25 November 2016

5 years in a Net-Zero-Electricity Solar Home

"Everything you wanted to know about home solar energy, but did not know whom to ask"

Victor Yakovenko

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http://physics.umd.edu/~yakovenk/solar-home/

College Park, near Metro Station

Installed by StandardSolar.com

10 PV panels (2.15 kW) installed January 25-26, 2011 with battery backup

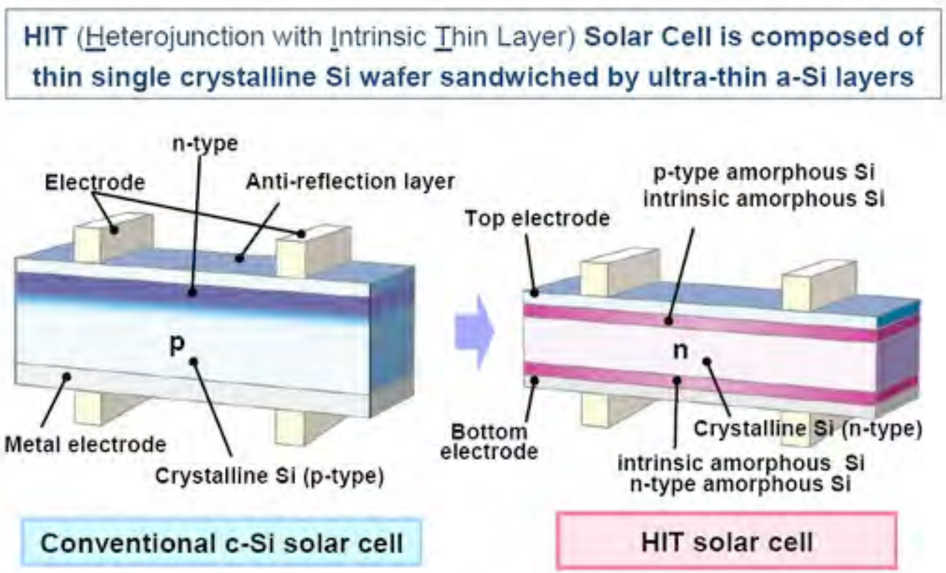
Continuously operated since Mar 9, 2011

Extra 3 PV panels (2.8 kW total) installed Oct 26, 2011, area 12.6/16.4 m^2

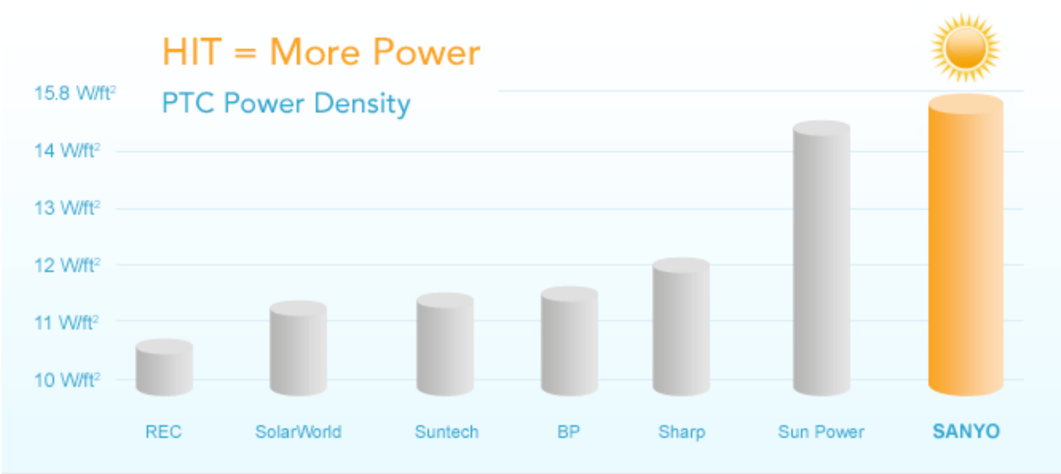
Sanyo HIT 215A; efficiency: cell 19.3%, module 17.1%; same as on the winning UMD Solar Decathlon House 2011

Generated 16 MWh in 5.5 years = 7.8 kWh/day, >100% of consumption

Novel HIT design by Sanyo



HIT Double collects light from two sides.

