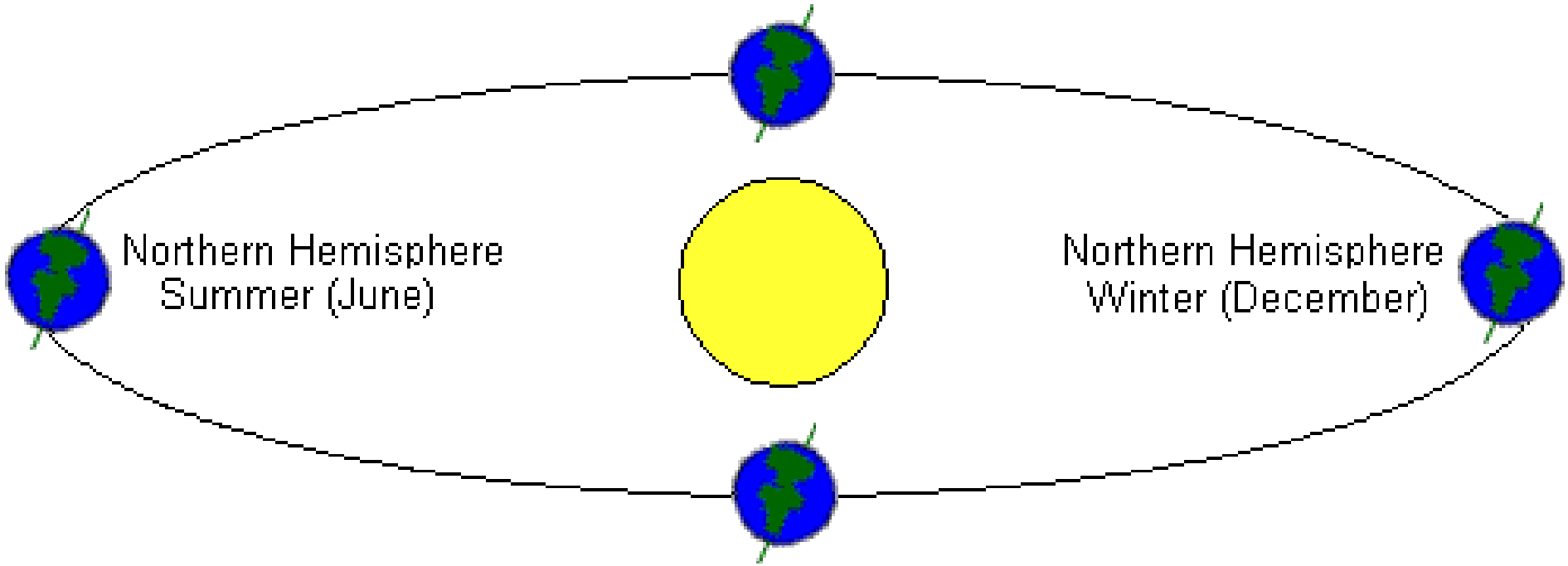
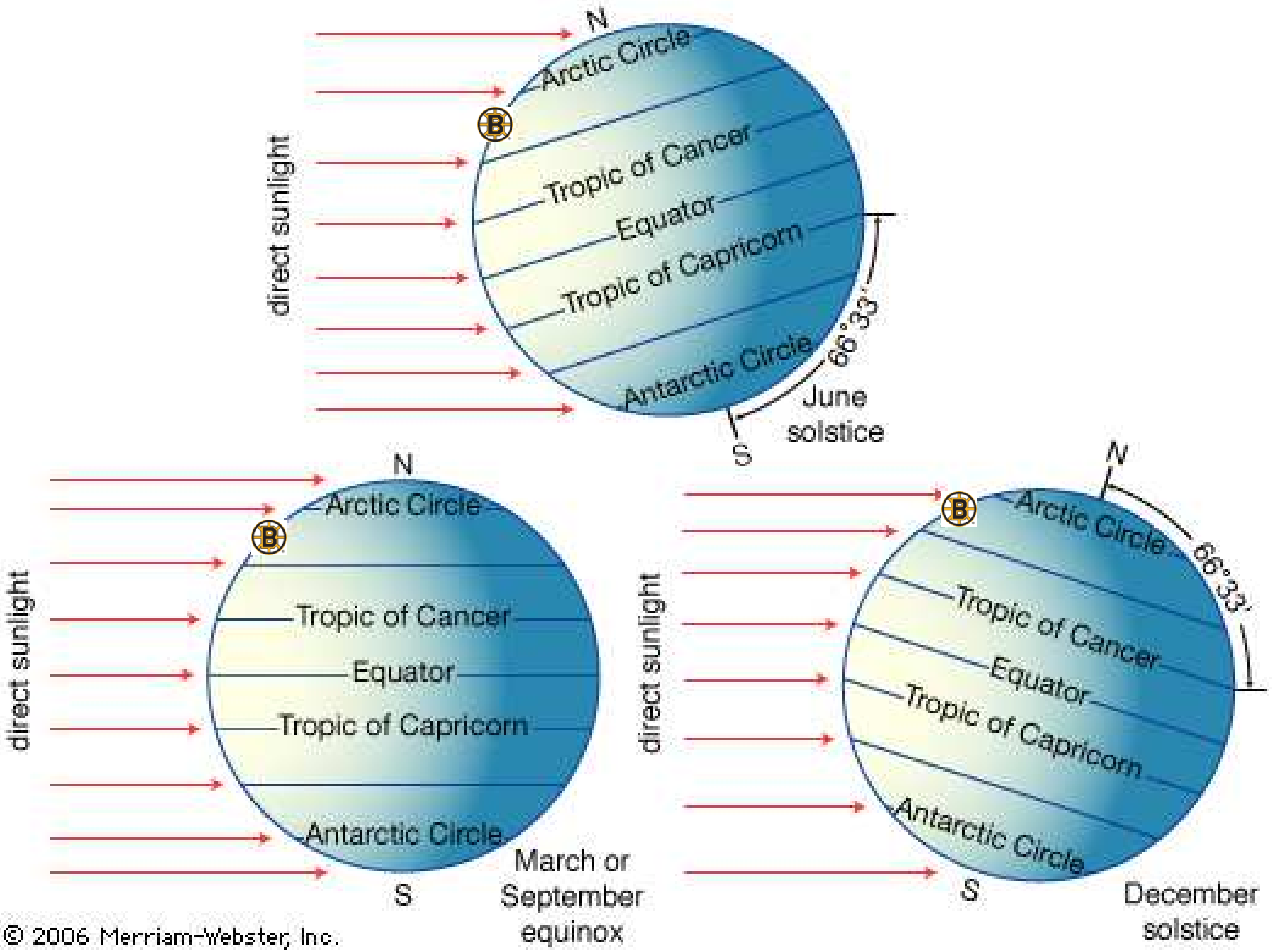
Thinking Problem of the Day

