Solar on Agricultural Lands

Agrivoltaics offers opportunities to:

- Improve economic resilience of our food system and farmers
- Keep agricultural lands in production and in beneficial use
- Enable cost-effective solar development
- Avoid land-use conflicts

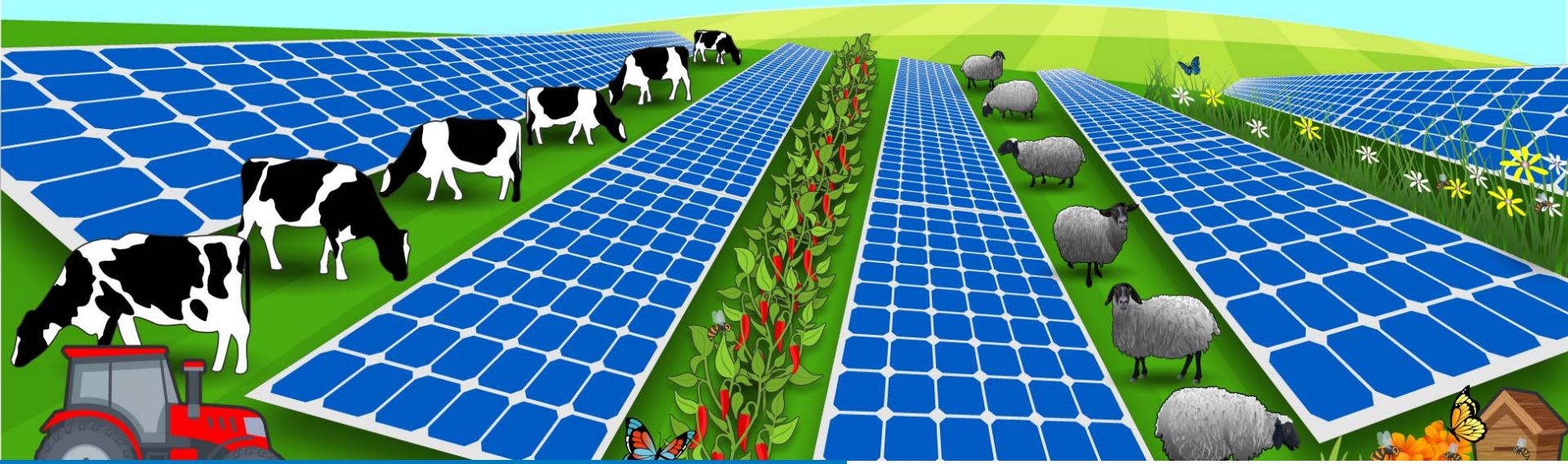
Source: Heath, Garvin, Dwarakanath Ravikumar, Silvana Ovaitt, Leroy Walston, Taylor Curtis, Dev Millstein, Heather Mirletz, Heidi Hartmann, and James McCall. Environmental and Circular Economy Implications of Solar Energy in a Decarbonized US Grid. No. NREL/TP-6A20-80818. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2022

Vision: Mutual Benefits of Solar with Land and Agriculture

Agrivoltaics 101

Agrivoltaics is agriculture performed underneath and around solar arrays. The solar panels placed on the same land where crops are cultivated allow growers to harvest the power of the sun twice.

Agrivoltaics could help us meet our national renewable energy targets, save water, and create a sustainable long-term food system.



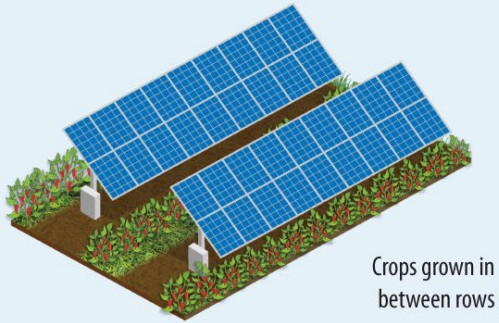
What is Agrivoltaics?

Agricultural activities performed underneath and around solar arrays:

- ❖ Crop production
- ❖ Grazing
- ❖ Pollinator Habitat (Ecovoltaics)
- ❖ Solar Greenhouses

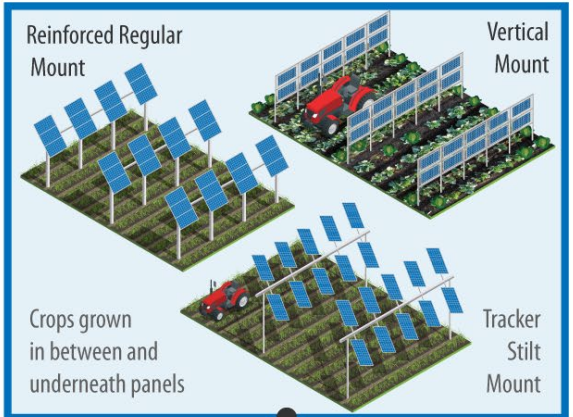
Traditional utility-scale configurations

