Climate Change Challenges: *Dual Use Solar, Food Production and Farmland Protection*

Mass Land Conservation Conference

March 23, 2023

Heidi Ricci, Mass Audubon

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Ambitious, Interconnected Goals

Goal 1

Protect and Steward Resilient Landscapes

Goal 2

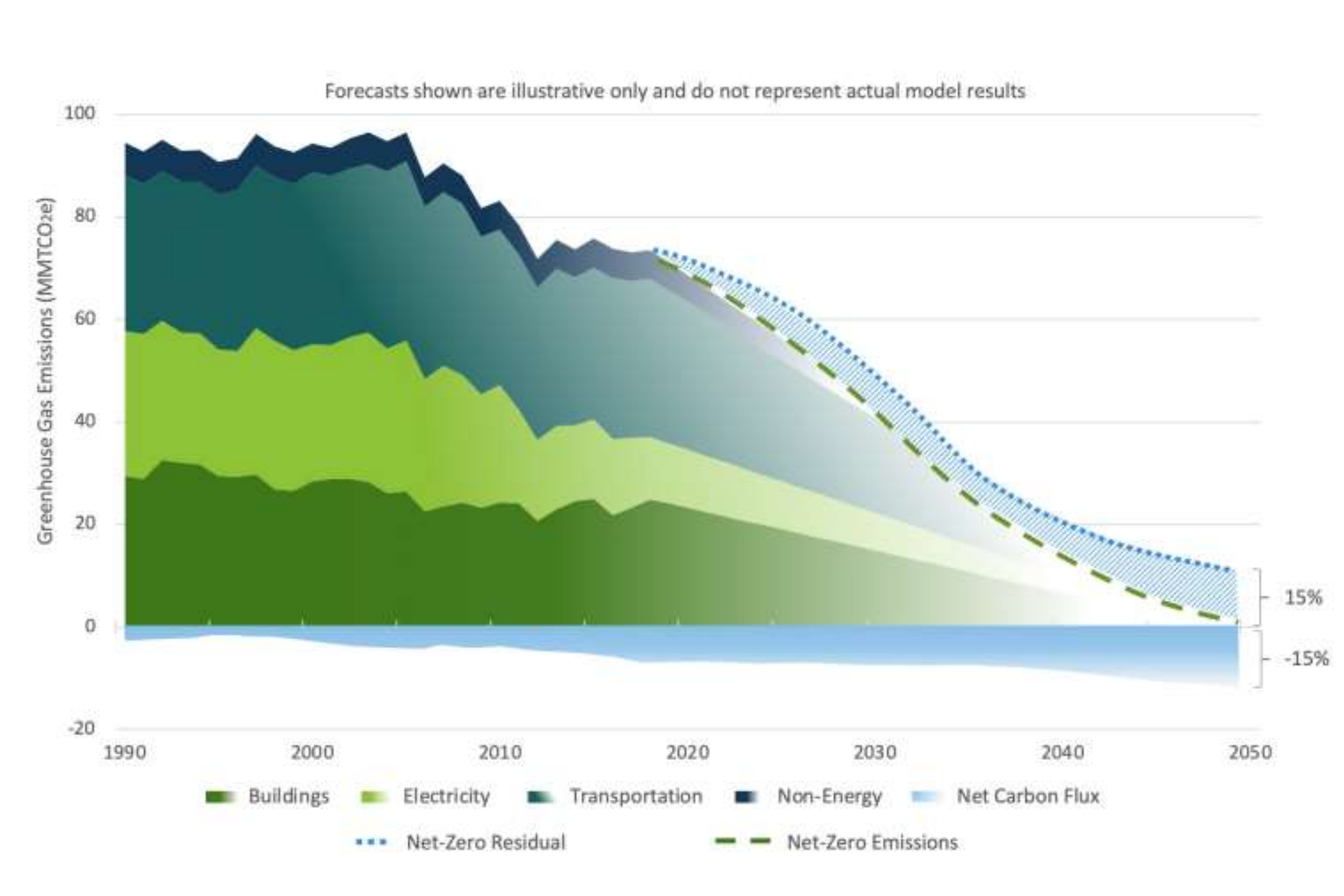
Advance Inclusive and Equitable Access to Nature

Goal 3

Mobilize to Fight Climate Change

Mass Audubon

In Massachusetts, the Next-Generation Climate Roadmap requires ambitious GHG reductions…



- Meeting Roadmap goal of Net-Zero by 2050 will require significant GHG emission reductions:
  - 50% below 1990 levels by 2030
  - 85% below 1990 levels by 2050…
  - …and, carbon removal of 15% of emissions

➢ Natural and working lands currently remove 7% of annual GHG emissions

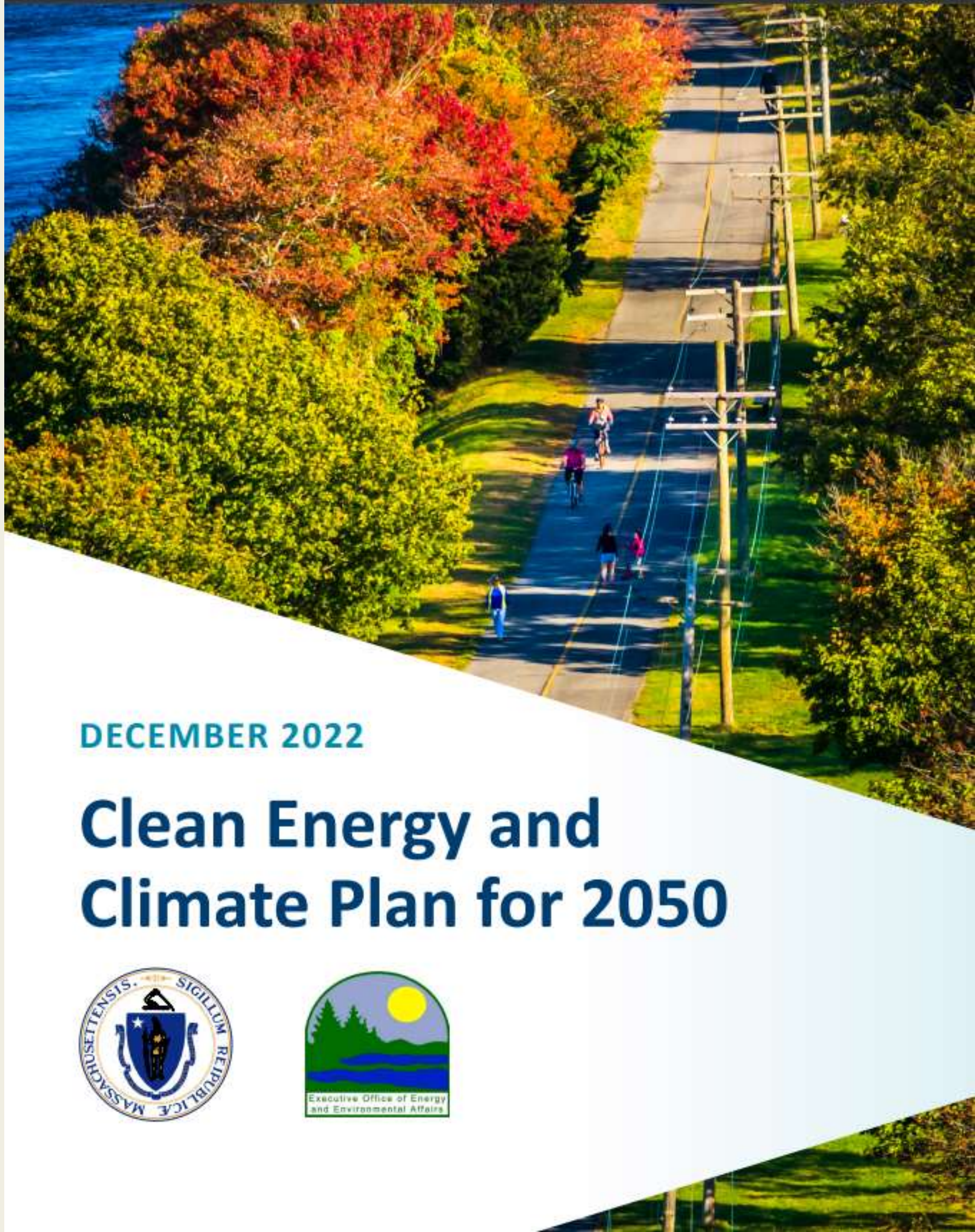
Source: MA Decarbonization Pathways report (2021).