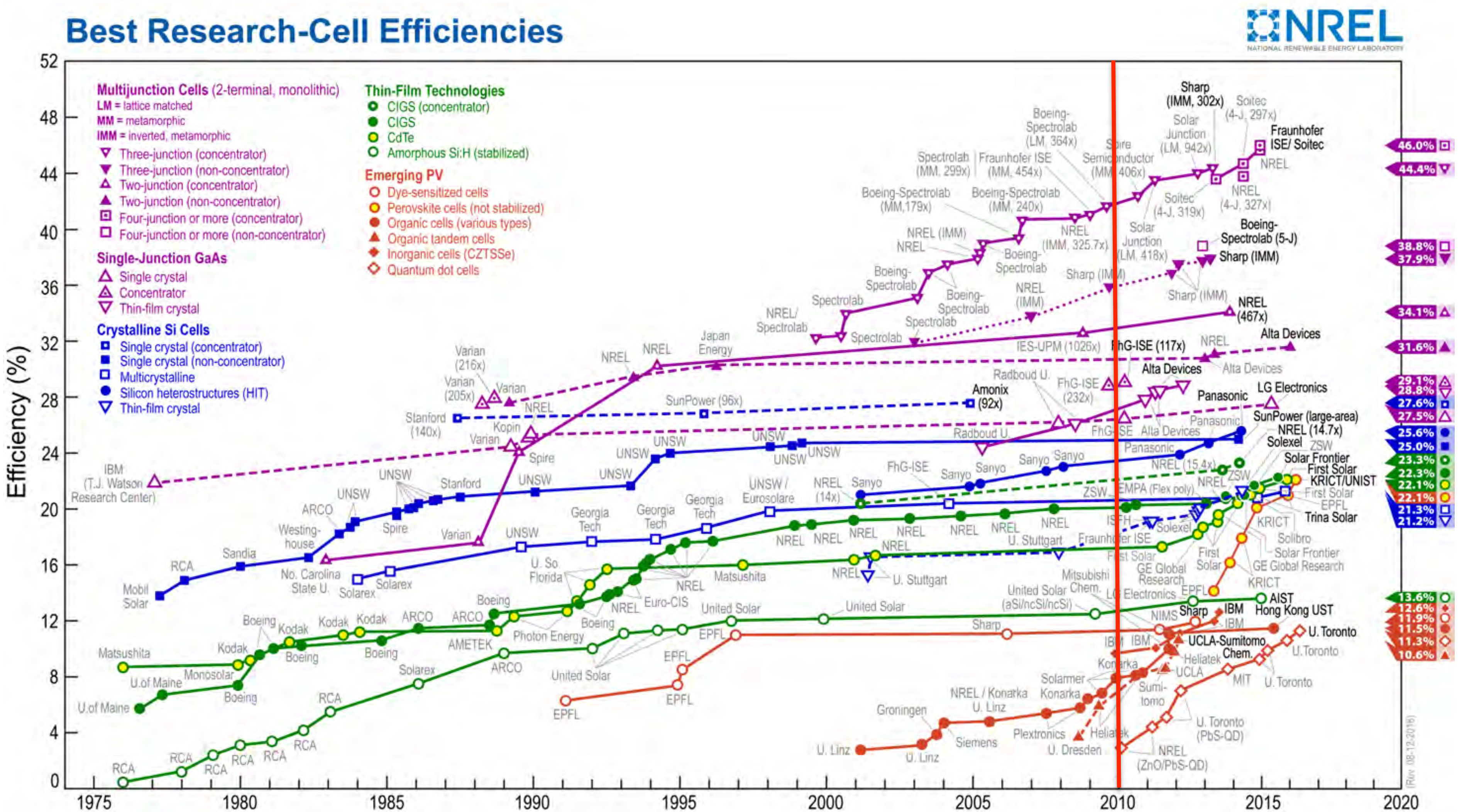


http://us.sanyo.com/Solar/

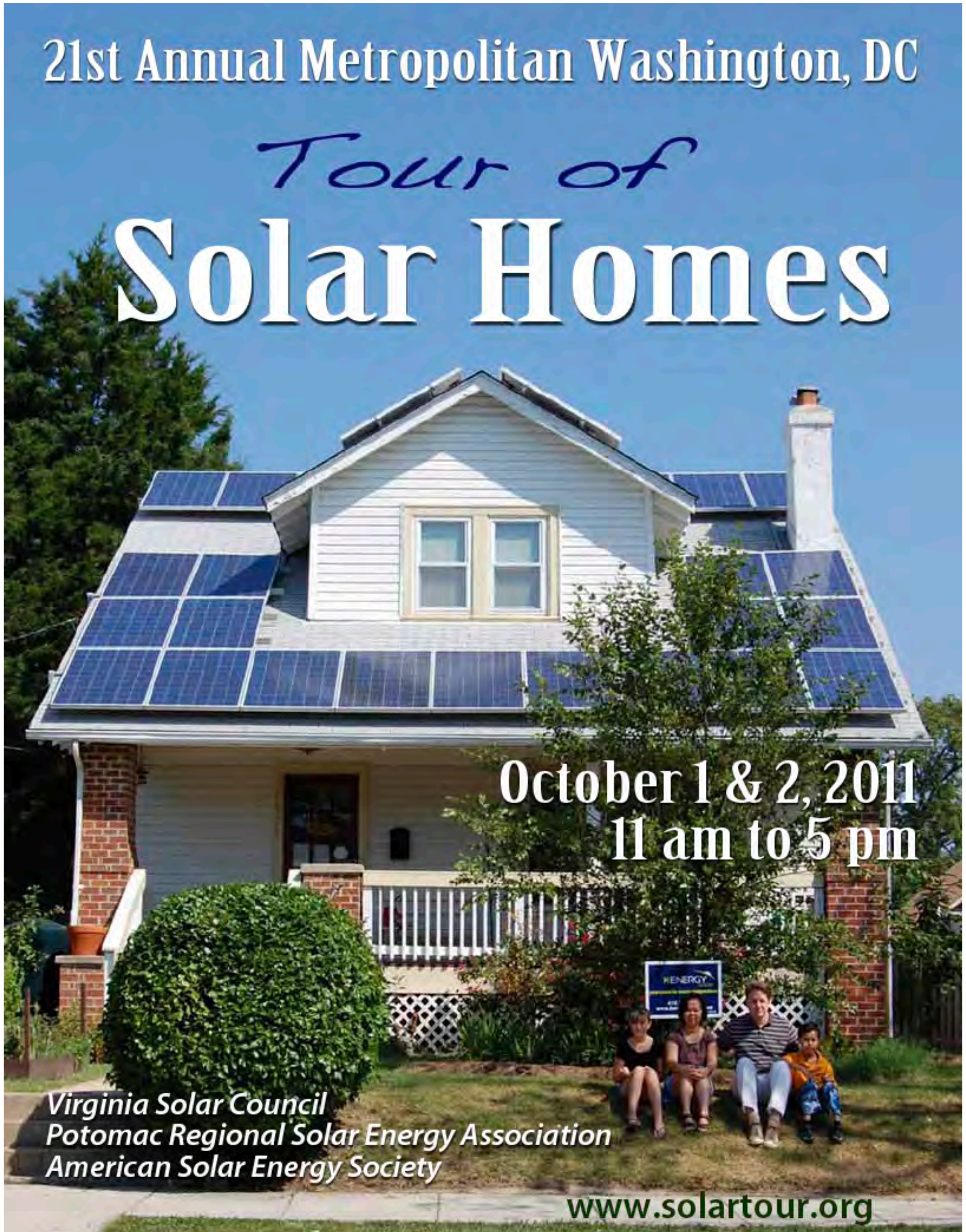
Sanyo solar panels HIT 215A 215 W, cell efficiency 19.3%, module efficiency 17.1%.