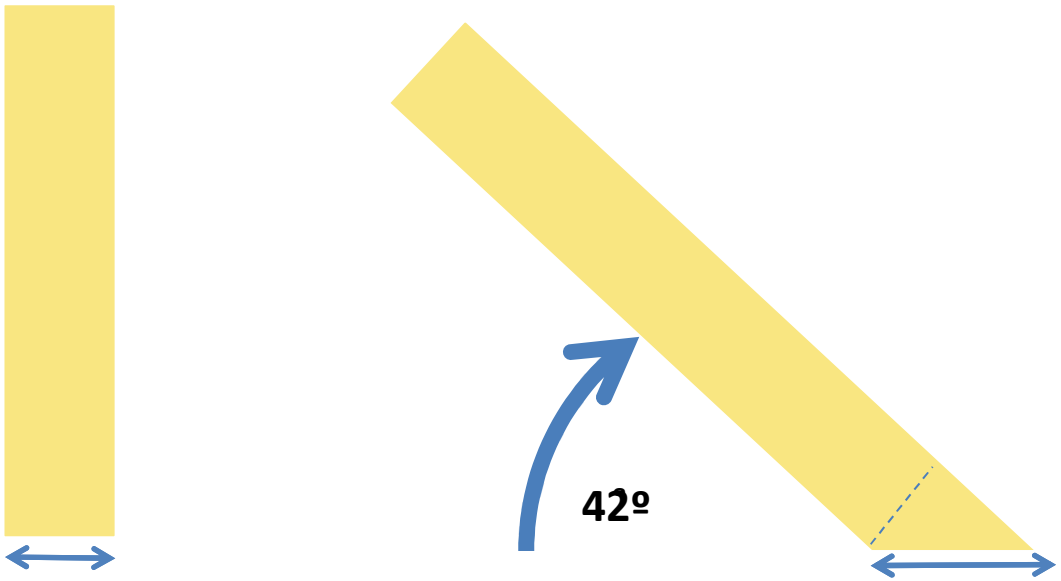
With the sun directly overhead (for example, high noon anywhere on the equator), and no clouds, the sun provides about 1000 W/m^2 of power. The land area of MA is about 20,000 km^2. About how much energy does the sun provide MA each day for each household?

(Hint: MA has about 2.5 million households, and you'll need to estimate how "good" our hours of sunlight are compared to noon at the equator!)


Northern Hemisphere
Summer (June)
Northern Hemisphere
Winter (December)



