NATIONAL RENEWABLE ENERGY LABORATORY

Overview of opportunities for co-location of agriculture and solar PV

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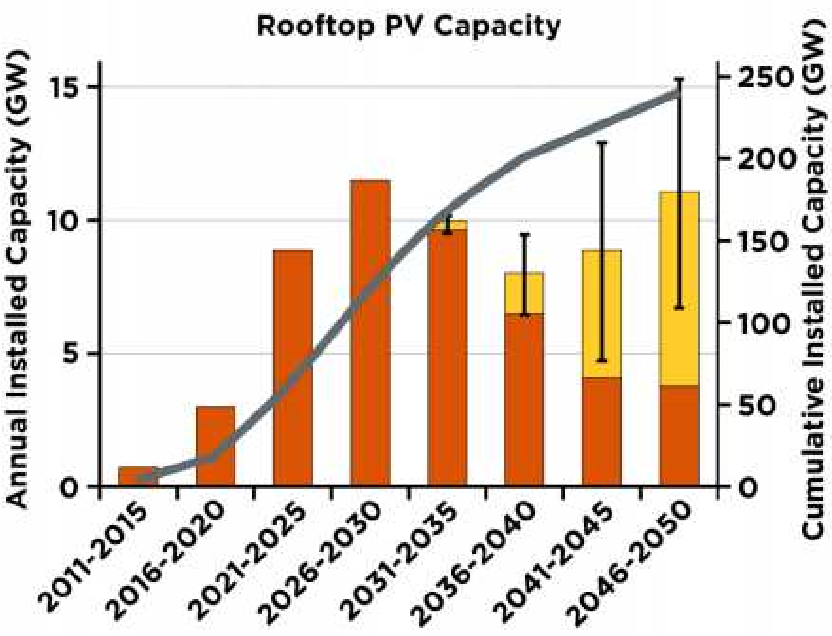
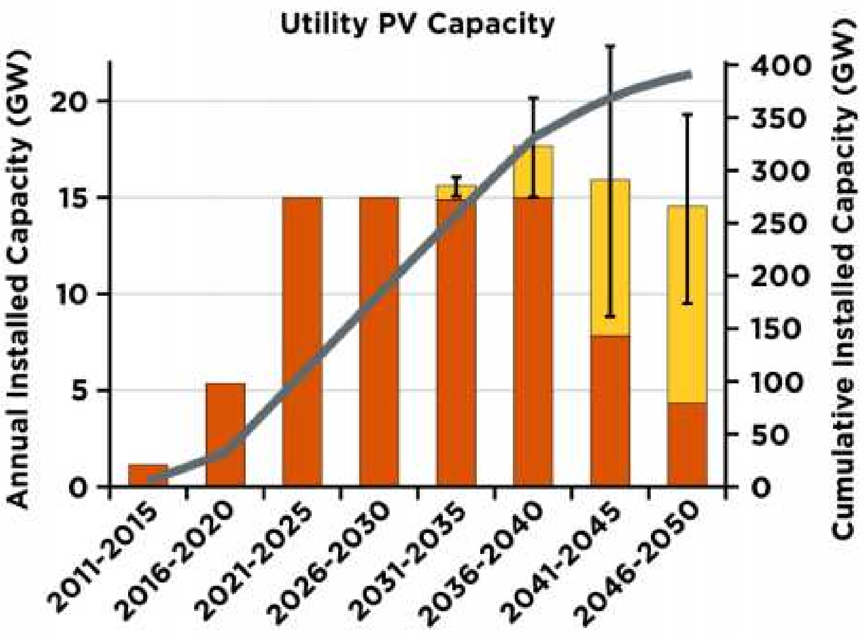
June 14th, 2016
Clean Energy Economy Conference
Utica, NY

