

Modules, Systems, and Reliability

Lecture 17

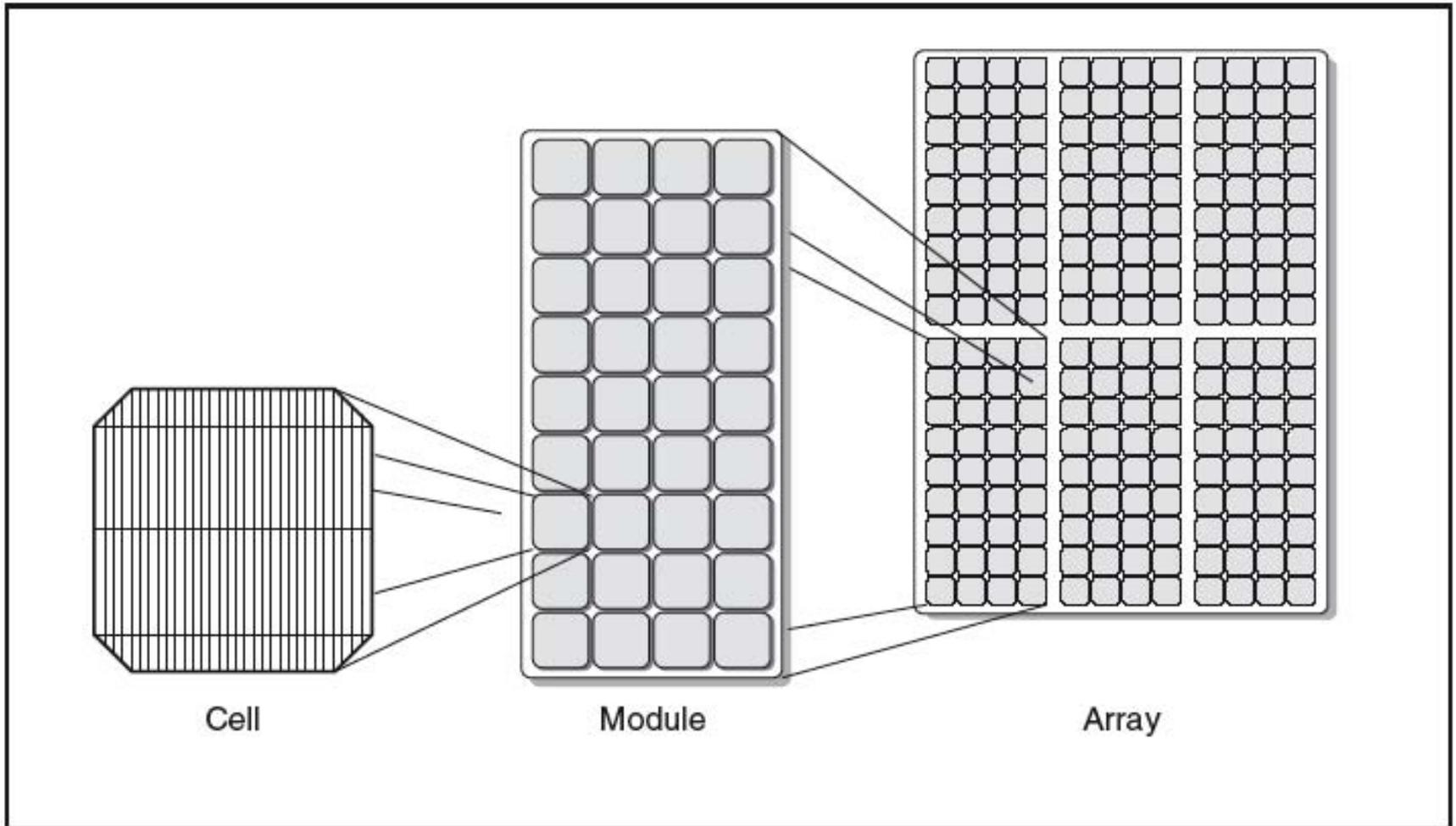
MIT Fundamentals of Photovoltaics
2.626/2.627 – 11/10/2011

Prof. Tonio Buonassisi

Learning Objectives: Modules, Systems, Reliability

1. Describe how PV modules are manufactured.
2. Describe how PV module power output is affected by cell mismatch losses
3. Describe how microinverters and microelectronics can improve module performance output.
4. List the necessary tests a PV module must pass to ensure reliable multi-decade service life in the field, as well as the shortcomings of these tests.
5. Describe the differences between various types of PV systems: Grid-tied and stand-alone, tracking and non-tracking.
6. List major balance of system components.
7. Describe current consensus of life cycle analysis studies, and recycling of modules.

Definitions

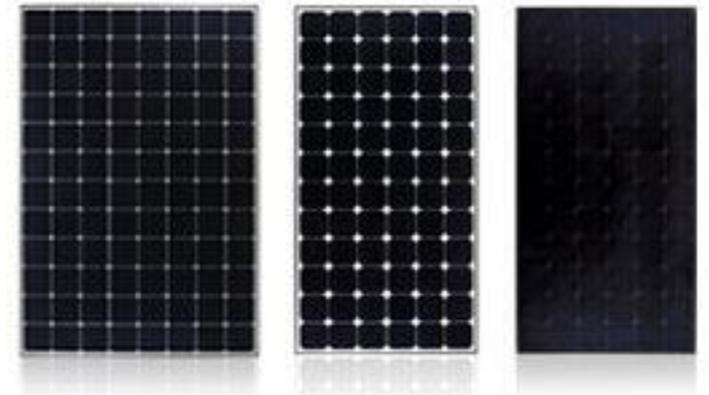


Photovoltaic cells, modules and arrays *The building blocks of solar electricity are modular in nature, allowing great flexibility in applications.*

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Solar Modules

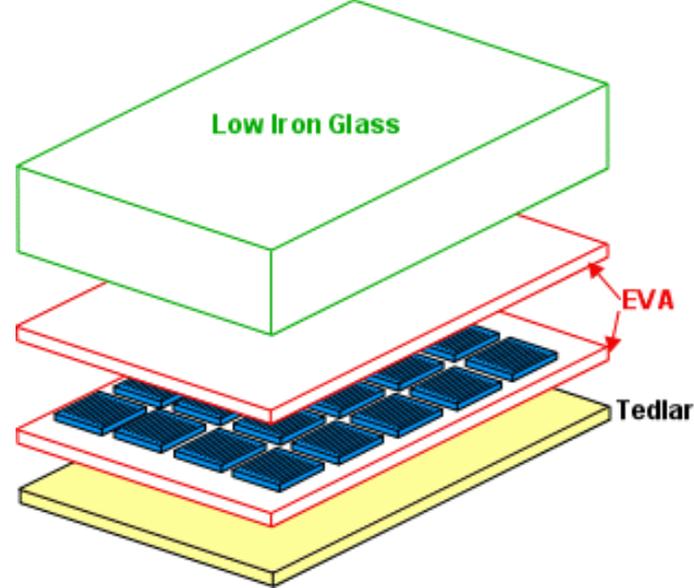
- Modules require little maintenance
 - Water rinse 2-3 time/year
- Typically no moving parts
- Typical 20-30 year manufacturer warranty



SunPower Modules

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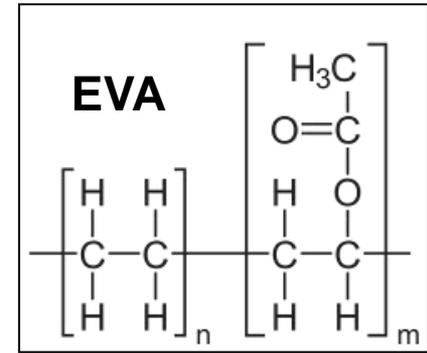
Solar PV Module DNA



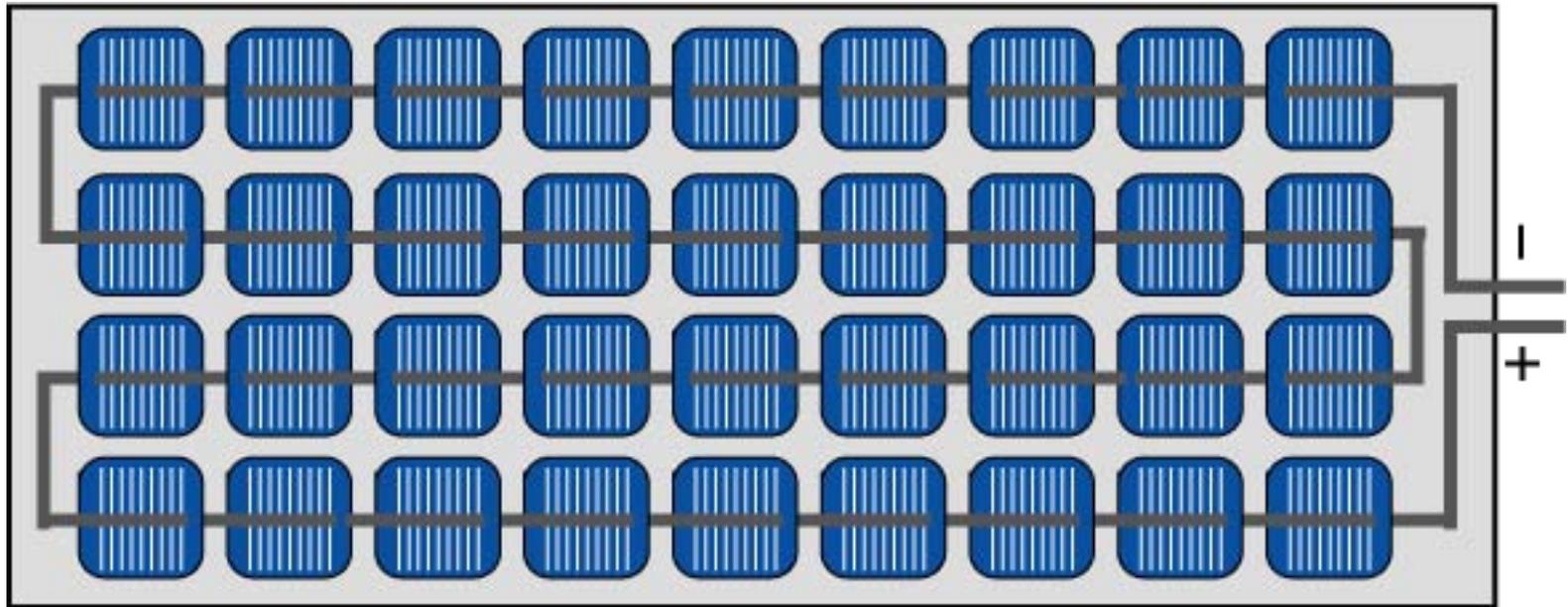
Source: PVCDROM

Courtesy of [PVCDROM](#). Used with permission.

- Low-iron glass ensures good transmission of light.
- Ethyl Vinyl Acetate (EVA) flows at intermediate temperatures, encapsulating the cells. Thin film modules often use polyvinyl butyral (PVB), which is less reactive and has lower permeability than EVA.
- Tedlar forms an impenetrable back layer.
- Aluminum frame provides rigidity.
- Junction box provides electrical connections.