Solar Power

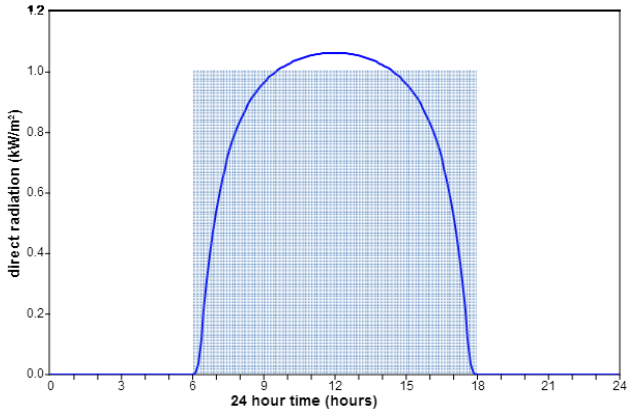


Direct light at equator

Indirect light at higher latitudes

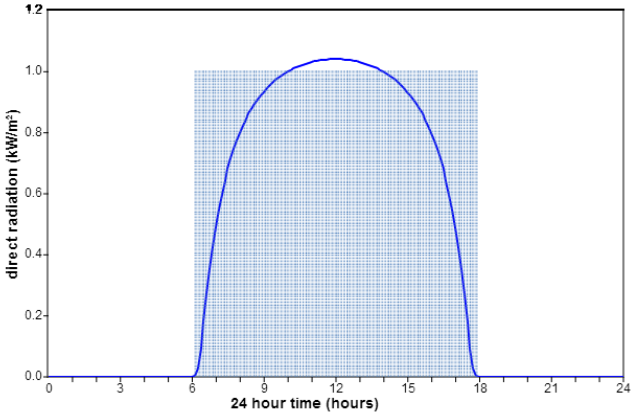
http://www.pveducation.org/pvcdrom/properties-of-sunlight/calculation-of-solar-insolation

"Isolation"

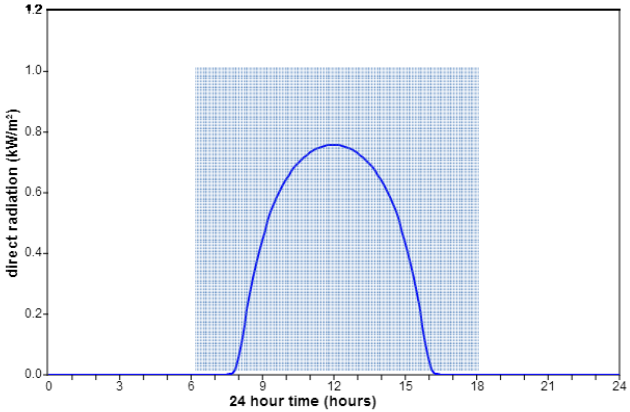


Equinox

Equator

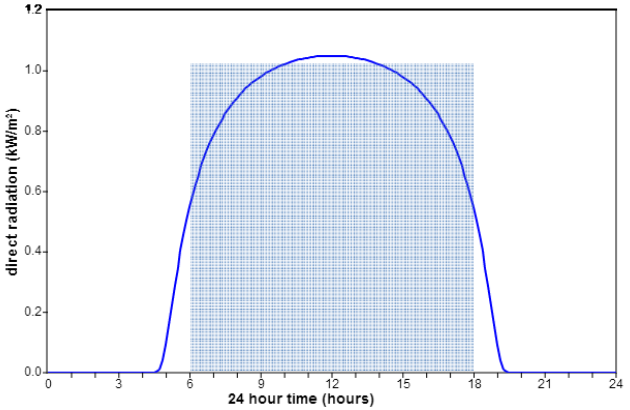


Solstice



Winter Solstice

Boston



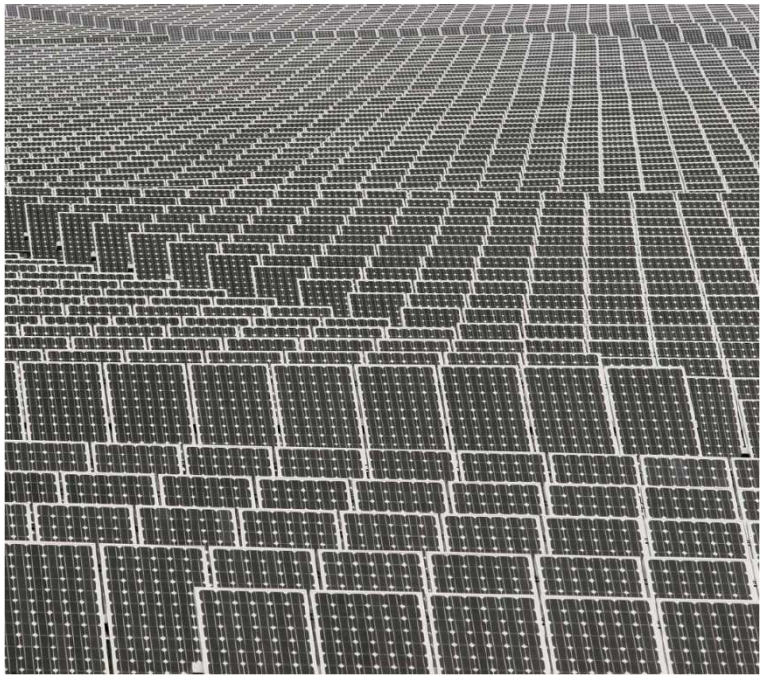
Summer Solstice

Solar Power in MA

- Midday at equator — 1000 W/m^2
- Avg. daylight hours — 500 W/m^2
- Angle of sun — 375 W/m^2
- Avg. intensity vs. midday — 260 W/m^2
- Clouds — 130 W/m^2