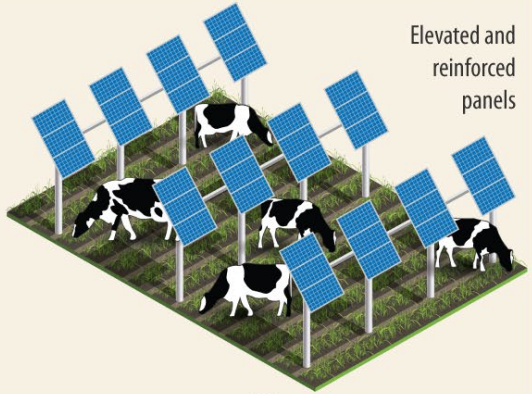
Crop Production



Animal Husbandry

Ecosystem Services





Greenhouse Solar

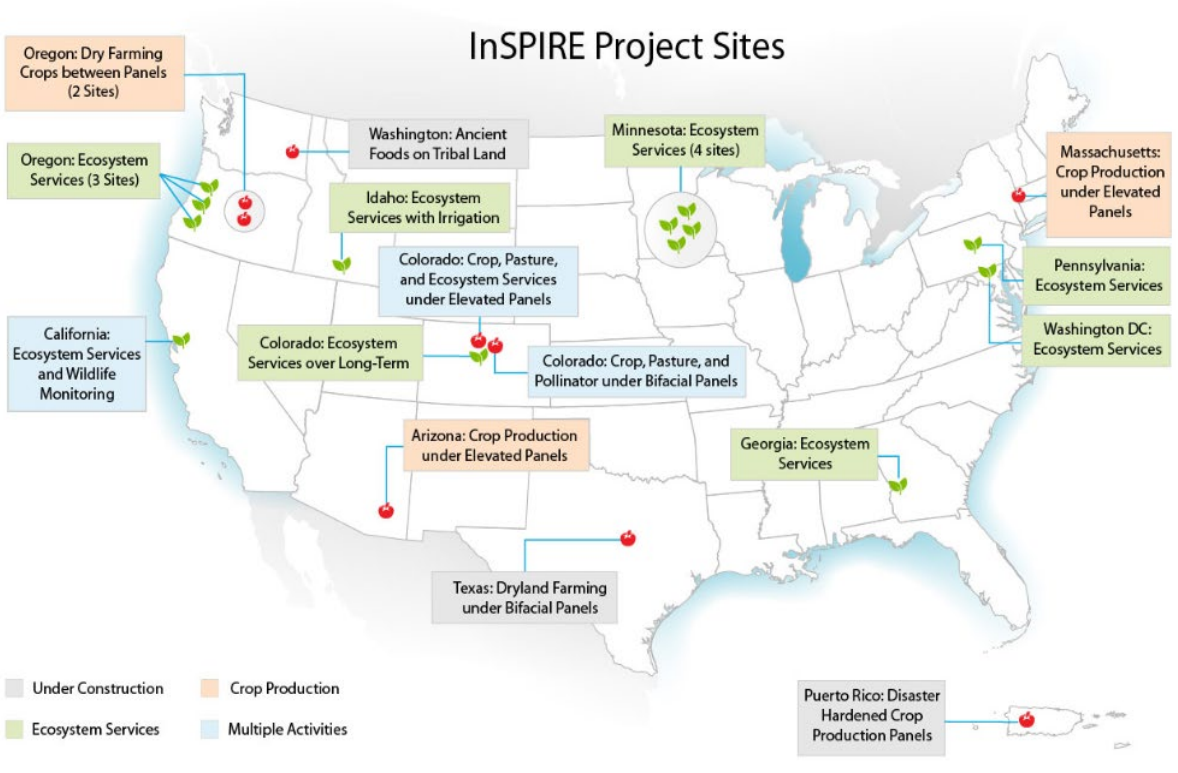
Alternative configurations

The InSPIRE Project-

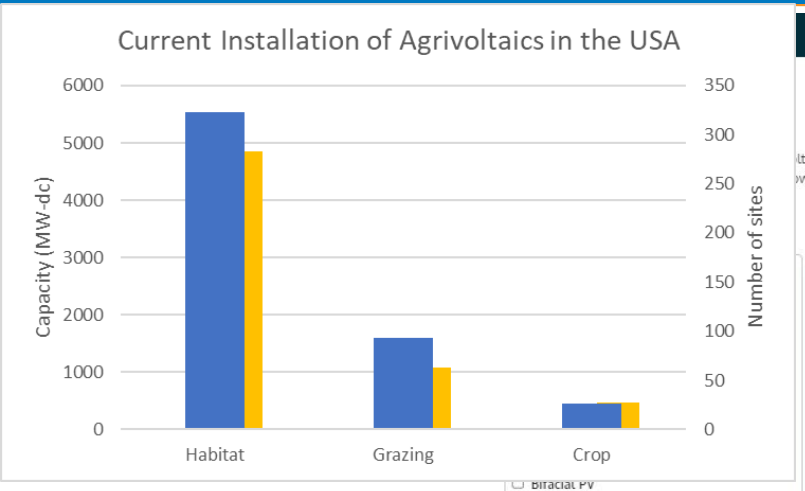
Innovative **S**olar **P**ractices **I**ntegrated with **R**ural Economies and **E**cosystems

- InSPIRE has 24 active field research projects across the U.S.
- **Analytical research:**
  - Cost-benefit tradeoffs of different agrivoltaic configurations
  - Assessing research gaps and priorities
  - Tracking agrivoltaic projects across the U.S.
- **Field-based research:**
  - Novel agrivoltaic and traditional utility-scale PV designs integrated with multiple activities
  - Assessing agricultural yields and irrigation requirements in arid environments
  - Grazing standards and best practices
  - Pollinator habitat and ecological services

https://openei.org/wiki/InSPIRE



Current Status of Agrivoltaics in the United States



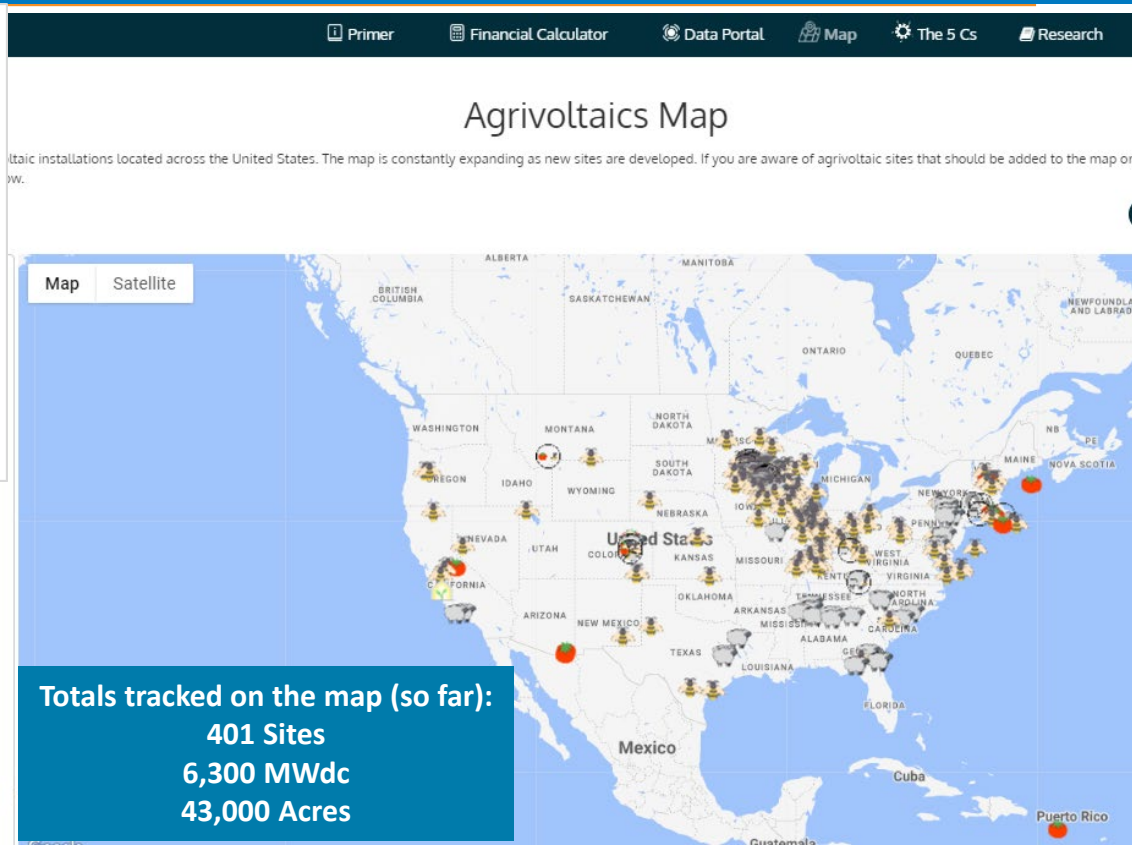
Bifacial PV
Translucent PV

System Size MWdc
- < 1 MW
- 1-5 MW
- 5-10 MW
- >10 MW

Type of Array
- Fixed
- Single-axis Tracking
- Dual-axis Tracking

Active Research

InSPIRE Research Site



Interactive Map (updated weekly): https://openei.org/wiki/InSPIRE/Agrivoltaics_Map

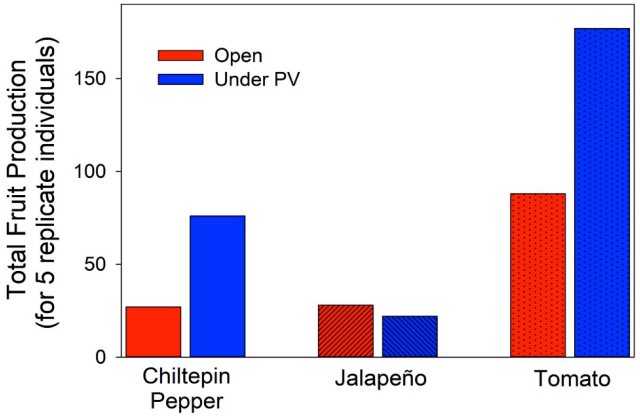

What is Agrivoltaics? Crop production under and around solar panels

- Crops can be grown directly underneath elevated panels or in between rows
- Hand-harvested or small machine-harvested crops
- Crop performance varies based on location and solar design configurations

Cost and Design Factors

- Increased panel heights (optional)
- Increased panel spacing (optional)
- Change in O&M needs (more frequent presence on-site)
- Access to water
- Agricultural revenue

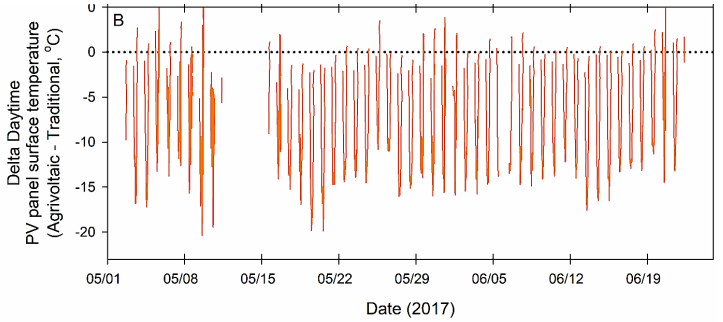
Agrivoltaics at the Biosphere 2 Living Lab



