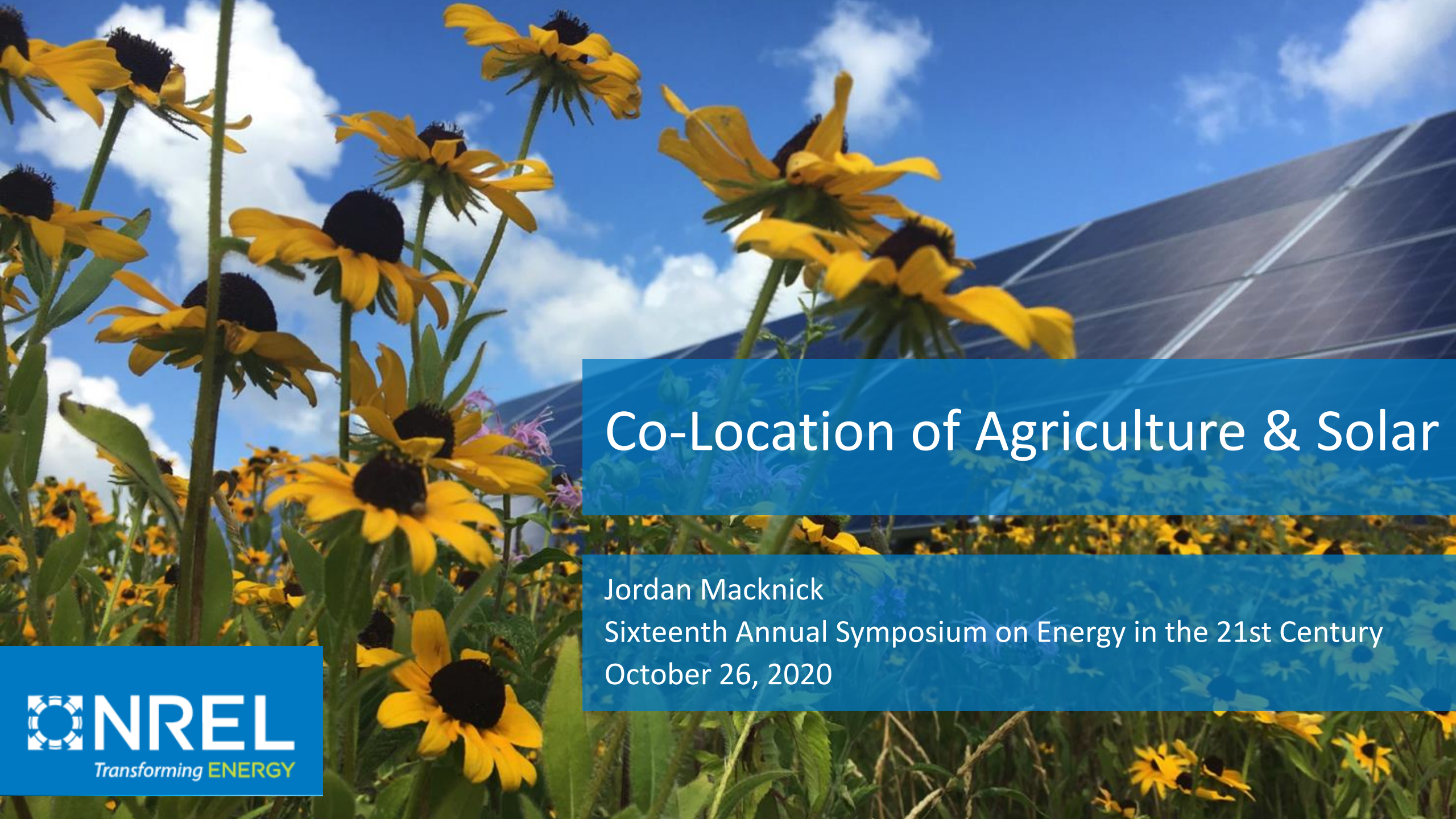


Co-Location of Agriculture & Solar

Jordan Macknick

Sixteenth Annual Symposium on Energy in the 21st Century

October 26, 2020

NREL
Transforming ENERGY

NREL at a Glance

2,307

Employees

plus more than

460

early-career researchers and visiting scientists

World-class

facilities, renowned technology experts

about 900

Partnerships

with industry, academia, and government

Campus

operates as a living laboratory

Renewable Power

- Solar
- Wind
- Water
- Geothermal

