An Overview of Agrivoltaics

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What is Agrivoltaics?

- Agrivoltaics is a term used to describe the co-location of crops and grazing under and adjacent to solar photovoltaic panels.

- Other common terms:
- Agrisolar
- Solar grazing
- Ecovoltaics

There are Several Applications of Agrivoltaics:

- Solar + Crops
- Solar + Greenhouses
- Solar + Grazing
- Solar + Beekeeping
- Pollinator-friendly solar
- Aquavoltaics (solar on aquaculture, such as a fish farm)

Why?

Solar developments will cover over 3 million acres in 10 years.

If these lands become energy-only production it will impact farms, habitat, soil health, and communities.

When designed and managed with best practices, agrivoltaics can:

- Diversify farm revenue,
- Increase rural energy independence,
- Decrease crop irrigation by half in heat-stressed areas,
- Increase solar panel efficiency,
- Promote grazing as vegetation management,
- Increase soil organic matter and carbon accrual,
- Improve ecosystem health and support native species,
- Triple local pollinators like bees, butterflies, birds, and bats.

Crop Co-location

1. Plants get enough sunlight under solar panels.
   - Solar panels that move on tracking systems and follow the sun allow the crops to receive ample sunshine and protection from extreme temperatures and excessive evapotranspiration.
2. Plants under the panels increase the solar panel efficiency.
   - The microclimate created by the crops results in a cooler temperature for the solar panels, which operate more efficiently at lower temperatures
3. Growing under panels can lead to greater yields and longer growing seasons.
   - Cool season crops like lettuce can grow well into summer and the solar provides frost protection in spring and fall.
4. Growing crops under solar panels decreases water usage.
   - They are dryland farming under panels in Oregon and in Arizona, crops need 75% less water when grow under a solar array.

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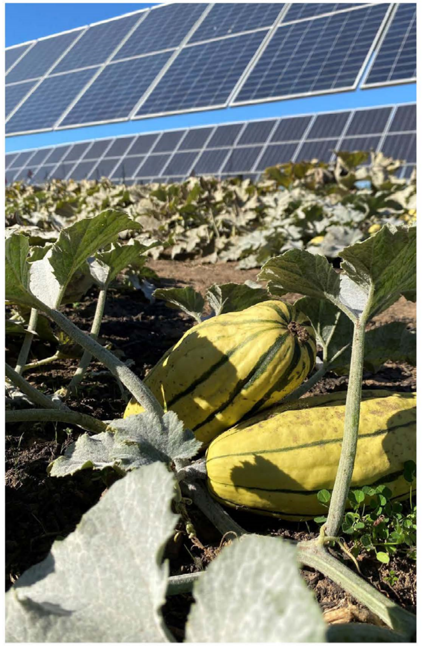
Fact Sheet:
Making the Case for Crops + Solar

CENTER *for* RURAL AFFAIRS

By Stacie Peterson, PhD, NCAT and
Heidi Kolbeck-Urlacher, Center for Rural Affairs
March 2024



INTRODUCTION

Agrisolar practices, also called agrivoltaics, are the co-location of agriculture and solar within the landscape. They include solar co-located with crops, grazing, beekeeping, pollinator habitat, aquaculture, and farm or dairy processing. Agrisolar practices offer an opportunity to allow solar and agriculture to co-exist while meeting demands for clean energy and resilient rural infrastructure. One agrisolar approach is crop production under and adjacent to solar photovoltaics. Farms and research sites across the country demonstrate agrisolar as an opportunity to diversify farm revenue, decrease crop irrigation, increase crop yield, increase soil moisture, improve solar panel efficiency, and increase rural energy independence (Barron-Gafford, 2019; MacKnick, 2022; and Adeh, 2019).

Extreme heat and weather events from climate change, including the long-term drought in the American west, have led to water shortages, decreased crop yields, and increased heat stress for farm workers. Climate projections show this trend continuing, resulting in a marked decrease in crop yield in the future (Hsiagn, 2017). At the same time, an increasing population has elevated the need for nutritious local foods and food sovereignty.

Solar energy development is also on the rise, with an estimated 10.3 million acres of land projected to be used for solar energy production by 2050 (Ardani, 2021). This could include up to 1% of U.S. cropland (USDA Rural Development, 2024). Between 2001 and 2016, 99% of the 11 million acres of farmland converted out of agricultural production were attributed to urban and suburban expansion, and 1% was attributed to solar development (USDA Rural Development, 2024).