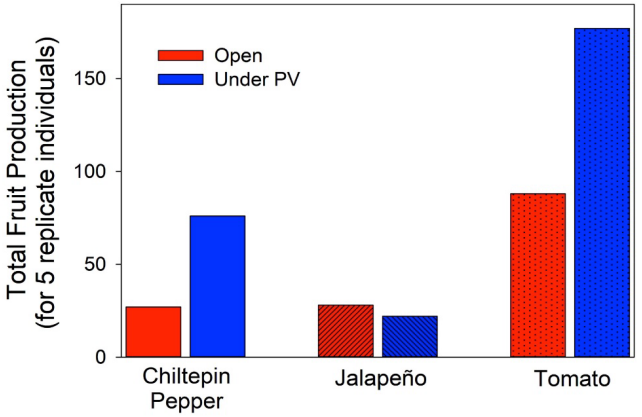
Barron-Gafford et al. (2019) *Nature Sustainability*

Key Highlight: Energy+Water+Food Benefits of Agrivoltaics

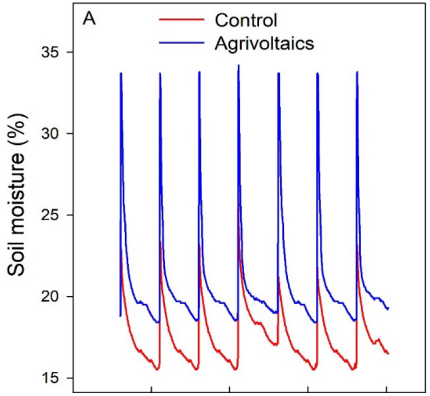
- **Energy Benefits**
  - Summertime average cooling from vegetation underneath panels: ~9°C
  - Annual generation increase: ~2%



- **Food Benefits**
  - 3x yield for chiltepin peppers
  - 2x yield for tomatoes
  - Same yield for jalapeno pepper



- **Water Benefits**
  - Peppers need 50% less water
  - Tomatoes need 30% less water



University of Arizona Agrivoltaics system
- Elevated (10 ft) solar panels
- Tucson, AZ (Professor Greg Barron-Gafford)
- Barron-Gafford et al. (2019) *Nature Sustainability*
- https://www.barrongafford.org/agrivoltaics.html

Crop yields as a function of crop placement: Broccoli in Massachusetts

Massachusetts Test Facility

Broccoli Harvested in different locations under panels



What is Agrivoltaics? Pollinator-friendly Solar

- Native and pollinator-friendly vegetation can host beneficial insects
- Increased beneficial insect populations can benefit nearby farms
- Ongoing research evaluating species that thrive in partial shade of solar panels

Cost and Design Factors

- Panel heights (to increase or not to increase?)
- Seed mix selection and purchase
- Reduction (usually) in O&M needs over time
- Potential stormwater management benefits

2018 – 2022 Preliminary Results

Onsite floral abundance & plant species richness increased over time

2018

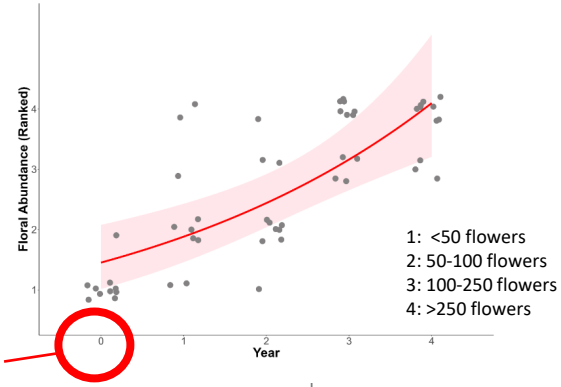
2022

Same transect, 4 years apart

2018 – 2022 Preliminary Results

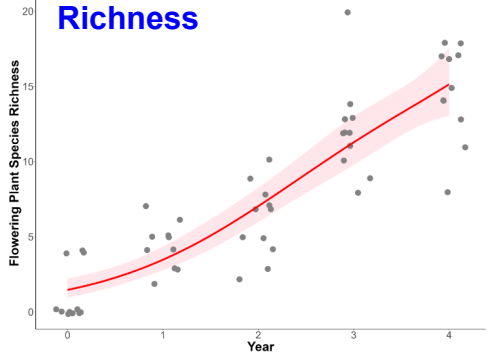
Onsite floral abundance & plant species richness increased over time

Floral Abundance



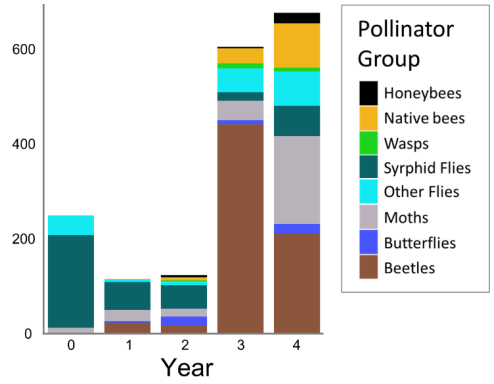
Seeding in Year 0 (2018)

Flowering Plant Species Richness



Pollinator Abundance & Diversity Increased

>650 transect observations
>13,000 insects identified to group



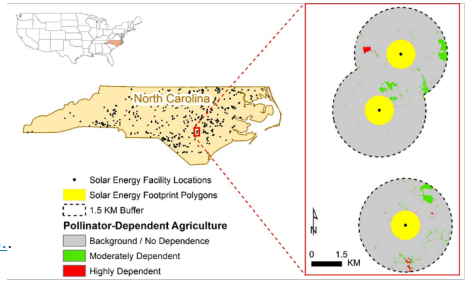
Soldier beetle (*Chauliognatha* sp.)

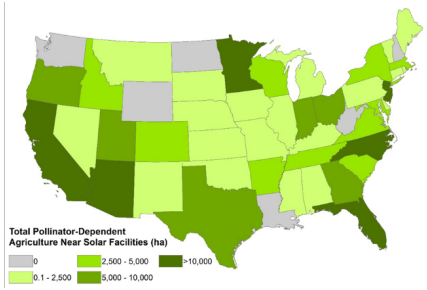
Syrphid fly (*Toxomerus* sp.)

Walston et al., in press

Key Highlight: Pollinator-Friendly Solar

Over 800,000 acres of agricultural land would benefit if existing solar facilities had pollinator-friendly vegetation





Examining the Potential for Agricultural Benefits from Pollinator Habitat at Solar Facilities in the United States..
Leroy J. Walston, Shruti K. Mishra, Heidi M. Hartmann, Ihor Hlohowskyj, James McCall,
Jordan Macknick 2018. Environmental Science & Technology Vol. 52 (13) 3 July 2018 pp. 7566-7576.

Solar Power World

TOP SOLAR CONTRACTORS SOLAR ARTICLES PRODUCTS LEADERSHIP SUBSCRIBE

Pine Gate Renewables, Old Sol Apiaries create largest solar farm apiary in America

By Kelsey Misbrener | June 15, 2018

Utility-scale solar developer Pine Gate Renewables, headquartered in Charlotte, North Carolina, is pleased to announce that honey bees are now living on Eagle Point solar farm in Jackson County, Oregon, thanks to the company's SolarCulture initiative. SolarCulture is a Pine Gate environmental stewardship initiative that promotes sustainable agriculture and collaborations with the community to support research for smarter solar development.

