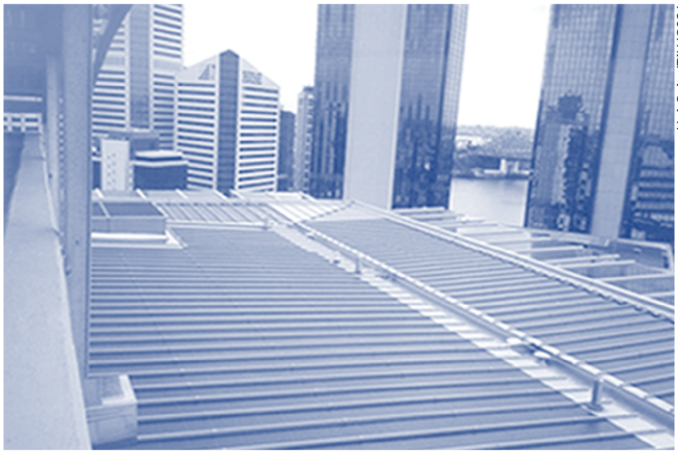
PV FAQs

How much land will PV need to supply our electricity?

If photovoltaics were a primary energy source, what would the world look like? Would PV collectors cover every square inch of available land? Contrary to popular opinion, *a world relying on PV would offer a landscape almost indistinguishable from the landscape we know today*.

The impact of PV on the landscape would be low for three reasons. First, PV systems have siting advantages over other technologies; for example, PV can be put on roofs. Second, even ground-mounted PV collectors are efficient from the perspective of land use. Third, adequate sunlight is ubiquitous and present in predictable amounts almost everywhere. As we move away from fossil-fuel energy, PV use will be crucial because of its land-use advantages.



Uni-Solar/PIX12961

Rooftop PV is practical in urban areas with high land costs. PV graces a rooftop in Brisbane, Australia.

PV's Low-Impact Siting for Flat-Plate Systems

In the United States, cities and residences cover about 140 million acres of land. We could supply every kilowatt-hour of our nation's current electricity requirements simply by applying PV to 7% of this area—on roofs, on parking lots, along highway walls, on the sides of buildings, and in other dual-use scenarios. We wouldn't have to appropriate a single acre of new land to make PV our primary energy source!

PV's Efficient Ratio of Produced Energy to Land Use

Even if it isn't installed on rooftops, flat-plate PV technology is the most land-efficient means to produce renewable energy. As the table to the right shows, PV has a competitive converter efficiency, a high capacity factor, and can be "packed" densely in a given area.

We still wouldn't have a land-use issue, even if we didn't use roofs for PV. We would need only 10 million acres of land—or only 0.4% of the area of the United States—to supply all of our nation's electricity using PV. Is 0.4% a lot of land? Not for something as important as producing electricity, and not in comparison to some of the other ways we use land.

One way to understand land-use issues for different energy sources is to realize that the federal government idles 30 million acres of farmland every year—or three times the area needed to generate all our electricity from sunlight. We also set aside 23 million acres of land for the Arctic National Wildlife Refuge, which is more than twice the acreage needed to generate all our electricity with PV.

Furthermore, we set aside hundreds of millions of acres for rangeland, military bases, airports, and rights-of-way for fossil fuel pipelines, drilling, and reserves every year—

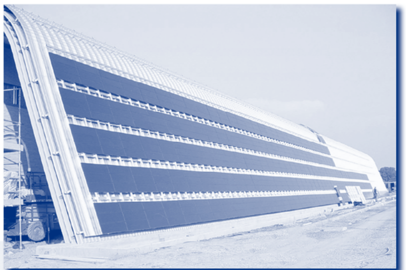
PV: The Land-Area Advantage

Technology	Converter Efficiency (%)	Capacity Factor (%)	Maximum Packing	Land per year for: GW	Land per year for: GWh
Flat-Plate PV	10%–20%	20%	25%–75%[d]	**10–50 km^2/GW**	**5000–25,000 m^2/GWh**[k]
Wind	Low to 20%[a]	20%[c]	2%–5%[e]	100 km^2/GW[g]	140,000 m^2/GWh[i]
Biomass	0.1% total[b]		High—plants compete for sunlight	1000 km^2/GW[h]	500,000 m^2/GWh[i]
Solar Thermal or PV Concentrators	15%–25%	25%	10%–20%[f]	20–50 km^2/GW[h,i] 20 km^2/GW[j]	10,000–20,000 m^2/GWh