Farmland is particularly appealing to solar developers because it is typically free of trees and rocks,

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Made in the Shade

Shade is also great for farm workers. Our studies show a 10-20F skin temperature drop under the panels all around the country.

- The resultant workplace mortality rate for farmworkers from heat-related illness is 20 times higher than the US civilian working population and this trend is increasing

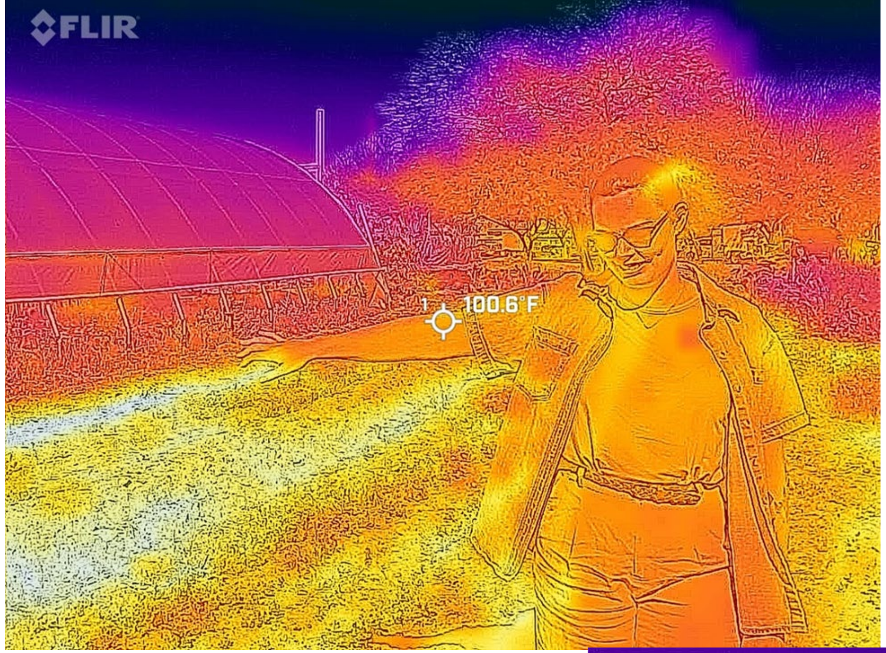

Photo 4. Skin Temperature Measurement Taken in the Full Sun

Photo 5. Skin Temperature Photo Taken 10 Minutes Later in the Shade of Solar Panel

Skin temperature measurements taken in full sun and under solar panels show differences ranging from ten to fifteen degrees Fahrenheit. The photos above show a 15-degree skin temperature difference between full sun and the shade of a solar panel in Colorado in September 2022.

Solar Grazing

1. Sheep are the most common solar grazers, with a lot of interest in other animals.
2. Solar grazing is growing rapidly.
   - Over 50,000 acres of solar sites are being grazed by over 70,000 sheep in the United States, with a lot more to come.
3. Solar grazing can go hand-in-hand with pollinator habitat and beekeeping.

Benefits of Solar Grazing

- Increased access to land for farmers
- Contractual farm income
- Abundant shade for the herd
- Restored ecosystem services
  - Increased biodiversity
  - Improve soil water holding capacity
  - Improved nutrient cycling
- Increased community acceptance

Solar Pollinator Habitat

1. Solar pollinator habitat can triple the number of pollinators, like bees, butterflies, birds, and bats.
2. Pollinator-friendly solar arrays are safe sanctuaries for honeybee hives and are great for beekeeping.
3. Pollinator-friendly seed mixture can cost the same as other seed mixes.
4. Pollinator habitat is great for soil.

Solar Pollinator Habitat

Seed mixture design is very important in developing solar pollinator habitat.

Groups like [Bee & Butterfly Habitat Fund] develop solar seed mixtures that include:

- One seed mix for inside the solar array, which accommodate lower panel heights, and
- One seed mix for outside perimeter, which can have an increased height and better-quality forage.