What is Agrivoltaics? Solar-Powered Honey Production

- Hives can be located in or outside of project fence
- Innovative branding and marketing opportunities
- Ongoing work evaluating honeybee and native bee preferences

Cost and Design Factors

- Seed mix selection and purchase
- Location of hives (inside or outside fence)
- Safety precautions

What is Agrivoltaics? Solar-Integrated Grazing

- Sustainable grazing practices can improve soils
- Potential cost reductions from standard mowing practices
- Ongoing work evaluating pastureland performance
- Can be compatible with pollinator habitat

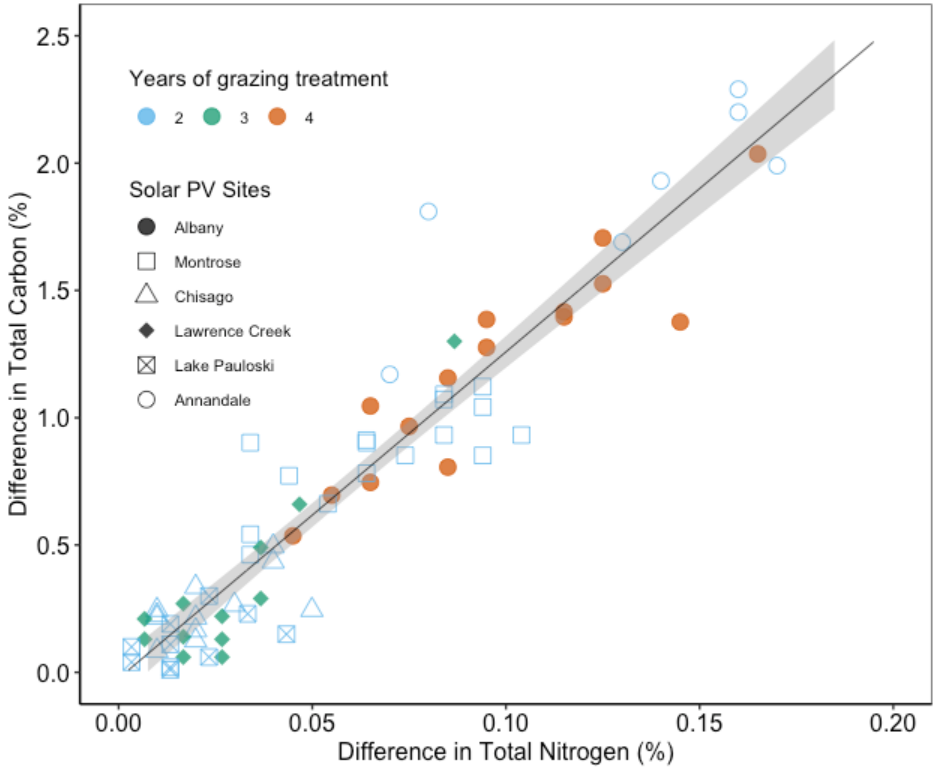
Cost and Design Factors

- Temporary fencing on-site
- Fencing considerations around site
- Water access
- Panel heights (for cattle)

https://solargrazing.org/

ASGA

Impacts of Sheep Grazing on Soil Carbon



- Higher content of both carbon and nitrogen in grazed sites compared to control sites
- No correlation with grazing frequency

6 commercial solar PV sites in Minnesota (ENEL Green Power)
Native pollinator friendly vegetation under panels
500-700 sheep grazing treatment for 2-3 weeks per year.



What is Agrivoltaics? Solar Greenhouses

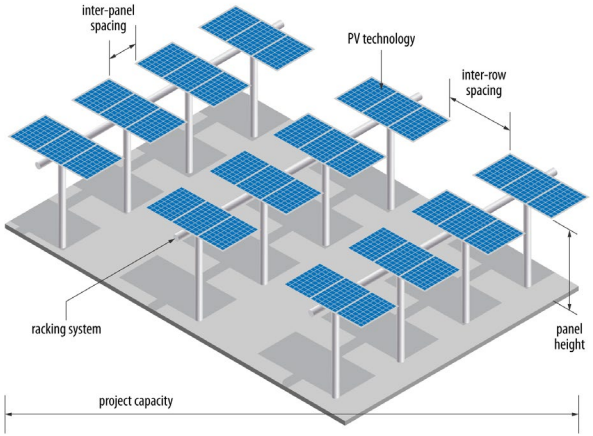
- Opportunities for direct use of electricity generated
- Tunable wavelength materials
- Variations in shading

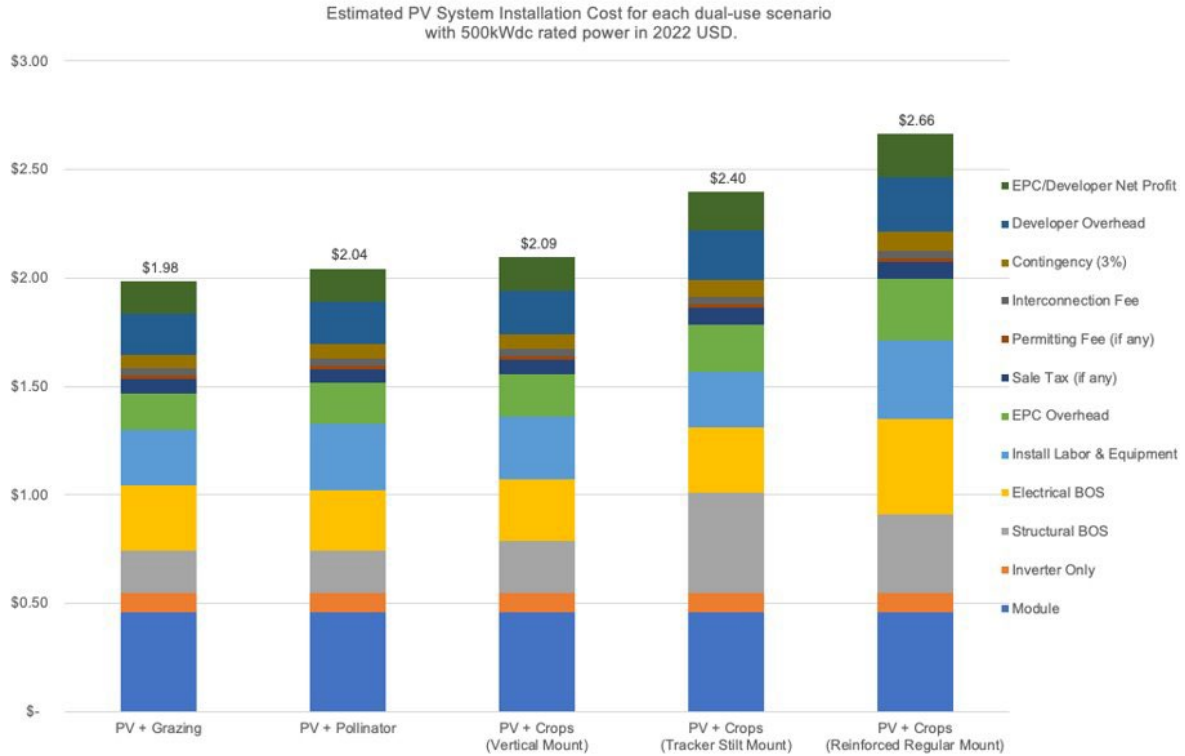
Cost and Design Factors

- Greenhouse vs. indoor vertical designs, etc.
- Solar technology material
- Light, wavelength optimization
- Electricity usage

Cost Factors to Consider for Agrivoltaics

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

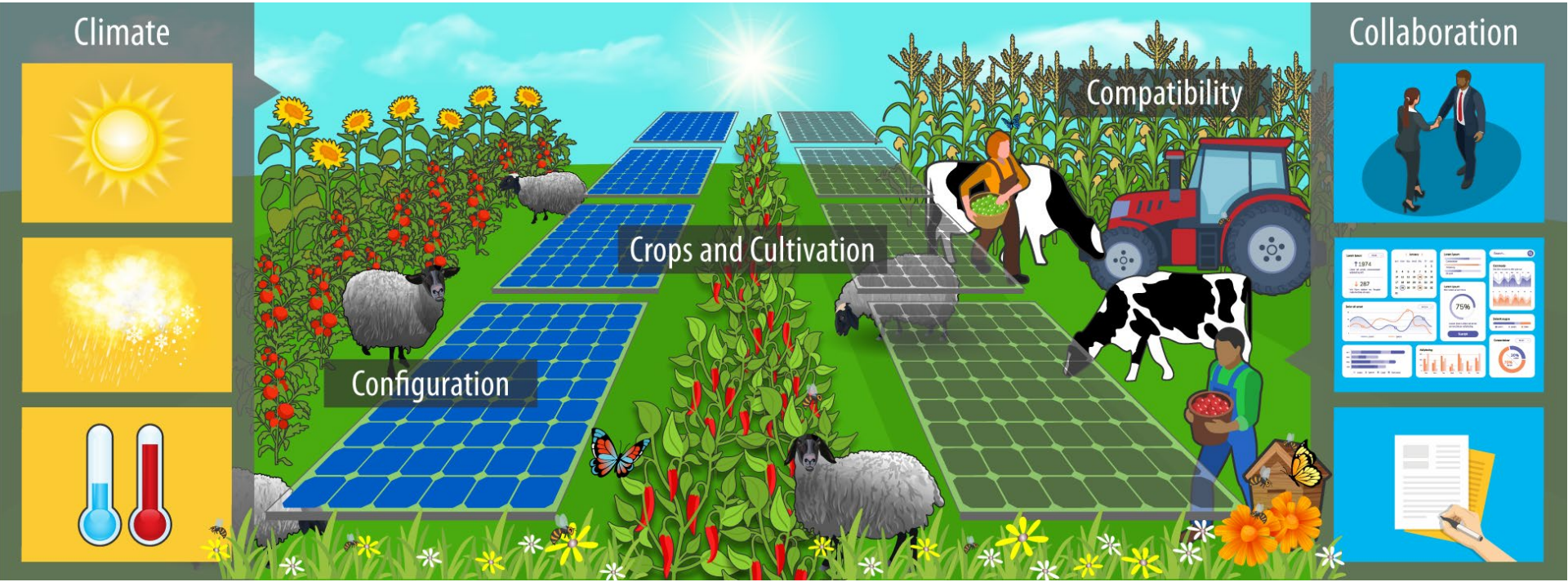




Results are for 500-kW systems. Results can vary at lower and higher installed capacities