SunPower and Sanyo make consumer modules of the highest efficiency.

We needed the highest efficiency because of our limited area of exposure.



Best Research-Cell Efficiencies
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Efficiency (%)
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells (not stabilized)
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells
46.0%
44.4%
38.8%
37.9%
34.1%
31.6%
29.1%
28.8%
27.6%
27.5%
25.6%
25.0%
23.3%
22.3%
22.1%
22.1%
21.3%
21.2%
13.6%
12.6%
11.9%
11.5%
11.3%
10.6%
(Rev. 08-12-2016)



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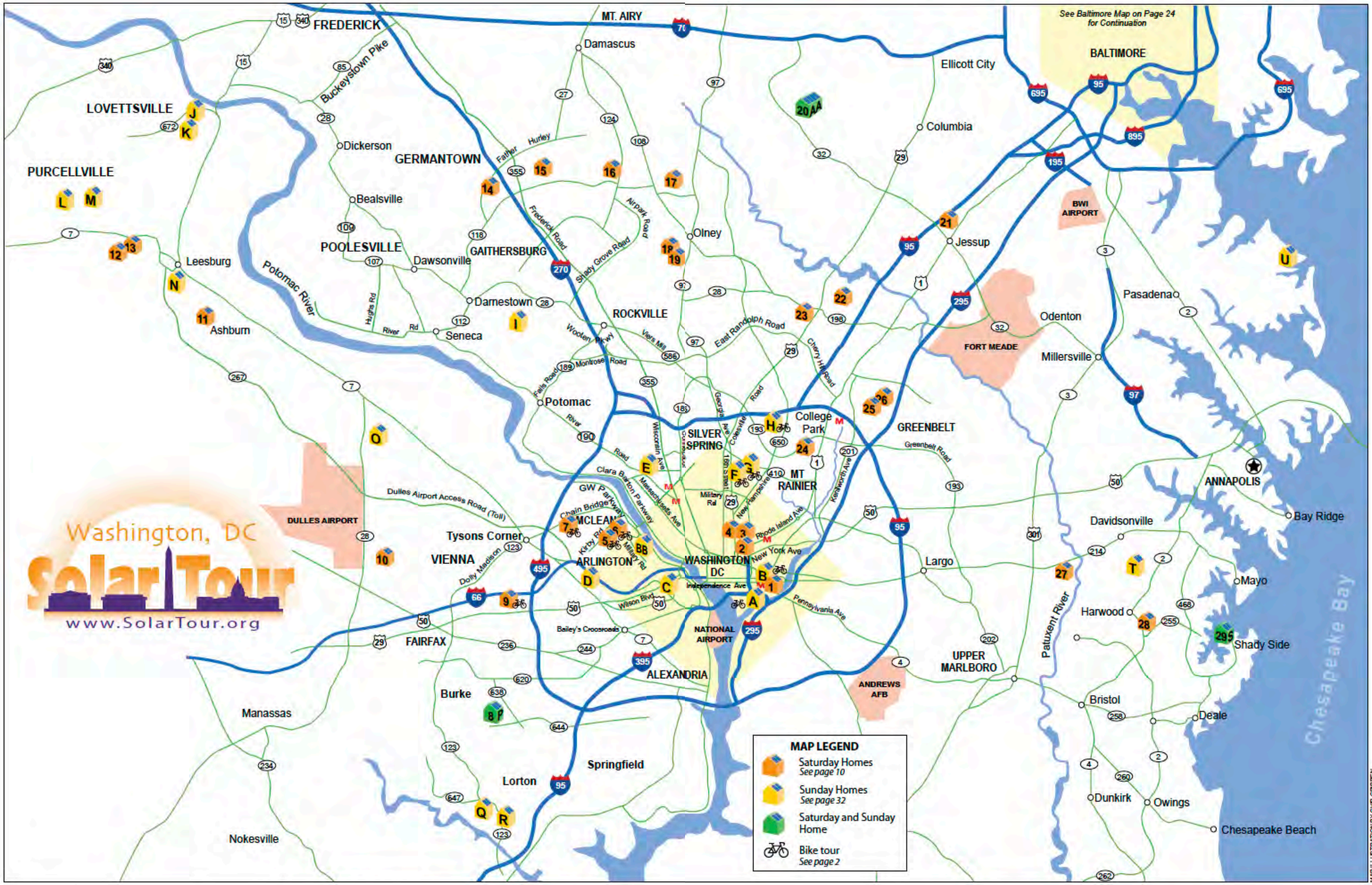
6573 Autumn Wind Circle, Clarksville, MD