Massachusetts Clean Energy and Climate Plan (CECP)

27 gigawatts (GW) of solar

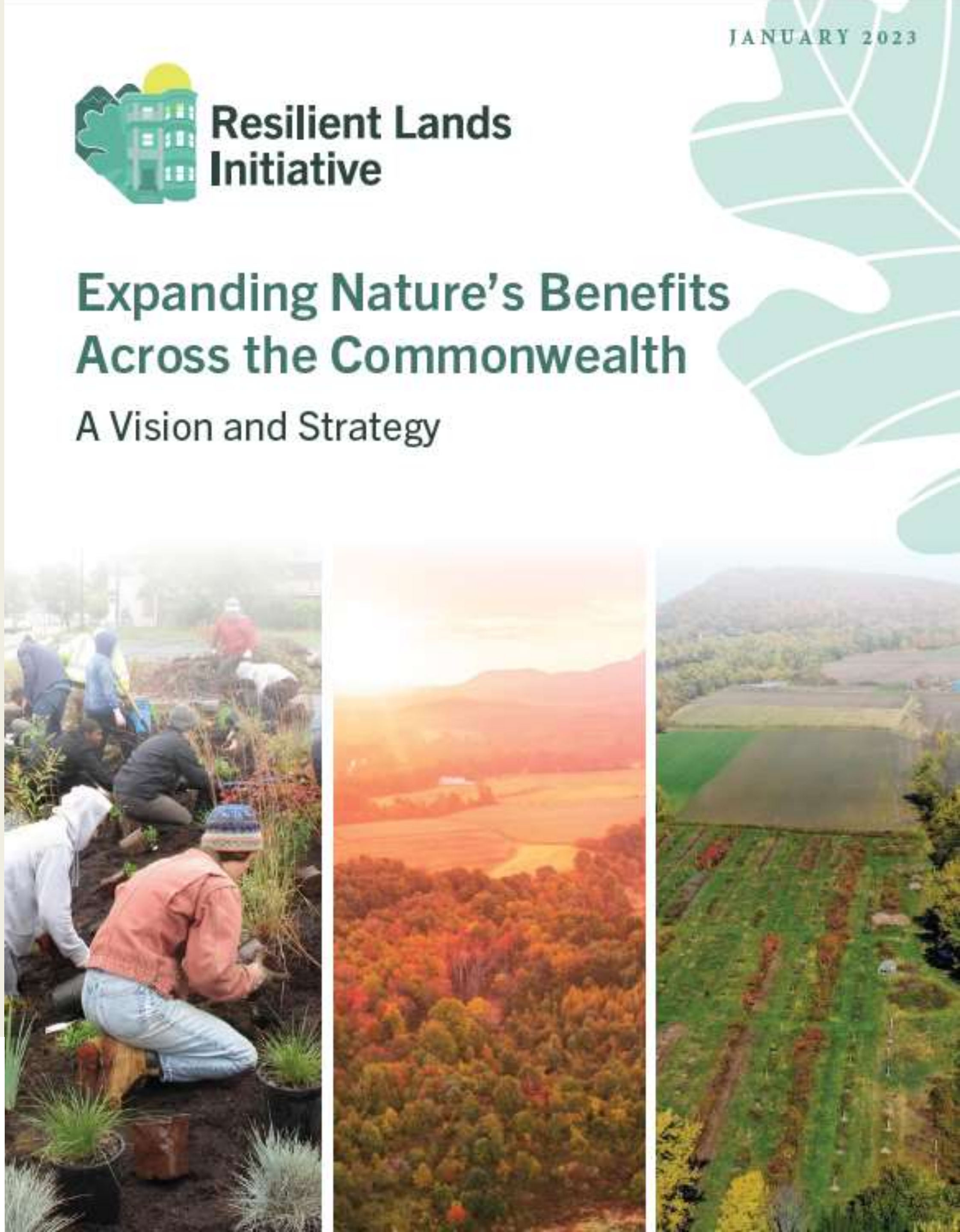
What are the roles of

- Built lands: rooftops, parking lots, gravel pits, landfills, etc.
- Natural and working lands: forests, farmland, wetlands?



Massachusetts Resilient Lands Initiative

- No Net Loss of Farms and Forests
- Reforesting thousands of acres
  - urban greenspaces, river corridors
- Protect 30% of MA by 2030
  40% by 2050



No net loss of Soil Organic Carbon between 2021 and 2050

Legal Boundaries of Local Regulation of Solar

Zoning Act Exemption MGL Ch. 40A S.3, 9th paragraph

"No zoning ordinance or by-law shall prohibit or unreasonably regulate the installation of solar energy systems or the building of structures that facilitate the collection of solar energy, except where necessary to protect the public health, safety or welfare."

Supreme Judicial Court

Tracer Lane II Realty, LLC v. City of Waltham, 489 Mass. 775 (2022)

"Like all municipalities, Waltham maintains the discretion to reasonably restrict the magnitude and placement of solar energy systems. An outright ban of large-scale solar energy systems in all but one to two percent of a municipality's land area, however, restricts rather than promotes the legislative goal of promoting solar energy. ***In the absence of a reasonable basis grounded in public health, safety, or welfare, such a prohibition is impermissible under the provision****."*

Legal Boundaries of Local Regulation of Solar

Dual Solar Agriculture (Agrivoltaics) provisions of Chapter 179, Acts of 2022

An Act Driving Clean Energy and Offshore Wind

Land in dual solar/agricultural use, aka agrivoltaics, qualifies as agriculture under both:

- **Ch. 61A (current use tax assessment)**, and
- **Ch. 40A S.3 paragraph 1 - Zoning exemption for agriculture**
  - Broader than the general solar exemption
  - Explicitly prohibits requiring a special permit, and
  - Does not include the exception for public health, safety, or welfare

Massachusetts Agriculture

Farm Facts

- 7,200 Farms
- 500,000 acres
- 26,000 jobs
- $475 million market value ($100 million direct market)
- Average farm size 68 acres

New England Food Vision
nefoodvision.org

Source: Mass Dept of Ag Resources

30 BY 30

Solar Siting Studies Underway

Department of Energy Resources (DOER) Technical Potential of Solar Study

- Stakeholder engagement
- Geospatial analysis – suitability of parcels for solar
- Story Map and online mapping tool
- Policy Considerations

Mass Audubon – *Gaining Carbon*

- Geospatial and carbon mapping, energy modeling
- Scenario modeling – potential to meet the CECP goals while locating most of the solar on buildings, parking lots, and other already developed or altered lands
- Minimize impacts on biodiversity, carbon, and other values of natural and working lands (forests, farmlands, wetlands)
- Policy Recommendations

Massachusetts Department of Energy Resources

Agrivoltaics in the SMART Program

March 25, 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
  - Agricultural (ASTGU)

Relative Costs & Compensation Values for Systems >25 kW AC

System Type	Building Mounted	Brownfield	Landfill	Canopy	ASTGU
Average Installation Cost ($/watt)	$2.63	$2.15	$2.01	$3.60	$2.51
Average System Size in SMART (kW AC)	186	2,240	2,260	438	1,400
Total System Count in SMART	1,116	12	37	221	12
Compensation Rate Adder Value ($/kWh)	$0.02	$0.03	$0.04	$0.06	$0.06

Program & ASTGU Statistics

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

12 projects qualified in SMART with the agricultural adder --> 17.14 MW, 1.03% of total approved capacity

15 projects that have received Pre-Determination letters of eligibility but have not applied yet --> 29.79 MW total

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

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

Challenges & Opportunities of Dual-Use

Challenges

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

Opportunities

- Additional revenue for farmers
- Contributing to Commonwealth's decarbonization goals
- Keeping land in agriculture

Looking Ahead

Technical Potential of Solar Study

- 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

BLUEWAVE

AGRIVOLTAICS:
Opportunities for Farming & Conservation

Jesse Robertson-DuBois
Director of Sustainable Solar Development

BLUEWAVE

Founded in 2010.