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
https://www.nrel.gov/docs/fy21osti/77811.pdf

The 5 C’s of Agrivoltaic Success



Macknick, Jordan, Hartmann, Heidi, Barron-Gafford, Greg, Beatty, Brenda, Burton, Robin, Seok-Choi, Chong, Davis, Matthew, Davis, Rob, Figueroa, Jorge, Garrett, Amy, Hain, Lexie, Herbert, Stephen, Janski, Jake, Kinzer, Austin, Knapp, Alan, Lehan, Michael, Losey, John, Marley, Jake, MacDonald, James, McCall, James, Nebert, Lucas, Ravi, Sujith, Schmidt, Jason, Staie, Brittany, & Walston, Leroy. The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study. NREL/TP-6A20-83566. https://doi.org/10.2172/1882930

Thank you!

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

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NREL
Transforming ENERGY

NASEO
National Association of State Energy Officials

NASEO Rural Energy Working Group Webinar: Agrivoltaics – The Benefits and Potential of Dual Use Solar on Agricultural Lands

November 14, 2023

Thank you to the U.S. Department of Energy Office of State and Community Energy Programs for their support of this event

Agenda

Moderator

- Jasmine Xie, Senior Program Manager, NASEO

Speakers:

- Jordan Macknick, Lead Energy-Water-Land Analyst, National Renewable Energy Laboratory
- Grace Fletcher, Program Coordinator, Massachusetts Department of Energy Resources
- Samantha Levy, Conservation and Climate Policy Manager, American Farmland Trust

Creating a Clean, Affordable and Resilient Energy Future for the Commonwealth

DOER
Massachusetts Department of Energy Resources

Agrivoltaics in the SMART Program

November 14, 2023

Introduction

- SMART is a voluntary declining incentive structure program in which the utility companies compensate solar system owners per kWh generated
- Certain system types and land uses are more highly compensated through "adders"
  - Building mounted
  - Brownfields
  - Landfills
  - Canopies
  - Agrivoltaics

SMART
MASSACHUSETTS SOLAR PROGRAM

Relative Costs & Compensation Values for Systems >25 kW AC

System Type	Building Mounted	Brownfield	Landfill	Canopy	Agrivoltaic
Average Installation Cost ($/watt)	$2.64	$2.26	$2.04	$3.82	$2.51
Average System Size in SMART (kW AC)	170	2,112	2,155	439	1,424
Total System Count in SMART	766	8	20	83	3
Compensation Rate Adder Value ($/kWh)	$0.02	$0.03	$0.04	$0.06	$0.06

Program Statistics

SMART is a 3200 MW program with a goal of 80 MW of agrivoltaic capacity --> 2.5% of total

20 projects qualified in SMART with agricultural adder --> 31.9 MW, 1.8% of total approved capacity in the program

Existing project types: hay, livestock grazing, cranberries, vegetables, honey

Collaboration with Department of Agricultural Resources

- Development of Guideline and Pre-Determination Application
- Individual project reviews
- Site visits
- Stakeholder engagement
- Knowledge and expertise sharing

Project Review Process & Ongoing Requirements

Step 1	Applicant submits project plans to UMass Clean Energy Extension for input and revises as needed
Step 2	Applicant submits Pre-Determination Application to DOER and MDAR for joint review
Step 3	DOER issues a Pre-Determination letter
Step 4	Applicant submits full application to SMART program and receives a Preliminary Statement of Qualification --> construction begins
Step 5	Applicant receives Final Statement of Qualification when project receives Permission to Operate --> incentive term begins
Step 6	Applicant submits Annual Reports to DOER and MDAR to demonstrate the land continues to be used primarily for agriculture

Key Regulatory Requirements

System will not interfere with continued use of land for agriculture

Designed to optimize balance between electricity generation and agricultural productivity

Raised structure that allows for continuous growth of crops underneath panels

Elements of Pre-Determination Applications

- Property and soils map
- Comment letter from UMass CEE
- Solar array design and site plan
- Shading analysis
- Farm plan (crops, hay, livestock, poultry, etc)
- Demonstration of compliance with regulatory requirements

Challenges & Opportunities of Agrivoltaics

Challenges

- Extended interconnection timelines
- Optimizing solar production while maintaining agriculture as primary use
- More research and data needed

Opportunities

- Additional revenue for farmers
- Diverting solar development from forests and open space
- Keeping land in agriculture and preventing development

Looking Ahead

Technical Potential of Solar Study

- Statewide parcel-by-parcel analysis of the total technical potential for solar installation and the suitability for solar (biodiversity, embedded CO2, ecosystem services, grid infrastructure, etc)
- Online mapping tool to examine suitability across variety of metrics

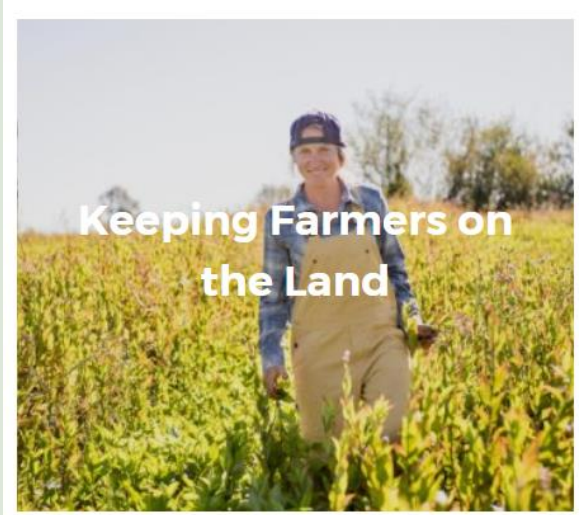
Commission on Agrivoltaics

- Examine research and data, solicit stakeholder input, and develop recommendations for legislative and regulatory changes
- Consider land use impacts, water quality, soil health, food production, carbon accounting

Ongoing research and data gathering

- Annual reports for SMART projects on crop and/or herd productivity, needed changes
- UMass Clean Energy Extension Dual-Use Research