The homeowner has reduced the dependency on fossil fuels by various conservation measures and reliance on renewable sources of energy. The solar panels are grid-tied with net metering so that the electric meter runs backward when the panels provide more energy than needed. It is connected to a battery back-up system, useful during power outages. Prior to the installation of the solar panels, the homeowner took a comprehensive approach to reducing energy use through conservation. This included installation of foam insulation in all of the exterior walls. A whole house fan was installed reducing the need for air conditioning. Insulating film was placed on most of the windows to reflect the sun's heat in the summer. All light bulbs are energy efficient. For winter heating, a highly efficient pellet fireplace was installed.

These measures cut the consumption of electricity from the electric company from a high of 2000 kWh to below 500 per month. Additional efforts at reducing the reliance on fossil fuels include an electrical rechargeable lawn mower and a hybrid automobile. The homeowners have installed a rain water collection system for gardening. Finally, children in the house are charged 25 cents for leaving a light on!

DIRECTIONS

From Route 95, take Route 32W towards Columbia. Proceed 5.9 miles and take Exit 19 toward Great Star Dr. and turn left onto Great Star Dr. Go 0.3mi and turn right onto Autumn Wind Circle and proceed down hill to 6573.



22 2011 Washington DC Metropolitan Area Tour of Solar H www.solartour.org 23

Solar Tour in DC area: 1st weekend of October every year SolarTour.org

Besides photovoltaic (PV) modules (solar panels), inverters are needed to transform direct current (dc) from PV into alternating current (ac) in the electric grid.

Old style: One big inverter on the wall for all roof panels connected in series. One panel blocks all.

New style: Individual microinverters for each panel on the roof. Parallel, independent operation, data communication, scalability.

Typically, a PV system is connected to the grid, so energy flows out on a sunny day and in at night. The electric utility company (PEPCO) bills monthly for the difference (net metering). Negative balance (credit for generation) carries over, but once a year PEPCO pays cash for the net credit.

To operate PV during grid outage, it is necessary to have a battery backup to stabilize the system. Otherwise, PV shuts down when grid goes down.