Sustainable Transportation

- Bioenergy
- Vehicle Technologies
- Hydrogen

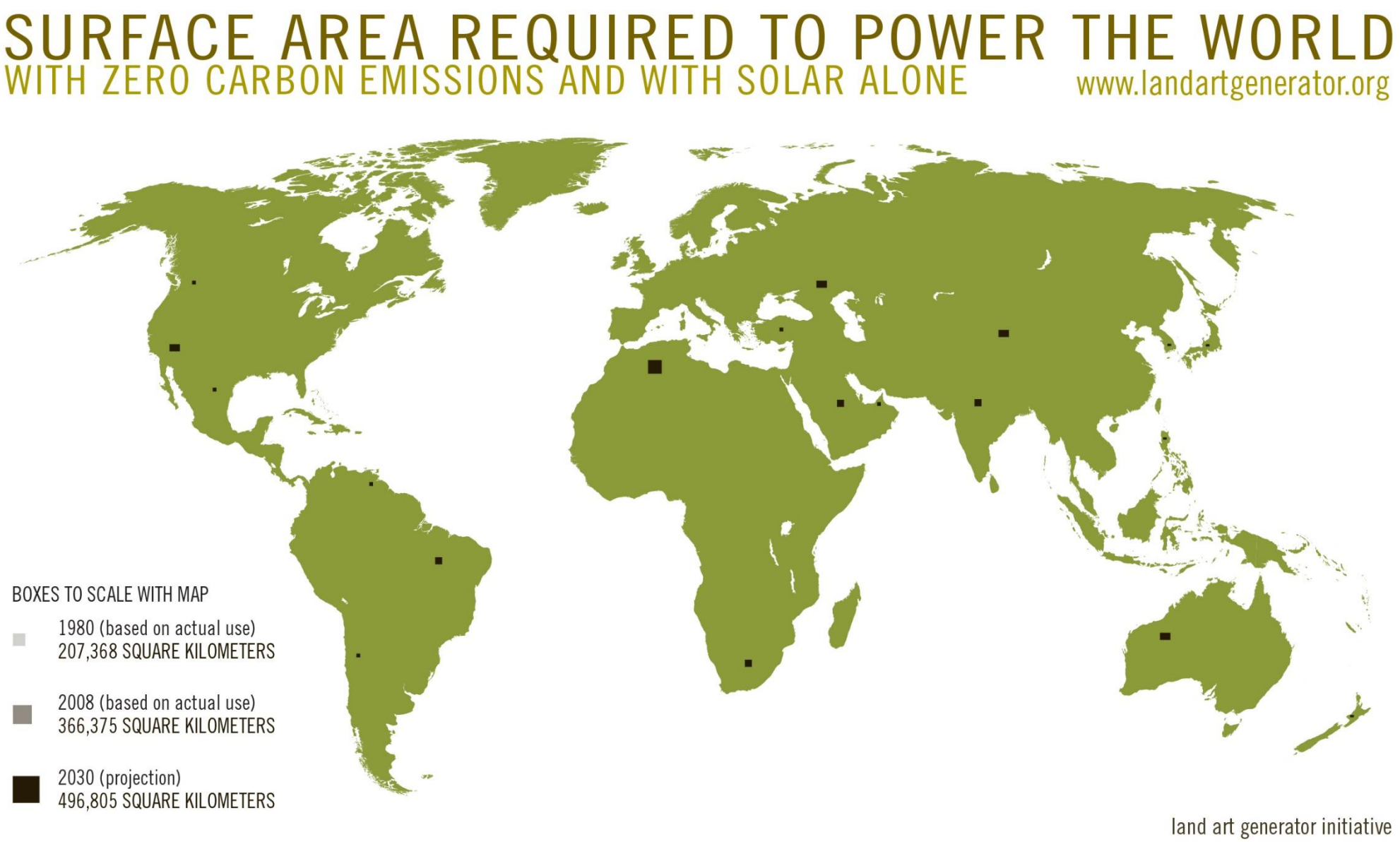
Energy Efficiency

- Buildings
- Advanced Manufacturing
- Government Energy Management

Energy Systems Integration

- Grid Integration
- Hybrid Systems

A relatively small amount of land is needed for solar



Land use requirements are distributed across countries

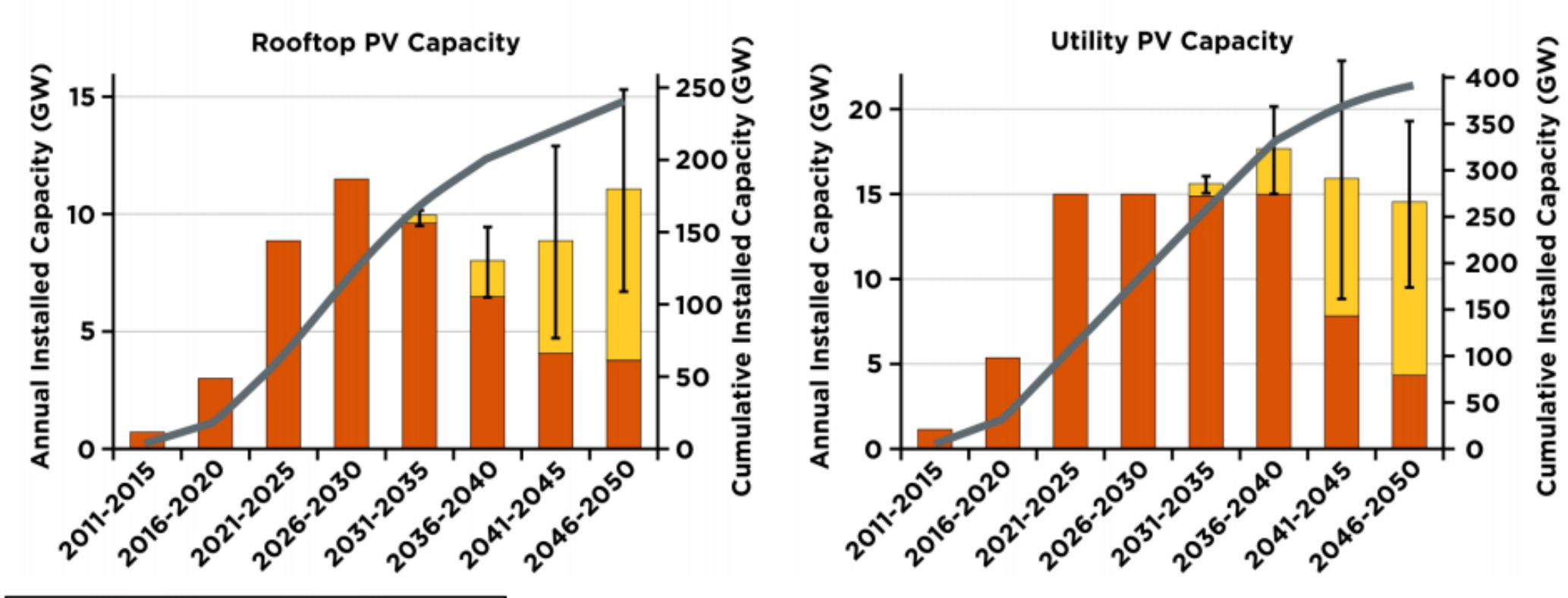
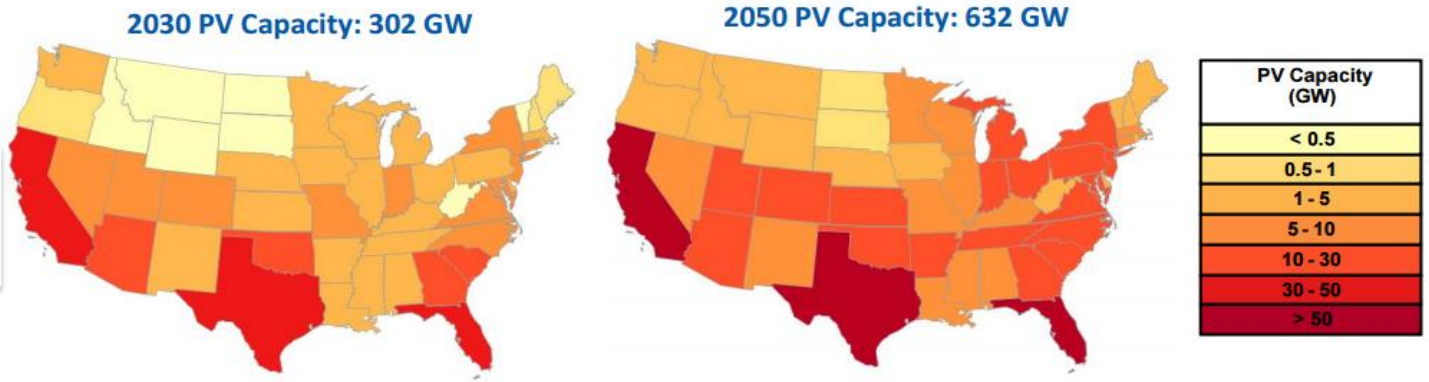
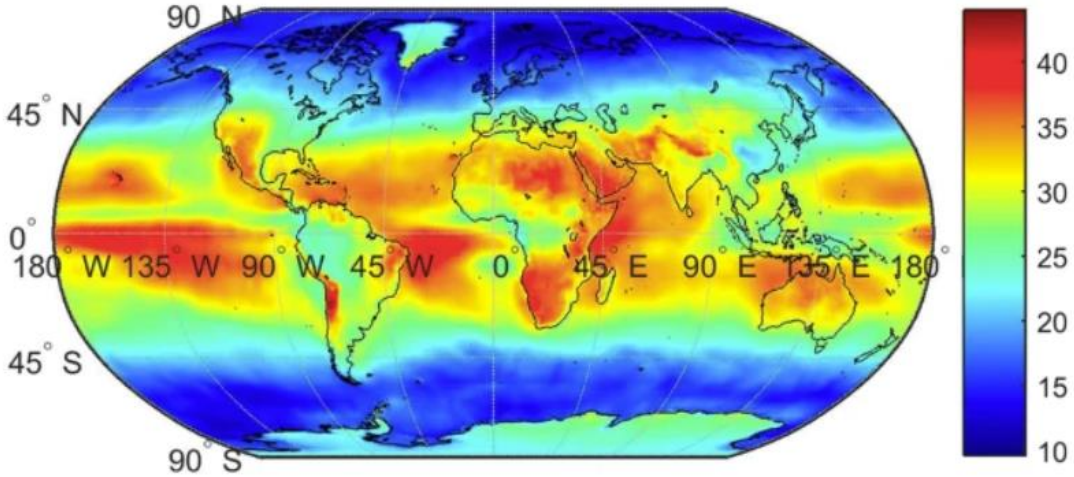