American Farmland Trust's Mission: to Save the Land that Sustains us



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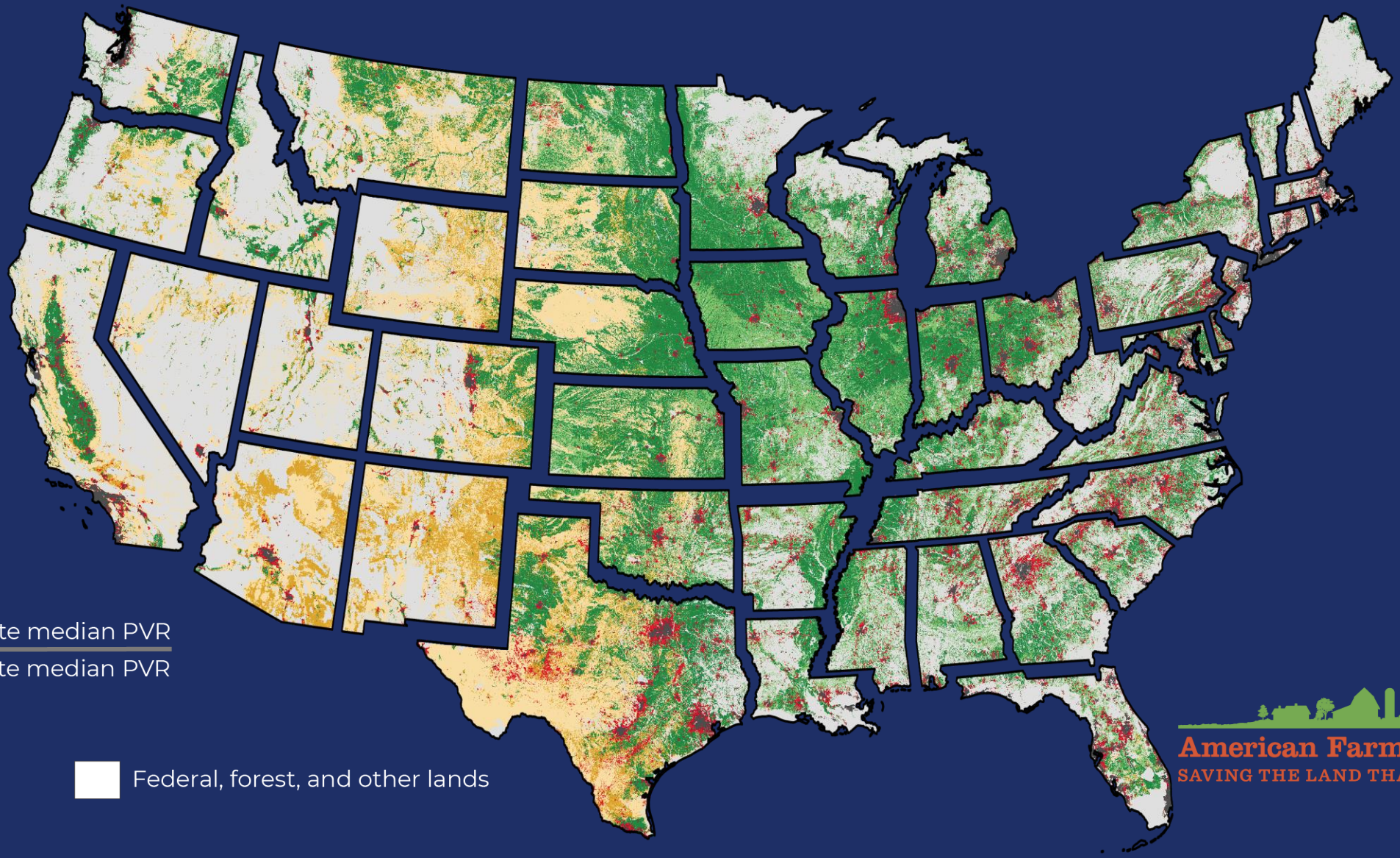
FARMS UNDER THREAT