Solar “Photo-Voltaic” Power

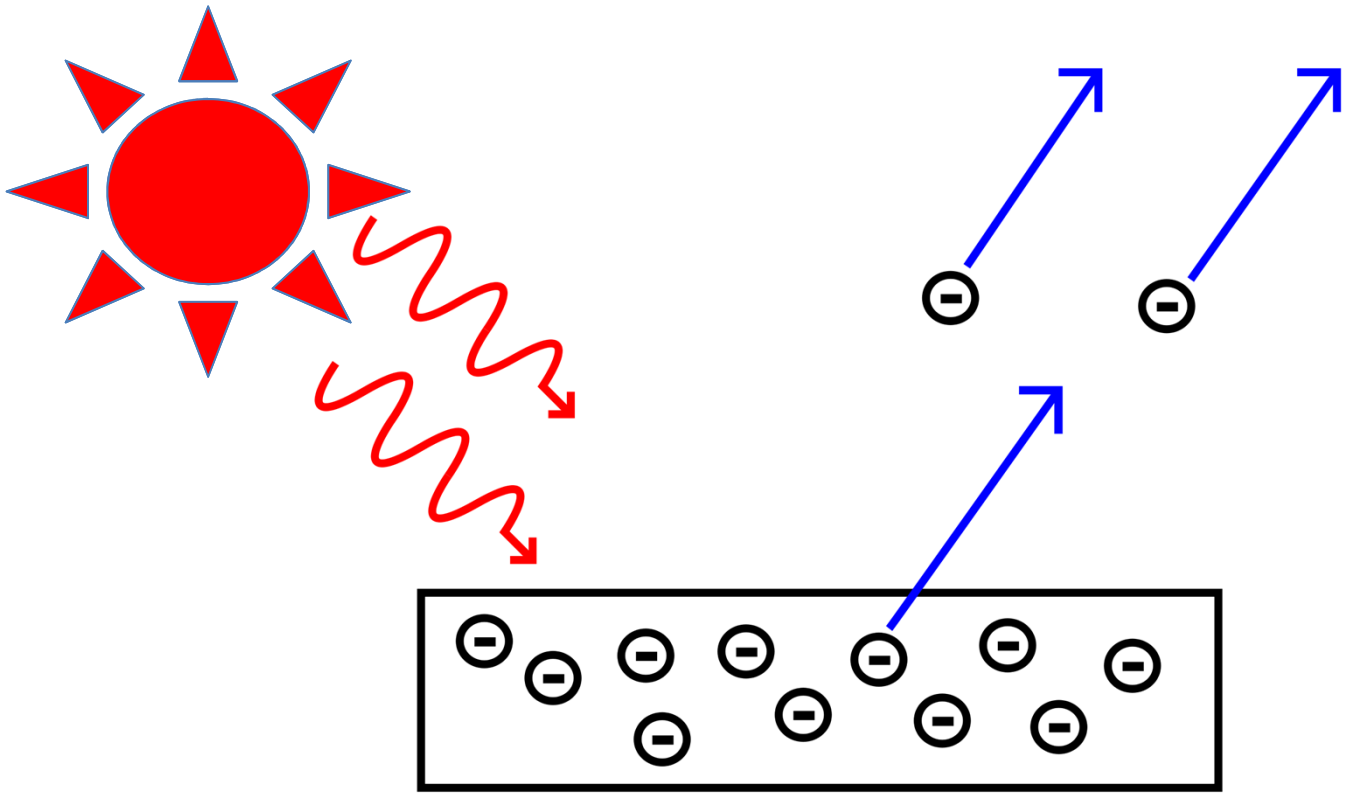
Rooftop



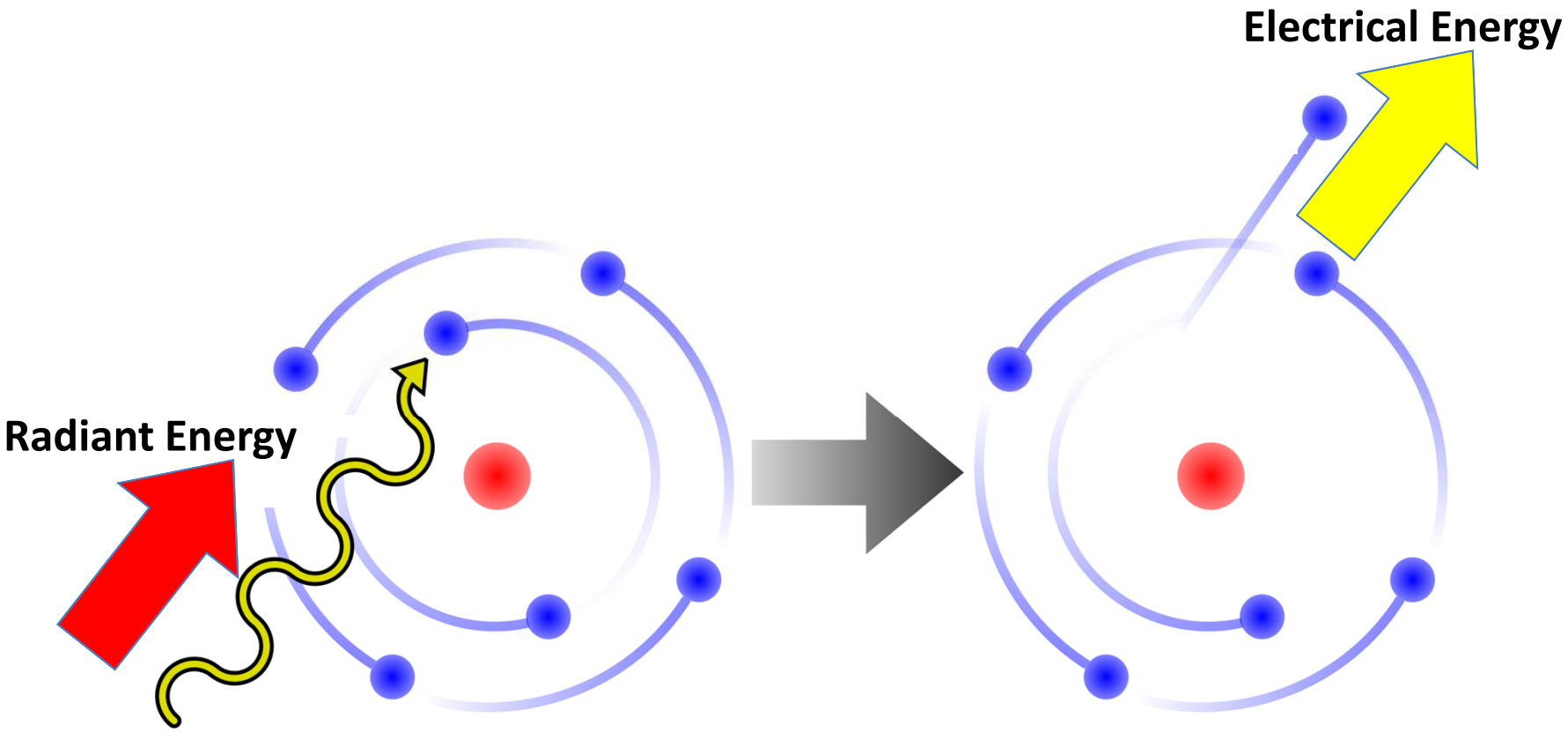
Solar “Farms”