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Fact Sheet:
The Science of Solar-Pollinator Habitat:
How Current and Future Research Can Help Us Understand the Role of Pollinator-Friendly Solar in Biodiversity Conservation

By Leroy J. Walston, Heidi Hartmann, and Laura Fox, Argonne National Laboratory

Example image of solar-pollinator habitat at a solar site in Minnesota. Photo: Argonne National Laboratory

Many climate scientists, energy planners, and governments agree that continued deployment of solar energy is needed to achieve our country's grid decarbonization and net zero goals. With these goals in sight, and the decreasing costs of solar energy technologies, it may come as no surprise that solar has recently emerged as the nation's fastest growing source of electricity.[1] And this rapid rate of solar development is expected to continue. For example, approximately 1,000 gigawatts of solar energy – most of which is generated by ground-based photovoltaic (PV) solar plants – would be required by 2035 in order to put the United States on track for net zero CO2 emissions targets by mid-century.[2] That is more than 10 times our nation's current rate of solar development.[3]

Without a doubt, considerable amounts of land will be needed to meet future solar energy projections. The current rate of solar energy development has already increased the pressure on land resources for energy generation and other land uses (e.g., agriculture, habitat for biodiversity, etc.). Therefore, sustained development of solar energy will depend on proper siting to avoid ecological conflicts and land-sharing solutions that synergize this form of renewable energy development with other land uses.

The co-location of solar energy and native habitat restoration (i.e., "solar-pollinator habitat") has quickly gained attention as one dual-use method to safeguard biodiversity and increase the site's ecosystem service potential. Solar-pollinator habitat typically focuses on the planting and establishment of early successional native grasses and forbs among the PV panels and other portions of the solar facility. When effectively established, solar-pollinator habitat can function as a site of native habitat restoration, which could support insect pollinators and other wildlife and

1 Energy Information Administration, https://www.eia.gov/electricity/monthly/.
2 DOE Solar Futures Study, https://www.energy.gov/eere/solar/solar-futures-study.
3 Solar Energy Industries Association, https://www.seia.org/research-resources/major-solar-projects-list.

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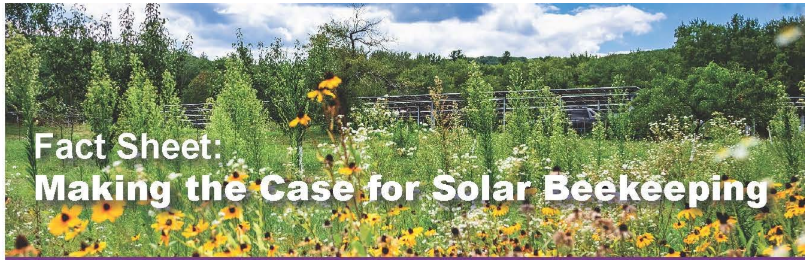

Fact Sheet: Making the Case for Solar Beekeeping

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Written for the AgriSolar Clearinghouse by Center for Rural Affairs

As demand for solar energy continues to grow, agrivoltaics offers an opportunity to maximize usage of land allocated for solar projects. The co-location of solar and agriculture offers opportunities for conservation, food production, increasing pollinator habitat, and adding additional farm revenue streams while producing affordable renewable energy.

Photo Courtesy of Center for Pollinators in Energy

Solar beekeeping is the practice of placing beehives on or near solar sites. While photovoltaic panels are generating energy from the sun, bees are busy making honey and pollinating the native and non-invasive plant species below the panels.

Beekeeping at solar sites can enhance the value of the land by keeping it in agricultural production, providing new streams of income for local farmers, and adding such environmental benefits as water filtration, reduced erosion, and enhanced soil health due to the presence of native and non-invasive vegetation.

Economics

Solar beekeeping offers financial opportunities for local beekeepers and landowners. This business model stacks benefits by using the land for multiple purposes simultaneously. Project developers benefit from the solar energy produced by the photovoltaic panels, beekeepers gain resiliency from a diverse source of pollen for honey production, nearby farmers profit from pollination services, and the landowner sees a positive impact from improved soil health.

Additionally, project developers can save money on maintenance costs by seeding the ground with native and non-invasive vegetation. Industry experts say developers can expect to spend as much as three times less on operation and maintenance costs over 20 years when compared to managing turfgrass sites.[1]

[1] Argonne National Laboratory, produced for the U.S. Department of Energy's InSPIRE Study. Obtained via personal communication with Fresh Energy, April 2020.

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Sweet Deal: Beekeeping at Solar Sites Offers Economic and Environmental Benefits

By Lindsay Mouw, Center for Rural Affairs

What's the latest buzz about solar energy? It's likely the thousands of honey bees that call solar fields home.

Commonly referred to as "agrisolar beekeeping," the practice of placing beehives on or near solar fields is a burgeoning industry. While photovoltaic panels are generating energy from the sun, bees are busy at work making honey and pollinating the native and non-invasive plant species below the panels.