11 Million Acres Converted, 2001-2016



Conversion

Farmland
Rangeland

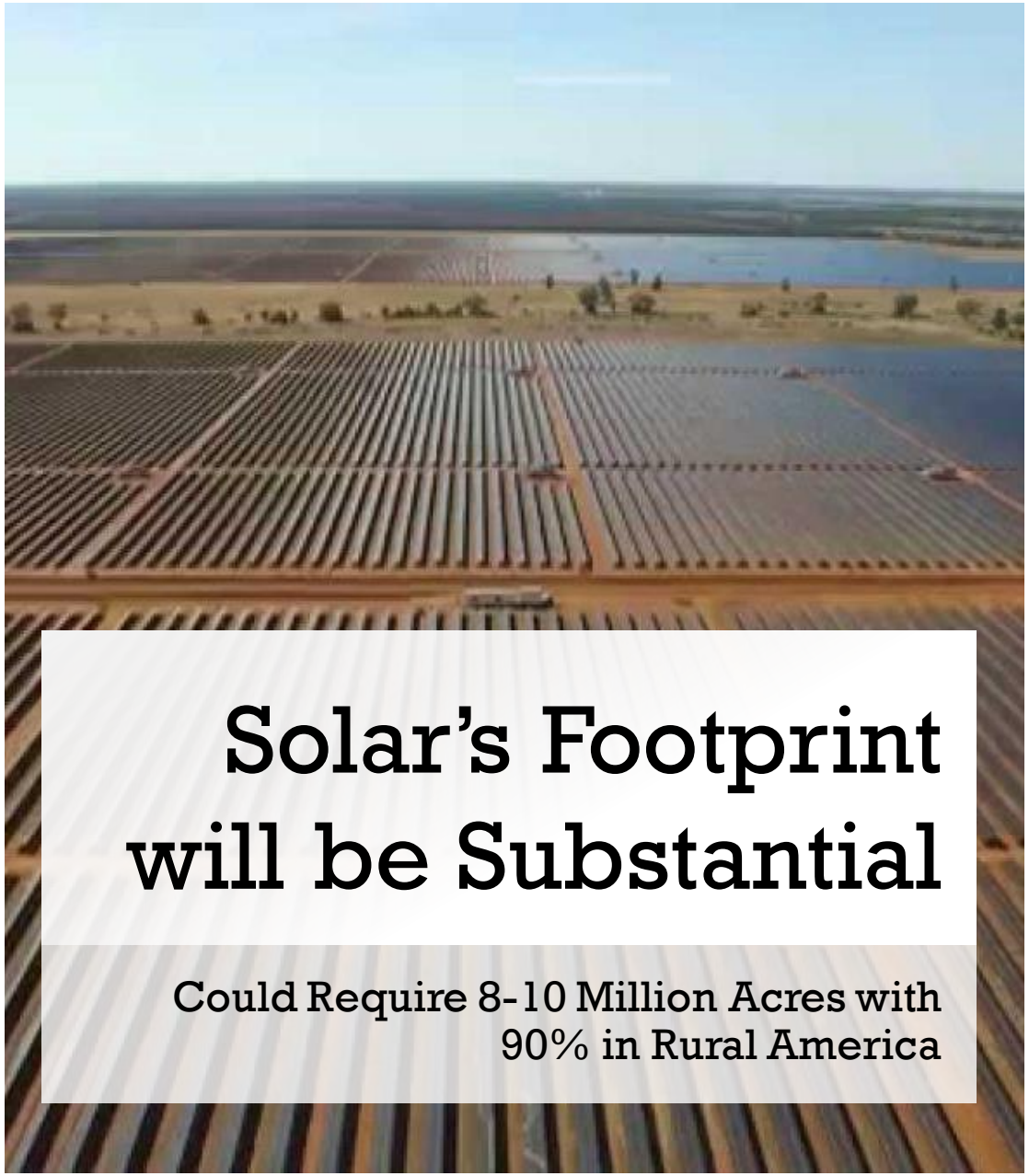
Above state median PVR

Below state median PVR

Urban areas

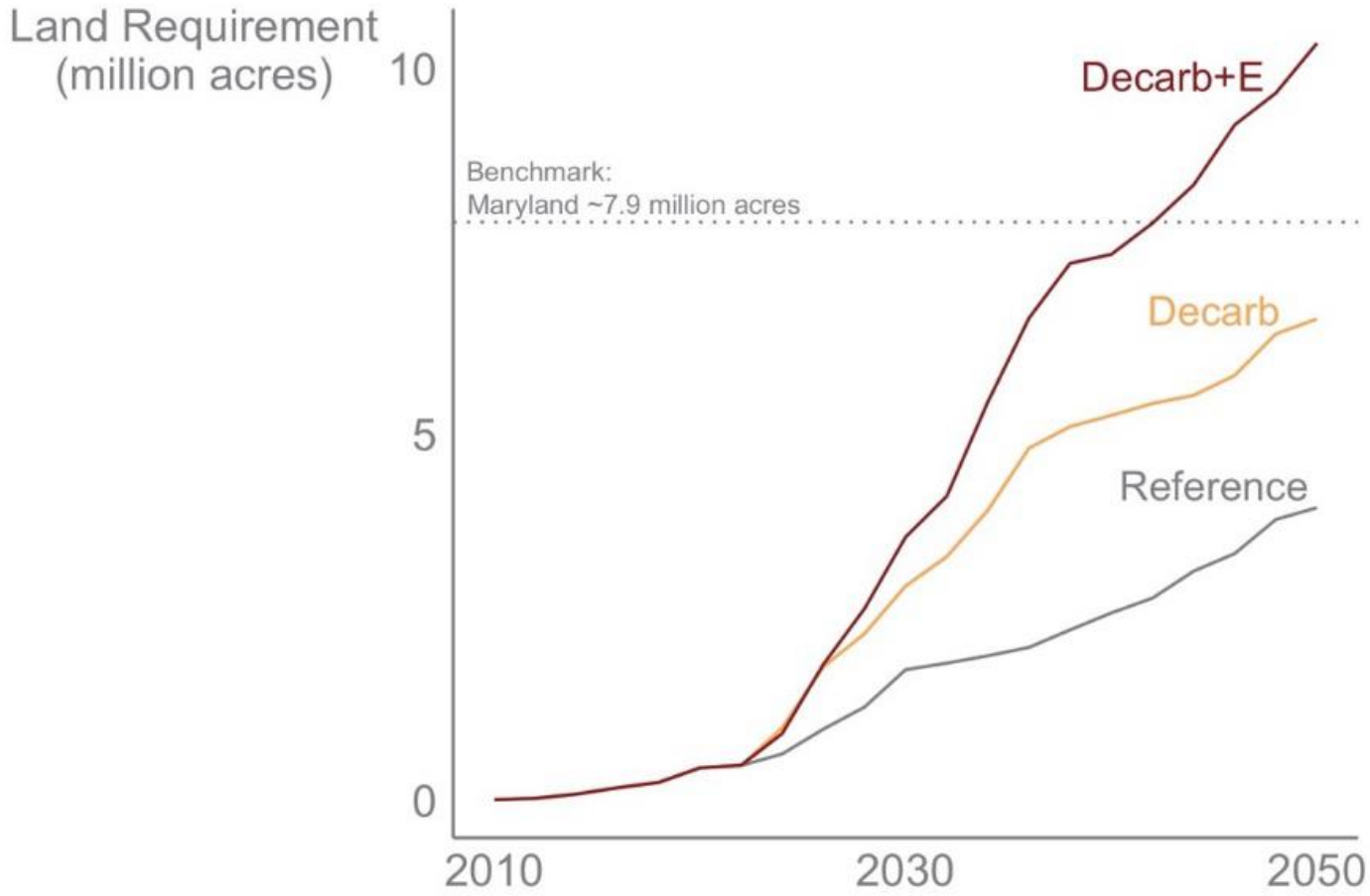
Federal, forest, and other lands

American Farmland Trust
SAVING THE LAND THAT SUSTAINS US



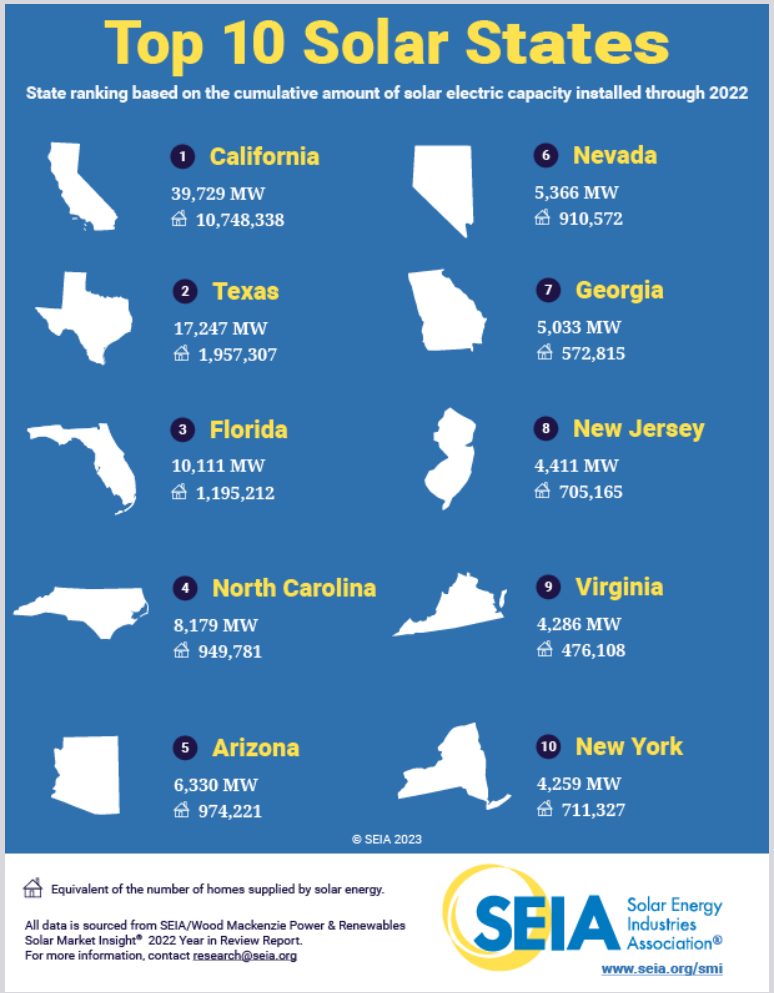
Solar's Footprint will be Substantial

Could Require 8-10 Million Acres with 90% in Rural America



Percent of Undeveloped Land Needed for Utility-Scale Solar in 2040

According to AFT's Farms Under Threat 2040 modelling, without intervention, **83%** of new solar development will be on farm and ranchland. **Half** of that is projected to be on nationally significant agricultural land.