Module Circuit Design

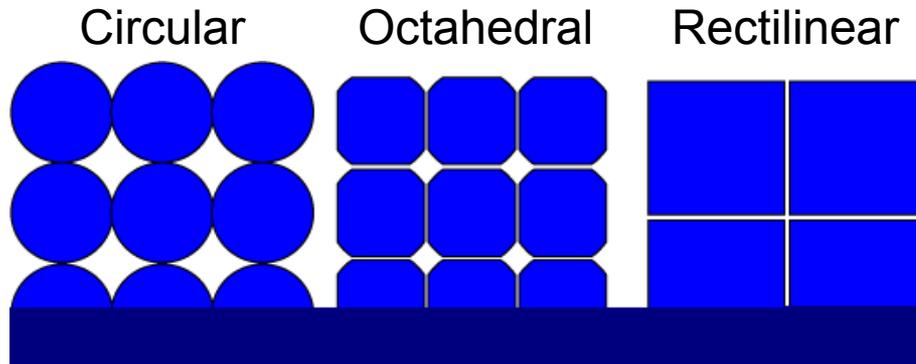


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Source: PVCDROM

- For historical reasons, typical c-Si modules have strings of 36 cells connected in series, yielding a V_{mp} under operating conditions of 17-18V. This enables charging of a typical battery ($\geq 15V$). As grid-tied systems become more common, this voltage constraint is reduced.

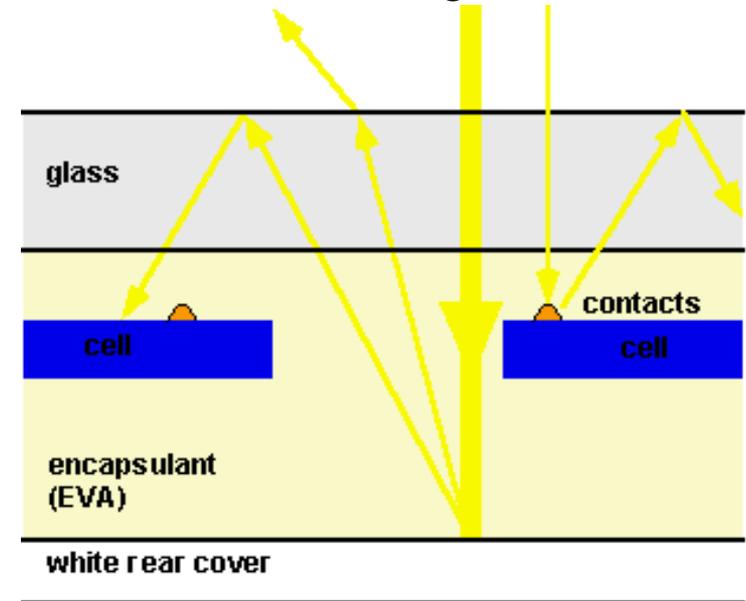
Packing Fraction in Modules



Courtesy of [PVCDROM](#). Used with permission.

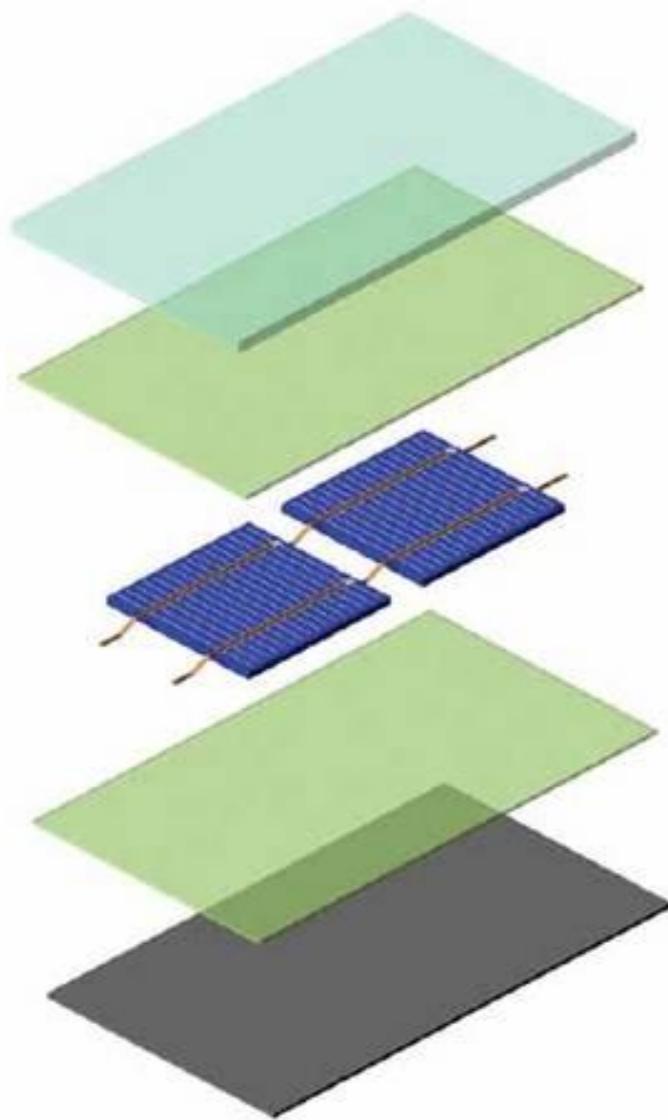
Source: PVCDROM

Light Concentration in Modules with Low Packing Fraction



- Higher packing fraction lowers glass, encapsulant costs per watt peak.
- Lower packing fraction increases optical concentration.

Solar Module Technology Trends: Cheaper, Better Materials



Transparent Front Surface (Glass Replacement)

Encapsulant (EVA replacement)

Cells

Encapsulant

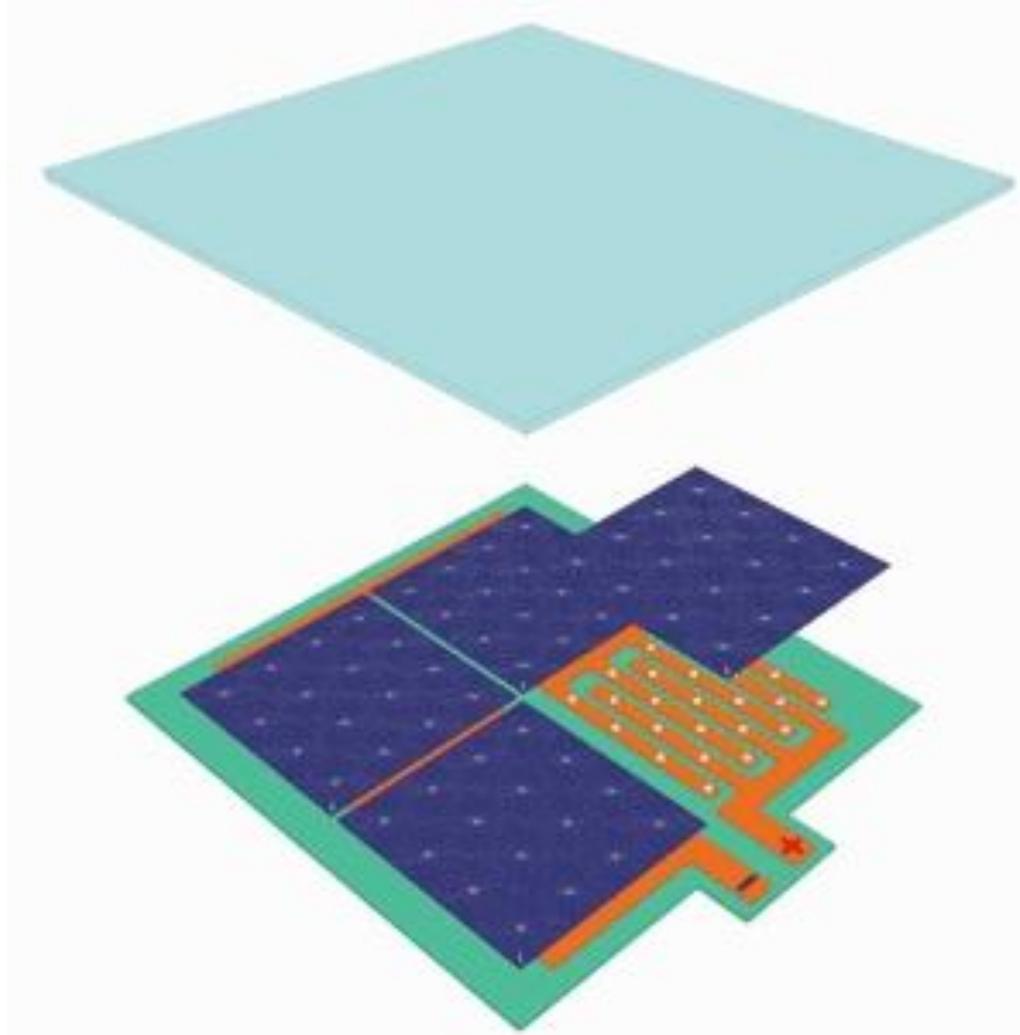
Backskin (Tedlar replacement)

Frame (Al replacement)



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Solar Module Technology Outlook: Back-Contacted Cells



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Sample PV Module Spec Sheet

Spec sheet samples removed due to copyright restrictions.
See lecture 17 video for discussion.

- Sharp Electronics ND-187U1
- Evergreen Solar ES-A
- First Solar FS Series 3

Learning Objectives: Modules, Systems, Reliability

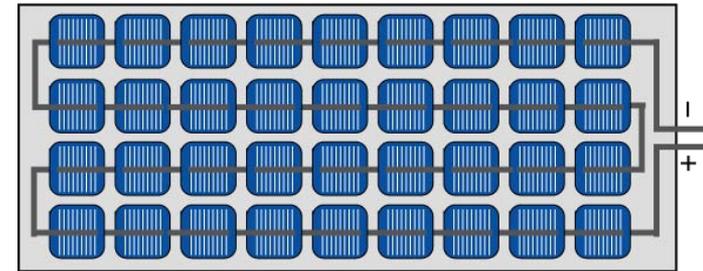
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Ideal Equivalent Circuit for Solar Module

$$I_{total} = MI_L - MI_0 \left[\exp\left(\frac{qV_{total}}{nkTN}\right) - 1 \right]$$

M = cells in parallel

N = cells in series



Courtesy of [PVCDROM](#). Used with permission.

Source: PVCDROM

In *practice*, current and voltage output reduced by mismatch losses.