This business model creates a multi-stacking of benefits by using the land for multiple purposes simultaneously. When solar panel fields are planted with native and non-invasive plant species, not only is that land generating carbon-free energy, but also providing critical habitat for bees, monarch butterflies, and other insects, birds, and animals. It also creates new economic opportunities for local beekeepers and for the community in the form of energy generation tax payments.

As solar developers become aware of these benefits and strive to demonstrate responsible land stewardship, they are reaching out to beekeepers, such as Dustin Vanasse, CEO of Bare Honey based in Minneapolis, Minnesota, who may be interested in this practice. When a developer reaches out, Dustin says it is best that the two parties draft a contract that outlines expectations and responsibilities in order to establish a sound relationship with no surprises before moving forward with a project.

Solar Design

- There are many ways to approach solar design and landscape design.
- In general, integrating crops, grazing, and pollinator habitat work best with higher racking systems for photovoltaic solar.
- In addition to elevated racking systems, there are many innovative designs, specific to agrisolar applications, such as semi-transparent panels, vertical panels, and thick poles for cattle grazing.



Solar Design Resources

- This Agrisolar Clearinghouse webinar provides an introduction to Innovative Solar Design.
- Our Information Library includes in-depth peer-reviewed publications regarding solar design considerations: Agrisolar System Design, Planning, and Analysis.
- We have many case studies that highlight different types of agrisolar design:
  - Sunzaun Vertical Solar System
  - Soliculture Research Greenhouse
  - UMass South Deerfield
  - Helical Solar
  - Jack's Solar Garden
  - Sandbox Solar/CO State ARDEC
  - Summit Plant Labs.

Solar Design Resources

- There are many software choices for your project.

- Here are a two options that can help you design your co-location project:
  - SPADE Agrivoltaic Design + Development
  - Solesca

Federally Funded Agrivoltaics Projects That Include Technical Assistance

- U.S. Department of Energy Solar Energy Technology's Office:
  - AgriSolar Clearinghouse
  - Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE): openei.org/wiki/inspire)
  - Foundational Agrivoltaic Research for Megawatt Scale (FARMS) projects

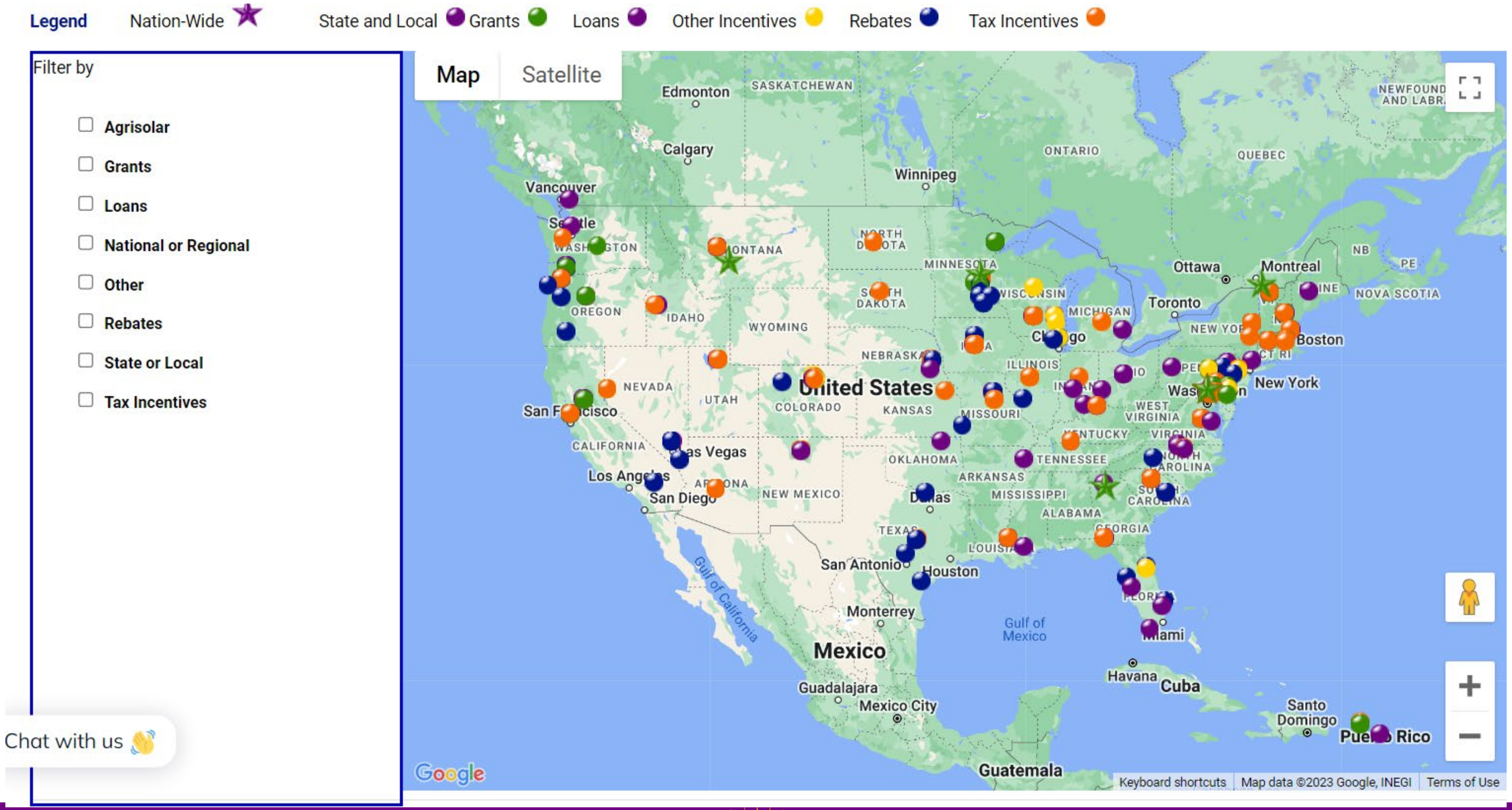
- USDA Partnerships for Climate-Smart Commodities
  - University of Texas Rio Grande Valley
  - University of Arizona Climate Smart Food