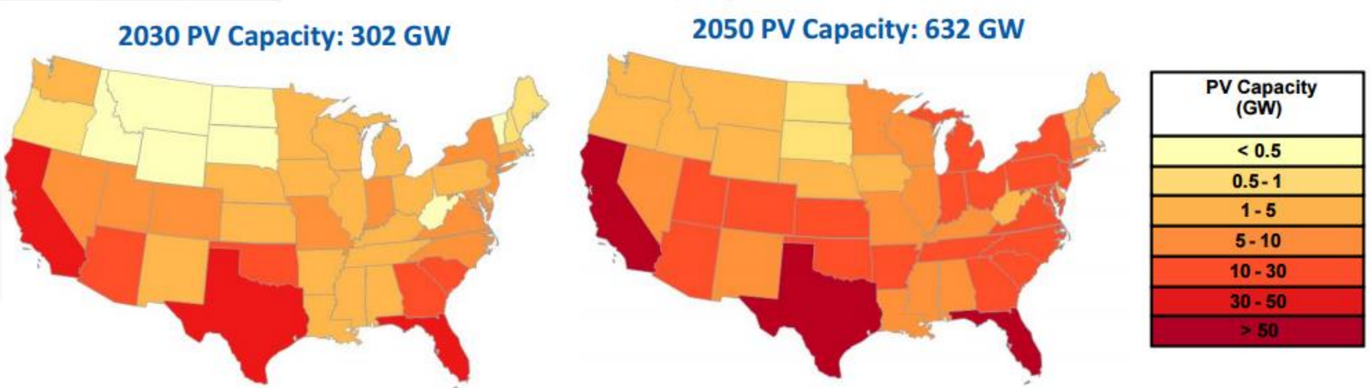
Motivation: Department of Energy SunShot Solar Goals





SunShot Annual Capacity Rebuilds (left axis)
SunShot Annual Capacity Growth (left axis)
SunShot Cumulative Capacity (right axis)

Cumulative Installed PV and CSP Capacity in the SunShot Scenario in 2030 and 2050



2030: 3 million acres
2050: 6 million acres

Motivation: Conventional Utility-Scale Solar Land Preparation Approach

Site preparation costs and impacts

Site preparation costs for utility-scale solar projects are expected to account for 20% of utility-scale PV installed costs in 2020.

Reducing site preparation costs via low-impact site development can lead to cascading reductions in other environmental-related costs and risks.

Site Preparation Practice	Cost Contribution	Estimated Reductions
Geotechnical Investigation	2.6% (0.7%)	0% - (25%)
Clearing and Grubbing	4.3% (1.2%)	25% - 90%
Soil stripping and stockpiling	1.5% (0.4%)	20% - 90%
Grading	4.2% (1.2%)	50% - 90%
Soil Compaction	1.9% (0.5%)	50% - 75%
Foundation for vertical support	22.1% (6.3%)	2% - 5%

Cost contribution values represent percent of total civil works costs; values in parentheses represent total installed capital costs for 100MW utility-scale PV