Sources: DOE, 2021, *Solar Futures Study;* AFT, 2022, *Farms Under Threat 2040*

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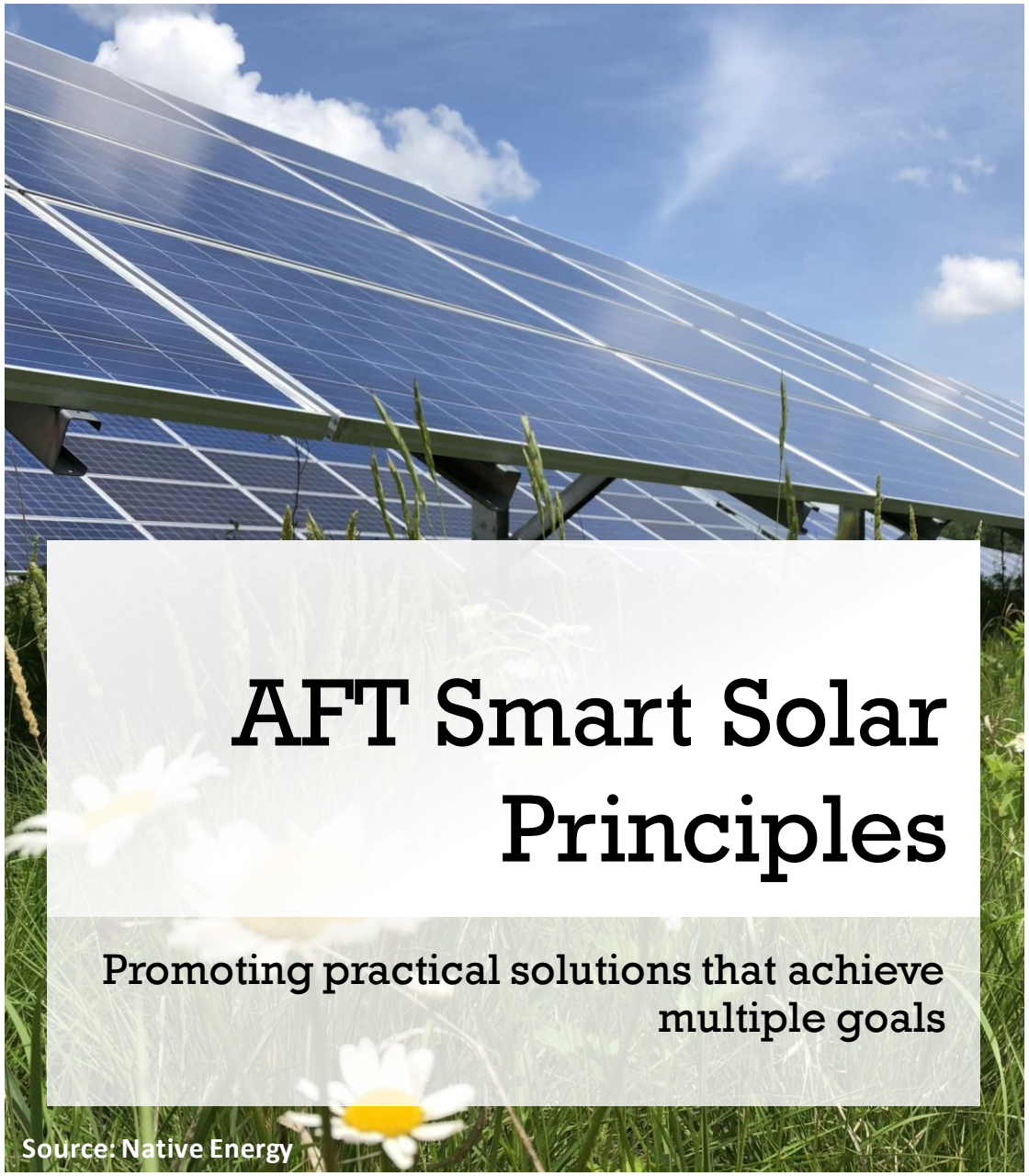
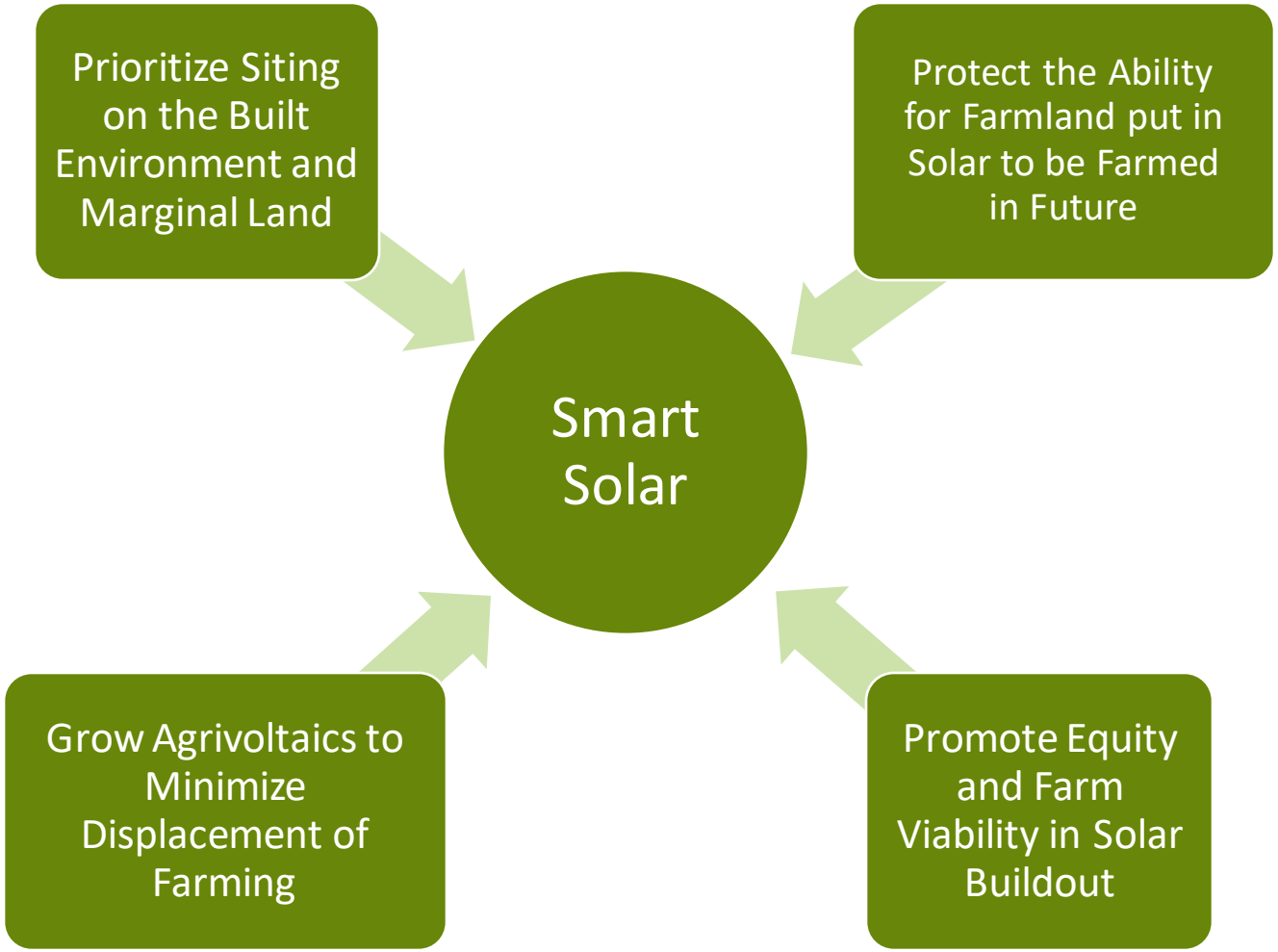


AFT Smart Solar Principles

Promoting practical solutions that achieve multiple goals

Source: Native Energy



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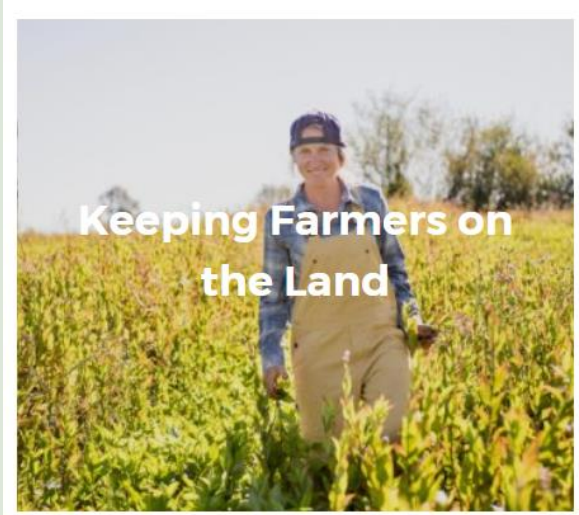

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Draft Policies to Advance Smart Solar Principles

Prioritize Siting on the Built Environment and Marginal Farmland

- Invest in Research
- Least Conflict Processes
- Implement Incentives and Disincentives (mitigation fees)
- Collect Information in Permitting and Procurement

Safeguarding the Ability to Farm the Land After the Life of the Array

- Invest in Research
- Require that Installers Follow Minimum Standards to Protect Soil Health and Productivity
- Bank Water Rights for Future Use
- Require Decommissioning Plans and Funding
- Provide Training and Education to Installers

Advance Farm Viability and Equity

- Invest in Research on Impacts
- Support Smart Distributed Solar
- Ensure an Adequate Base of Farmland in Communities
- Provide Information to Landowners
- Reduce Energy Burden on LMI Customers

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Policies to Expand the Deployment of Agrivoltaics

- Invest in Research and Demonstration
- Incentivize Small and Large Scale Agrivoltaic Arrays
- Support Agrivoltaic Farmers

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Incentivizing Farm-Centered Agrivoltaic Development

Agencies Implementing the Policy:

- Need a strong qualification definition
- Need the ability to ensure farming continues with spot checks and penalties
- Should prioritize projects that support operations led by historically marginalized farmers
- Should periodically report on the agrivoltaic systems they are supporting

The Definition for what Qualifies as Agrivoltaics:

- Should be created by the Department of Agriculture with farm groups, in consultation with energy agencies
- Needs to ensure the continual production of a marketable agricultural product throughout the full life of the array
- Should take into account the agricultural products traditionally grown in the community/state
- In order to qualify for an incentive, developers need to demonstrate that they are, at a minimum:
  - **Working with a farmer** with a viable business plan
  - **Incorporating design changes** that will both maximize the possibility that this will support a viable farm operation for the life of the array, and enable the farmer to adjust what they raise or grow to respond to changes in market demand
  - **Working with an installer** who can implement these designs properly

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More Exciting Policy Work to Come!

- **AFT Smart Solar Policy Recommendations** for state and local governments: December 2023
- **Solar in the Farm Bill!** Agrivoltaic Research and Demonstration Act (Heinrich/Braun) and Protecting our Future Farmland Act (Baldwin/Grassley)
- **Smart Solar in State-Level Policy:**
  - New Jersey and New York Agrivoltaic Research and Demos
  - Maine and Virginia Mitigation Fees and interaction with Agrivoltaics

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Feedback and Questions?

www.farmland.org/solar

www.farmland.org/farmsunderthreat

Keep in touch! Slevy@farmland.org