Shown: 11 MW on 90 acres
Portugal

Solar “Photo-Voltaic” Power

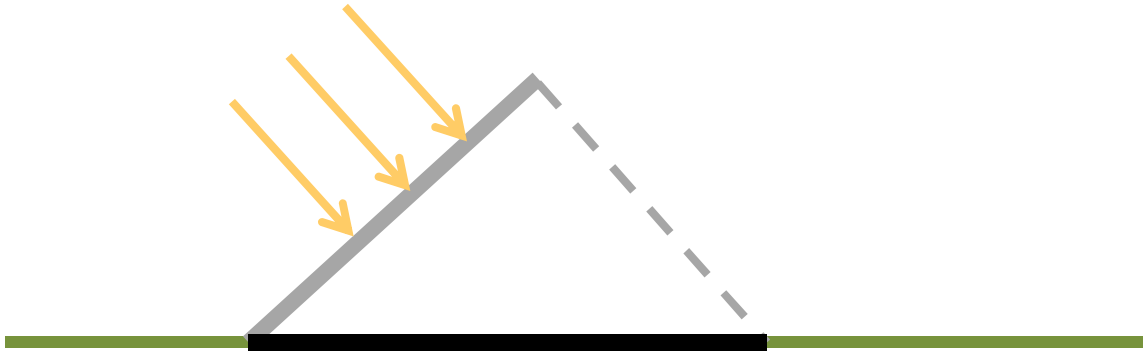


Solar PV Power

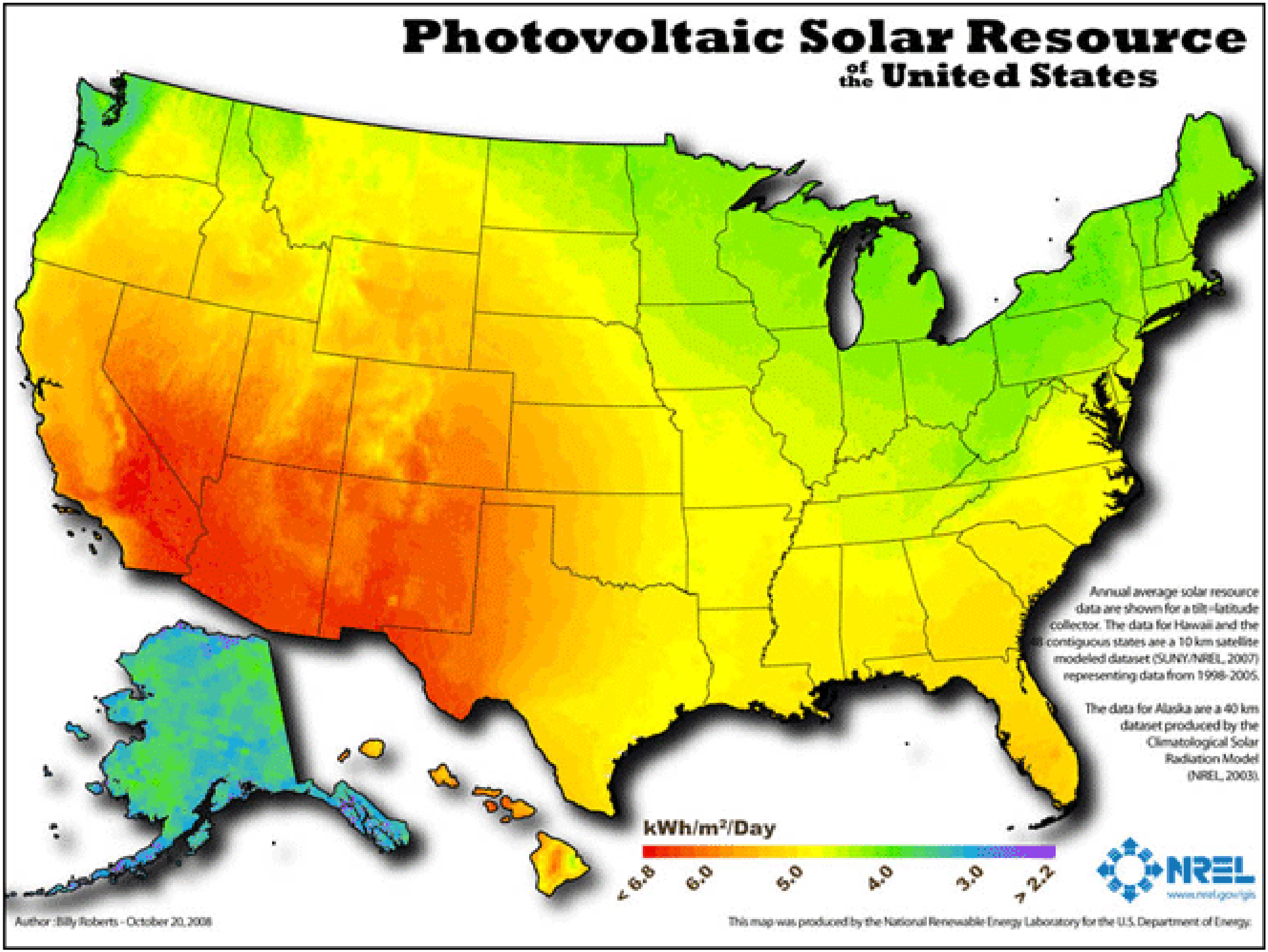


Solar Photovoltaic (PV)

- Solar Power 130 W/m^2
- **Bohr Model efficiency (~20%) 25 W/m^2**
  - Current 15-20
- Best: panel facing south, tilted 42º
  - Note: 1 m^2 panel takes ~1.3 m^2 land



Photovoltaic Solar Resource of the United States