OUR MISSION

Revolutionize energy with simple, powerful solar and storage solutions.

OUR VISION

Protect the planet by transforming access to renewable energy.

BLUEWAVE

2010

BlueWave founded with the vision of protecting the planet by transforming access to renewable energy

2011

Launched our **solar development business** with our first small contract in Massachusetts

2013

Pioneered and built the first **community solar** projects in Massachusetts

2017

Achieved B Corp certification for our commitment to the people, the partners and the places we do business

Certified B Corporation

2021

Growth in **energy storage** and **dual-use solar,** developing the first agrivoltaic project over a wild blueberry farm in Rockport, Maine.

2022

BlueWave acquired by Axium Infrastructure and transitions from development only to owning and operating projects.

SUSTAINABLE SOLAR TERMINOLOGY

"Sustainable Solar"
Combining solar development with land management rooted in conservation and agriculture to create a multifunctional system with a variety of **ecological**, **agricultural**, and **energy** benefits.

Dual Use: Pollinator-Friendly
Solar sites that maintain or seed wildflowers, pollinator-friendly plants, and native species to create habitat for native pollinators to thrive in.

Dual-Use: Conservation
Solar sites designed in consultation with conservation groups focused on restoring ecosystem integrity / vitality via on-site measures.

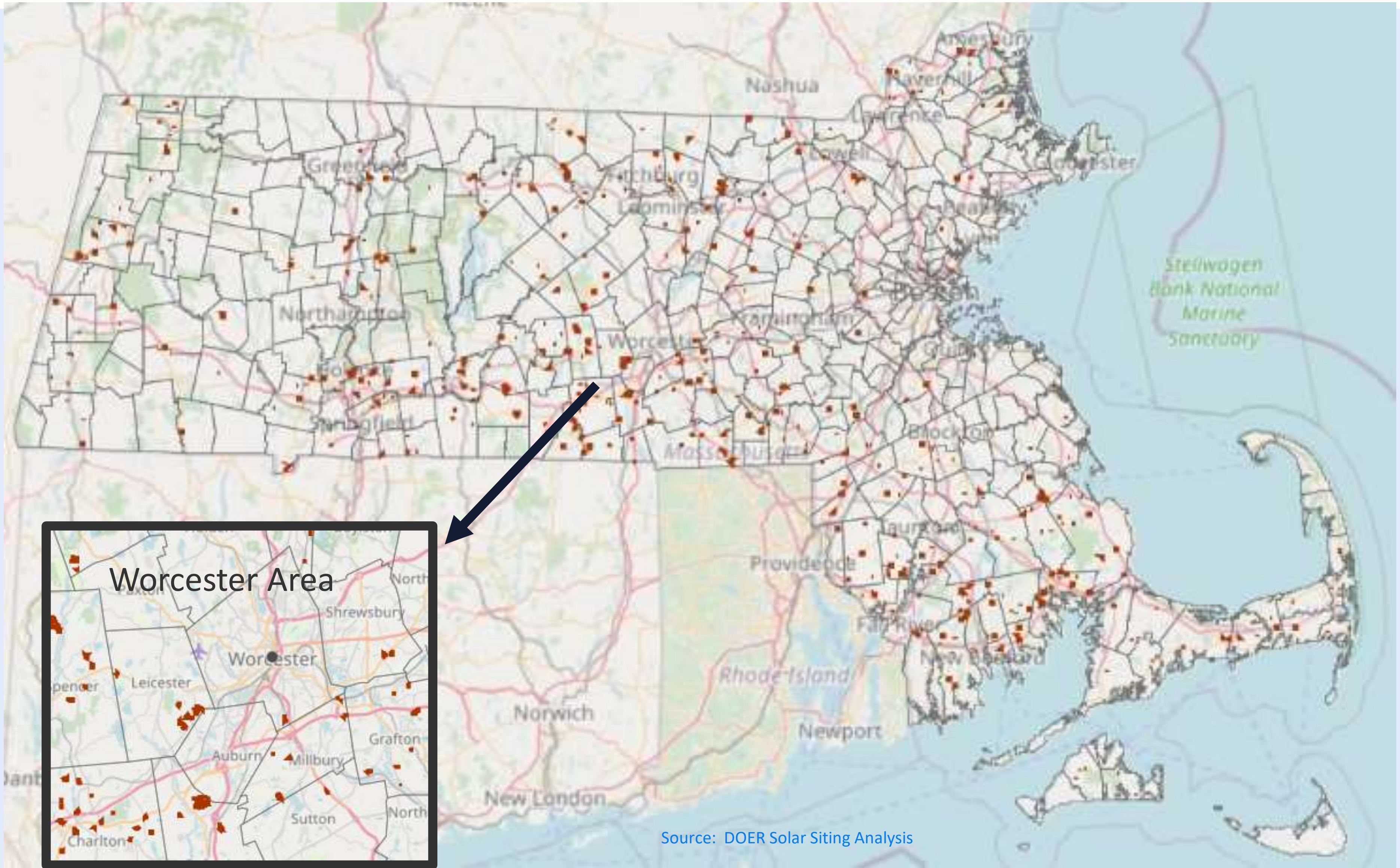
Dual-Use Agrivoltaics: Sheep Grazing
Solar sites that incorporate sheep grazing (and small-scale forage harvesting) as part of the overall landscape maintenance plan to replace mowing.

Adaptive Agrivoltaics: Crops & Cattle Grazing
Solar sites with specialized designs, construction and/or equipment that facilitate crop cultivation, cattle grazing, and/or forage harvesting under and around the panels (e.g. via people and equipment).

Ag-Ready Agrivoltaics: Large-scale Crops, Livestock & Equipment
Solar sites designed to accommodate a broad range of normal agricultural practices and equipment at typical scale of production, with only limited restrictions on agricultural use.

AGRICULTURAL SOLAR TARIFF GENERATION UNITS (ASTGUs)
> Design standards for minimum height and maximum shade

MASSACHUSSETTS COMMERCIAL SOLAR
circa 2019



Source: DOER Solar Siting Analysis

ADAPTIVE AGRIVOLTAICS
Challenges and Opportunities

EARLY LEADERS
- France, Germany, Italy, Japan, Korea, Israel
- Highly specialized systems

ADAPTIVE AGRIVOLTAICS
Challenges and Opportunities

MORE APPROPRIATE CROPS

- Shade tolerant: leafy greens, roots and shoots
- Light-limited/scald-prone: soybeans, fruits
- Vulnerable to hail/frost/ drought
- Labor-intensive: berries, hand-pick