Shade from trees can be measured. See also SunNumber of zillow.com

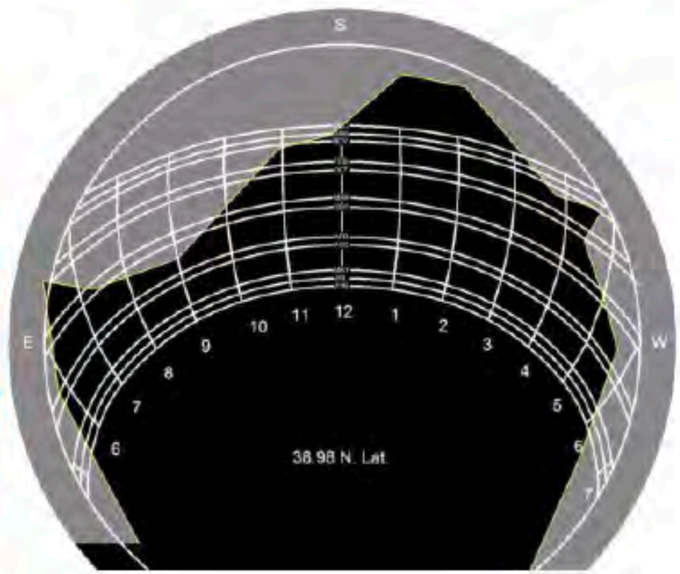
Solar Site Analysis Report

Image File IMG_2652.JPG

Solar Obstruction Data

Month	Unshaded % of Ideal Site Azimuth=180 Tilt=38.98	Actual Solar Rad w/ Shading Azimuth=180.0 Tilt=25.0 KWH/m^2 /day	Actual AC Energy (KWH) w/ shading Azimuth=180.00 Tilt=25.00	Actual AC Energy (KWH) w/o shading Azimuth=180.0 Tilt=25.00	Ideal AC Energy (KWH) w/o shading Azimuth=180.0 Tilt=38.98	Solar Cost Savings 0.11 ($/KWH)	PVWatts Unshaded % Actual Site Azimuth=180.0 Tilt=25.00	Actual Site Efficiency % Azimuth=180.0 Tilt=25.00	Ideal Site Efficiency % Azimuth=180.0 Tilt=38.98
January	50.36%	1.42	81.24	157.00	174.00	$8.94	50.52 %	45.21 %	50.00 %
February	71.16%	2.50	129.80	178.00	191.00	$14.28	71.76 %	66.08 %	70.82 %
March	81.81%	3.73	205.56	248.00	255.00	$22.61	81.93 %	79.48 %	81.94 %
April	99.22%	5.66	284.14	285.00	277.00	$31.26	99.39 %	100.00 %	99.41 %
May	98.86%	4.96	252.82	253.00	236.00	$27.81	98.94 %	100.00 %	98.90 %
June	99.05%	5.91	285.00	285.00	262.00	$31.35	99.09 %	100.00 %	99.04 %
July	99.10%	5.79	285.00	285.00	264.00	$31.35	99.17 %	100.00 %	99.18 %
August	98.87%	5.60	275.68	277.00	264.00	$30.35	99.04 %	100.00 %	99.12 %
September	84.86%	4.18	205.70	242.00	243.00	$22.63	84.33 %	83.32 %	84.46 %
October	71.56%	3.41	176.64	251.00	269.00	$19.43	70.09 %	65.38 %	70.12 %
November	56.68%	1.65	84.18	151.00	167.00	$9.26	55.49 %	50.11 %	55.16 %
December	44.33%	1.25	67.79	152.00	173.00	$7.46	43.60 %	38.37 %	43.35 %
Totals	**79.66%** Unweighted Yearly Avg	**46.05** Effect: 83.59% Sun Hrs: 3.84	**2,333.75**	**2,764.00**	**2,775.00**	**$256.71**	**79.45 %** Unweighted Yearly Avg	**77.33 %** Unweighted Yearly Avg	**79.29 %** Unweighted Yearly Avg

Notes: [None]



SolarPathFinder.com

Sequence of steps (done by the installation company):

- Initial e-mail contact with Standard Solar, check satellite view of the house on Google maps, decide on feasibility
- House visit of a representative, discuss parameters of a contract, pay initial deposit
- Engineering design, get building and electric permits, procure parts
- Installation, usually < day. Better in a cool season to protect roof shingles
- Electric inspection by the county, change of electric meter, approval from the utility company, switch on
- Apply for rebates (state, county, federal), sign a contract with a SREC aggregator (e.g. Sol Systems), register the system for SRECs, receive cash
- Watch electric meter spinning backwards ☺

After signing of the contract and in preparation for PV installation, we replaced a leaky plywood panel and shingles on the roof. We installed Solaris brand of shingles from CertainTeed with enhanced reflection coefficient to keep the roof cooler.

Overheating of the attic is a serious problem: with the air temperature 100 F (38 C), the attic temperature was 137 F / 59 C (2008), but decreased to 110 F / 43 C (2011) after installing ridge vent, reflective sheets inside, Solaris shingles, PV panels, and thick bats of fiberglass insulation between the attic and the 2nd floor.

PV installation and snowstorm afterwards

Jan 25, 2011, PV done on the 1st day

Jan 28, 2011, after a huge snowstorm

Installation and wiring of the battery backup was finished on the 2nd day, Jan 26, at 4 pm. At 8 pm, a huge snowstorm arrived, and the grid went down. We survived the night on battery backup, which powered gas furnace, kitchen fridge, sump pump, Internet, and some lights and outlets. Next day, we generated 4 kWh of PV energy and recharged batteries back to full. On our block, the grid was restored after 20 hours, but in some areas it was down up to 5 days!

Battery backup in the basement

Energy-saving measures

After the snowstorm, I measured our critical-load electric consumption using Kill A Watt. Our kitchen fridge consumed about 2 kWh/day. We bought a new fridge of the same size by General Electric, which consumes 1 kWh/day.

Then, I measured electric consumption of all pluggable electric devices in the house and put all sleeping electronic devices on switches. I replaced a 300 W halogen floor lamp by a 13 W compact fluorescent bulb, etc. This measures have reduced the baseload electric consumption by about 30%. All lights in the house are fluorescent and LED.

How to balance energy budget: increase production and reduce consumption!

Better insulation of the house with poured-in foam

Liquid phenolic foam is pumped between exterior and interior walls and fills all cavities, then turns into solid closed-cell foam. Done by USAinsulation.net