Parallel Mismatch

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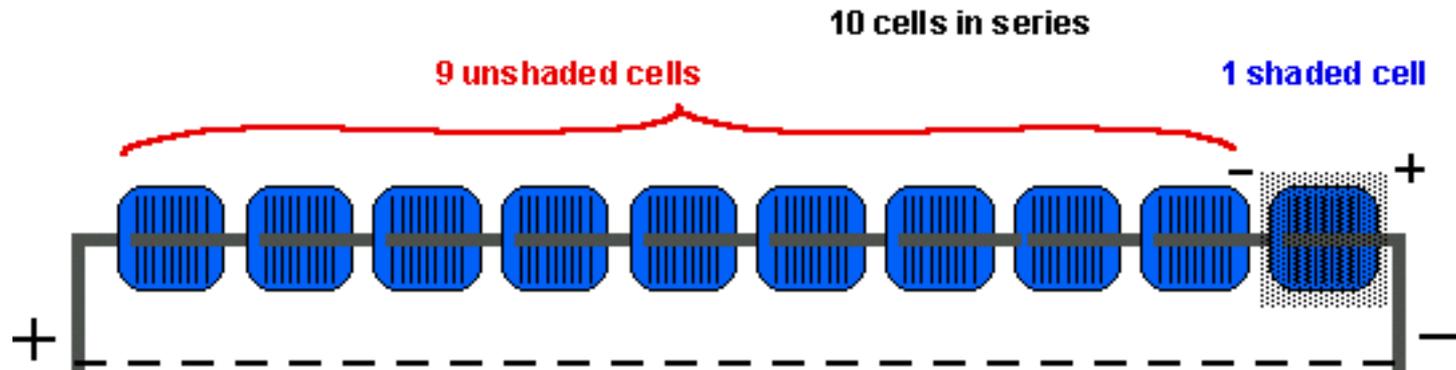
Figures 5.2 (schematic) and 5.3 (graph) from Wenham, S. R., et al. *Applied Photovoltaics*. 2nd edition. Routledge, 2007. [Preview with [Google Books](#)]

Series Mismatch

Images removed due to copyright restrictions. See Lecture 17 video.

Figures 5.5 (schematic) and 5.6 (graph) from Wenham, S. R., et al. *Applied Photovoltaics*. 2nd edition. Routledge, 2007. [Preview with [Google Books](#)]

Shaded Cells



If the terminals of the module are connected (module Isc), the power from the unshaded cells is dissipated across the shaded cell.

Courtesy of [PVCDROM](http://pvcdrom.org). Used with permission.

<http://pveducation.org/pvcdrom/modules/hot-spot-heating>

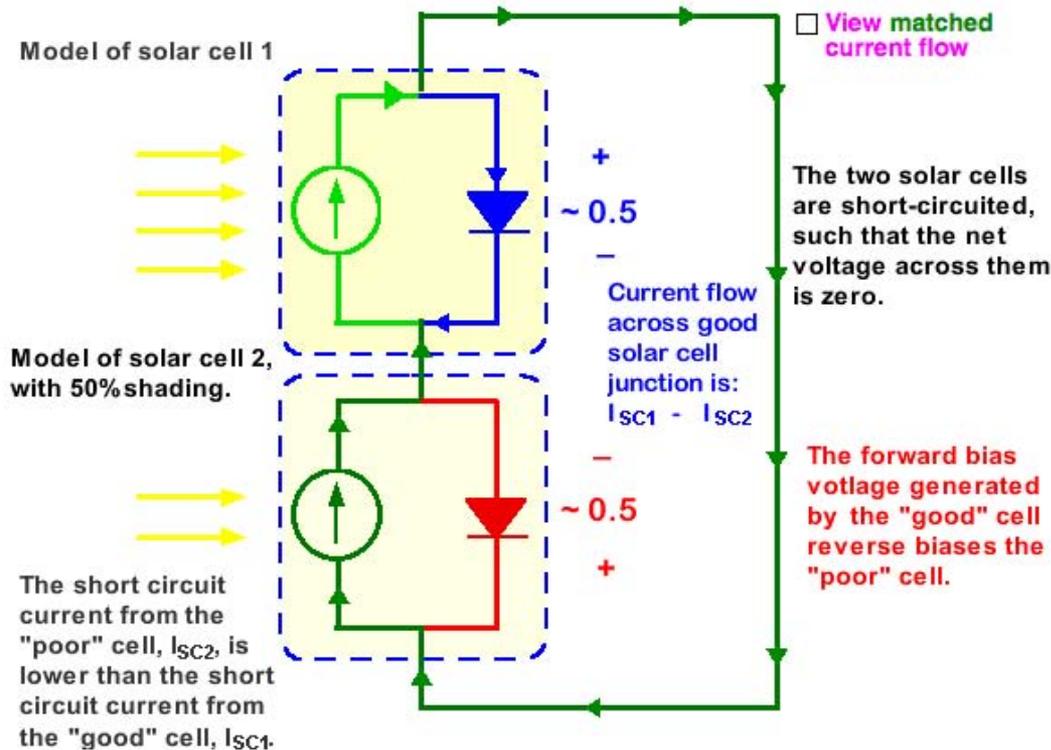
Images removed due to copyright restrictions. See Lecture 17 video.

Figures 5.8 (schematic) and 5.9 (graph) from Wenham, S. R., et al. *Applied Photovoltaics*. 2nd edition. Routledge, 2007.

Example from PVCDROM

SERIES CONNECTED SOLAR CELLS WITH MISMATCHED SHORT CIRCUIT CURRENTS

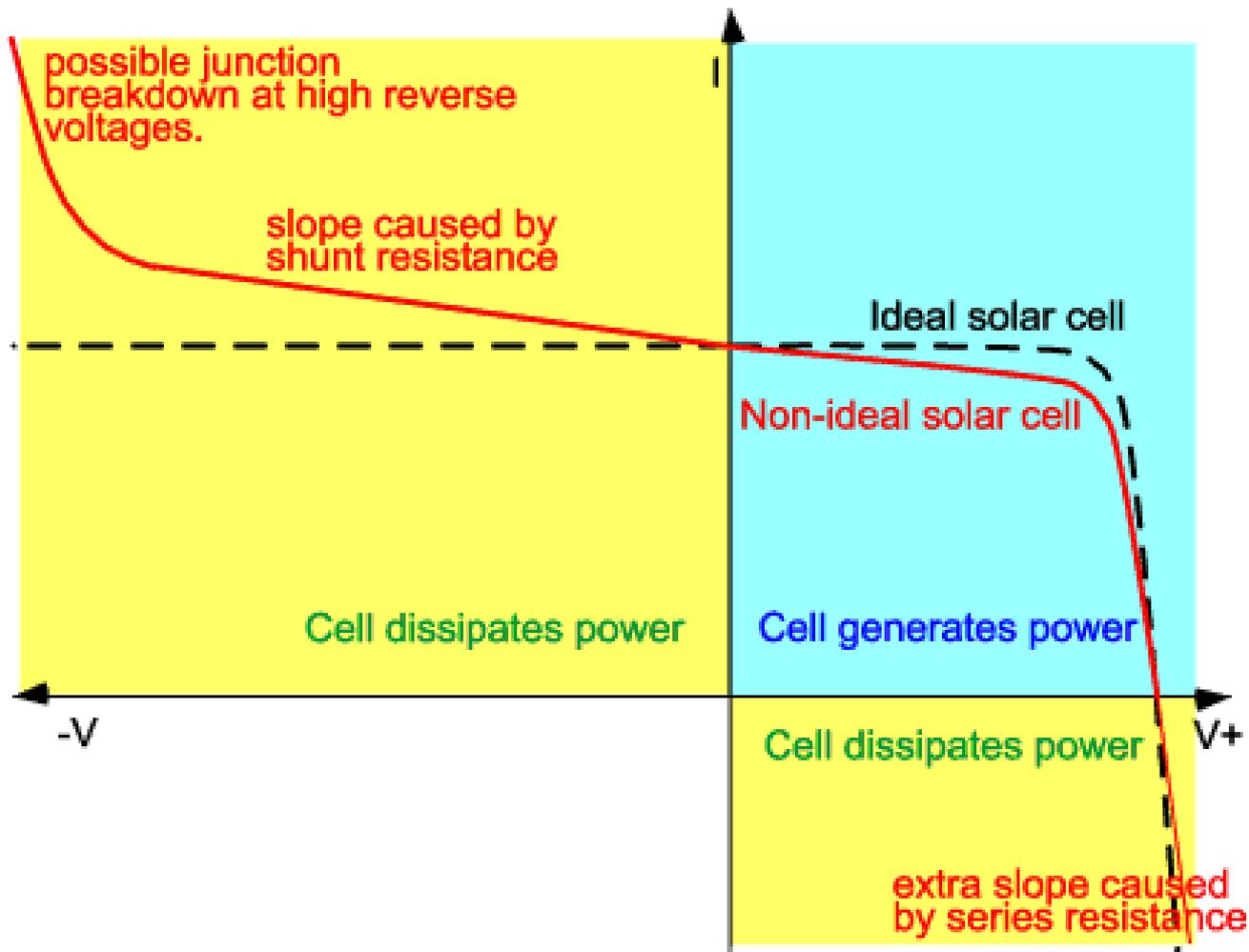
The short circuit current from the poor cell, I_{SC2} , is the maximum current that can flow in the external circuit. Therefore, extra current from the good cell, mathematically given by $I_{SC1} - I_{SC2}$, is forced to flow across the good solar cell junction, forward biasing it and generating a voltage.



In the animation, cell 2 has a lower output voltage than cell 1.

Courtesy of PVCDROM. Used with permission.

Mismatch Losses and Breakdown



Courtesy of [PVCDROM](http://pvcdrom.com). Used with permission.

Underperforming Cells & Hotspots

Image depicting Lock-In Thermography removed due to copyright restrictions.
See Lecture 17 video.

<http://www.renewableenergyworld.com/rea/images/lock-in-thermography-enables-solar-cell-development/51184>

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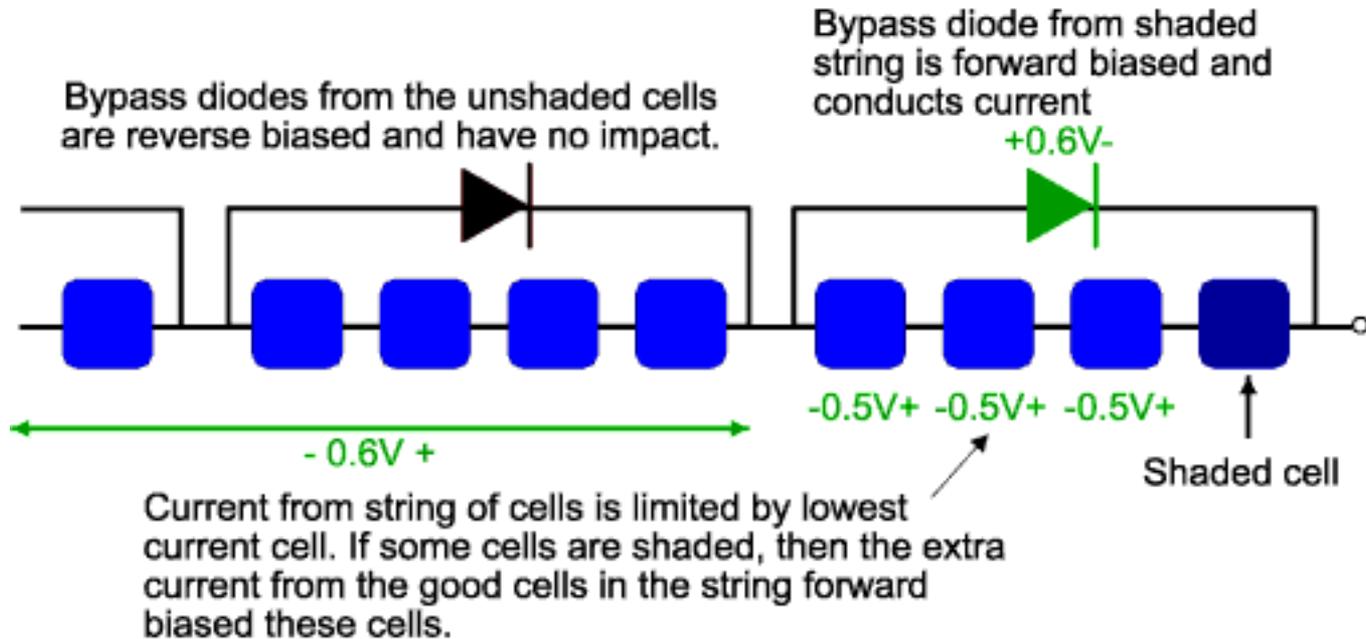
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Bypass Diodes