MORE CHALLENGING CROPS

- Tall, highly-mechanized, warm-season, shade-intolerant

ADAPTIVE AGRIVOLTAICS
Crop Suitability

Light saturation and compensation points of major crops

Species	Saturation Point: % Daylight (PAR / 1680)	Saturation Point: PAR values	Compensation Point: % Daylight (PAR / 1680)	Compensation Point: PAR values	Remarks
Rice	40-50	672-840	0.5-1.0	8-17	Murata (1961)
Barley	50	840	n/a	n/a	Takeda (1978)
Corn/Maize	80-100	1344-1680	1.8	30	Hesketh & Moss (1963)
Sugar beet	80	1344	n/a	n/a	Hesketh (1963)
Soybean	20-25	336-420	1.0-1.5	17-25	Bohning & Burnside (1956)
Kidney bean	20-25	336-420	1.0-1.5	17-25	
Sweet Potato	30	504	n/a	n/a	Tsuno & Fuzise (1965)
Potato	30	504	0.8-1.0	n/a	Chapman & Loomis (1953)
Castor Bean	20-25	336-420	2.4	40	Ito (1965)
Tobacco	20-25	336-420	1.0-1.5	17-25	Bohning & Burnside (1956)
Cotton	20-25	336-420	1.0-1.5	17-25	
Tomato	70	1176	n/a	n/a	Tatsumi & Hori (1969)
Eggplant	40	672	2.0	34	
Red Pepper	30	504	1.5	25	
Cucumber	55	924	n/a	n/a	
Squash	45	756	1.5	25	
Melon	55	924	0.4	7	
Watermelon	80	1344	4.0	67	
Cabbage	40	672	2.0	34	
Chinese cabbage	40	672	1.5-2.0	25-34	
Turnip	55	924	4.0	67	
Taro	80	1344	4.0	67	
Pea	40	672	2.0	34	
Celery	45	756	2.0	34	
Lettuce	25	420	1.5-2.0	25-34	
Cryptotaenia	20	336	1.0	17	
Zingiber mioga	20	336	1.5	25	

From: "Effects of Various Radiant Sources on Plant Growth," Shinji Tazawa, Japanese Agricultural Research Quaterly 33 (1999)

BLUEWAVE

Shading and light saturation dynamics for crops have been well-understood for decades!

- Shading is not a primary limiting factor

Additional factors:

- Photo-response periods
- Temperature sensitivity
- Foliage canopy effects
- Wind & airflow impacts
- Pest & disease dynamics

ADAPTIVE AGRIVOLTAICS
Forage (pasture) performance

Relative yields of forage species under shaded conditions

Species	Spring-Early Summer 50% Shade	Spring-Early Summer 80% Shade	Summer-Fall Season 50% Shade	Summer-Fall Season 80% Shade
Introduced cool-season grasses				
Kentucky bluegrass	51%	30%	99%	65%
Orchardgrass 'Benchmark'	71%	58%	85%	46%
Orchardgrass 'Justus'	99%	74%	95%	81%
Ryegrass 'Manhattan II'	47%	42%	87%	68%
Smooth bromegrass	58%	48%	124%	99%
Tall Fescue 'KY31'	70%	67%	122%	60%
Tall Fescue 'Martin'	68%	50%	95%	49%
Timothy	66%	47%	88%	54%
Introduced warm-season grasses				
Bermudagrass			66%	15%
Native warm-season grasses				
Big bluestem	49%	25%	74%	39%
Buffalograss			46%	20%
Indiangrass	42%	23%	73%	40%
Switchgrass	51%	19%	72%	33%
Introduced cool-season legumes				
Alfalfa 'Cody'	62%	28%	86%	60%
Alfalfa 'Vernal'	64%	25%	76%	45%
Alsike clover	51%	12%	57%	32%
Berseem clover	65%	35%	43%	18%
Birdfoot trefoil hybrid Rhizomatous	27%	8%	65%	35%
Birdsfoot Trefoil 'Nocern'	39%	23%	65%	30%
White clover	48%	44%	81%	59%
Red clover	64%	28%	61%	30%
Introduced warm-season legumes				
Korean Lespedeza			70%	32%
Korean Lespedeza 'Summit'	49%	18%	37%	21%
Striate Lespedeza 'Kobe'	45%	44%	83%	51%
Serecia Lespedeza			68%	44%
Native warm-season legumes				
Desmodium canescens	84%	77%	132%	130%
Desmodium paniculatum	62%	61%	125%	110%

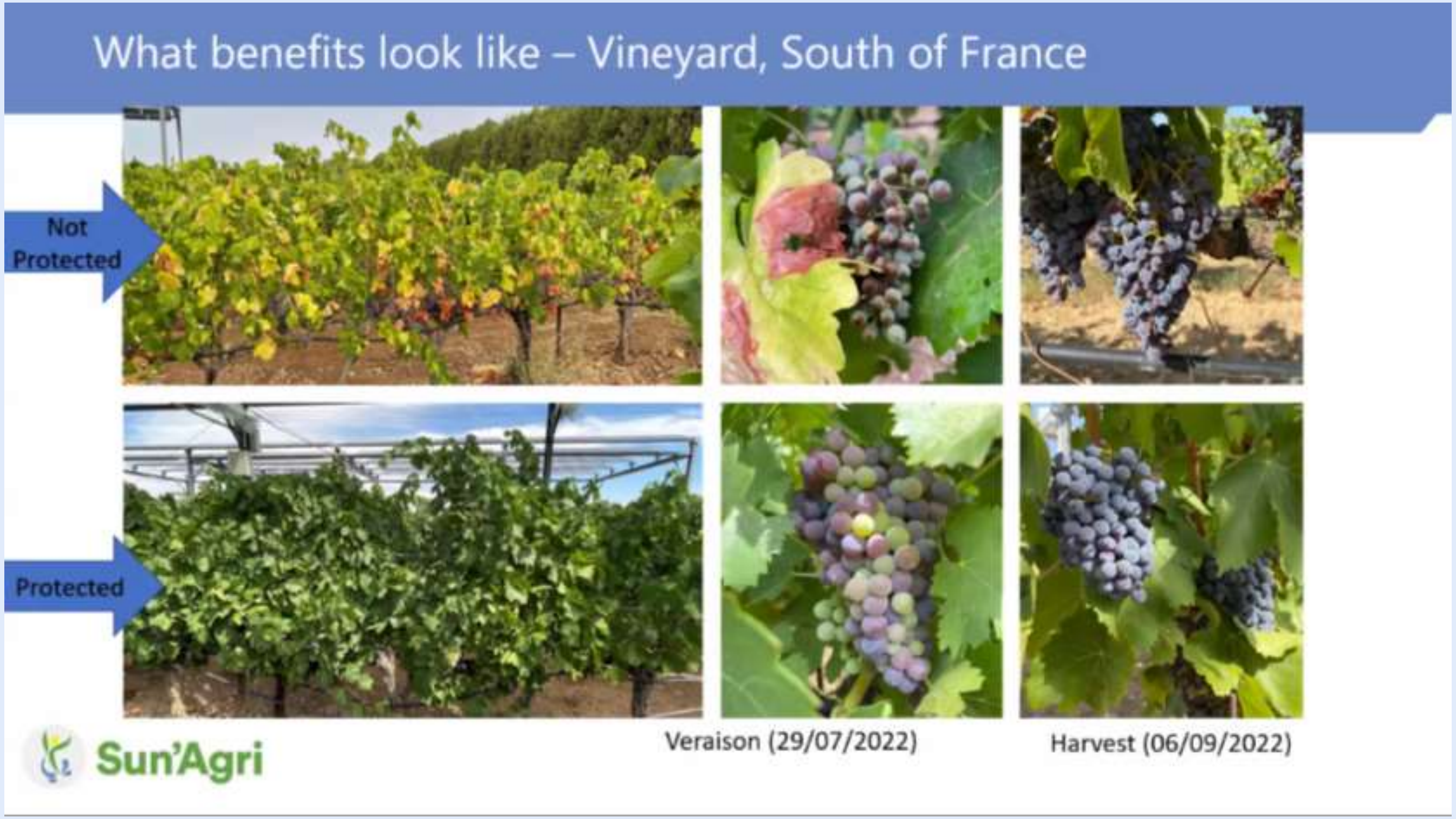
From C. H. Lin, et al, "Shade effects on forage crops with potential in temperate agroforestry practices," *Agroforestry Systems*, 1999

BLUEWAVE

- Several grass species outperform open field production under partially shaded conditions during the summer and fall season
- Forage species selection can significantly impact yields
- Spring yields are generally reduced more than summer-fall yields

How can we successfully design
AGRIVOLTAIC SYSTEMS
for agricultural flexibility & success?