Figure 3-6. Cumulative Installed PV and CSP Capacity in the SunShot Scenario in 2030 and 2050



2030: 3 million acres
2050: 6 million acres

Farms are often ideal locations for 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.

Rural communities can resist solar development on farms

Sections

The Washington Post
Democracy Dies in Darkness

Get 1 year for $29

Georgetown's 'green' plan to destroy a forest for a solar farm is met with resistance

METRO | SPORTS | BUSINESS | OPINION | RHODE ISLAND | POLITICS | EDUCATION | LIFESTYLE | MARIJUANA | ARTS | MAGAZINE | CARS

Solar projects increasingly meeting local resistance

By Katheleen Conti Globe Staff, May 5, 2013, 12:00 a.m.

The New York Times

He Set Up a Big Solar Farm. His Neighbors Hated It.

A push toward renewable energy is facing resistance in rural areas where conspicuous panels are affecting vistas and squeezing small farmers.

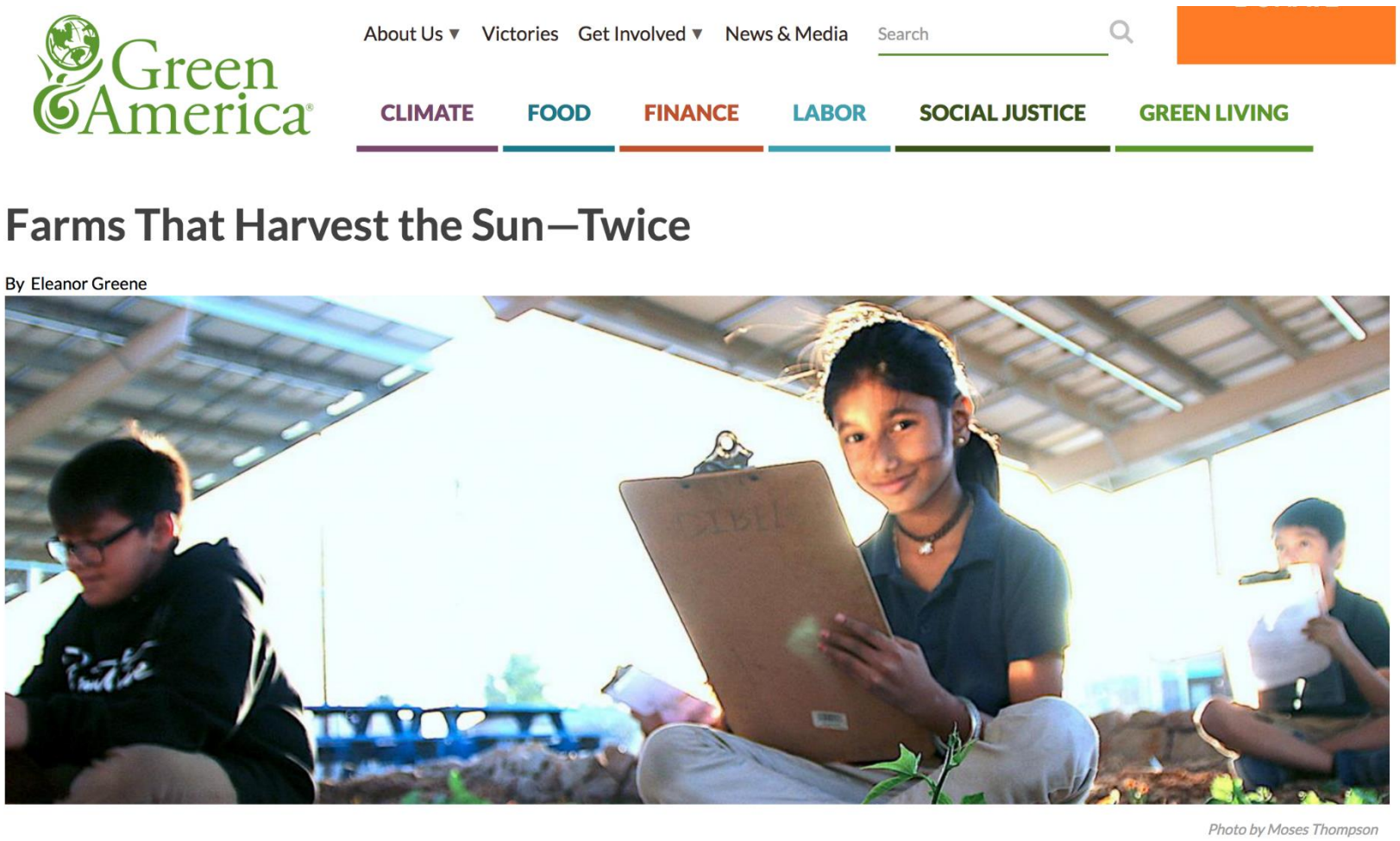
Ground mounted solar: What does it look like?