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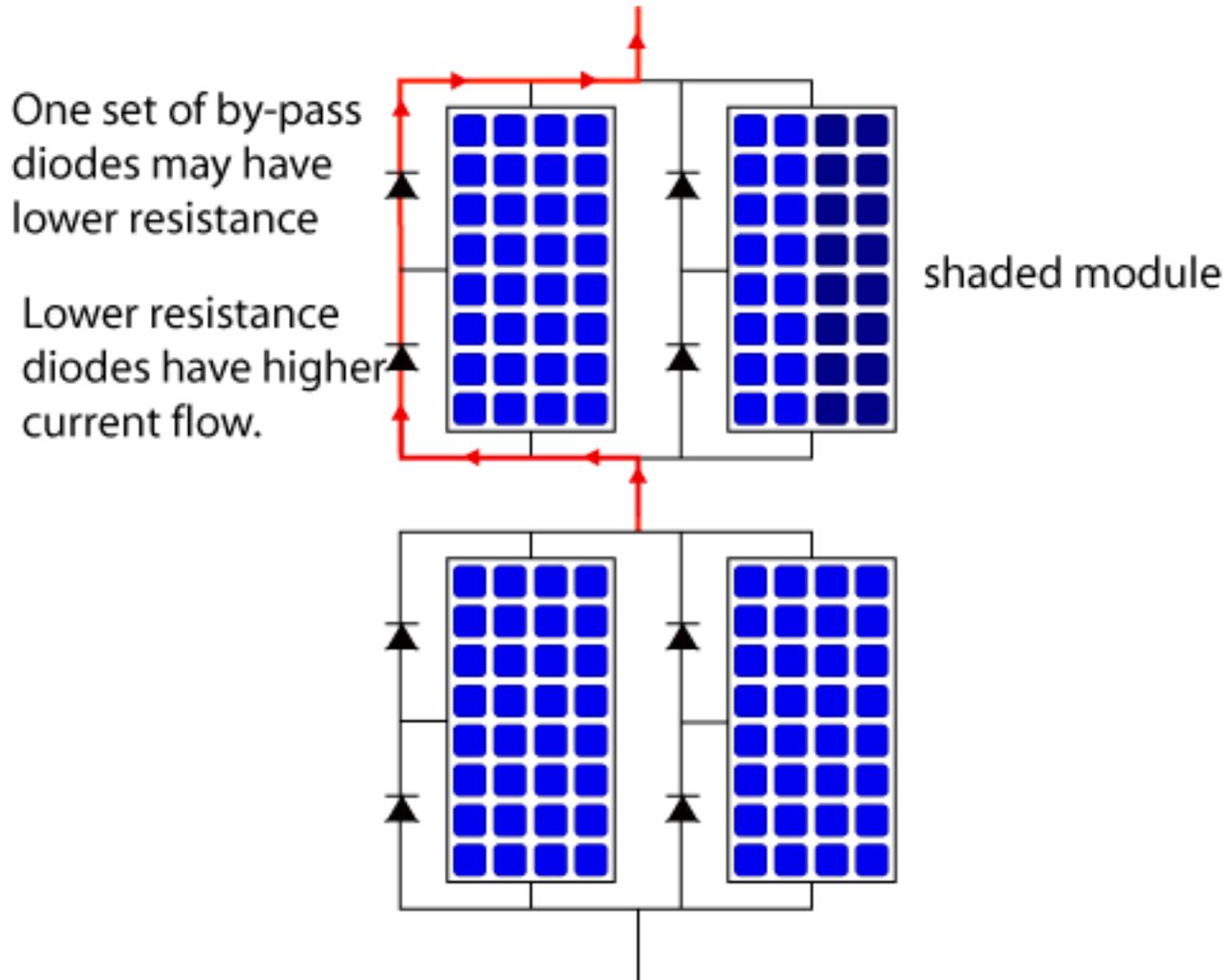
Figures 5.12 and 5.13 from Wenham, S. R., et al. *Applied Photovoltaics*. 2nd edition. Routledge, 2007.

Bypass Diodes



Courtesy of [PVCDROM](http://pvcdrom.com). Used with permission.

Bypass Diodes

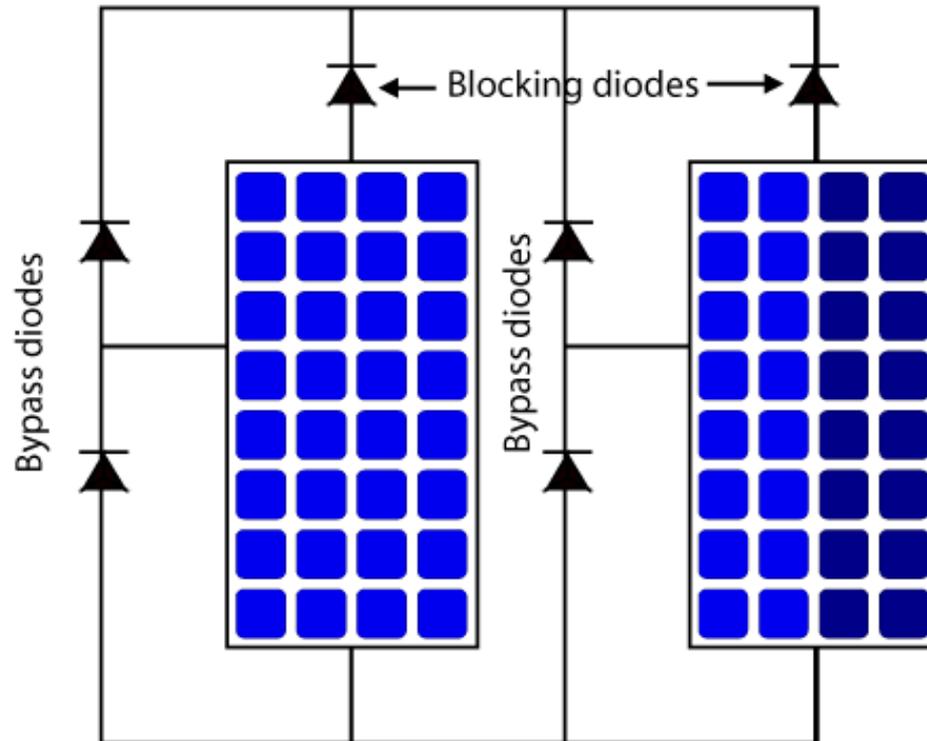


Courtesy of [PVCDROM](http://pveducation.org/pvcdrom/). Used with permission.

<http://pveducation.org/pvcdrom/modules/mismatch-effects-in-arrays>

Blocking Diodes

The blocking diode on shaded module prevents current flow into shaded module from the parallel module.



Bypass diodes reduce the impact of mismatch losses from modules connected in series.

Courtesy of [PVCDROM](http://PVCDROM.com). Used with permission.

Power Optimizers and Microinverters

- Power optimizers are DC-to-DC electronics that optimize each module at the maximum power point.
- DC-to-AC microinverters transform DC electricity directly to AC at the module.
- Advantages of integrated power electronics include: Maximum power point tracking to increase system performance, ability to integrate several modules with different power outputs (*e.g.*, shading, angle on roof).
- Disadvantages of integrated power electronics include: Decreased mean time between failure, more difficult to replace distributed components when failure occurs, greater expense per peak watt.
- “Hot” topic in PV. Podcast debate:

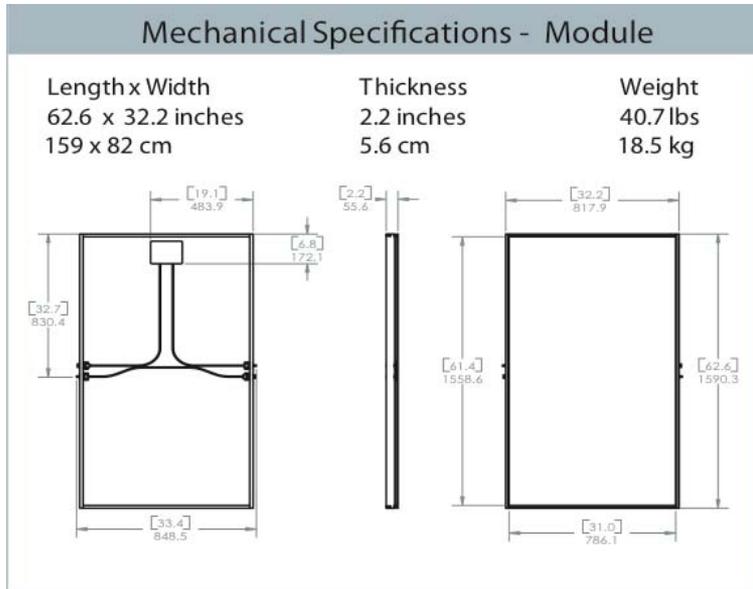
[central-inverters-is-there-a-clear-winner](#)

Solar Module Technology Trends: BIPV Modules

Photos removed due to copyright restrictions. See Lecture 17 video.

Four photos of Building-Integrated Photovoltaic (BIPV) modules.

Towards Facile Installation



Mechanical Specifications - System

	ST175-1	Non-Andalay
Racking hardware	Integrated	External
Grounding wires	Integrated	External
Wiring connections	Factory-assembled	Installer-assembled
Module-module connections	Integrated (Threaded)	External (Friction Clips)
Space between modules	1/8"	Up to 3"
Roofing penetrations	25% Fewer	Standard

UCILIA WANG: DECEMBER 10, 2009

Do-It-Yourself Solar at Lowe's

Akeena Solar's Andalay systems are designed to make it possible for handy homeowners to do their own installations.

It's inevitable: More do-it-yourself solar panels will be available, this time in your nearest Lowe's.

Lowe's is now carrying solar panels from Los Gatos, Calif.-based **Akeena Solar** that feature built-in wiring and racks and an installation technique that aims to simplify the steps and shorten the time it takes to put solar panels on a rooftop (see **video from Akeena**).



Lowe's is selling the Andalay at **\$893 per panel**, available at 25 stores in California. Akeena said handy homeowners could install the panels themselves if they don't want to hire people to do it, but they might still need an electrician to connect the rooftop system to the home's circuit.