ADAPTIVE AGRIVOLTAICS
Potential Benefits to Agriculture



ADAPTIVE AGRIVOLTAICS
Challenges and Opportunities

COMMERCIAL CHALLENGES

- Costs (extra steel, labor)
- Engineering
- Code compliance (UL)
- Insurability & bankability
- Scale of ag operations

Need to work with readily available solar equipment!

ADAPTIVE AGRIVOLTAICS
Available Equipment in the U.S.

Fixed tilt
- South-facing with east-west rows
- Banded light pattern
- Aisles can only fit mid-scale equipment
- Works fine for specialty crops, grazing
- Elevated ASTGU = “forest of steel”

Single-Axis Tracker
- North-south rows with panels rotating from east to west
- Current industry PV standard
- More even light distribution
- Slightly wider aisles
- 10,000s of acres being grazed at utility-scale solar facilities
- Can be elevated as an ASTGU (still expensive!)
- Can be 1P, 2L, or 2P format

1-PORTRAIT TRACKER SYSTEMS

- Single axis tracker
- 1 module in portrait (1P)
- ASTGUs require 10’ vertical clearance below panels in horizontal position
  - Typically 5-6’ +/- at horizontal
- Row spacing varies with panel size, design choices
- Some systems have inter-row driveline
- 125-150W per linear foot

Million Little Sunbeams

- Monson, MA
- 250 kW
- 10’ height

Jack's SOLAR GARDEN

Colorado Agrivoltaic LEARNING CENTER

Sprout City Farms

Jack’s Solar Garden

- Longmont, CO
- 1.2 MW
- 6-7’ height

AGRIVOLTAIC DESIGN APPROACH
Massachusetts DOER Shade Analysis Tool

- Developed by BlueWave
- Grant funded by Mass DOER
- Released in 2019
- Solar design + agricultural planning
- Simulates shade/sun per square foot
- Validated by Fraunhofer
- Underpins DOER review (SMART)

ASTGU REQUIREMENTS: directly shaded hours during growing season on any square foot of ground <=50%

OPTIMIZING FOR AGRICULTURE
1P vs 2P Single-Axis Trackers

LEFT:
- 1P SAT, 20’ inter-row aisle, ~213 kW/ac
- Shade: 46% max, 36% avg, 12% min

RIGHT:
- 2P SAT, 40’ inter-row aisle, ~213 kW/ac
- Shade: 74% max, 36% avg, 10% min

ASTGU REQUIREMENTS: 8’+ clearance for fixed tilt; 10’+ clearance for SAT in horizontal position; 2P tracker will fail shade threshold

2-PORTRAIT TRACKERS: INHERENT BENEFITS FOR AG

Wider Aisle Spacings

- Wider farm equipment
- More crop rows in aisle

Fewer Rows

- Less interference
- Fewer and wider turns
- Lower risk of accidents
- 250W-300W per linear foot

Both Shadier AND Sunnier

- More shade under panels
- More sunlight in aisles
- Promotes differentiation of crop management areas and adaptive strategies

Aisle Cropping Area

- Can be spaced to fit standard farm crops & practices (even corn)
- Very low shade levels at wider spacings

Array Module Area

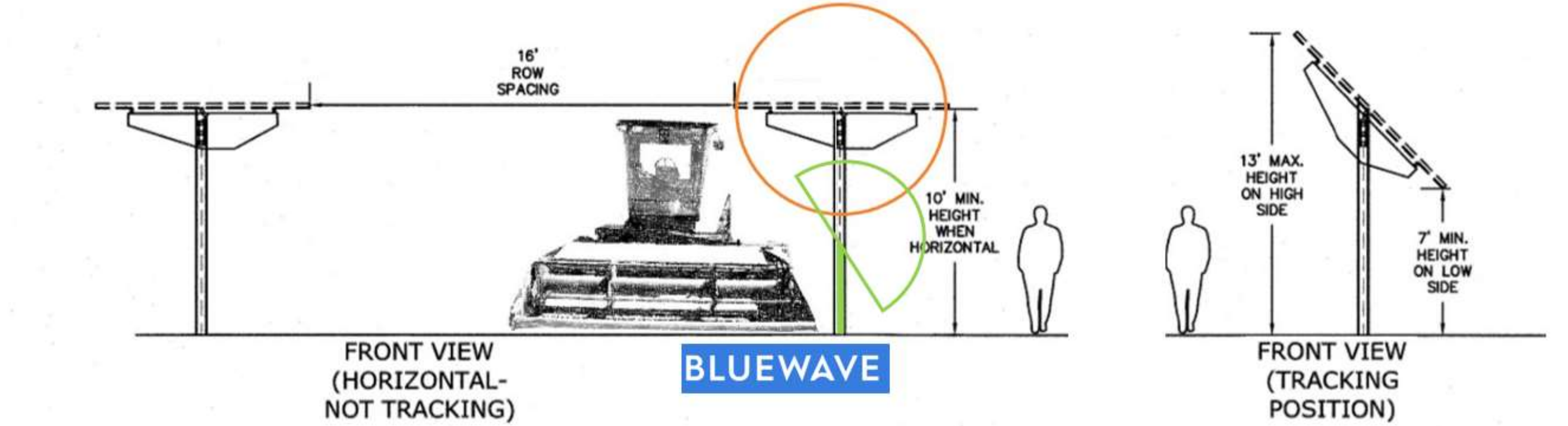
- Wider shaded area accommodates pasture forage, specialty crops
- 8'-11' horizontal heights
- **>50% shade levels**

NOT (YET) APPROVED IN MASSACHUSETTS

ADAPTIVE AGRIVOLTAICS
Designing for <u>Agriculture</u>

1P SAT system, Massachusetts incentive program, ~10’ torque-tube height

- Panels on 24’+ centers with 16’+ inter-row spacing



- Tracker dispatch can avoid conflicts by allowing clearance for tractors & harvesters.
- “Tilted-away” position can accommodate work at much lower tracker height.
  - Example: 12’ mower-conditioner, to scale. Note clearance from panel rotation.
- The **<u>most significant constraints</u>** are **<u>equipment width</u>**, **<u>crop height</u> and <u>operations</u>!**
  - E.g., corn will shade trackers, not the other way around!
  - Must fit scale/location/business of farm—the operation, not just the field!