Photos courtesy of Rob Davis, Fresh Energy

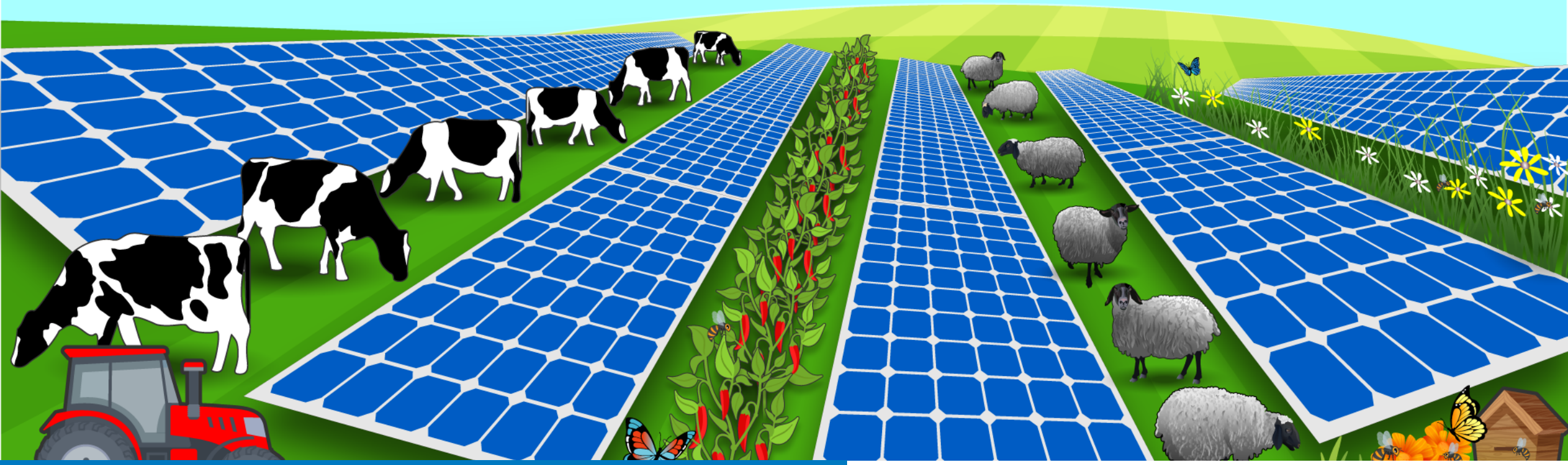
Vision: Low-Impact Solar Development

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

Agrivoltaics = agriculture + photovoltaics



*photovoltaics (PV)= renewable energy production from solar panels



What is Agrivoltaics?

Agricultural activities performed underneath and around solar arrays:

- Crop production
- Grazing
- Pollinator Habitat
- Apiaries

Source: Burton (NREL)

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

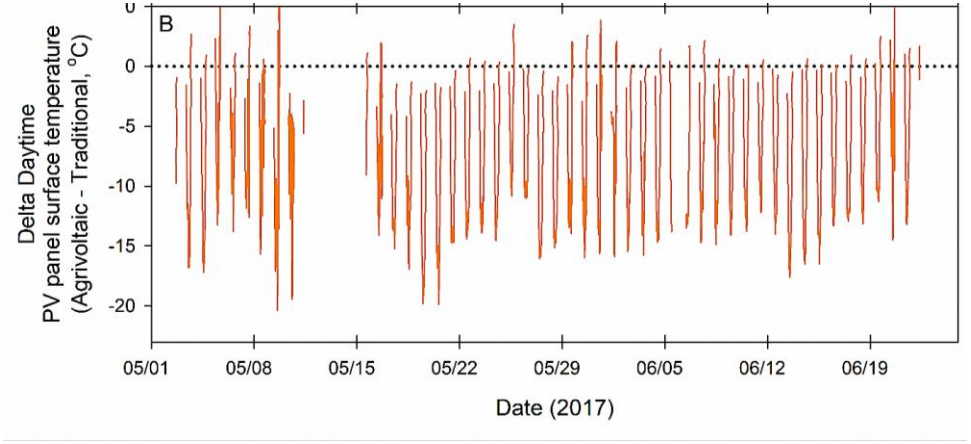
Crop performance varies based on location and solar design configurations

Cost and Design Factors

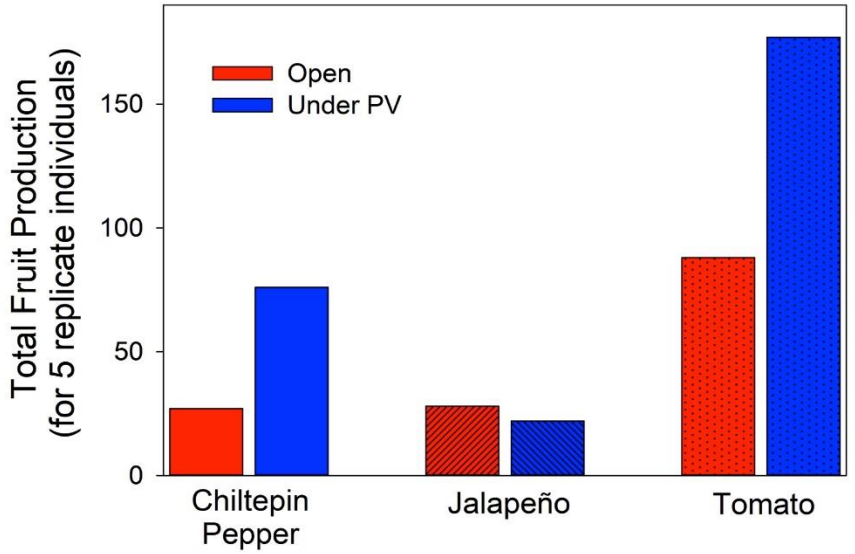
- Increased panel heights (optional)
- Increased panel spacing (optional)
- Change in O&M needs
- Access to water
- Agricultural revenue