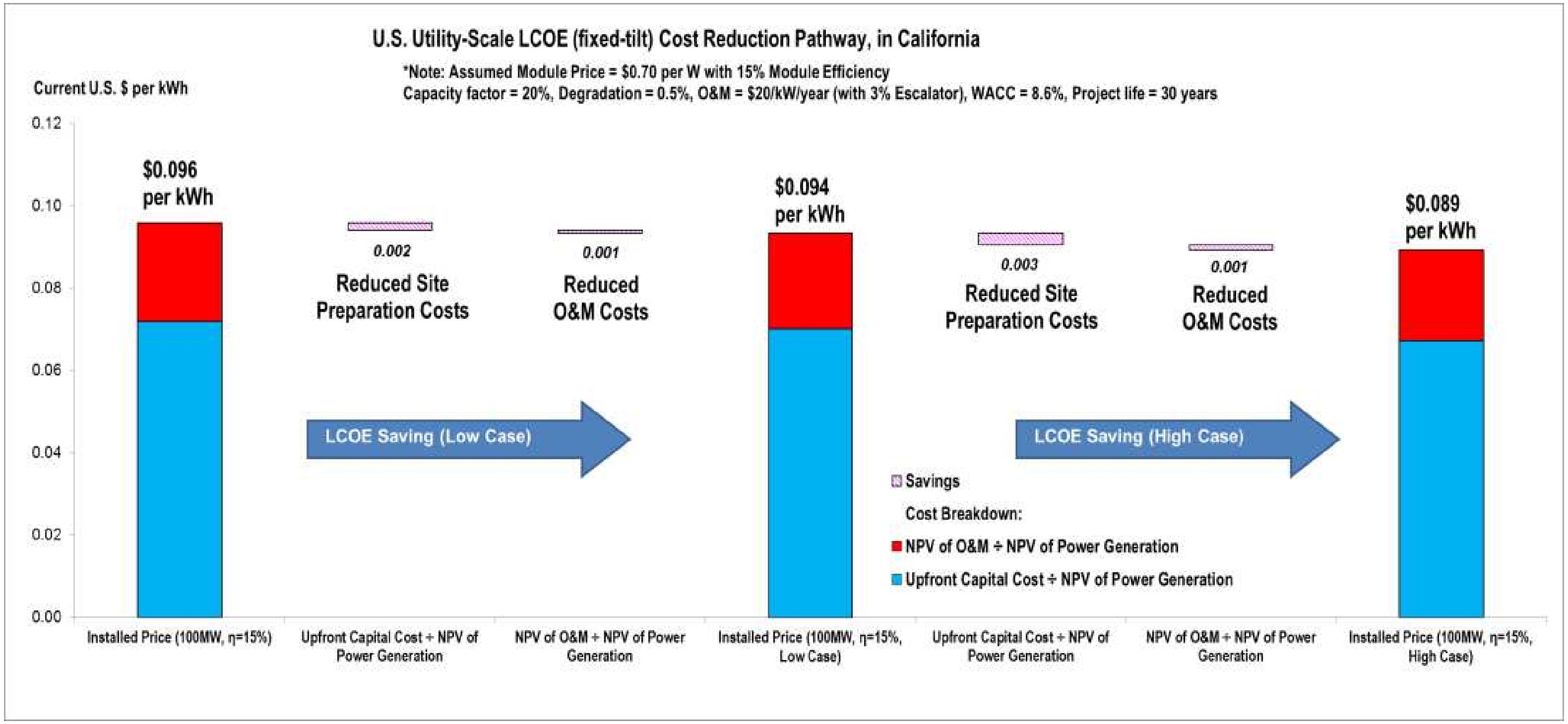
Other Cost Categories	Expected Impact
Land Acquisition	5-10% reduction in land requirements
Permitting	1-5% reduction in permitting costs
O&M for weed control	2-7% reduction in O&M
Degradation	1-3% improvement in annual panel degradation
Efficiency	1-3% improvement in efficiency due to temperature impacts

Overview of InSPIRE

FY2016-FY2018 NREL Project through U.S. Department of Energy

Meeting SunShot Cost and Deployment Targets through:
Innovative Site Preparation and Impact Reductions on the Environment (InSPIRE)

Reducing environmental impacts of solar projects through low-impact site preparation can have a cascading effect on lowering solar development costs:



InSPIRE Project Overview

Low Impact Site Development

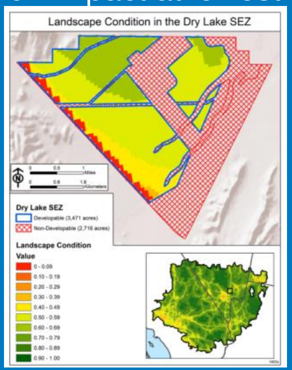
Reduces and identifies upfront capital costs, O&M costs, and risks

Reduces environmental impacts and costs that lead to further costs

Comprehensive Mitigation Plan

Reduces and identifies compensatory mitigation costs

Smarter regional planning for highest conservation impact at lowest cost



Innovative Siting Locations

Reduces and identifies costs on contaminated lands and co-located agricultural projects

Expands economically viable lands to meet SunShot deployment goals

Extensive Stakeholder Engagement

Data collection
Data and results validation
Dissemination
Frequent feedback and interaction

Smart, low-impact siting designs and planning can reduce installation and operation costs, financial risks, and environmental impacts of commercial and utility-scale solar projects.