ADAPTIVE AGRIVOLTAICS
Designing for <u>Agriculture</u>

APPEALED

<u>Northfield Pine Meadow Assemblage:</u>

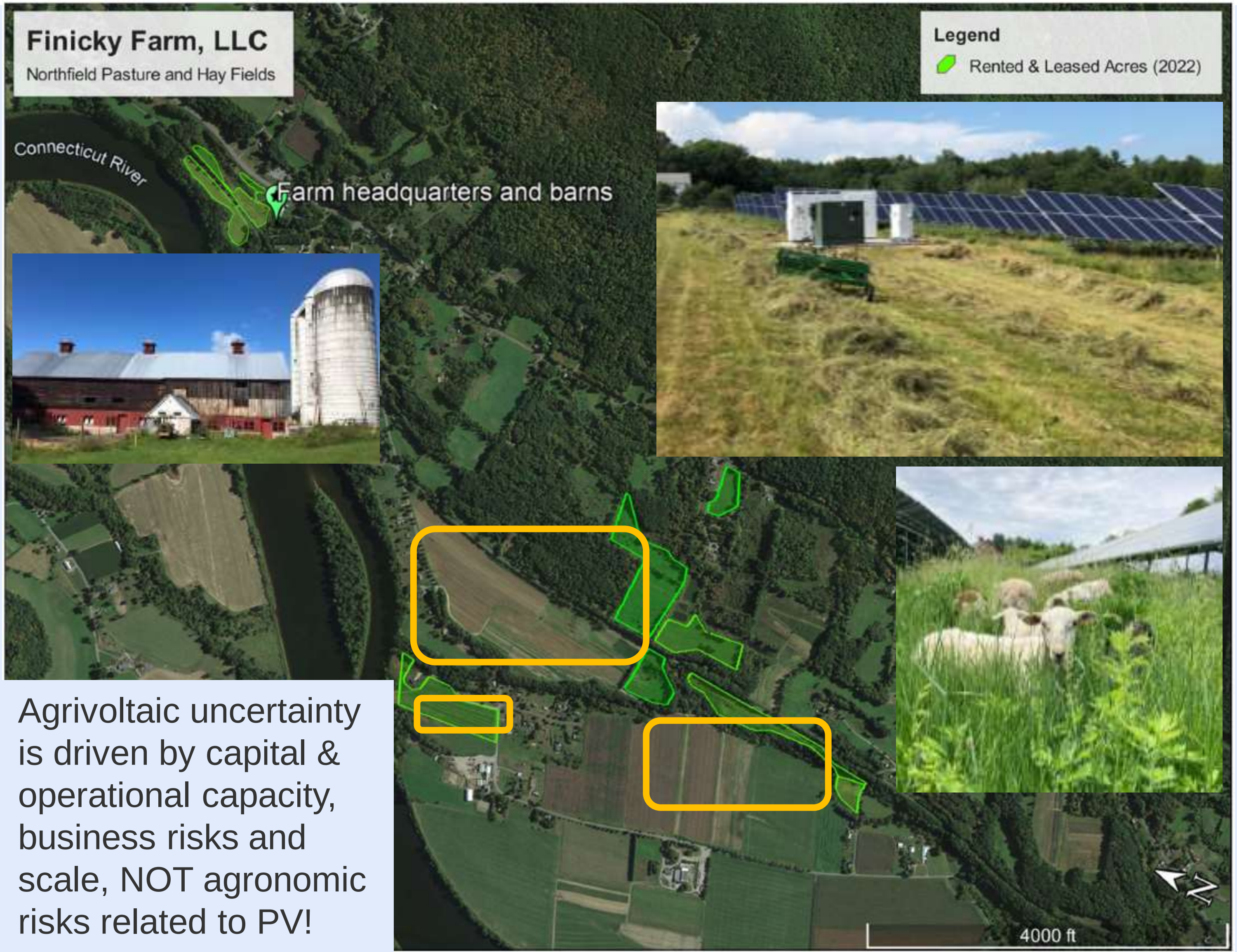
- 70+ acres in 3 parcels with 2 ASTGUs and 1 conventional array (convert to ASTGU?)
- Scale driven by agricultural and interconnection viability
- Facilitating intergenerational & management transitions

<u>Project includes:</u>

- Agricultural fencing
- New farm roads & barns
- "Pasture" plan -> **<u>forage harvesting</u>** (hay & baleage = winter feed)
- Support extensive grazing in conventional arrays & meat production
- Anticipate diversification: more livestock, vegetables, small fruits and grains

B

ADAPTIVE AGRIVOLTAICS
Pine Meadow Context



Agrivoltaic uncertainty is driven by capital & operational capacity, business risks and scale, NOT agronomic risks related to PV!

Agricultural, Family & Conservation Goals

- Facilitate retirements
- Bring in new managers and farm operations
- Rest the land, add regenerative practices
- Meet state policy

Support Agrivoltaic Farm Business

<u>2021:</u> 2 arrays, 25 acres, 30 ewes, <0.5 FTE evenings and weekends, year-to-year contract

<u>2023:</u> 11 arrays, 175 acres, 90 ewes, ~120 lambs(?), 1+ FTE, 5-year contracts, larger-scale forage harvesting

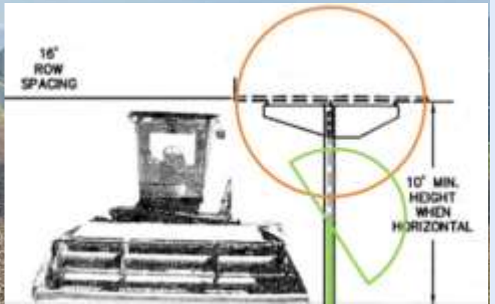
<u>2024-2025:</u> 300+ acres of conventional solar, 2+ FTE, large-scale solar hay, testing other crops

ADAPTIVE AGRIVOLTAICS
Vertical Bifacial Systems

Next2Sun, Baden-Württemberg, Germany

Ag operational characteristics:

- 1x triple mower @ ~30’ width
- 3x seed drill @ ~10’ width
- Can’t accommodate tall crops
- Uncultivated / unharvested area at ~10%



AG-READY AGRIVOLTAICS

Use caution with side-pull equipment!

- Hay/forage mowers
- Smaller square balers
- Vegetable harvesters (potatoes, onions, etc)
- Consider centerline alternatives
- Harvesting may require trucks or hoppers
- Equipment widths may prohibit canopy agrivoltaic systems

AG-READY AGRIVOLTAICS EXAMPLE: BWC MINOT BROOK

DENIED?

- 5+ MW SAT array, limited by interconnection capacity
- Prime farmland, highly developable frontage
- Active agricultural uses (corn, potatoes) need 60’ sprayer
- No specialized structural solution available in US market

Agrivoltaic array:

- Elevated SAT @ wide spacing
- 105 acres inside fence
- 8 acres obstructed by array rows
- 97 acres available for row crops
- 120’-wide crop blocks
- New irrigation mainlines offset acreage and yield loss
- Electrical equipment located in-line with array rows
- All road frontage and acreage committed to agrivoltaic use

Standalone array:

- 20 acres inside fence
- <85 acres remaining usable ag land
- Inter-row vegetation?
- Frontage development?

MASSACHUSETTS AGRIVOLTAIC PROGRESS
Leading the nation (with baby steps)

Massachusetts ASTGU Activity BlueWave and Others	BlueWave #	BlueWave MW AC	Others #	Others MW AC	TOTAL #	TOTAL MW AC
PSQ/FSQ*	3	6.0	9	11.2	12	17.1
PDA Letter Approval*	11	19.7	4	10.1	15	29.8
2023 Development Workplan	8	11.7	n/a			
Total Near-term Development	**22**	**37.3**	n/a		**50+ MW?**	

* BlueWave has 4 projects in construction in 2023, totalling 7.6MW AC, of which 2 have received PSQ and 2 only have PDAs.

BLUEWAVE

2023: Four projects in construction: diversified vegetables, butternut squash, hay, pasture (cattle and sheep)

2024: Anticipate construction on 10+ projects including apples, Xmas trees, pasture (cattle & sheep), corn, potatoes and diversified veggies

2025: ??? New PDA submissions have slowed dramatically (nearly stopped) due to tree cutting & comparable crops rules

LAND-USE, SITING & EQUIPMENT
Changing Public Perceptions & Policy Constraints

Tree-cutting is increasingly contentious, with short-sighted outcomes

- New ASTGU rule **prohibits removing even a single tree**
- Unintended consequence is to push solar away from pasture and towards cropland