[a] *www.windpower.org*
[b] 0.5% or less light-to-biomass; then 33% to electricity; 0.1% total
[c] Site dependent
[d] Tilted arrays at high latitudes versus flat ones at the Equator; room between for maintenance
[e] Pimentel 2002; Dohn Riley et al.
[f] Tracking arrays need wider separation to avoid shadowing
[g] Hansen 2003
[h] Hughes 2002
[i] Pimentel 2002
[j] Cohen 2003
[k] At 15% module efficiency, 12% module-to-system operating efficiency losses

and most of us barely notice this land use. Thus, even if we didn't put PV on a single existing structure, rooftop, or building, we'd still use only a tiny fraction of our available land to produce clean energy from PV.

A second way to compare energy sources is to see how much the cost of land contributes to overall electricity costs. Which technologies produce enough energy so that land cost is not relevant to the total cost of the energy produced? For PV, even if land were to cost more than $80,000 per acre, this cost would contribute *less than one cent per kilowatt-hour* to the cost of PV energy. Concentrator systems, or other solar systems that aren't flat-plate, offer similar land-efficient energy production. In contrast, wind and biomass are only able to "afford" land at less than $5,000 per acre to keep the land's contribution below one cent per kilowatt-hour. PV can convert sunlight efficiently into energy, with converters packed together densely. In cities and affluent suburbs, where land costs exceed $80,000 per acre, PV can be installed on roofs and structures. In other places, where land costs are lower, PV can be installed almost anywhere.



Shell Solar/PIX12960

Uni-Solar/PIX12965

PV installations often do not require land. Above, an 84 kW installation on a Quonset in North Wales; left, PV atop a carport in Santa Monica, California.

PV's Ubiquitous Energy Source

The sun's intensity doesn't vary by region as much as we might think. Looking at the extremes, the U.S. Desert Southwest gets only about 25% more sunlight annually than Kansas City. And Buffalo receives only 25% less sunlight than Kansas City. Because PV energy output is proportional to sunlight, its cost varies proportionally with local sunlight. If PV is cost effective in a location with average sunlight, such as Kansas City, it will be 25% more expensive in the cloudiest place, Buffalo. It will be 25% less expensive in the sunniest place, Arizona. Also consider that conventional energy prices vary by more than this range across the nation because of locally used hydropower, nuclear, natural gas, coal, or oil.

Once PV costs fall to competitive levels in an average solar location in the United States, more than 95% of the nation would have enough sunlight to produce economical energy with flat-plate PV. Compare this estimate to other technologies: 15% or less for wind, because wind speeds vary so much, and wind generation relates to the cube of wind speed; 20% for concentrator solar collectors, because they track the sun and use only direct sunlight, which limits them to less-cloudy climates; and 50% for the best-case biomass scenario, because crops must be grown on arable land with good water resources. Non-PV sources may be confined to locations that are far from markets or even off limits to energy development.

Advantage PV!

The use of PV affords numerous land-use advantages. PV has flexible siting, with rooftops and other urban settings being ideal locations for PV collectors. Even ground-mounted PV produces the most energy per unit of land area. And PV uses a natural resource available across the United States and the world.

We started by asking: What would our world look like if we used PV to produce significant amounts of electricity? The answer is that instead of our sun's energy falling on shingles, concrete, and under-used land, it would fall on PV—providing us with clean energy while leaving our landscape largely untouched.

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For more information on PV, please read the other *PV FAQs* in this series. You can order hard copies of the FAQs from the National Center for Photovoltaics, or visit our Web site at *www.nrel.gov/ncpv*.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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