Key Highlight: Energy+Water+Food Benefits of Agrivoltaics

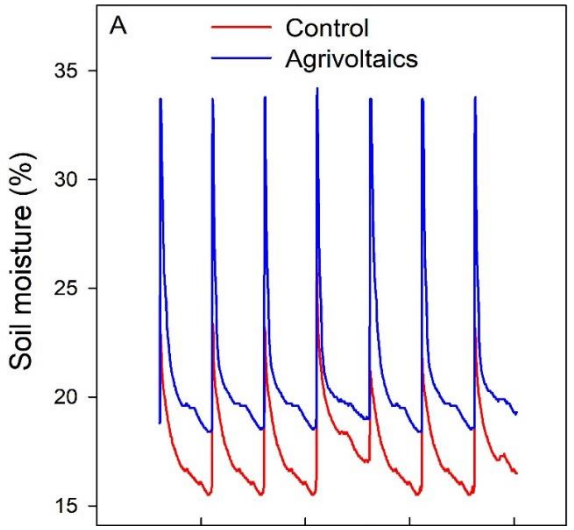
- **Energy Benefits**
  - Summertime average cooling from vegetation underneath panels: ~9°C
  - Annual generation increase: ~2%



- **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



What is Agrivoltaics? Pollinator-friendly Solar

Native and pollinator-friendly vegetation can host beneficial insects

Increased beneficial insect populations can benefit nearby farms

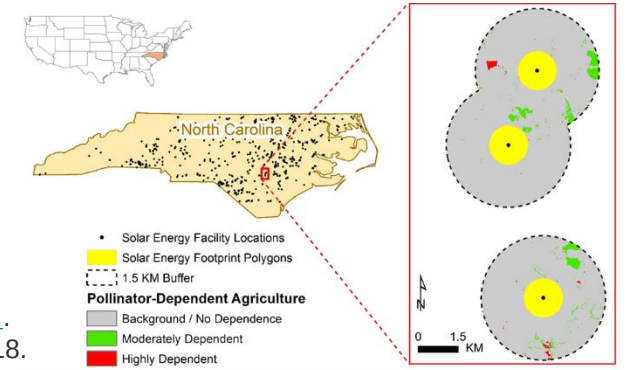
Ongoing research evaluating species that thrive in partial shade of solar panels

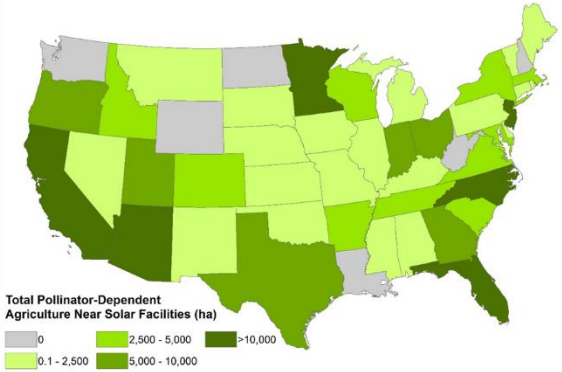
Cost and Design Factors

- Seed mix selection and purchase
- Reduction (usually) in O&M needs
- Stormwater management benefits