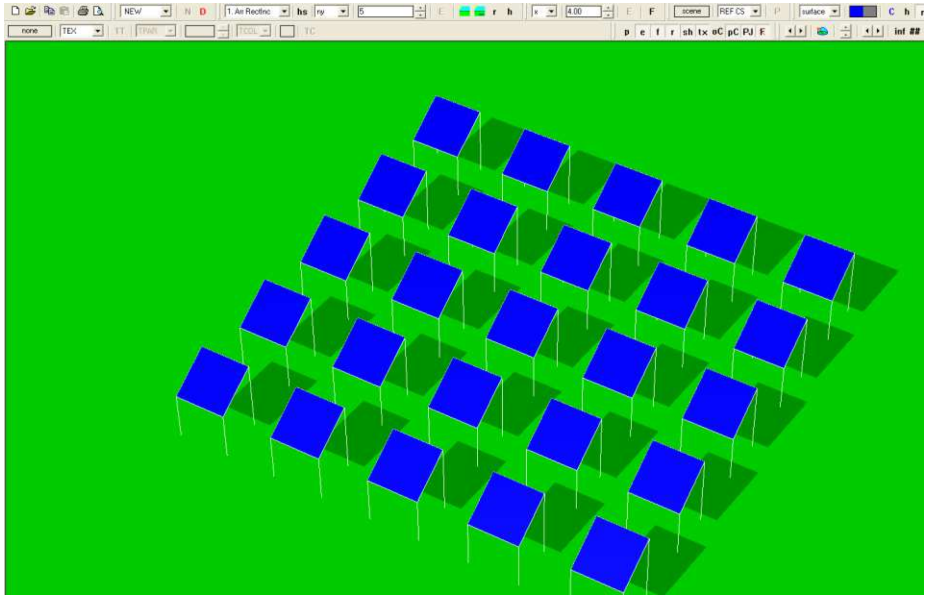
Partners and Stakeholders

Experienced project team leverages expertise from across US and world

IEA PVPS

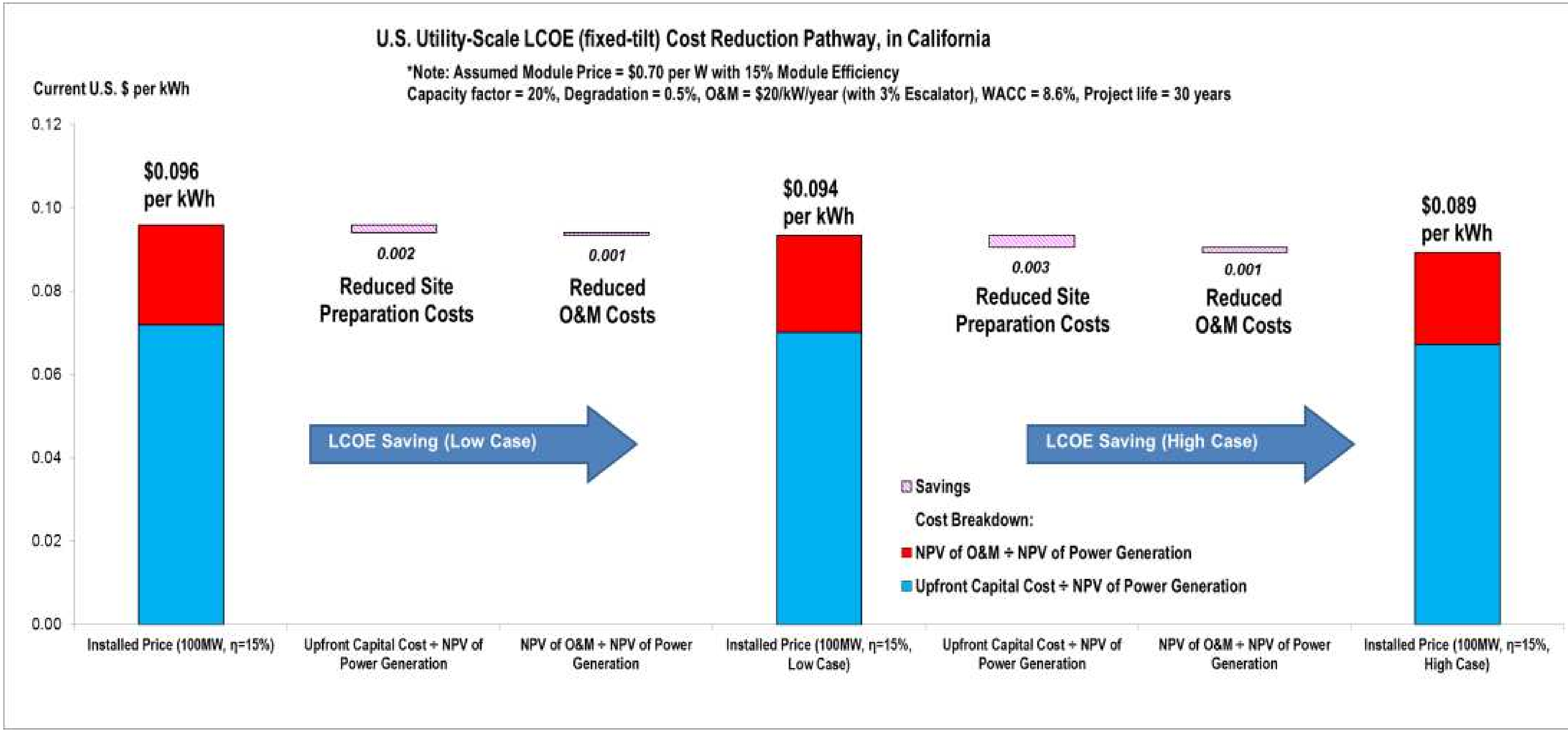
- Enhanced stakeholder engagement ensures timely and relevant products to the market
  - Solar Energy Industry Association (SEIA) and the Large-Scale Solar Association (LSA)
  - EPA and BLM
- Results integrated into NREL's soft cost and solar technology modeling tools
- Complementary, non-duplicative products informed by industry needs
- Frequent interaction and validation from industry