The announcement brings home what Akeena and some other solar companies see as the future of residential solar market. Instead of hiring contractors or roofers, homeowners could install solar panels themselves and save on labor costs (see **An Ikea for Solar?** and **Getting Solar Energy Cheap and Easy**).

A number of startups are developing this kind of do-it-yourself solar energy systems, including Armageddon Energy (see **video**). Meanwhile, companies such as Dow Chemical are working on solar cell-embedded roofing materials, which will require strong insulation to protect the cells from moisture and other weather elements (see **Dow to Roofers: Our Solar Shingles Are Coming**).

Other big-box retailers such as **Home Depot already sell solar panels** and related parts, though they sell them along with installation services and even financing.

Courtesy of Greentech Media. Used with permission.

<http://www.greentechmedia.com/articles/read/do-it-yourself-solar-at-lowes/>

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Why Module Testing?

Value

- Ensure customer gets what (s)he pays for.

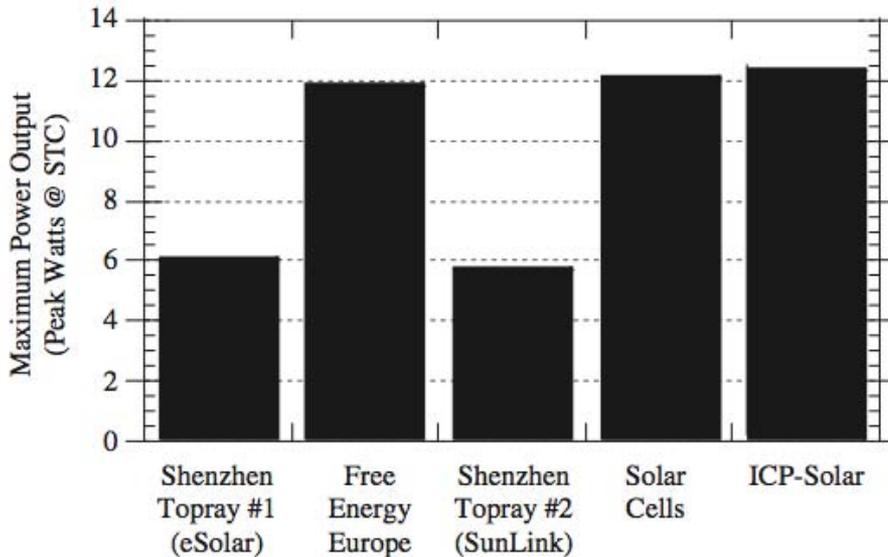


Fig. 5. Average stabilized maximum power output for five brands of 14 W rated amorphous silicon solar modules sold in Kenya. (Maximum Power at Standard Test Conditions, STC, of 1000 W/m² and 25 °C.)

Courtesy of Elsevier, Inc., <http://www.sciencedirect.com>.
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SOLAR PANEL SCANDAL!!

• 14 WATT LABEL
• ONLY 8.1 WATTS..!
• ONLY 1 YEAR WARRANTY
• MADE IN CHINA

← CHARGE ←

• 14 WATT LABEL
• OVER 17 WATTS
• 10 YEAR WARRANTY
• MADE IN U.K. BY ICP SOLAR

← CHARGE ←

BEWARE OF THE SILVER FRAME

LOOK FOR THE GOLD FRAME

Tests carried out at Loughborough University in U.K. have shown that 14 watt panels made in China only give out half the power they should do !! They are therefore actually only 8 watt panels and should cost not more than Kshs 2000/= each. They can be identified by their **silver frames**.

This scandal has been reported to the Kenya Bureau of Standards. The detailed test results can be viewed at any Sollatek Solar Distributor, Sollatek Service Centre or www.sollatek.co.ke

LOOK FOR THE PANEL WITH THE GOLD FRAME MADE IN U.K. BY ICP SOLAR AND SOLD EXCLUSIVELY BY SOLLATEK IN E. AFRICA TO BE GUARANTEED GOOD VALUE FOR YOUR MONEY.

The choice is yours!

Sollatek™

SOLAR

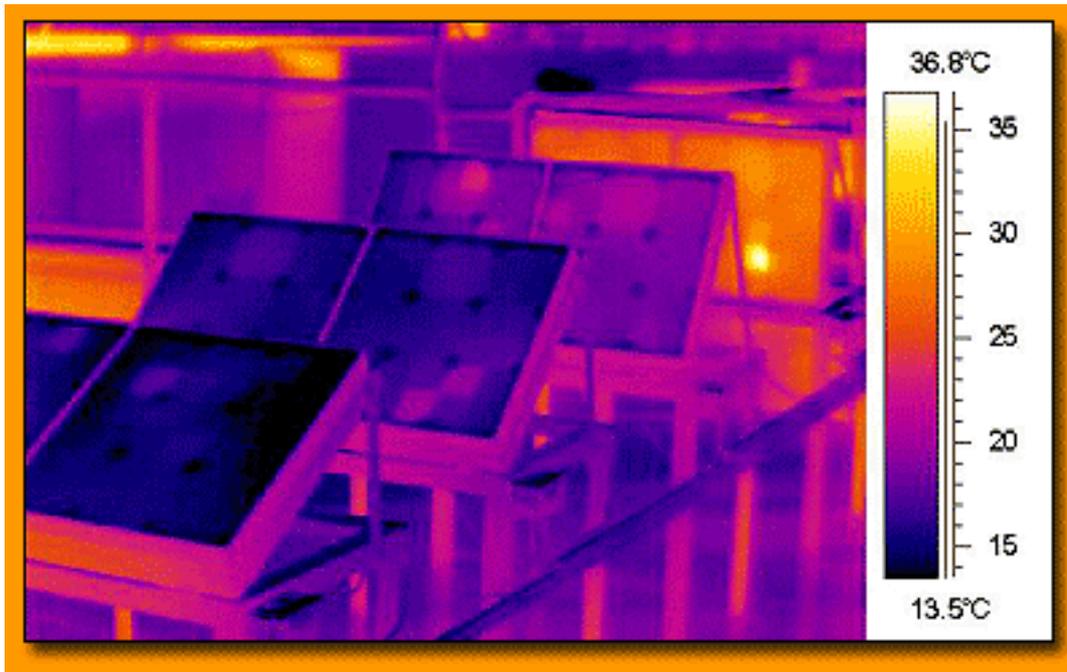
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P.O. Box 34246, Mombasa, 80118 Kenya. Telkom: (041) 5486250/1,2,3 Fax: 5486259,
Mobiles: 0733 615727 /610753 or 0722 764643
e-mail: sales@sollatek.co.ke

A. Jacobson and D. Kammen, “Engineering, institutions, and the public interest: Evaluating product quality in the Kenyan solar photovoltaics industry,” *Energy Policy* **35**, 2960 (2007).

Why Module Testing?

Safety

- Poorly made modules can have electrical arcs in their junction boxes or hotspots on the module itself, which can cause fires.



Hotspot on solar module imaged by thermography:
http://www.chemeng.ntua.gr/solarlab/Research_Photovoltaiic.html

How Module Testing?

Standard IEC Tests for crystalline silicon and thin film modules:

http://www.iecee.org/ctl/equipment/pdf/pv/EL_IEC61646_Ed1_final.pdf

http://www.iecee.org/ctl/equipment/pdf/pv/EL_IEC61730-2_approved.pdf

http://www.iecee.org/ctl/equipment/pdf/pv/EL_IEC61215_Ed1_final.pdf

Photos of PV module testing removed due to copyright restrictions.
See Lecture 17 video.

Reliability & Safety

Reliability and Safety

Tested by leading international institutes and certified for reliability and safety.

- Certified to IEC 61646
- Certified to IEC 61730
- CE Mark
- Safety Class II @ 1000 V

- UL 1703 and ULC 1703 Listed
(Class C Fire Rating)
- Eligible CSI PV Module
- FSEC Certification



<http://www.firstsolar.com/>

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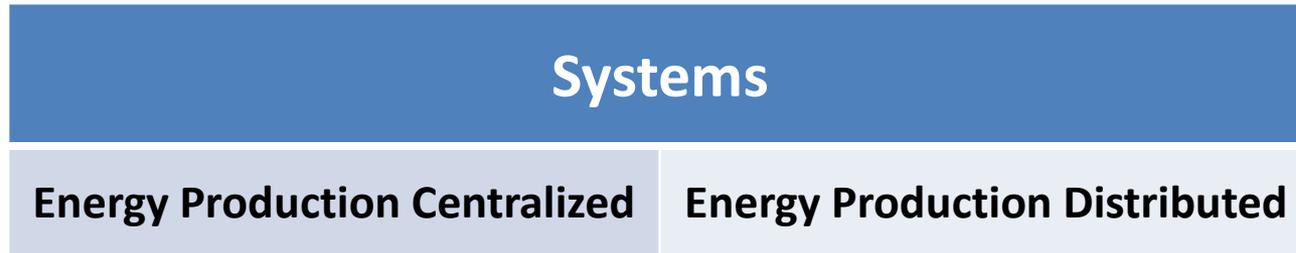
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Systems: Grid-tied and stand-alone.

System Design

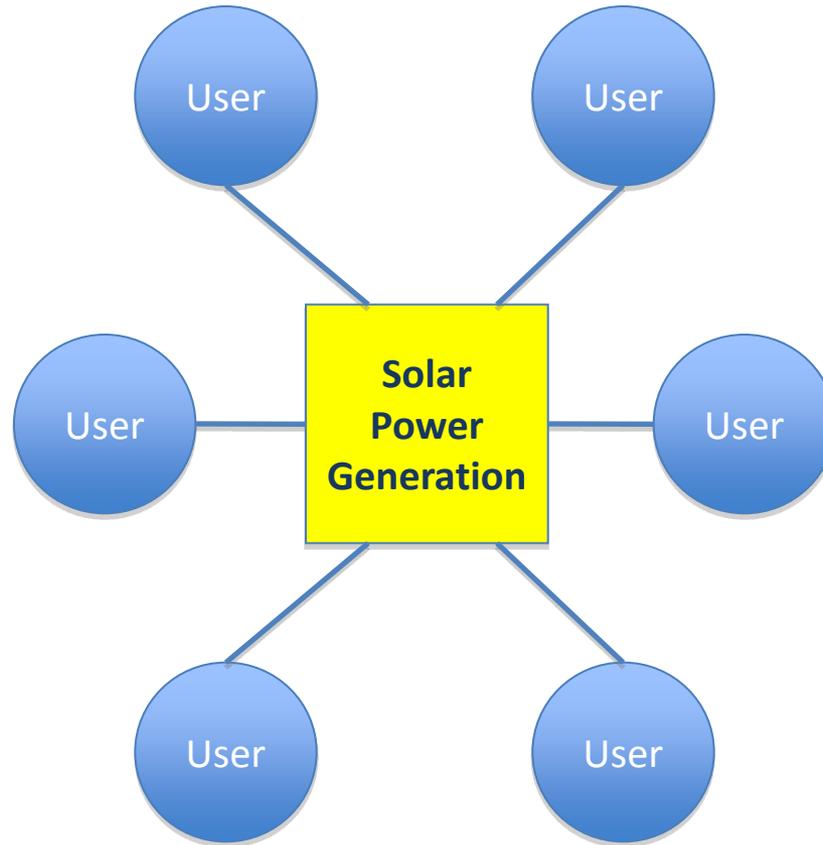
(Infrastructure Beyond Conversion Devices)



Systems

Energy Production Centralized

Energy Production Distributed



Today's typical centralized installation typically exceeds 500 kW_p.