The most efficient dehumidifier on the market

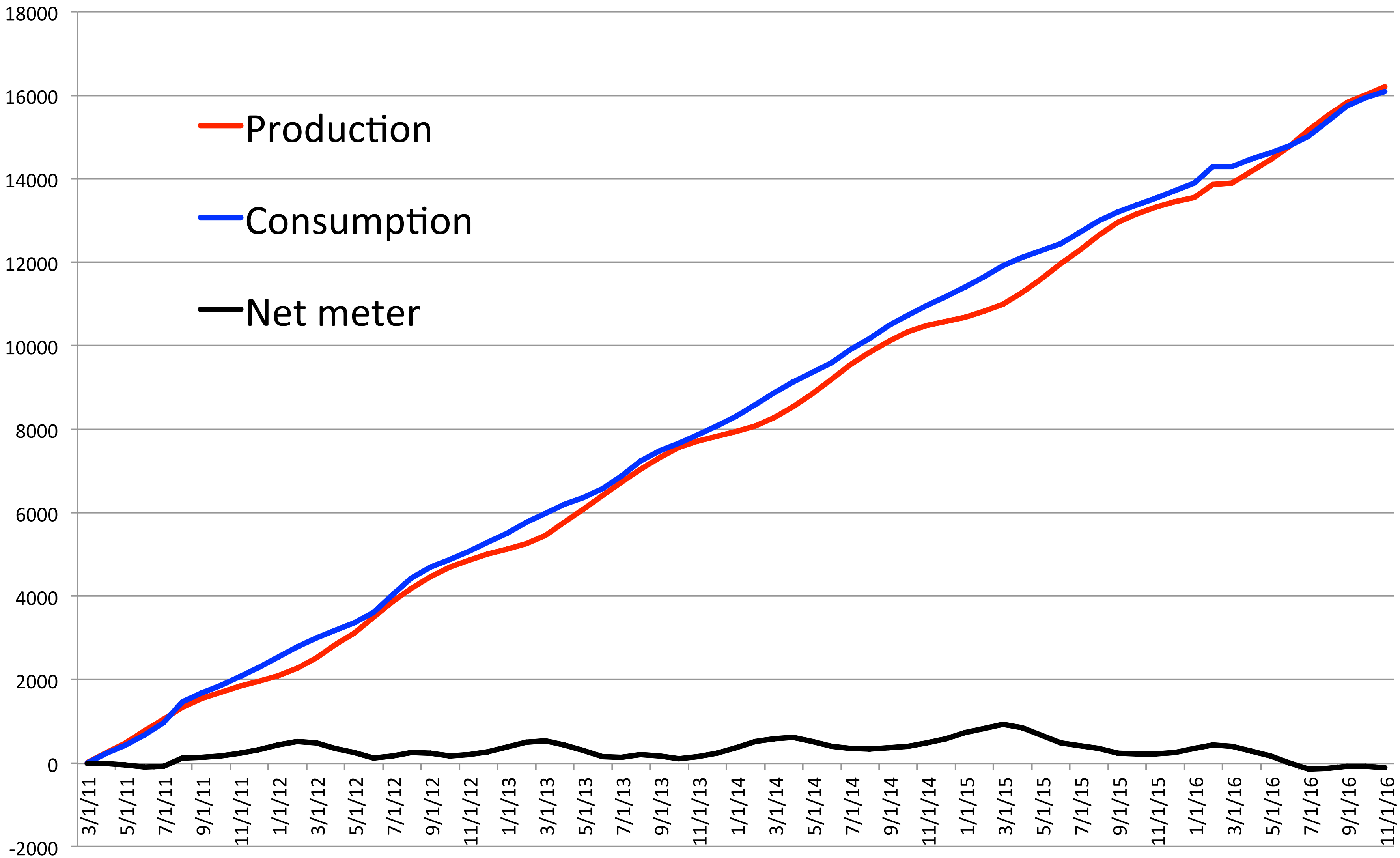
Santa Fe Impact XT, seasonal consumption ~200 kWh, dehumidifies the whole basement and house (using central fan).

It often substitutes air conditioner and can be operated during outage.

We used air conditioner for 47 days in 2011 and 31 day in 2012.

Energy consumption of all electric appliances is listed at EnergyStar.gov by DOE.

Cumulative 5 years 8 months, 9 March 2011 – 9 November 2016



Annual PV 2.87 MWh, usage 2.5 MWh now vs. 6 MWh in 2010, typical home 14 MWh

UMD people who have residential PV installations

Jeffrey Lynn, NIST Fellow and Team Leader, Adjunct Professor of Physics

Reinhard Radermacher
Professor of Mechanical Engineering, Director of Center for Environmental Energy Engineering

Peter Shawhan
Associate Professor of Physics

Marla McIntosh, Professor of Plant Sciences
https://enlighten.enphaseenergy.com/public/systems/drUs9509

They all have much bigger PV installations (x3) than mine

Conclusions

- Technology is mature: PV efficiency pushing to 20%, PV warranty 20 years, slick microinverters, warranty 15 years
- Service: well-established installation companies with long record and experience
- Cost: affordable, unprecedented subsidies, 30% Federal tax credit + MD state + PG county + SRECs (solar renewable energy credits) – total discount > 50%
- PV module prices are decreasing: overcapacity due to collapse of European subsidies, ramped-up Si production for PV instead of electronics leftovers
- We wanted a backup system. Grid outages in DC area became endemic (4 last year): winter (no heat), summer (food spoils), rain (water in buckets, no sump pump), just too hot (chain explosions of overloaded transformers)
- Yet, a backup would be used only 1% of time. PV + battery backup looks like a good combination: generates power all year, but also in emergency.
- Battery backup vs. generators: no fuel, no moving parts, no maintenance, indoor installation, easy electric connections, but a finite number of charge cycles.
- Web link http://physics.umd.edu/~yakovenk/solar-home/