Solar and agriculture co-location: Research design



- Crop varieties
- Solar configurations
- Regional variations
- Field studies located throughout the U.S.
- Desktop analysis and modeling

Impact: 19% or more $/kWh of SunShot cost reduction goal



Preliminary cost modeling estimates suggest that a portion of the strategies in this proposal could constitute:

– 3-8% of the $/W cost reductions and
– 5-19% of the $/kWh cost reductions necessary to achieve SunShot cost goals in 2020;

Additional cost reductions (e.g., reduced mitigation costs, construction timelines, litigation costs) will increase impact;

Expansion of economically viable lands for solar development;

Direct and frequent interaction with industry stakeholders.

Opportunities for low-impact solar development

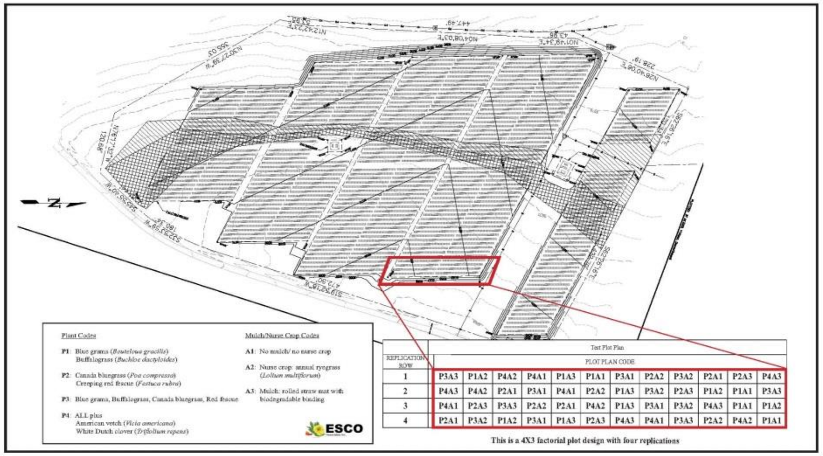
- Solar Centric
  - Minimal changes to solar configuration
  - Low-lying vegetation for ground cover and habitat

- Vegetation Centric
  - Minimal changes to vegetation design
  - Large spacing in solar technologies

- Co-Location and Co-Optimization
  - Solar and vegetation configurations are designed jointly for maximum dual output

NREL Wind Site: Solar-Centric Approach

Figure 1. Plot Layout - Revegetation Test Plots. Sun Edison PV Array, National Renewable Energy Laboratory (NREL) Test Site, Jefferson Co., Colorado



REPLICATION ROW	Test Plot Plan — PLOT PLAN CODE											
1	P3A3	P1A2	P4A2	P4A1	P1A3	P1A1	P3A1	P2A2	P3A2	P2A1	P2A3	P4A3
2	P4A3	P4A2	P2A1	P3A1	P4A1	P2A2	P1A3	P3A2	P2A3	P1A2	P1A1	P3A3
3	P4A1	P2A3	P3A3	P2A2	P2A1	P4A2	P1A3	P3A1	P3A2	P4A3	P1A1	P1A2
4	P2A1	P3A2	P1A2	P3A1	P1A3	P2A3	P4A3	P4A1	P3A3	P2A2	P4A2	P1A1

This is a 4X3 factorial plot design with four replications

How well does vegetation grow underneath and between solar panels?