Annual average solar resource data are shown for a tilt=latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

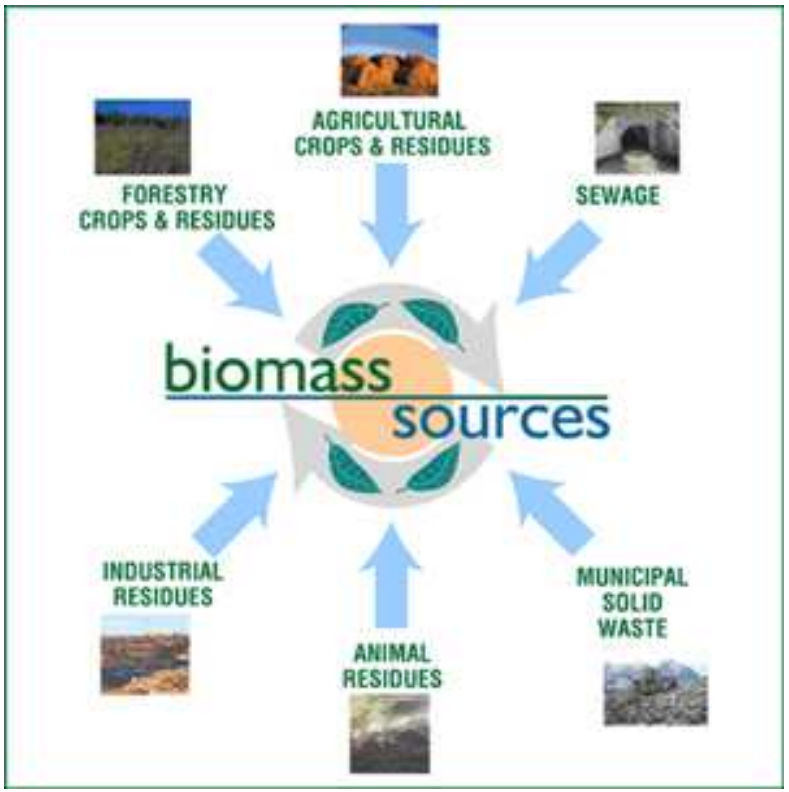
NREL
www.nrel.gov/gis

Author : Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Burn “Biomass”

- Puts CO_2 back in air that was “recently” taken out of the air (e.g., wood)
- Generate electricity
- Bio-diesel replaces oil