Key Highlight: Pollinator-Friendly Solar

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

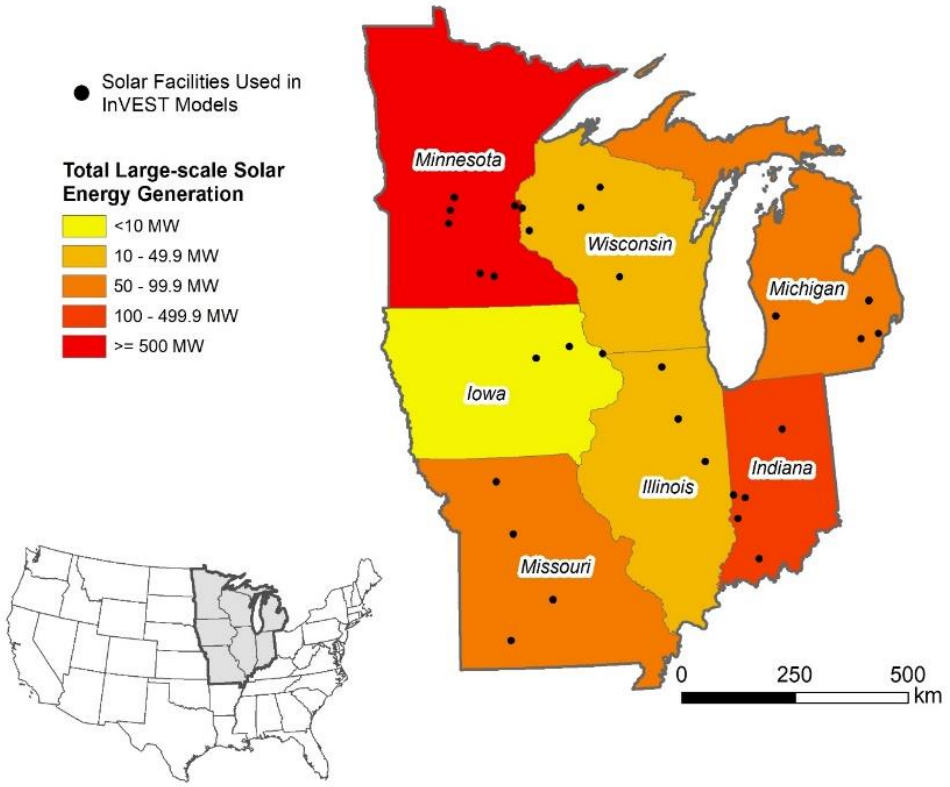


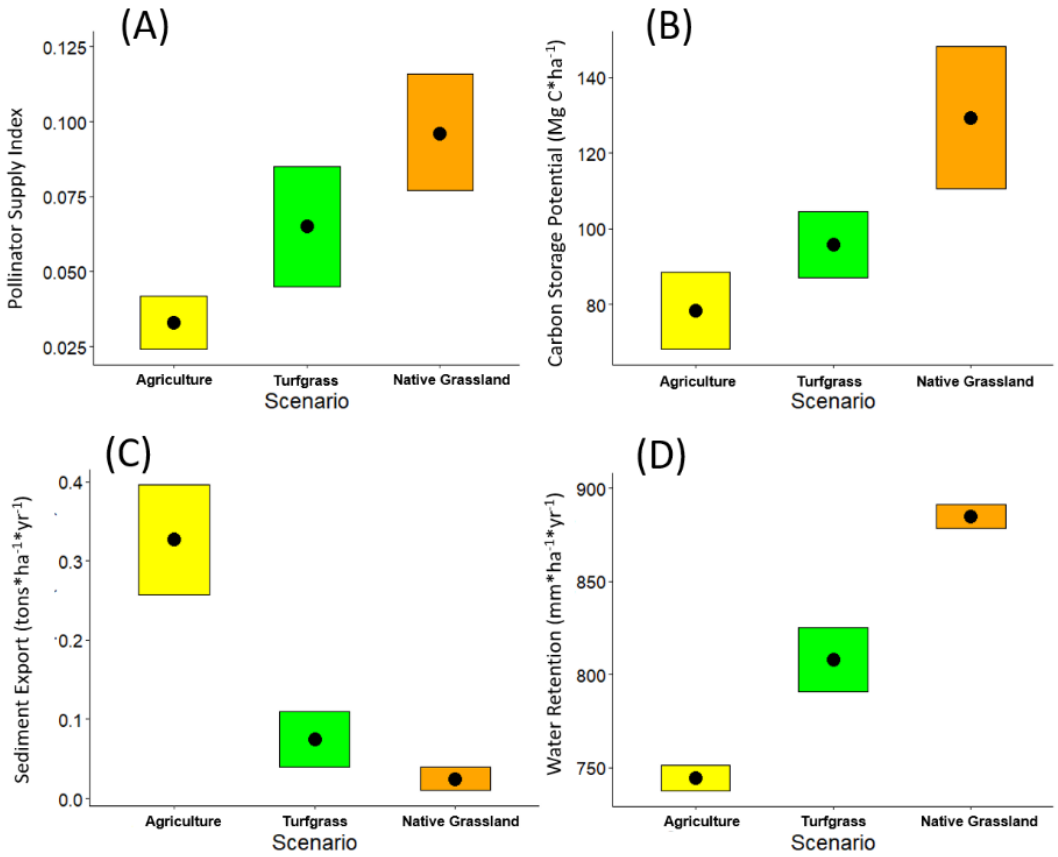


Examining the Potential for Agricultural Benefits from Pollinator Habitat at Solar Facilities in the United States.. Leroy J. Walston, Shruti K. Mishra, Heidi M. Hartmann, Ihor Hlohowskyj, James McCall, Jordan Macknick 2018. Environmental Science & Technology Vol. 52 (13) 3 July 2018 pp. 7566-7576.

InSPIRE Research Highlight: Minnesota Pollinator-Friendly Solar

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





Under Review at [Ecosystem Services]

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

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

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 inside 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
- Safety precautions

What is Agrivoltaics? Solar-Integrated Grazing

Sustainable grazing practices can improve soils

Cost reductions from standard mowing practices

Ongoing work evaluating pastureland performance

Cost and Design Factors

- Temporary fencing
- Water access
- Panel heights (for cattle)

https://solargrazing.org/

ASGA

Design Factors to Consider for Agrivoltaics

- Solar Centric
  - Minimal changes to solar configuration
  - Low-lying vegetation for ground cover and habitat
  - Activities primarily in between rows

- Vegetation Centric
  - Minimal changes to vegetation/agricultural design
  - Oftentimes large spacing in solar technologies

- Co-Location and Co-Optimization
  - Solar and vegetation configurations are designed jointly for maximum dual output
  - Activities occur underneath and around panels

Source: Macknick, Jordan, Brenda Beatty, and Graham Hill. 2013. *Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation*. NREL/TP-6A20-60240, National Renewable Energy Laboratory, Golden. https://www.nrel.gov/docs/fy14osti/60240.pdf

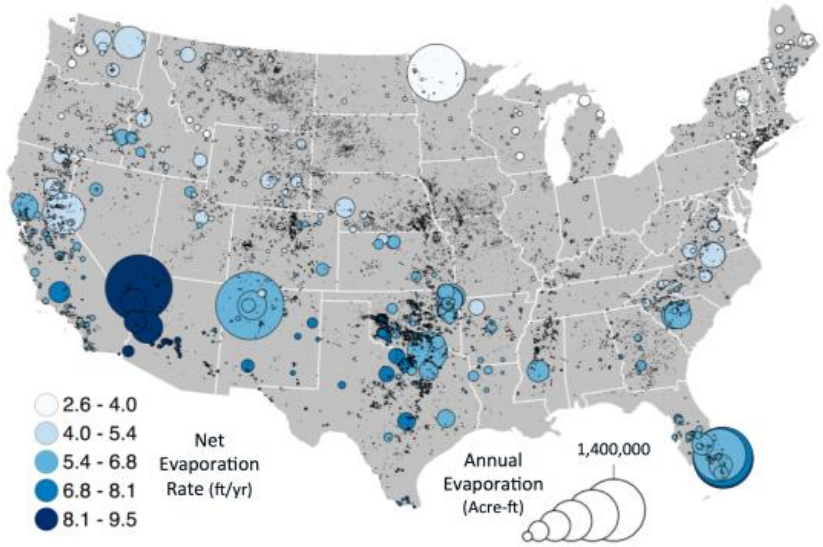
Key Highlight: Floating Solar on Agricultural Reservoirs