Sunflower Farm : Vegetation-Centric Approach

Sunflowers for oil production grown under panels in Wisconsin

Milwaukee Journal Sentinel, 2011

Solar and Agriculture Co-location

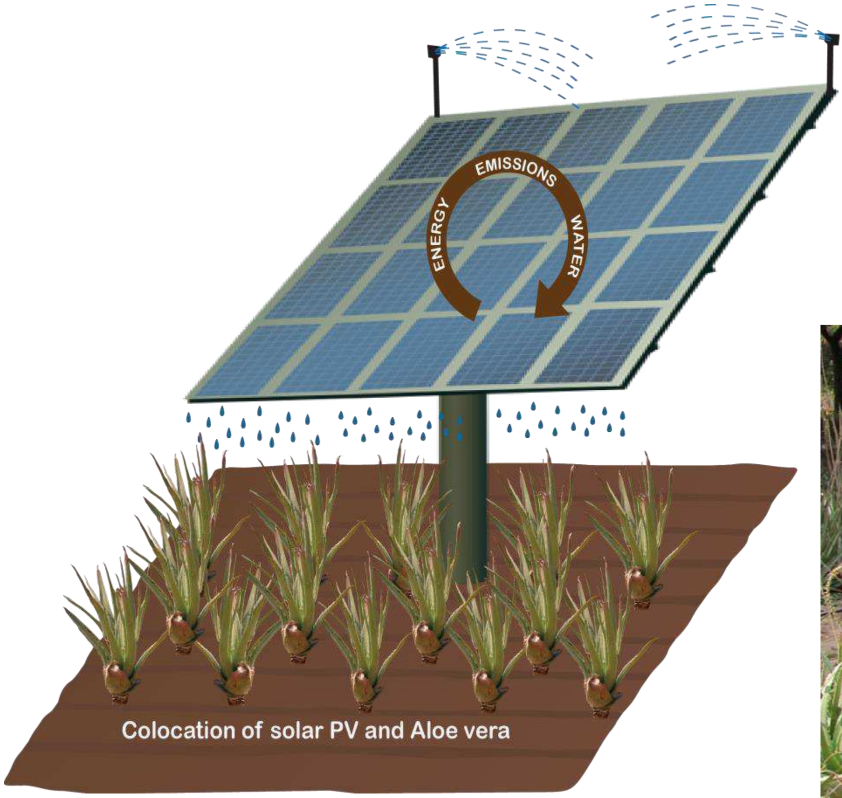
- Massachusetts Test Facility
- Innovative installation and structural design
- Multiple crop types
- U-MASS-Amherst
  - Agriculture
  - Structural Eng.
  - Electrical Eng.
  - Economics