Biomass Power in MA

- Solar Power — 130 W/m^2
- Photosynthesis – best case — 2.6 W/m^2
- MA climate — 0.5 W/m^2

wheat

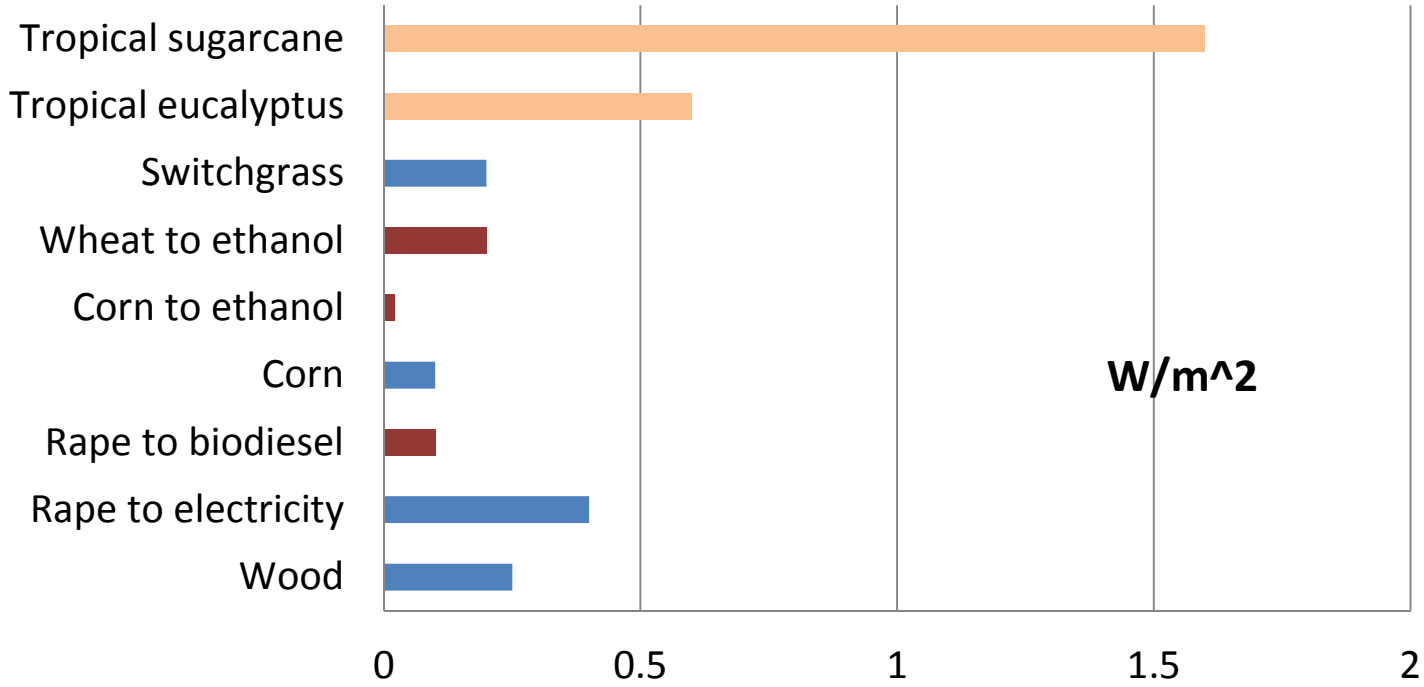
corn

switchgrass

rapeseed

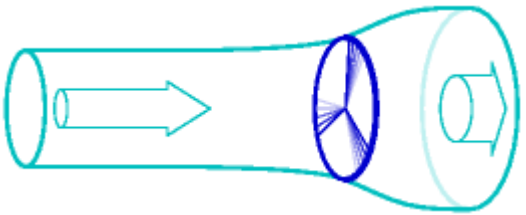
Biomass Power in MA

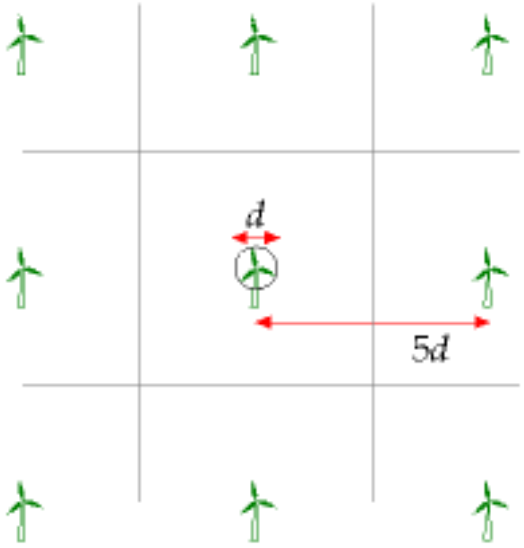
- **Burn for electricity or heat** **0.4 W/m^2**
- **Convert to oil substitute** **0.2 W/m^2**



Wind Power

- Windmills extract energy by slowing down wind, which spreads it out
- Doesn't work if wind speed is too slow, or too fast
- Bigger windmills:
  - More power
  - Must be further apart
  - Separate by 5*diameter





Wind Power in MA

- Wind (6m/s = 12mph) 140 W/m^{2*}
- Extractable 70 W/m^{2*}
- Spacing 5d apart = 32x area 2 W/m^2