Systems

Energy Production Centralized

Energy Production Distributed

Please see the Lecture 17 video for these three examples.

20 MW_p plant in Spain.

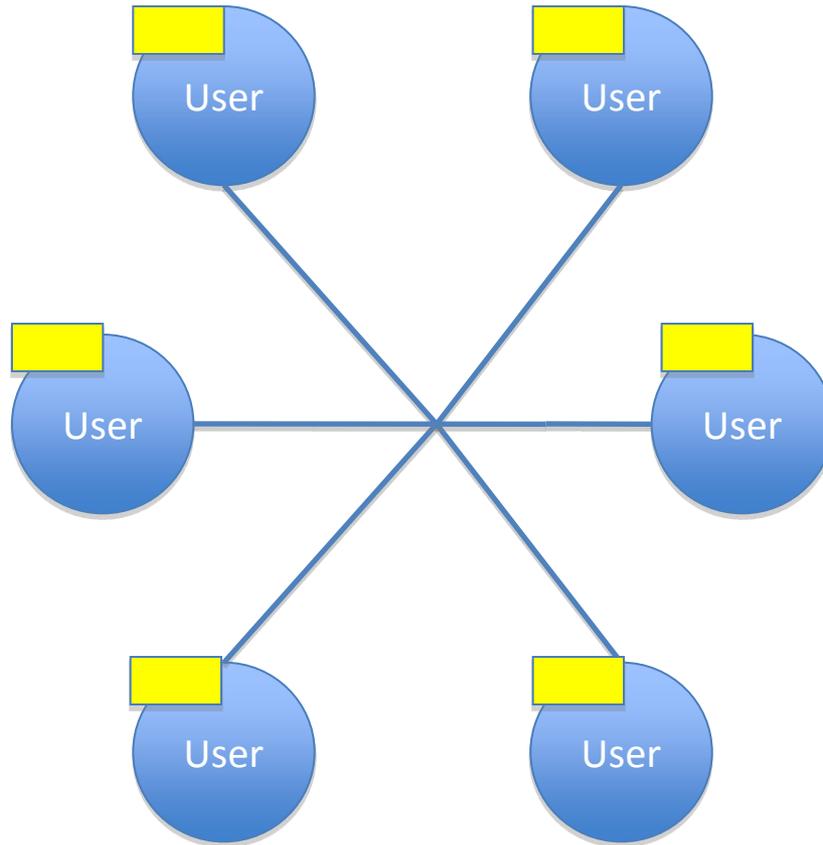
11 MW_p plant in Portugal

Bavaria, Germany

Systems

Energy Production Centralized

Energy Production Distributed



Today's typical distributed installation is typically less than 10 kW_p , but can 675 kW_p or larger.

Systems

Energy Production Centralized

Energy Production Distributed

Please see the Lecture 17 video for these three examples.

675 kW_p system, Moscone Center, SF.

Amersfoort, Netherlands

House in Rochester, NY

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Grid-Tied PV Systems

- PV array connected to utility grid via an inverter
- Excess power sent to grid (e.g., meter spins backwards)
- Relies on utility grid as “energy storage device” (no batteries required)
- Mounted on roof or ground
- Any business or residence can use grid tied solar

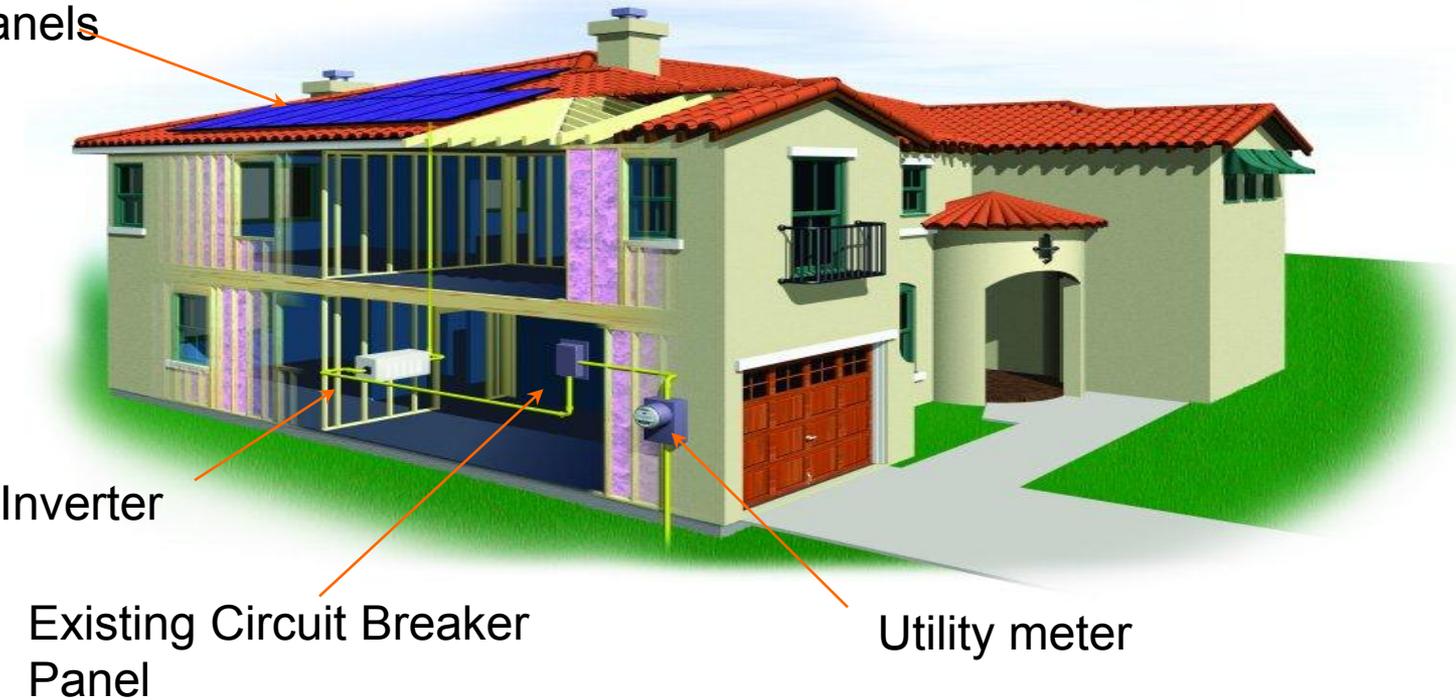


Picture credit: Borrego Solar

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Grid-Tied PV Systems

Solar Panels



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Inverters

- Typically use higher voltage string inverters
 - Battery backup is exception
- Sizes range from 700-6000W
- Modern efficiencies range from 94-99%
- All have maximum power point tracking (MPPT)
- 5 Year manufacturer warranty
- Usually governed by array considerations



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Mounting Methods

- Roof Mount or Stand Off
 - Least expensive
 - Usually require penetrations
- Ground Mount
 - More expensive
 - Usually only option for large arrays
- Pole Mount
 - Can be more expensive
 - Adjustable height, and flexible orientation



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Slide content courtesy of Borrego Solar

Grid-Tied PV Systems

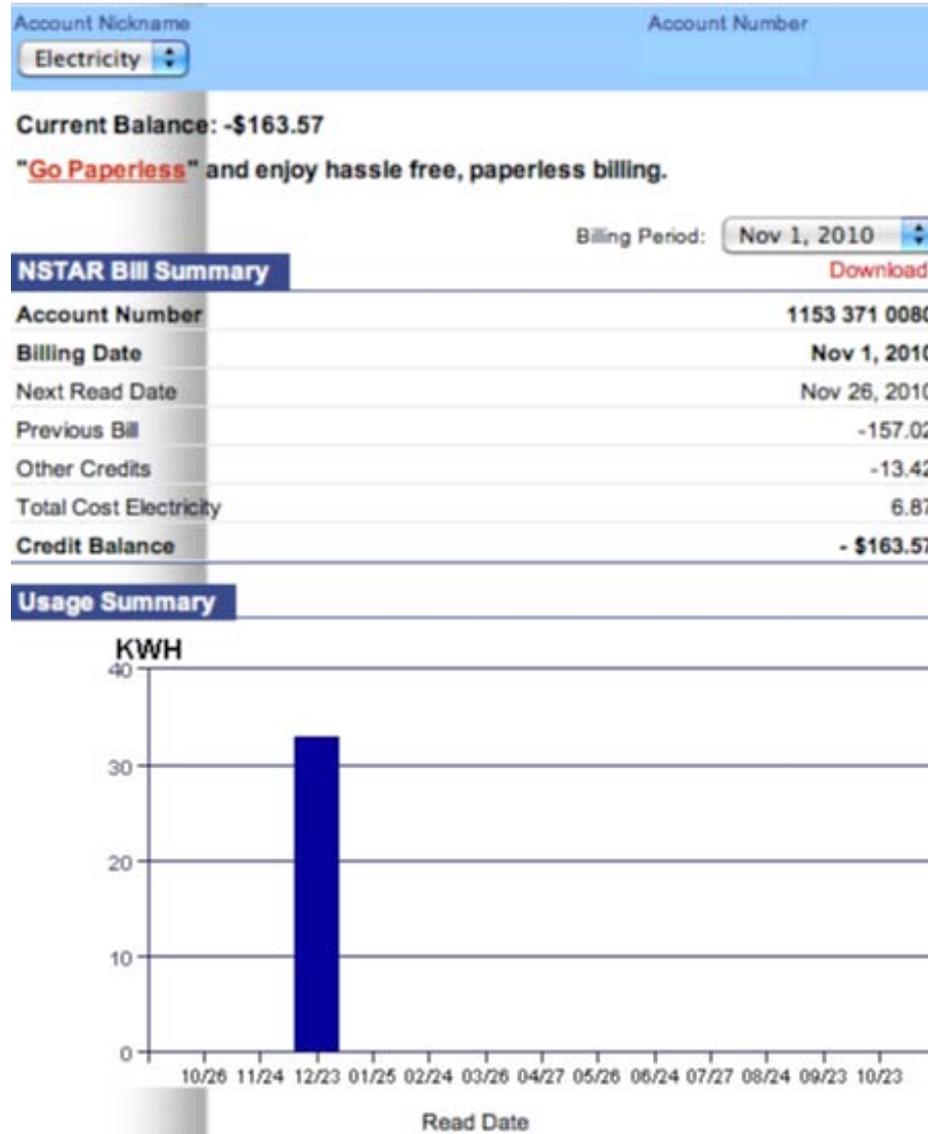
- Under “net metering” (i.e., same price for all electrons): When panels produce excess power meter spins backwards. Only pay utility for distance meter spins forwards. Only pay once a year.
- Under “feed-in tariff” or “time-of-use” (i.e., price for electrons varies depending on time of day, value of source): Separate meters, for energy consumed and produced.