- Other Agrivoltaic Resources:
  - American Solar Grazing Association: solargrazing.org
  - American Farmland Trust Smart Solar Program: farmland.org/solar

How Would I Pay for This?

Our Financial Atlas includes tax incentives, rebates, and other financial programs that can help you with your project. Click on the dots within your state to learn more about each opportunity. You can also participate in the forum discussion(s) in the category "funding opportunities."“

NREL’s agrivoltaic cost estimator is available here: https://openei.org/wiki/InSPIRE/Financial_Calculator



Financial Considerations

Fact Sheet:
Financial Considerations for Developing an Agrivoltaic System

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Colorado Agrivoltaic LEARNING CENTER

By Colorado Agrivoltaic Learning Center
at Jack's Solar Garden
February 2024

PURPOSE AND SCOPE

Compared to conventional solar energy developments, agrivoltaic systems may have different capital expenditures, cash flows, and risk impacts for a solar asset owner. Discussed herein are only broad, qualitative financial impacts, as there are too many agrivoltaic applications (e.g., over orchards, grasslands, croplands, livestock), solar designs (e.g., fixed-tilt, tracking, one or two panels in portrait), and local considerations (e.g., terrain, regulations, wildlife, agricultural markets) to share a concise financial impact assessment.

Financial impacts are labeled as either standard or potential considerations. Standard considerations are those that apply to agrivoltaic developments that can support diverse agricultural activities in addition to compatibility with small-scale machinery and agricultural laborers. Potential considerations are those that would apply only in specific circumstances.

This fact sheet focuses on new-build projects considering US federal and Colorado state-specific tax benefits, though most non-tax topics are more broadly applicable.

AGRIVOLTAICS EXPLAINED

Agrivoltaics is the coupling of agriculture with solar developments where solar panels are above and around agricultural activities. It requires partnerships between agricultural and solar industry professionals, improved safety considerations for agricultural workers and livestock, and adjustments by both the agricultural and solar industry partners to effectively integrate their businesses together.

Agrivoltaics utilizes the microclimates created by solar panels to influence agricultural activities. Solar panels shade the land around them, thereby reducing temperatures, limiting evaporation, increasing soil moisture retention, and redirecting precipitation, which can benefit plants and animals. Humidity produced by the transpiration of vegetation growing underneath and around solar infrastructure may cool the solar panels, reducing heat losses and improving electrical efficiencies.

The Colorado Agrivoltaic Learning Center showcases clean energy generation coupled with local food production to educate and inspire our community into taking action to improve land stewardship within solar arrays.