"Comparative crops" rule is poorly defined and discourages innovation

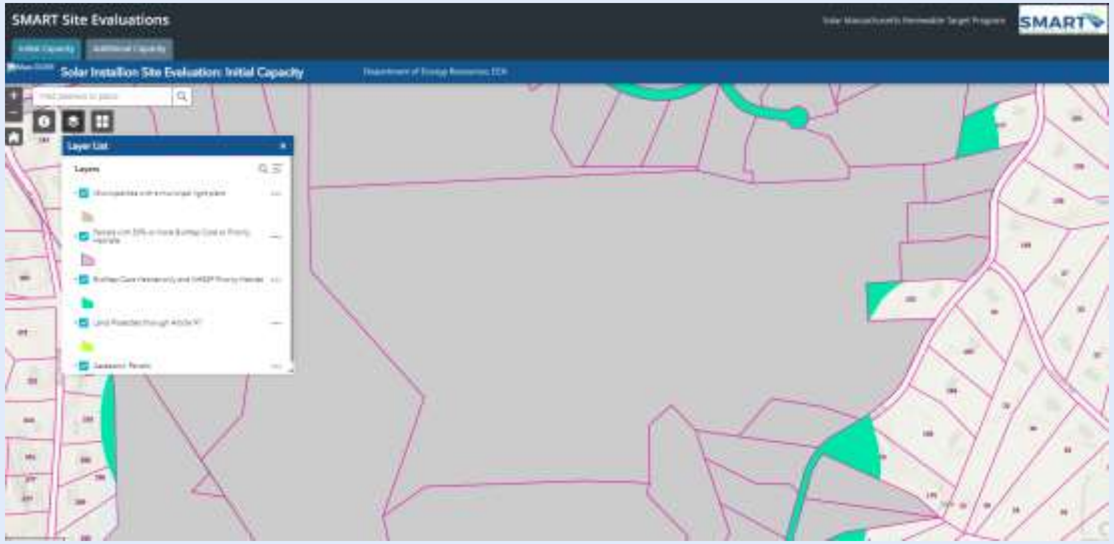
- Commercial agriculture needs **efficiency** and **scale**

Over-emphasis on shading and "every square foot" discourages agrivoltaics

- Commercial agriculture needs **width** and **specialization**. Most crop farms dedicate significant acreage to tire tracks, travel & turn lanes, etc—they aren't cropping every square foot!

Agrivoltaics **can** become a major subsector of both solar & agriculture, rather than a niche… **IF** we can get past the NIMBY issues!

SOLAR DEVELOPMENT
Good or Bad, Policy Drives All Decisions



- Mapped prime/important soils
- Mapped priority/core habitat
- Appears ineligible as priority/core
- Stripped for gravel
- Could be restored as hay/pasture ASTGU producing both ag and habitat benefits
- Can't be restored as ASTGU b/c trees
- Requires non-ag determination to qualify as non-ag previously-developed
- Will likely have minimal soil restoration w/ mowing and not grazing… unless habitat concerns prohibit mowing, then dead…

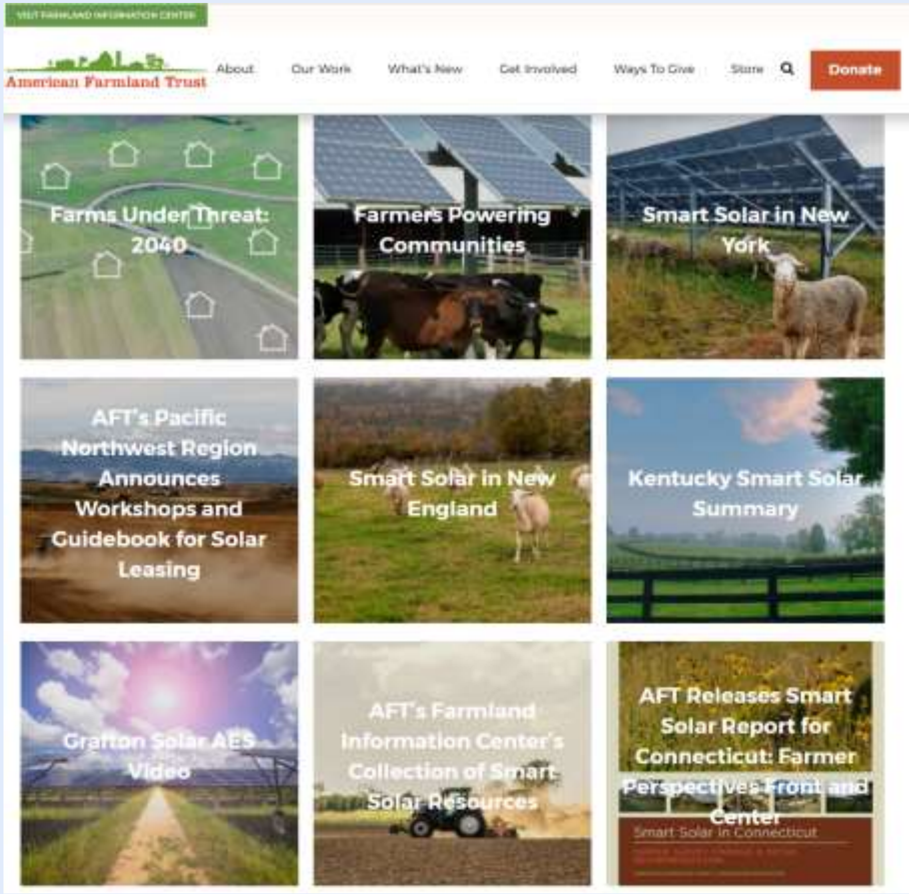
  … commercial development or houses?

AGRIVOLTAICS
Good, Bad or Ugly!? Solar Farms are Better than the Alternatives!

AGRIVOLTAIC RESEARCH RESOURCES

American Farmland Trust

www.farmland.org/solar



AGRIVOLTAIC RESEARCH RESOURCES

UMASS Clean Energy Extension:

https://ag.umass.edu/clean-energy/research-initiatives/dual-use-solar-agriculture

AGRIVOLTAIC RESEARCH RESOURCES

The AgriSolar Clearinghouse is
a nationwide hub developed by the National Center for Appropriate Technology.
www.agrisolarclearinghouse.org


Solar-Suitable Crops

- Effects of shade and deficit irrigation on maize growth and development in fixed and dynamic Agrivoltaic systems
- Agrivoltaics: The Environmental impacts of Combining Food Crop Cultivation and Solar Energy Generation
- Delayed grape ripening by intermittent shading to counter global warming depends on carryover effects and water deficit conditions
- Price for covering cropland with an agrivoltaic system: PV panels replacing shading nets in Chilean blueberry cultivation
- Ground-Mounted Photovoltaic and Crop Cultivation: A Comparative Analysis
- The Impacts of Agrivoltaics on Crop Production
- Yield Response and Physiological Adaptation of Green Beans to Photovoltaic Greenhouses
- Effect of Shading on the Performance of Vitis vinif era L. cv. Cabernet Sauvignon
- Current status of agrivoltaic systems and their benefits to energy, food, environment, economy, and society
- Effects of Shading Nets on Reactive Oxygen Species Accumulation, Photosynthetic Changes, and Associated Physiochemical Attributes in Promoting Cold-Induced Damage in Camellia sinensis (L.) Kuntze
- Agrivoltaic Systems Enhance Farmers' Profits through Broccoli Visual Quality and Electricity Production without Dramatic Changes in Yield, Antioxidant Capacity, and Glucosinolates


- Design and analysis of a tracking / backtracking strategy for PV plants with horizontal trackers after their conversion to agrivoltaic plants
- Impact of an Agriphotovoltaic System on Metabolites and the Sensorial Quality of Cabbage (Brassica oleracea var. capitata) and its High-Temperature-Extracted Juice
- Lettuce Production under Mini-PV Modules Arranged in Pattern Designs
- Water Status, Irrigation Requirements and Fruit Growth of Apple Trees Grown Under Photovoltaic Panels
- The Effect of Gap Spacing Between Solar Panel Clusters on Crop Biomass Yields, Nutrients, and the Microenvironment in a Dual-Use Agrivoltaic System
- Solar Sharing for Both Food and Clean Energy Production: Performance of Agrivoltaic Systems for Corn, A Typical Shade-Intolerant Crop
- Solar Photovoltaic Architecture and Agronomic Management in Agrivoltaic System: A Review
- Semi-Transparent Organic Photovoltaics Applied as Greenhouse Shade for Spring and Summer Tomato Production in Arid Climate
- Productivity and Radiation Use Efficiency of Lettuces Grown in the Partial Shade of Photovoltaic Panels
- Performance of Agrivoltaic Systems for Shade-Intolerant Crops: Land for Both Food and Clean Energy Production
- Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation
- Improvement in Lettuce Growth Under Solar Panels
- Agrivoltaics Provide Mutual Benefits Across the Food-Energy-Water Nexus in Drylands
- Saffron and Solar Farms: A Win/Win for Environment and Agriculture
- Assessment of New Functional Units for Agrivoltaic Systems