Meter Spins Backwards!

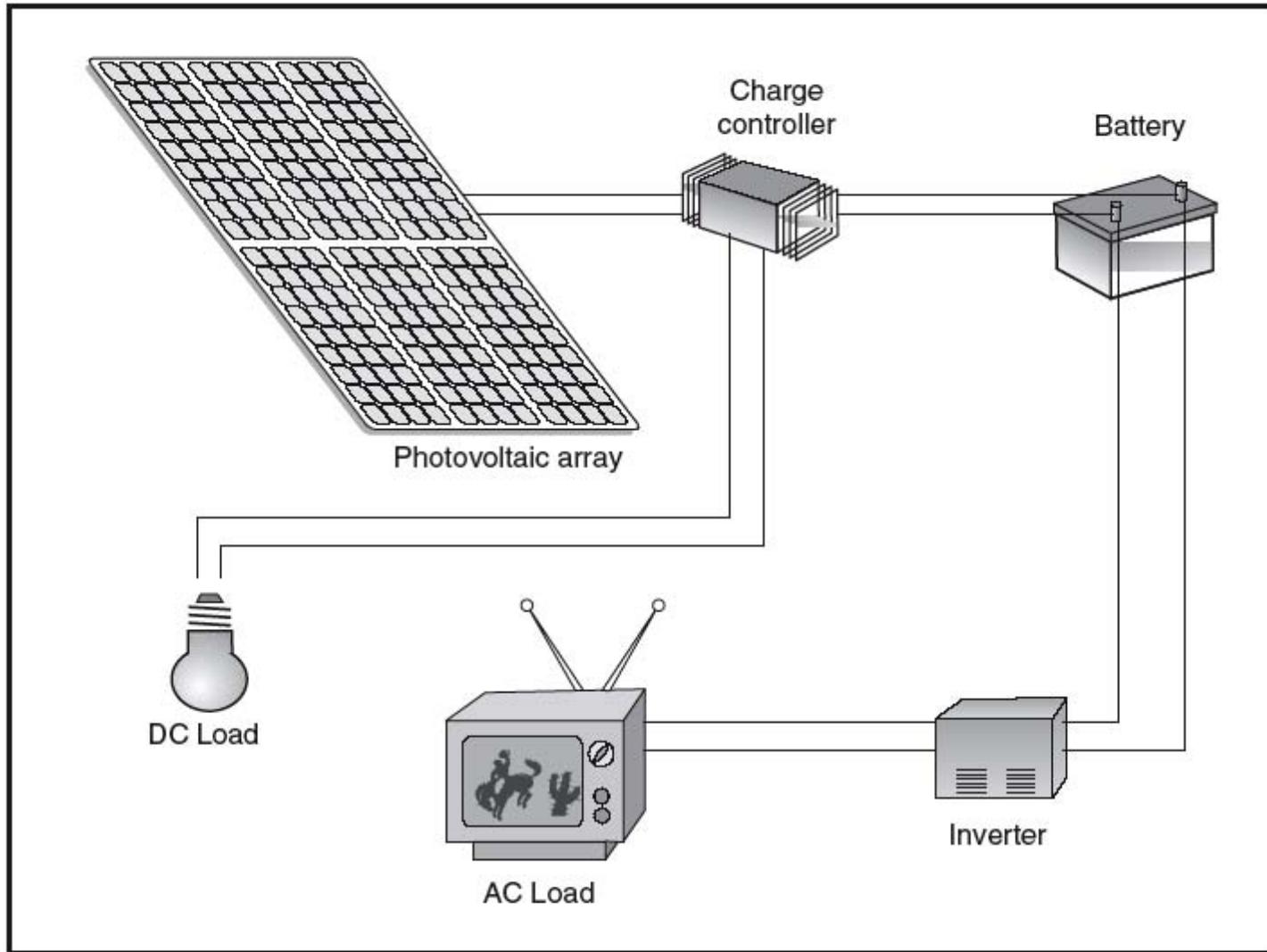


Photo courtesy of [coldtaxi](#) on Flickr.

Prof. Buonassisi's Electricity Bill



Off-Grid PV Systems



Components of a typical off-grid PV system *Solar electricity can be used for many purposes, either directly, or by storing in batteries for use when the sun is not shining.*

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Life is Good as an Installer...

Module prices ~\$1/W_p...

...but installations ~\$5.20/W_p!

NEWS | SOLAR

ERIC WESOFF OCTOBER 14, 2011

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Solar Module Pricing: \$1.03 per Watt for c-Si

How low can it go?



Admittedly, Chinaland Solar Energy might not be the most bankable solar firm out there, but since they were kind enough to approach me via email, I figured, let's get a price quote.

I requested a quote for 100 units of a 200-watt solar panel and received this response within 30 minutes.

Chinaland Solar Energy Co., Ltd.

Address: Feidong New City Economic Development Zone, Hefei, 231600, Anhui Province, PR China

TEL: 0086 551 7758558-8029 Mobile: 0086 13275799897 FAX: 0086 551 7758555

E-mail chn2012@chnland.com

website www.chnland.com

Image	Model	Specification
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Polycrystalline solar panel

Remark: The Specification is just for reference, the exact one subjects to flash report tested for each shipment.

	CHN200-72P	Cell type	Monocrystalline	
		Max Output Power	200W	
		Max Power Voltage	37V	
		Max Power Current	5.41A	
		Open Voltage	45V	
		Short Circuit Current	5.8A	
		Dimension of module	1580*808*40 mm	
		20ft/40ft container	372pcs/784pcs	
		Cell type	156*156mm 72pcs	
		Conversion efficiency	18.31%	
		Certificate	CE, TUV, IEC, MCS, ISO	
		Life time	25 years	
			1*20'FCL/1*40'FCL	372pcs/784pcs
		Payment terms	30% DEPOSIT 70% AFTER SENDING SCANNED ORIGINAL BL	
Price	FOB USD1.03/W			
Delivery time	5 days after receiving 30% deposit			

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US Has an Average Solar System Price of \$5.20/W

Decrease of just 3 percent in Q2 2011



Average weighted photovoltaic installation price decreased just 3 percent in the second quarter of 2011 to \$5.20 per watt, according to GTM Research and the Solar Energy Industries Association's latest quarterly **U.S. Solar Market Insight** report.

Residential system prices were virtually flat quarter over quarter, increasing slightly from \$6.39 per watt in the first quarter to \$6.42 per watt in the second quarter of 2011. Residential systems are typically slow to adjust... [Read More](#)

Source: www.greentechmedia.com

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6. List major balance of system components.
7. Describe current consensus of life cycle analysis studies, and recycling of modules.

Life Cycle Analysis (LCA) of PV Technologies

Key Factors:

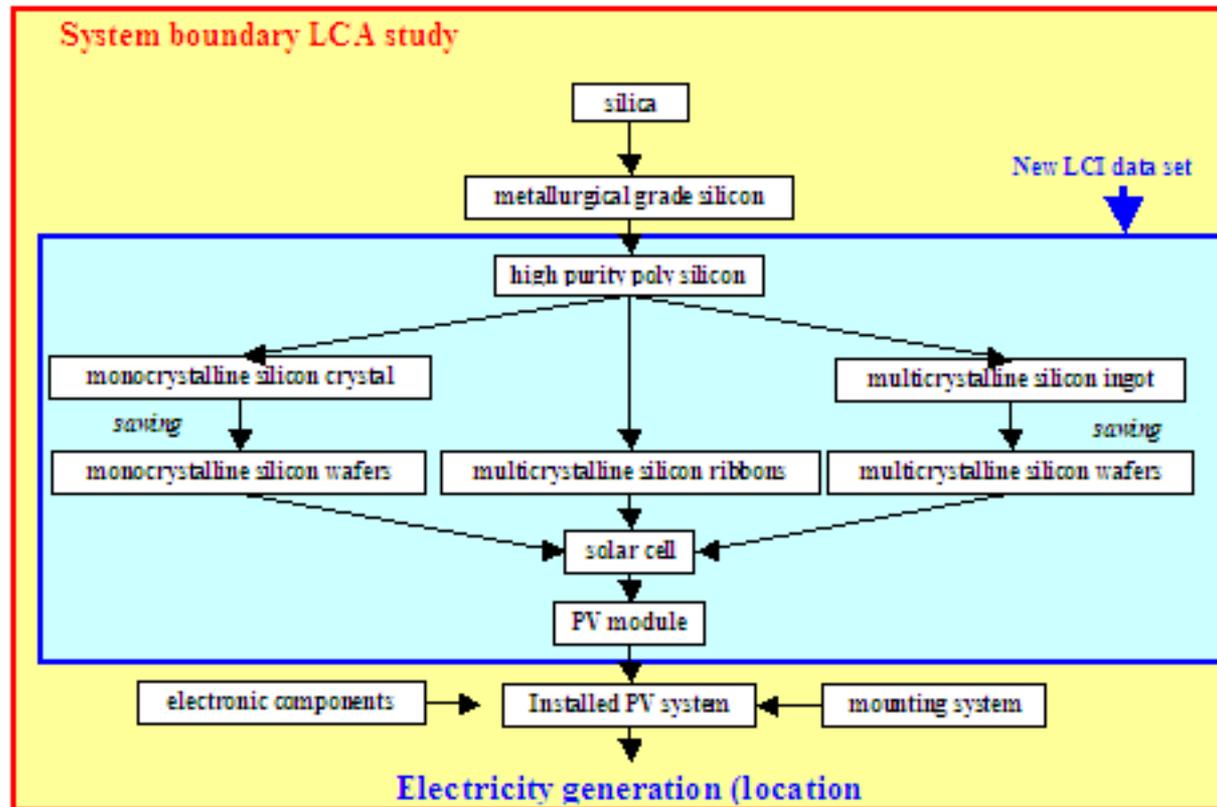
- Boundary Conditions
- Inputs
- Outputs

Notable Groups:

- Vasilis M. Fthenakis (Brookhaven National Laboratory)
- Energy Center of the Netherlands

LCA Boundary Conditions

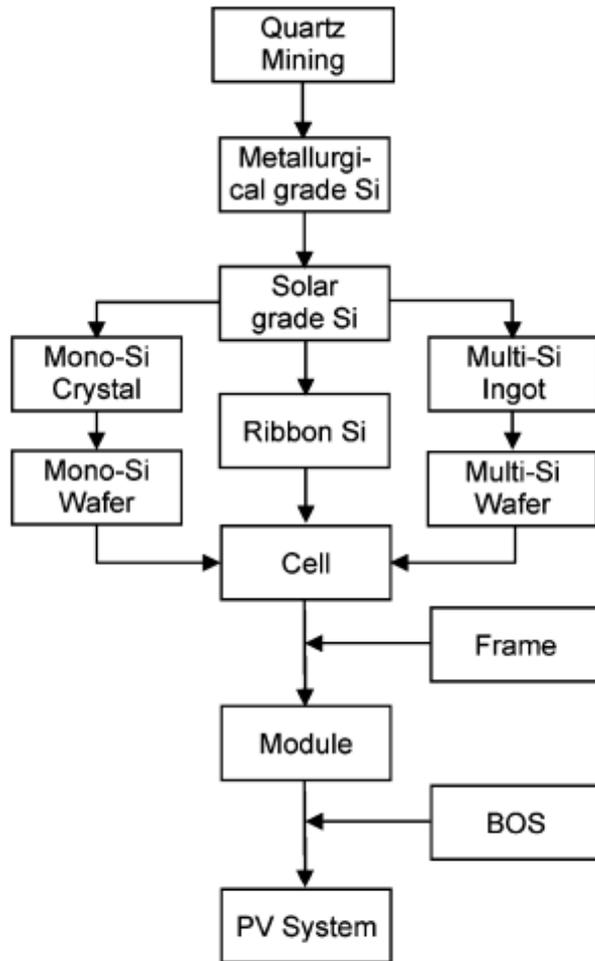
Boundary conditions define the scope. *Limited boundary conditions may compromise validity of the study!*