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AGRIVOLTAIC CASH FLOW INCREASES

Standard Considerations:

- Reduced vegetation management, as it is managed by agricultural partners.
- Farmers may accept lower land lease rates in exchange for continued agricultural production.
- Reduced down time when agricultural partners in the field can expeditiously alert the solar operator of faults.
- Fewer operational issues due to safer wire management.
- Increased revenue due to reduction of heat losses.
- Increased Production Tax Credit (PTC) value from reduction of heat losses.
- Potential for extended useful life due to reduction of heat losses.
- Increased tax benefit of accelerated depreciation due to higher capital cost of agrivoltaics.

Potential Considerations:

- Exempt personal property tax via Colorado Senate Bill 23-092, only if project design qualifies, for 2024-2029. See link below for details. leg.colorado.gov/bills/sb23-092
- Reduced soiling losses due to dust suppression of vegetation and overwintering cover crops.
- Higher residual value of solar equipment due to additional scrap materials available.
- Higher residual value of land due to land stewardship practices that do not degrade soils over the project's life.
- Potential increase in Power Purchase Agreement (PPA) and/or Renewable Energy Certificates (RECs) for electricity produced from an agrivoltaic site, assuming governments and/or off-takers financially incentivize land stewardship (e.g., conservation, marketing, etc.).
- Decreased operations and maintenance costs if farmers/ranchers are cross-trained in repairing site issues.

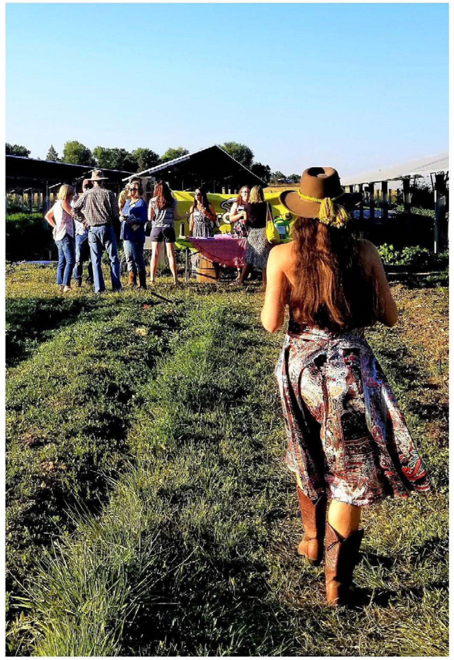
AGRIVOLTAIC CASH FLOW DECREASES

Standard Considerations:

- Increased debt service due to higher capital cost of agrivoltaics.
- Increased insurance premiums due to increased underlying capital cost/value of agrivoltaic equipment.

Potential Considerations:

- Increased preventative and/or corrective maintenance labor cost due to OSHA fall protection practices, only if equipment height exceeds 6 feet.
- Reduced revenue potential, only if inter-panel spacing is increased above optimal ground coverage ratio for solar design to accommodate farming equipment.



State/Local regulations and Incentives

It is important to understand your state and local regulations, including the tax implications of solar development in agricultural areas as well as agricultural development with solar arrays.

You should consult your local planning department and ask for guidance.

These two guides provide an excellent overview of policy approaches and existing agrisolar policy in the United States:

- Policy Approaches for Dual-Use and Agrisolar Practices
- Agrisolar Policy Guide

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AGRISOLAR POLICY GUIDE

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Introduction

The AgriSolar Policy Guide was designed to facilitate policy learning and innovation in the United States. By collating existing initiatives and key provisions, this guide serves as a resource for regulators, land use planners, decision makers, and others who are interested in state of the art agrisolar policy. The AgriSolar Clearinghouse is impartial towards policy; the intention of this guide is not to advocate for certain initiatives, but to provide a central platform for education and engagement. The goal of this guide is to support policy innovation for better co-location.

The policy initiatives included in this guide were selected to feature a full suite of state-level and a sampling of county-level regulatory strategies across different types of agrisolar practices (crops, grazing, and pollinator habitat). These policy initiatives showcase a range of approaches to drive innovation in farmland solar, including market mechanisms, scoring systems, mandates, and voluntary programs.

Despite the diversity of approaches, one common goal persists across all initiatives: to promote the expansion of renewable energy in a manner that mitigates impacts to farmland. To that end,

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Inspiration and Lessons Learned for Your Project

Our Storytelling Atlas is an interactive tool for finding agrisolar projects across the United States. Visit the atlas to see how others are implementing agrisolar in their projects at: www.agrisolarclearinghouse.org/atlas/.