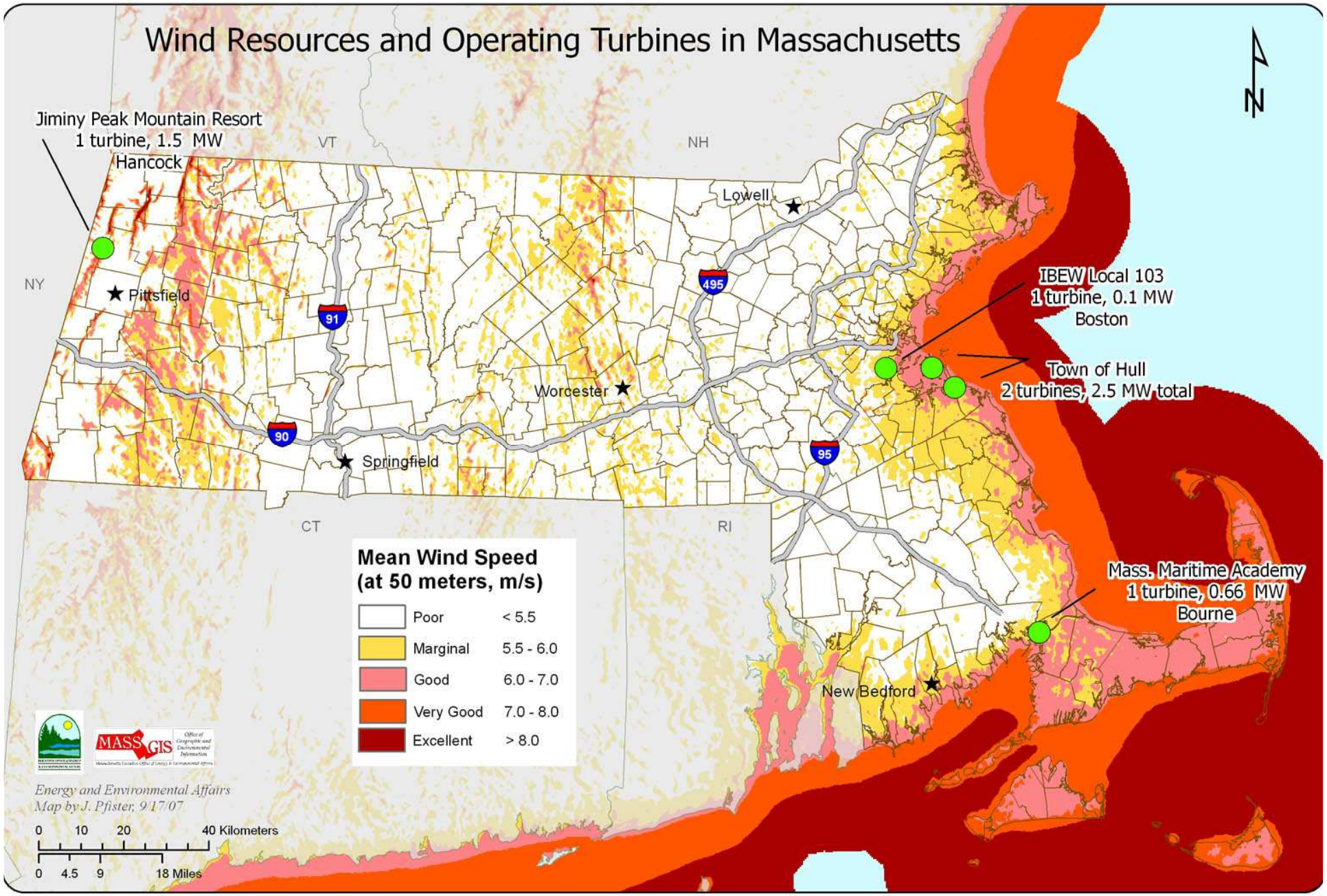
* Circular area of blades

MA Onshore Wind

- Hoosac Wind Power — 2.6 W/m^2
  - "Ridgeline" development
- Whispering Willow, Iowa — 0.6 W/m^2
  - Farmland
- **Optimistic Assumption — 2.0 W/m^2**

MA Onshore Wind

	Capacity	Avg Power	Efficiency
Hoosac	28.5 MW	8 MW	28%
US Average			29%
Assume			**30%**


Wind Resources and Operating Turbines in Massachusetts
Jiminy Peak Mountain Resort
1 turbine, 1.5 MW
Hancock
VT
NH
NY
Pittsfield
Lowell
IBEW Local 103
1 turbine, 0.1 MW
Boston
Town of Hull
2 turbines, 2.5 MW total
Worcester
Springfield
CT
RI
Mass. Maritime Academy
1 turbine, 0.66 MW
Bourne
New Bedford
91
495
90
95
Mean Wind Speed
(at 50 meters, m/s)
Poor < 5.5
Marginal 5.5 - 6.0
Good 6.0 - 7.0
Very Good 7.0 - 8.0
Excellent > 8.0
MASS GIS
Energy and Environmental Affairs
Map by J. Pfister, 9/17/07
0 10 20 40 Kilometers
0 4.5 9 18 Miles

MA Offshore Wind

- Cape Wind — 2.8 W/m^2
- Kentish Flats (UK) — 2.6 W/m^2
  - Designed for 3.2
- **Optimistic Assumption — 3.0 W/m^2**

Cape Wind from closest point on shore

Kentish Flats

MA Offshore Wind

	Capacity	Avg Power	Efficiency
Cape Wind	468 MW	174 MW	37%
Denmark			39%
Assume			**40%**