Solar and Agriculture Co-location

Ranching and grazing

Solar and Agriculture Co-location

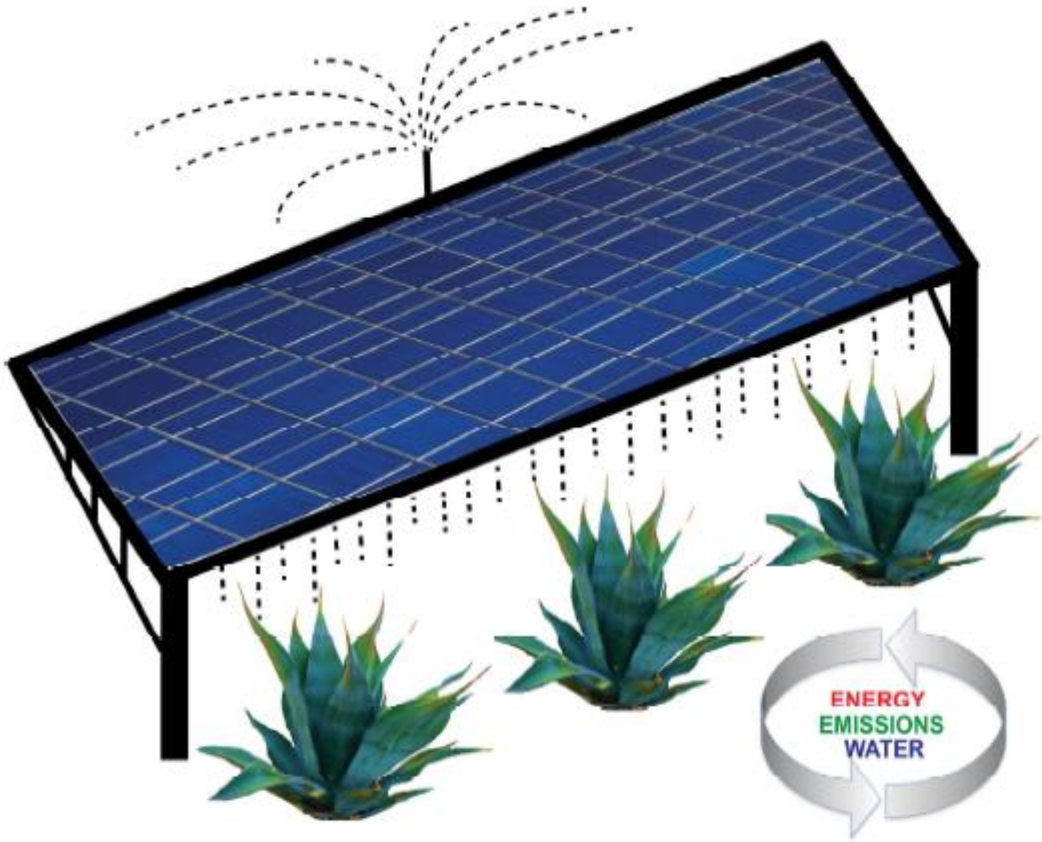
India: Aloe Vera



Ravi *et al.*, 2016

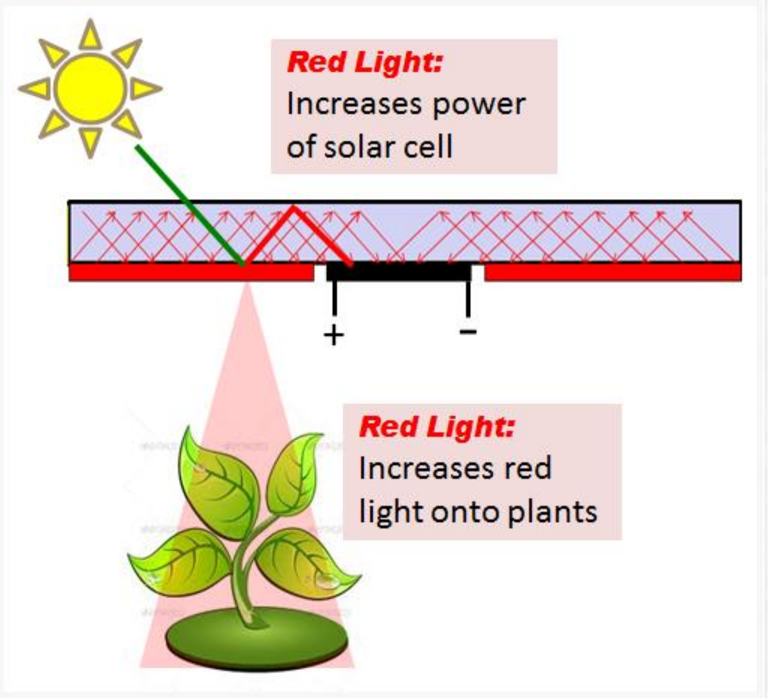
Solar and Agriculture Co-location

Desert Southwest and Mexico: Agave



Ravi *et al.*, 2014

Solar and Agriculture Co-location



Greenhouses

Benefits of Co-Location of Solar and Agriculture

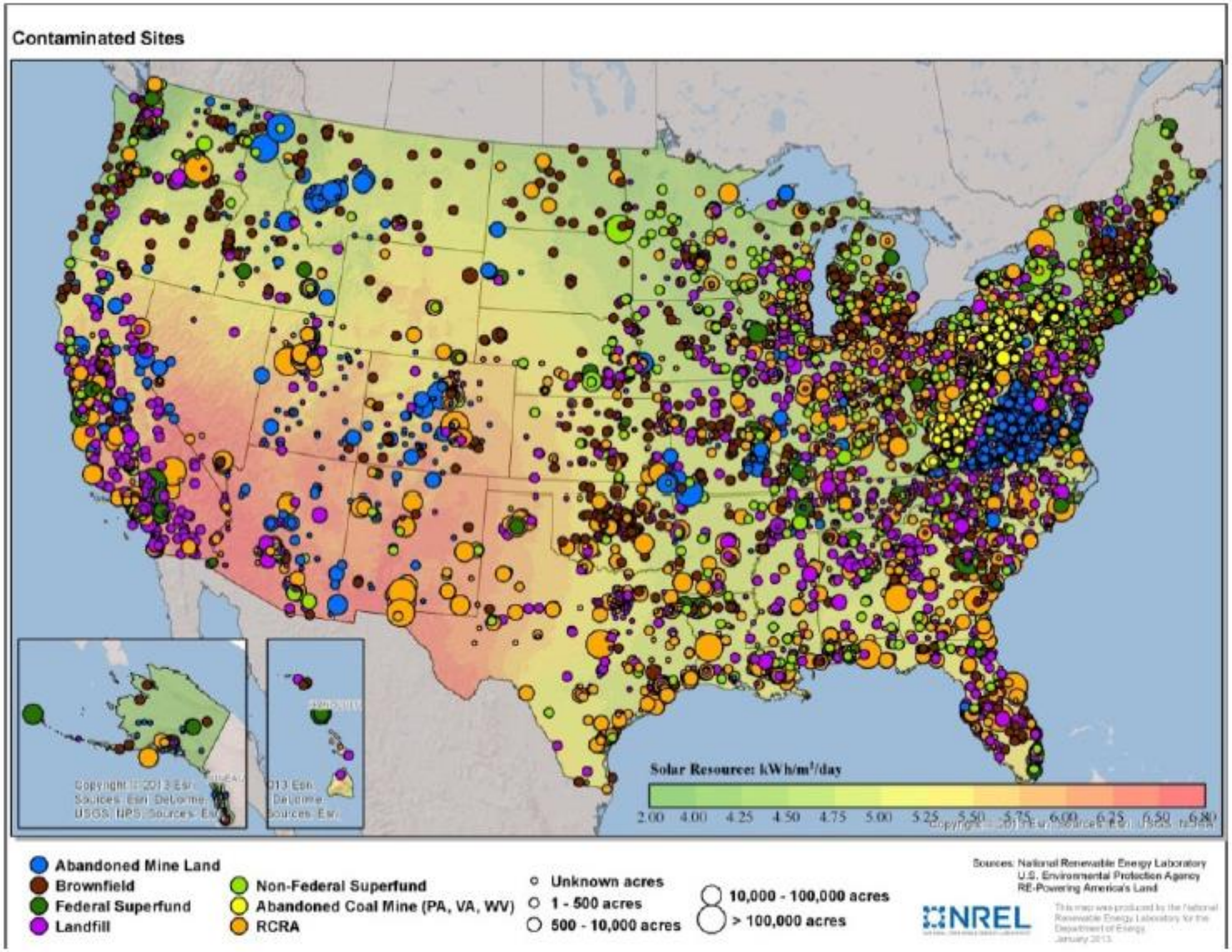
Benefits to Land Owners

- Self-generation of electricity and reduced energy bills
- Additional income stream and increased revenue security
- Control of wind and soil erosion
- Compatible with grazing activities, provides shade and cover for livestock
- New market opportunities for shade tolerant crops
- Protection of natural habitat
- Safeguarding soil health
- Improved habitat for pollinator species

Benefits to Solar Developers

- Reductions in site preparation and installation costs
- Reductions in O&M costs
- Reduced need for dust suppression
- Reduction in litigation vulnerability
- Decreased permitting time
- Increased solar energy production from cooler air zone created under modules
- Reduction in environmental mitigation investments

Contaminated and Disturbed Lands in the United States



There are sufficient areas of disturbed and contaminated lands to meet U.S. Department of Energy SunShot Solar goals without utilizing one acre of agricultural land

Macknick et al., 2013

Closing Thoughts

- There are opportunities for synergies between agricultural and solar energy communities
- Solar projects can be designed and constructed in ways that minimize environmental impacts and reduce costs
- Test facilities and systematic demonstrations of various configurations are needed to quantify potential benefits
- Greater interaction with multiple stakeholders can improve viability of solar and agriculture in the future

Thank you

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