Case Study: Oregon Agrivoltaic Research Facility

Cantaloupe melons growing between rows of solar panels.

NREL'S Compressive Agrivoltaic Map

Available at: https://openei.org/wiki/InSPIRE/Agrivoltaics_Map

584	10064	62352
Sites	Megawatts	Acres

Agrivoltaic Activities

- ☐ Crop Production
- ☐ Habitat
- ☐ Grazing
- ☐ Greenhouse

Photovoltaic Technology

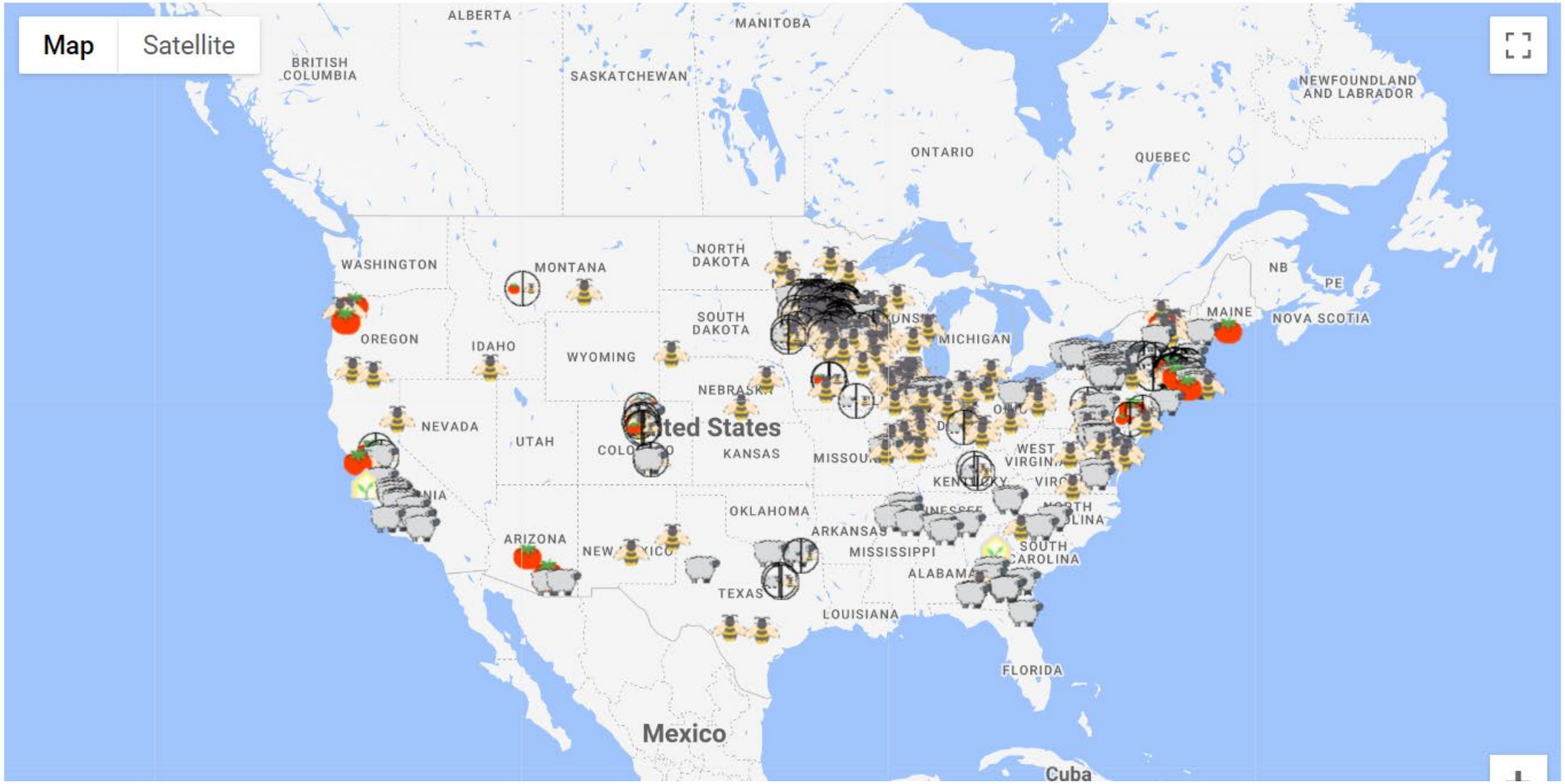
- ☐ Monofacial PV
- ☐ Bifacial PV
- ☐ Translucent PV