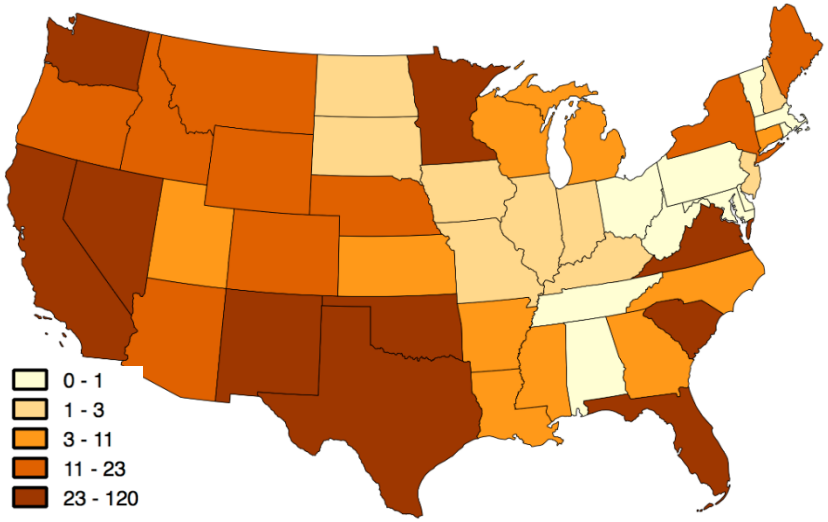
Siting on reservoirs can reduce evaporation and algae growth

Avoid conflicts with land used for agriculture

Using ~25% surface area of 25,000 man-made reservoirs could supply 10% of U.S. power

Recent NREL study identified synergies with hydropower



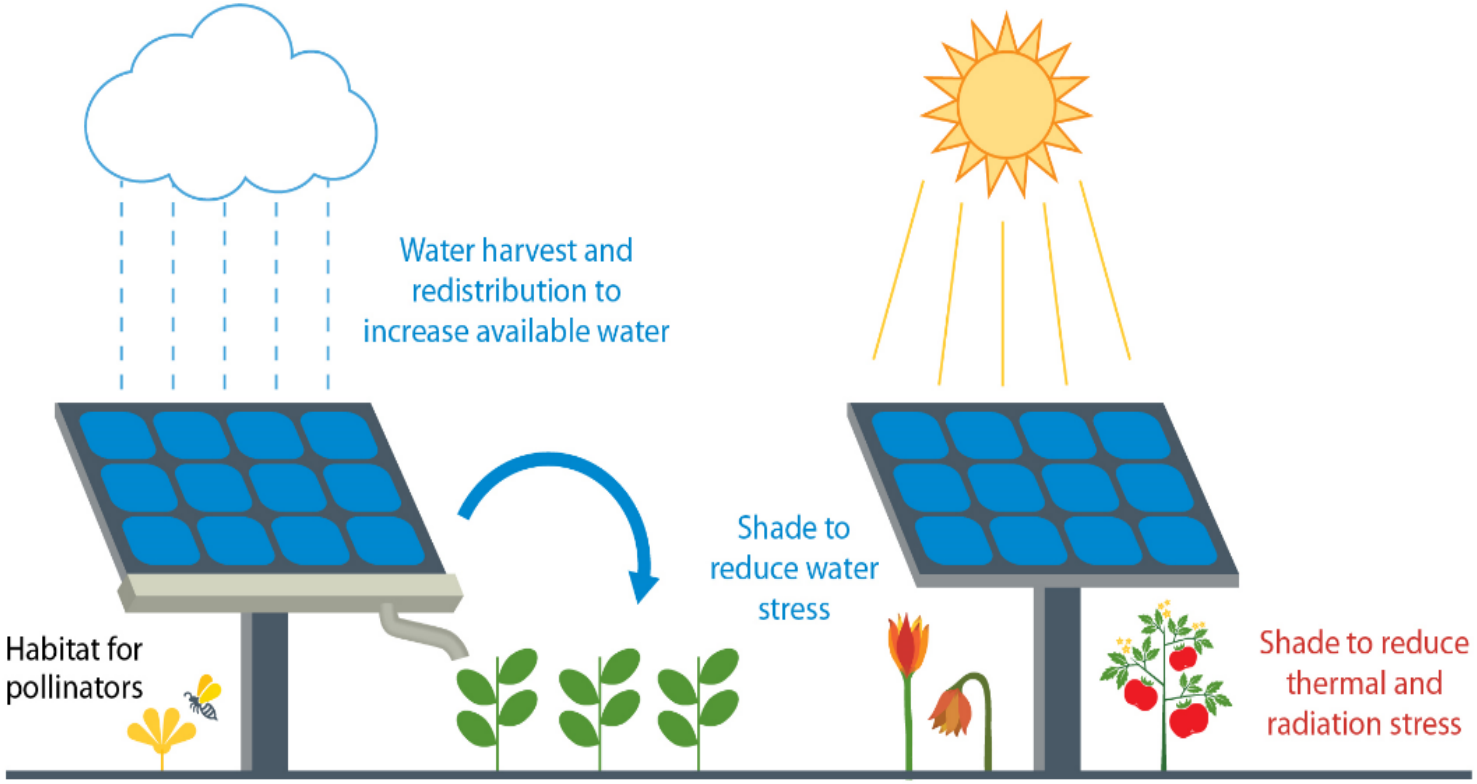


Generation Potential (TWh/year)

Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States. Robert S. Spencer, Jordan Macknick, Alexandra Aznar, Adam Warren, and Matthew O. Reese. Environ. Sci. Technol., 2019, 53 (3), pp 1680–1689

Hybrid Floating Solar Photovoltaics-Hydropower Systems: Benefits and Global Assessment of Technical Potential. Nathan Lee; Ursula Grunwald; Evan Rosenlieb; Heather Mirletz; Alexandra Aznar; Robert Spencer; Sadie Cox. Renewable Energy. 2020, 162, pp 1415-1427

InSPIRE Project Overview



Field-based research topics:

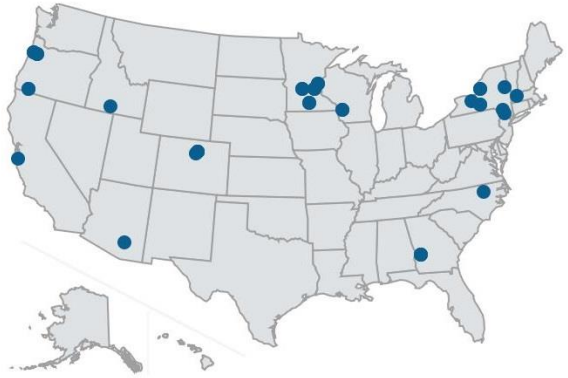
(1) Economic viability of solar-agriculture co-location configurations
(2) Increasing agricultural yields in arid environments
(3) Energy, water, and food security in remote, off-grid areas
(4) Pollinator habitat and ecological services