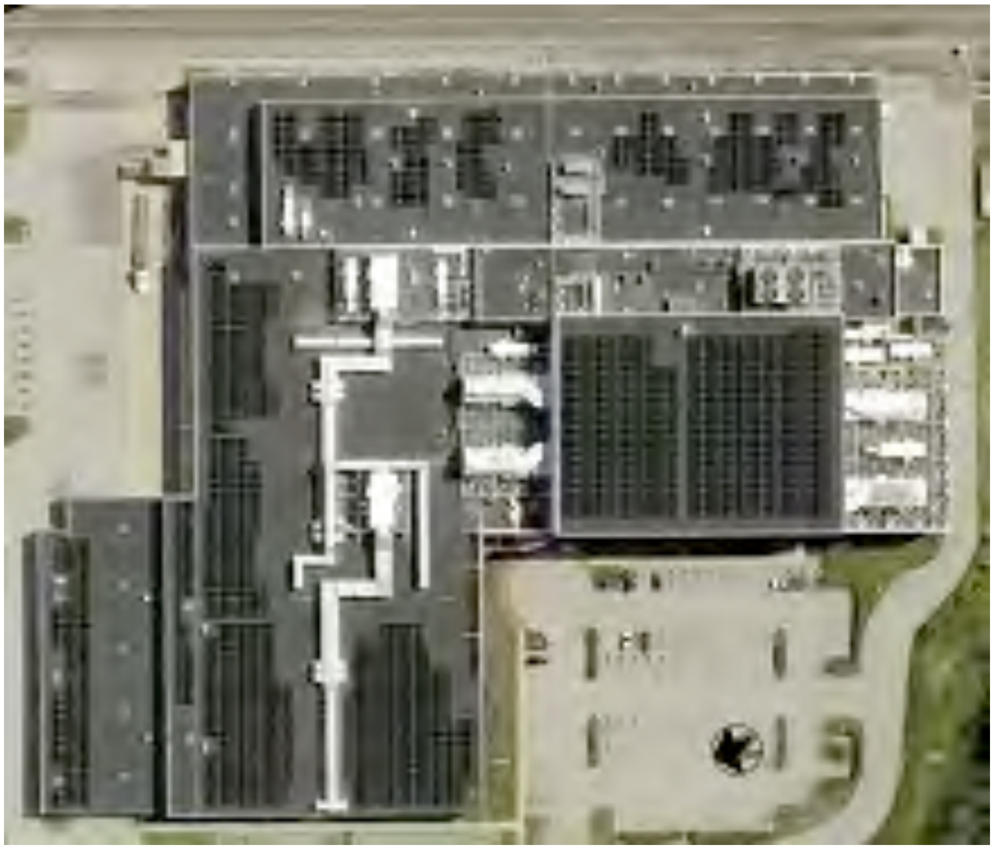
Now is the time to do it!

The time for massive adoption of solar power has arrived.

UMD installed PV system on the former Washington Post printing plant in College Park (August 2011)

http://newsdesk.umd.edu/scitech/release.cfm?ArticleID=2341

http://datareadings.com/client/moduleSystem/Kiosk/site/bin/kiosk.cfm?k=5QJba0pN



http://www.standardsolar.com/node/1292

Severn Building UMD:
2,600 solar panels
631 kW power
792 MWh annual
Standard Solar installer

American University:
532 kW power,
637 MWh annual,
on Katzen Arts Center,
Bender Library, etc.,
Standard Solar installer,
Washington Gas Energy Services owner & operator

Severn Building UMD, also Lowe's, IKEA, etc.

University Park
Community
Solar LLC,
Church of the
Brethern,
22 kW,
May 2010,
Standard Solar
installer

SURFACE AREA REQUIRED TO POWER THE WORLD
WITH ZERO CARBON EMISSIONS AND WITH SOLAR ALONE

www.landartgenerator.org

BOXES TO SCALE WITH MAP

1980 (based on actual use)
207,368 SQUARE KILOMETERS

2008 (based on actual use)
366,375 SQUARE KILOMETERS

2030 (projection)
496,805 SQUARE KILOMETERS

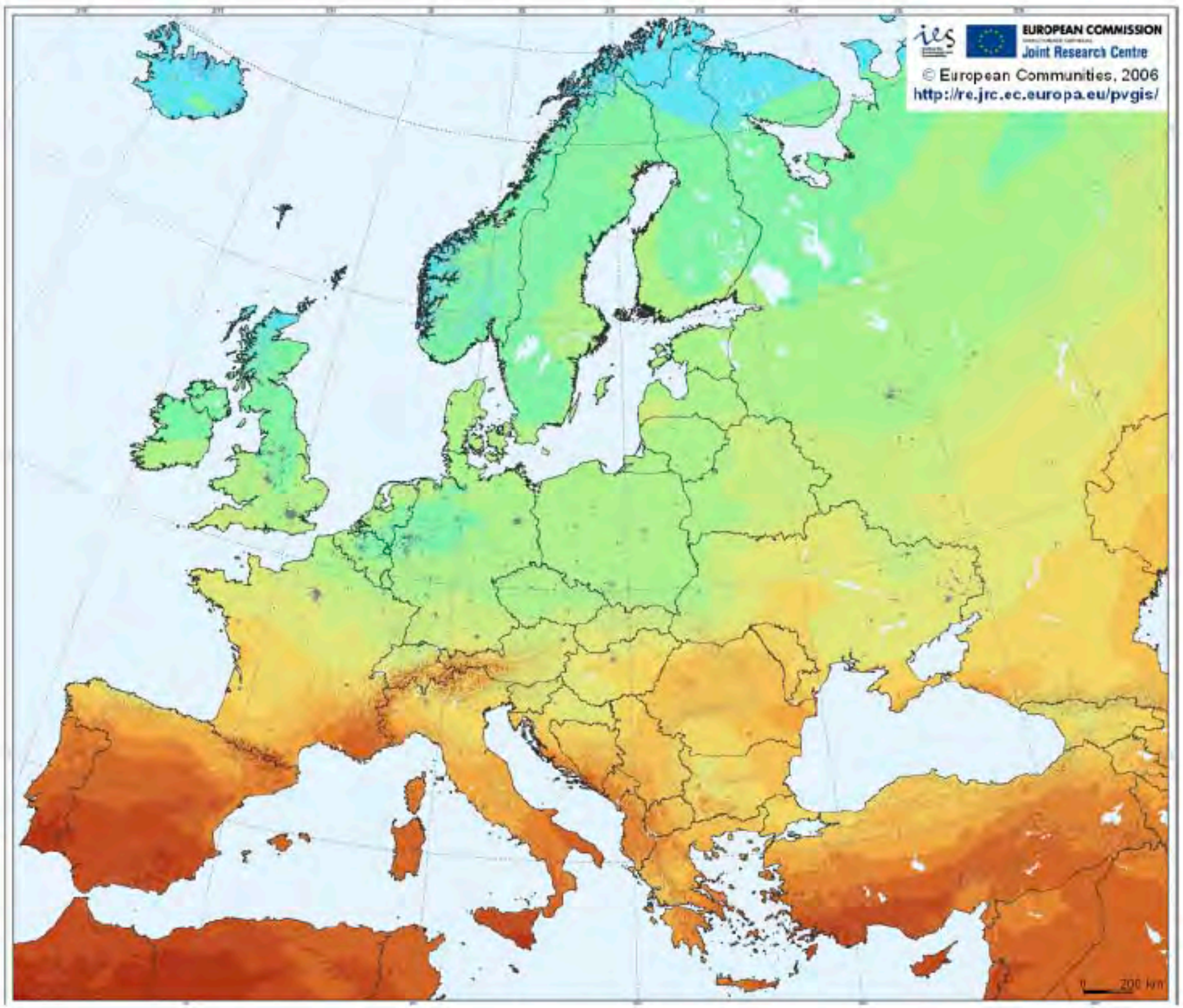
Required area that would be needed in the year 2030 is shown as one large square in the key above and also as distributed around the world relative to use and available sunlight.