System Size MWdc

- ☐ < 1 MW
- ☐ 1-5 MW
- ☐ 5-10 MW
- ☐ 10-100 MW
- ☐ >100 MW

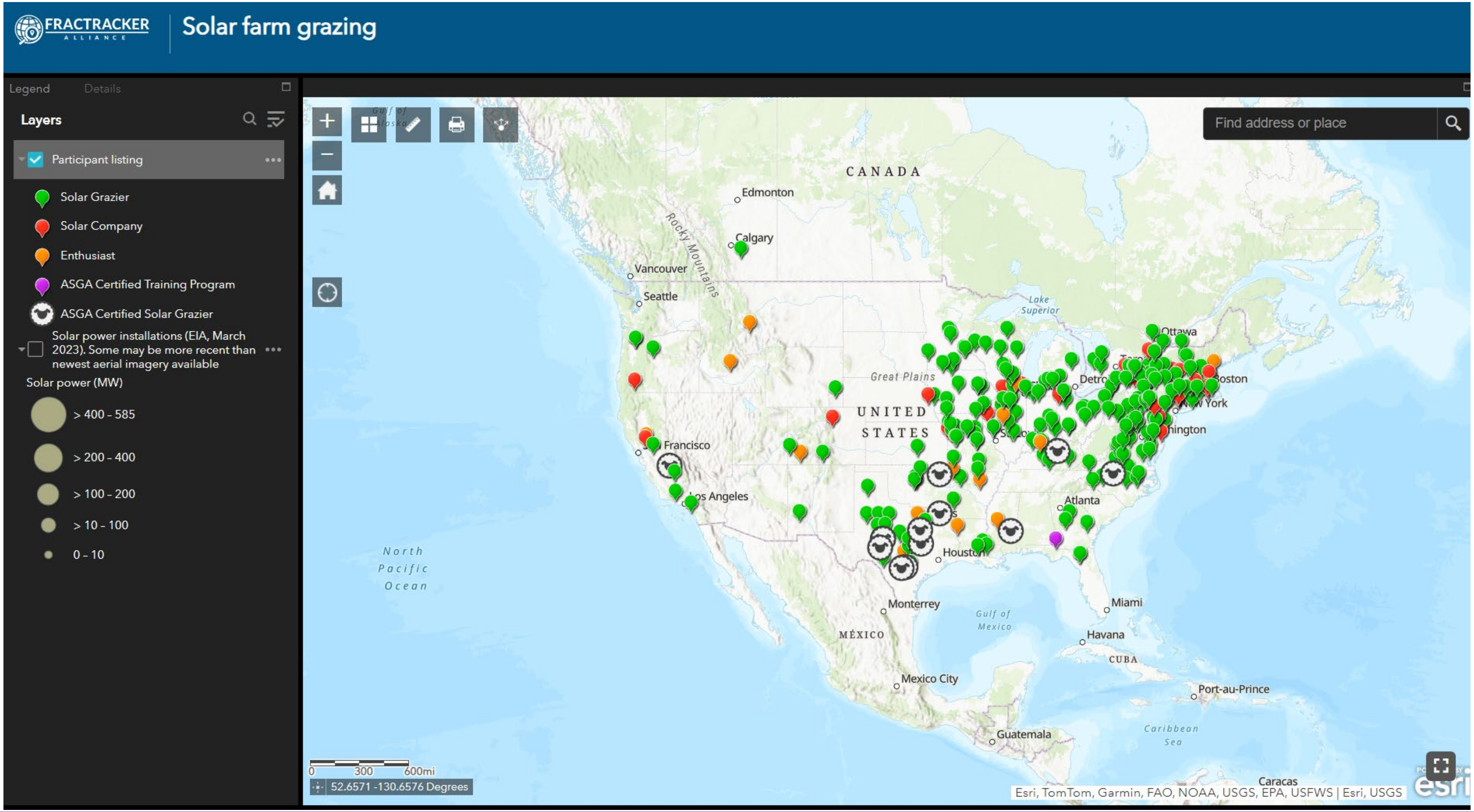
Type of Array

- ☐ Fixed
- ☐ Single-axis Tracking
- ☐ Dual-axis Tracking



ASGA Map of Solar Grazing

https://solargrazing.org/map/



Thank you!