Analytical research topics:

(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

InSPIRE Project Sites

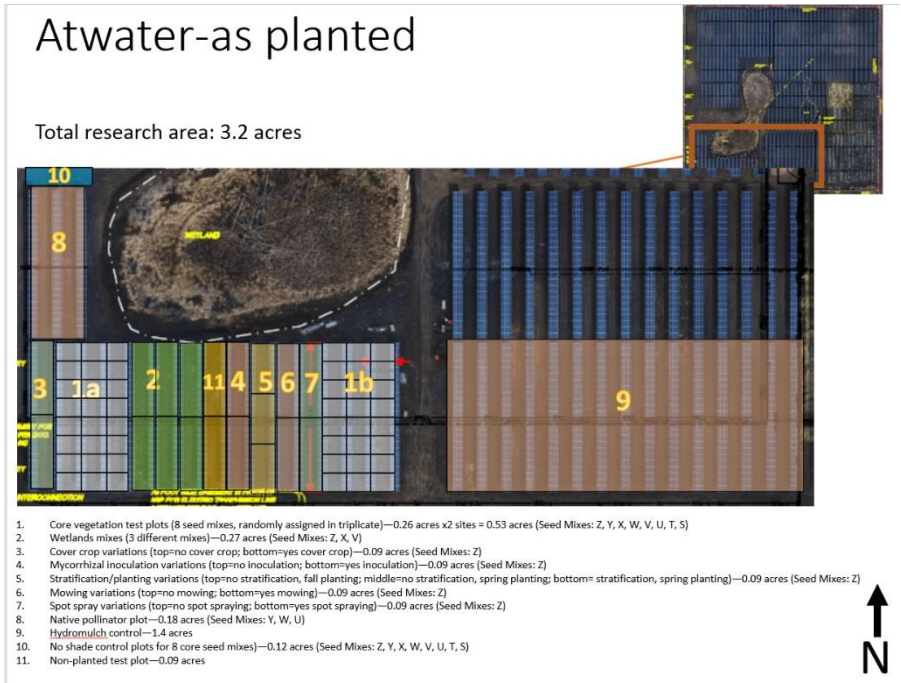


Select from the options below to display all sites using that technology.

- Beekeeping
- Co-location of Solar and Agriculture
- Native Vegetation
- Solar-Integrated Greenhouse
- Beneficial Predators
- Dryland Agriculture Co-location
- Pollinator Habitat

NREL National Renewable Energy Laboratory

Oregon State University · The University of Arizona · University of Massachusetts Amherst · Argonne National Laboratory · Temple University · Hyperion Systems "Harvest the Sun!" · Cornell University Founded A.D. 1865 · Colorado State University · PINEGATE RENEWABLES · REGENERATE Integrated Systems for People and Place · Fresh Energy · Minnesota Native Landscapes · enel Green Power

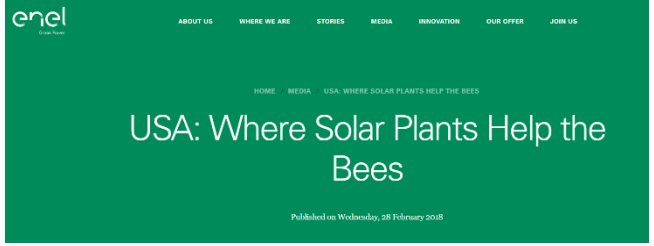


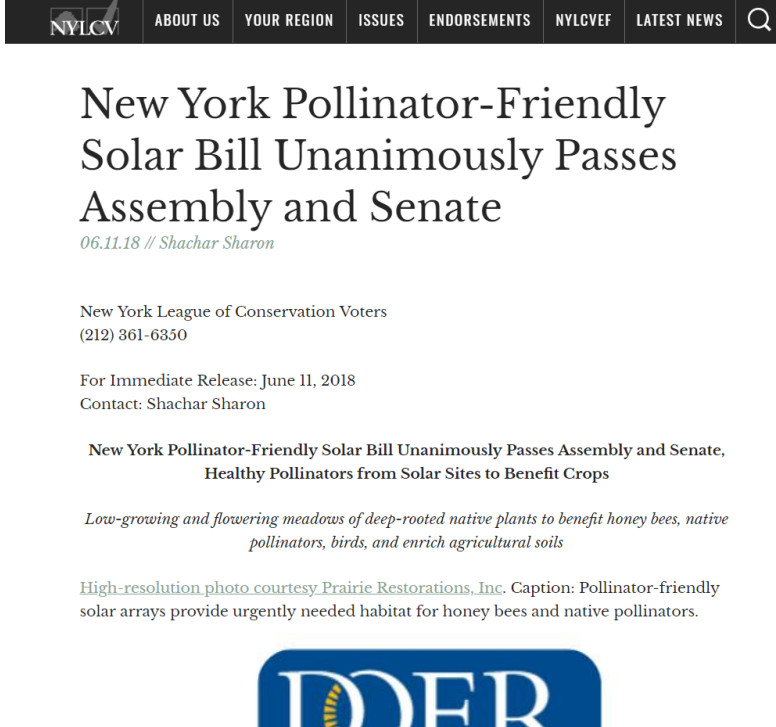
Key Highlight: Education through field research

Educational benefits through internships, field trips, work experience, tours

Elementary school through PhD students

State agency, academic, and professional training





PRESS RELEASE: ILLINOIS POLLINATOR-FRIENDLY SOLAR ENERGY BILL PASSES, ADDS MOMENTUM TO SOLAR ENERGY DEVELOPMENT

Organic Valley Announces Next Phase of Community Solar Partnership To Become 100 percent Renewably Powered in 2019

DOER
Massachusetts Department of Energy Resources

Solar Massachusetts Renewable Target (SMART) Program

Key Highlight: Broad Stakeholder Impacts

Pollinator-Friendly solar standards and scorecards

State Agency partnerships and technical assistance

Direct partnerships with solar and agricultural industry

University initiatives

Photo courtesy of Rob Davis, Fresh Energy

Thank you

Jordan.Macknick@nrel.gov

https://openei.org/wiki/InSPIRE

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