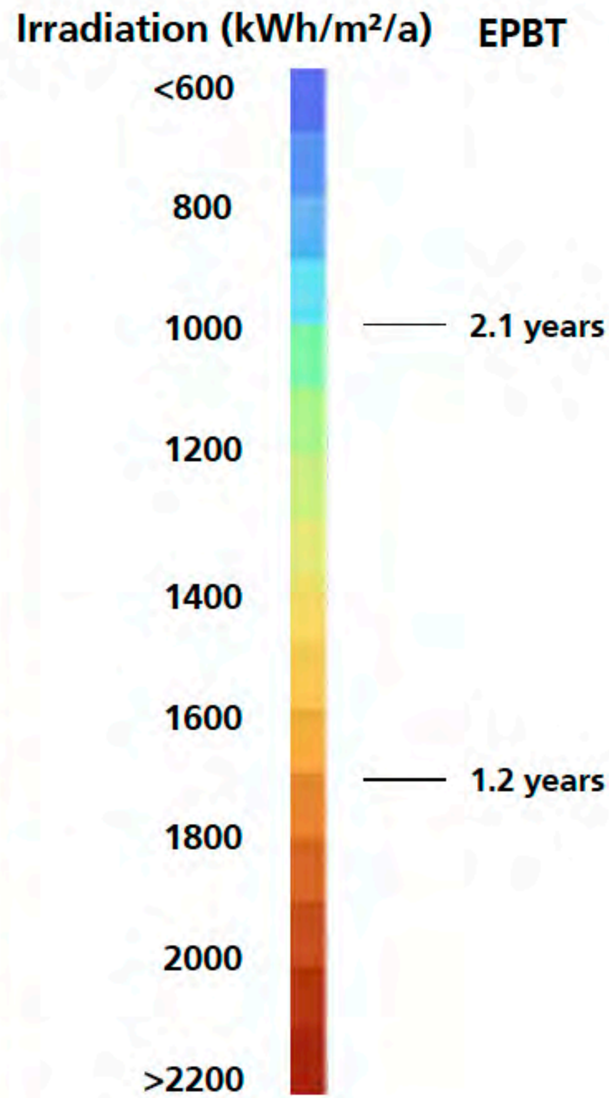
- Areas are calculated based on an assumption of 20% operating efficiency of collection devices and a 2000 hour per year natural solar input of 1000 watts per square meter striking the surface.
- These 19 areas distributed on the map show roughly what would be a reasonable responsibility for various parts of the world based on 2009 usage. They would be further divided many times, the more the better to reach a diversified infrastructure that localizes use as much as possible.
- The large square in the Saharan Desert (1/4 of the overall 2030 required area) would power all of Europe and North Africa. Though very large, it is 18 times less than the total area of that desert.
- The definition of "power" covers the fuel required to run all electrical consumption, all machinery, and all forms of transportation. It is based on the US Department of Energy statistics of worldwide Btu consumption and estimates the 2030 usage (678 quadrillion Btu) to be 44% greater than that of 2008.
- Area calculations do not include magenta border lines.

LAND ART GENERATOR INITIATIVE

Energy Pay-Back Time of Multicrystalline Silicon PV Rooftop Systems - Geographical Comparison

Fraunhofer Institute for Solar Energy report, 17 November 2016





Can photovoltaics save the world?

- Global total energy consumption is about 15 TW = 15,000 GW
- Current global annual PV installation rate is about 50 GW/year
- At the current rate, it would take 300 years to switch global energy to PV
- PV installation rate has to increase by x10 to reduce the time to 30 years