- Investigation of Pear Growth Under Foldable Agrivoltaic Structure
- Guide to Farming Friendly Solar
- Crop Selection for APV Systems: Overview of Performances, Potentials, and Perspectives for Germany
- Crop Production in Partial Shade of Solar Photovoltaic Panels on Trackers
- Coproduction of Solar Energy on Maize Farms – Experimental Validation of Recent Experiments
- Combining Photovoltaic Modules and Food Crops: First Agrivoltaic Prototype in Belgium
- Application of Photovoltaic Systems for Agriculture: A Study on the Relationship between Power Generation and Farming for the Improvement of Photovoltaic Applications in Agriculture
- Agrivoltaic Systems to Optimize Land Use for Electric Energy Production
- Agrivoltaic System Impacts on Microclimate and Yield of Different Crops Within an Organic Crop Rotation in a Temperate Climate
- Agrivoltaics Provide Mutual Benefits Across the Food-Energy-Water Nexus in Drylands
- A Case Study of Tomato (Solanum lycopersicon var. Legend) Production andWater Productivity in Agrivoltaic Systems

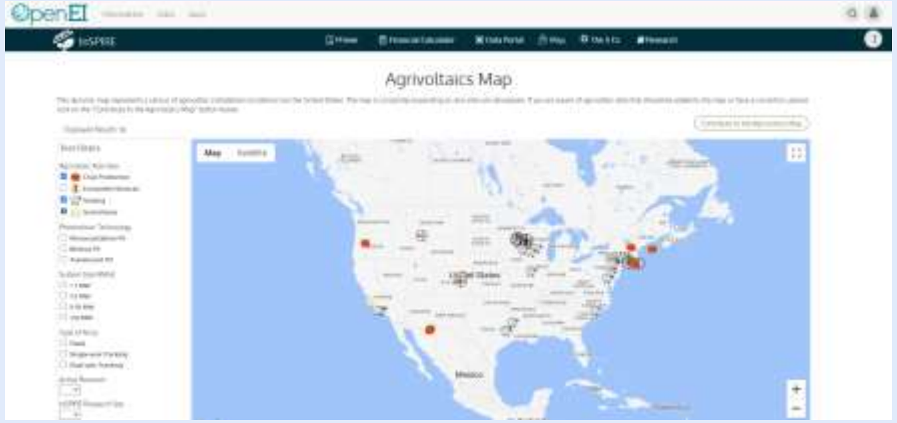
THE LATEST

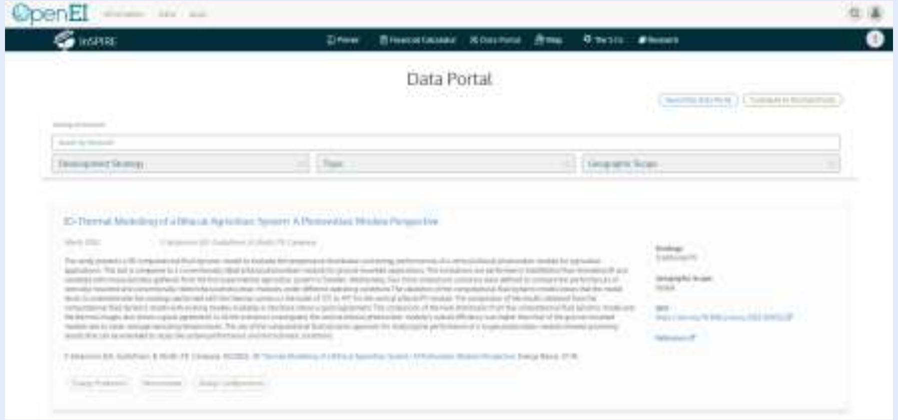
DON'T MISS

NATIONAL CENTER FOR APPROPRIATE TECHNOLOGY

AGRIVOLTAIC RESEARCH RESOURCES

U.S. Department of Energy's InSPIRE project: https://openei.org/wiki/InSPIRE





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SOLAR TERMINOLOGY & AGRIVOLTAIC RESOURCES

Equipment Descriptions

- **Photovoltaic Modules** (aka **panels**) produce **direct current** (DC) electrical voltage when energized by **solar radiation**. A typical commercial **PV module** in current use for **groundmount** systems will have a rated capacity of 450-600 **watts**.
- DC current may be stored in an onsite **Battery Energy Storage System** (BESS) but must be converted to **Alternating Current (AC)** by an **Inverter** before connecting to the utility grid at the **Point of Interconnection** (POI, or IX more generally). The availability and cost of IX is the single most important factor in solar site feasibility.
- **Groundmount PV systems** typically include **screw or driven-pile foundations**, to which **racking** and **modules** are mounted.
- **Racking** is the structural system that supports the solar modules. It can be fixed-tilt or tracking and is assembled in blocks called **tables** or **trackers**. Most **fixed-tilt racking** systems face south; most tracking systems are **Single-Axis Trackers (SATs)**.
- **Single-Axis Tracker (SAT or HSAT)** systems rotate daily over a horizontal single axis, often referred to as a **torque tube**, following the sun from east at sunrise, then horizontal at noon, then west at sunset (typically +/- 60 degrees).

Definitions

- **Aisle Width:** the width between solar array rows, measured between the primary ground-level structural posts. It is typically wider than inter-row spacing, but is height-limited.
- **ASTGU**: Agricultural Solar Tariff Generation Unit (facility qualifying for agrivoltaic incentive within SMART program)
- **Gross Coverage Ratio (GCR):** ratio of total module area to total land in a PV array. It measures site layout density.
- **Inter-row Spacing:** the distance across the aisle between rows, measured from panel edge to adjacent panel edge.
- **PAR:** Photosynthetically-Active Radiation, sunlight in the wavelent
- **Pitch:** the distance from the east/south edge of module on one rack to east/south edge of module on next rack, i.e., center-to-center row spacing.
- **Watt (W):** basic unit of power, quantifying rate of energy transfer. A Kilowatt (kW) = 1,000 watts; a megawatt (MW) = 1,000,000 watts.

Research & Resources

https://ag.umass.edu/clean-energy/research-initiatives/dual-use-solar-agriculture

www.agrisolarclearinghouse.org/

https://openei.org/wiki/InSPIRE

AGRIVOLTAIC DEVELOPMENT PROCESS

Site acquisition
Interconnection capacity & queue, zoning review, landowner contacts

Lease Option Agreement
(5% Design)
Early due diligence: wetlands and site walks, title reviews, system sizing and utility study pre-application

Lease & Utility Study
(10% Design)
Financial analysis, site analysis, regulatory analysis, go-no-go decisions on utility study payment ($50k-$100k+) & lease

Development, Permitting & Interconnection Service Agreement (ISA)
Diligence and de-risk project through agrivoltaic predetermination qualification, surveys, site plans, all state and local permits, appeals & lawsuits, title commitment, execute utility ISA, make 25% IX payment

Pre-Construction
(90% Design)
RFP for Engineering, Procurement and Construction (EPC), engineering and long-lead procurement, financing & tax equity

NTP & Construction
(100% Design IFC)
Notice-to-Proceed with full procurement and construction, including site work, foundations, racking, modules, wiring, batteries & inverters, interconnection equipment, witness test, Commercial Operation

Agrivoltaic Farm!

Q & A and Discussion

- How can we address both MA Food Systems needs and Clean Energy needs?
- How do agrivoltaics intersect with farmland protection, public support, and the role of land trusts?
- Land protection grants and APRs?
- Tax implications for municipalities? Public support for Ch.61A?
- Public support for solar?
- What is the role of Agrivoltaics and farming?
    - Existing farm owners
    - Farmers who lease land
    - New farmers?