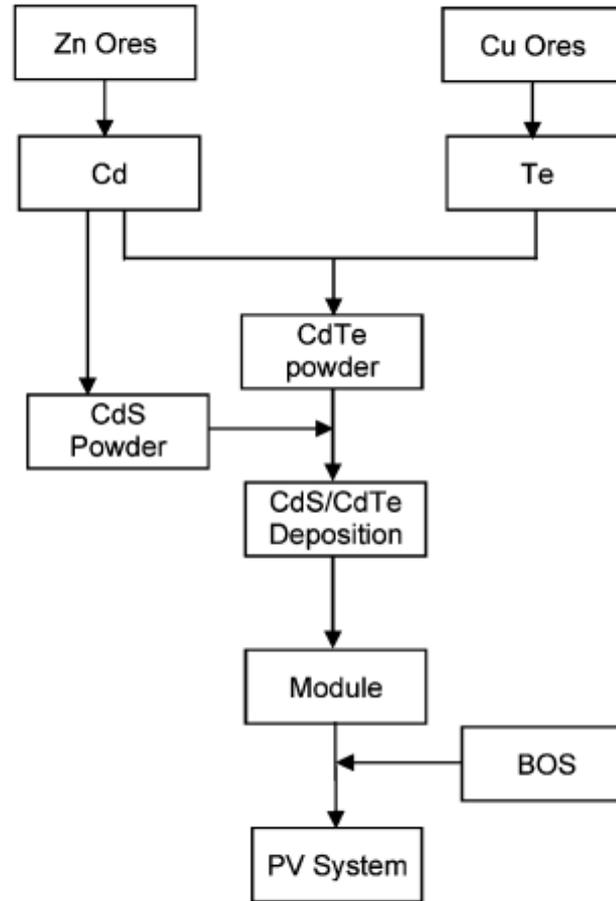
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“State-of-the-art photovoltaic systems have Energy Pay Back Times as low as 1.7 years.” *ECN News*, 15 May 2006.

LCA Boundary Conditions



(a) Silicon PVs



(b) CdTe PVs (frameless)

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Fthenakis, V. M., et al. "Emissions from Photovoltaic Life Cycles." *Environ. Sci. Technol.* 42, no. 6 (2008): 2168-2174.

See also "Photovoltaic Cells Are Still Very Green, Comparative Test Shows." *The New York Times*, Feb. 26, 2008.

LCA Inputs

Some Key Inputs (Assumptions!) into LCA Models:

- Module lifetime
- Wafer thickness
- Cell / module efficiency
- Manufacturing yield
- Energy mix

Nota bene:

The outputs of comparative LCA studies are extremely sensitive to these key inputs.

LCA Outputs

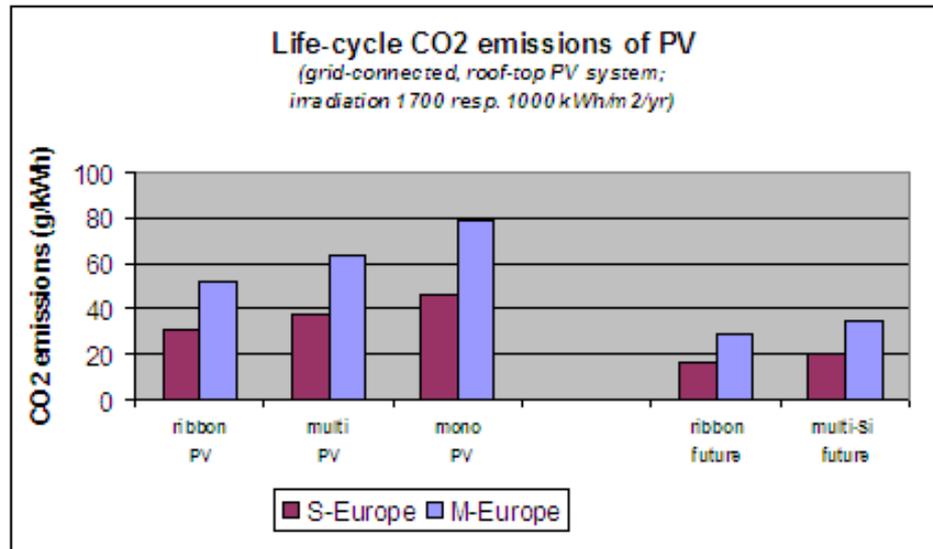
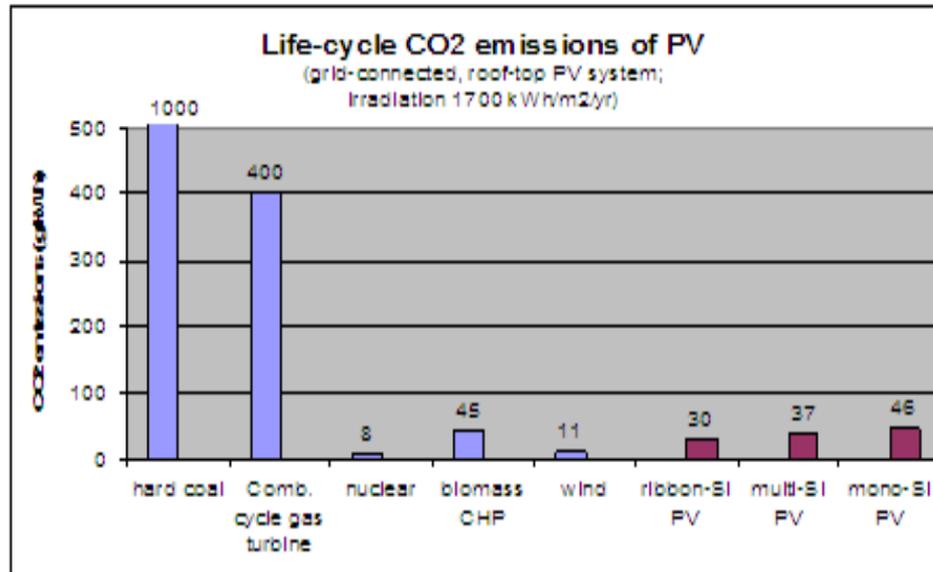
Some Key LCA Outputs:

- Energy payback time
- CO₂ emissions per unit energy produced
- Toxic releases

Nota bene:

The outputs of comparative LCA studies are extremely sensitive to key inputs and to the boundary conditions. Hence, variations of a few percent – even a few tens of percent – are not generally considered significant. These studies are helpful when comparing orders of magnitude.

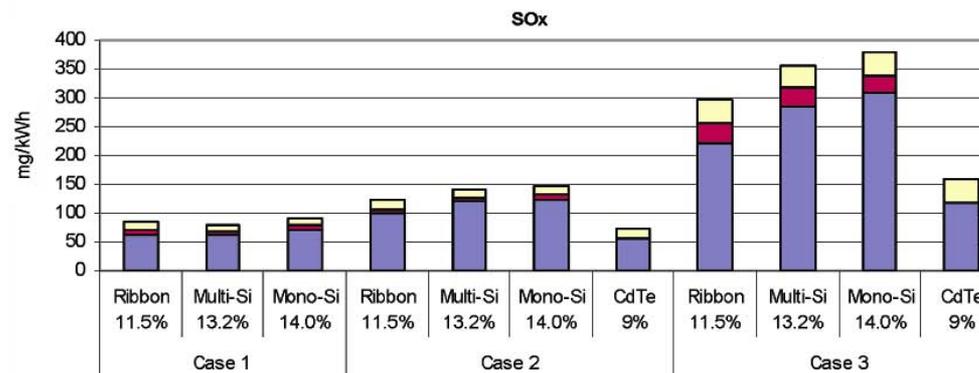
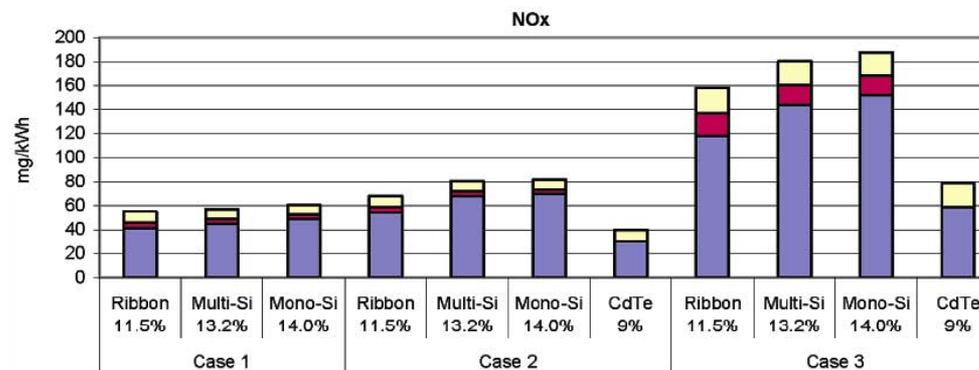
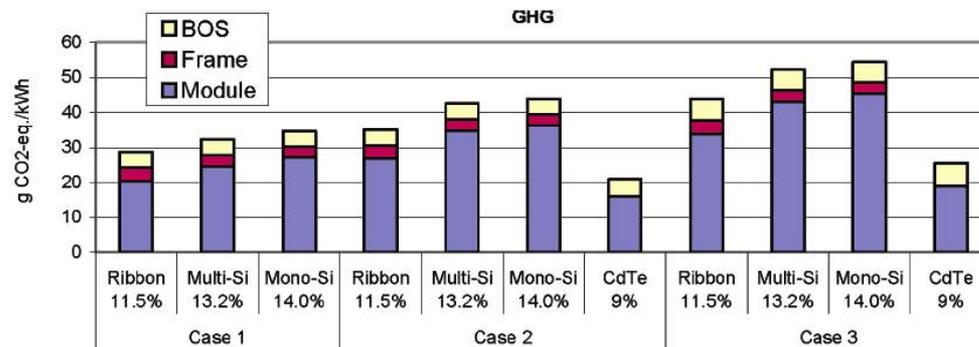
LCA Outputs: Life Cycle CO₂ Emissions



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“State-of-the-art photovoltaic systems have Energy Pay Back Times as low as 1.7 years.” *ECN News*, 15 May 2006.

LCA Outputs: Life Cycle CO₂ Emissions

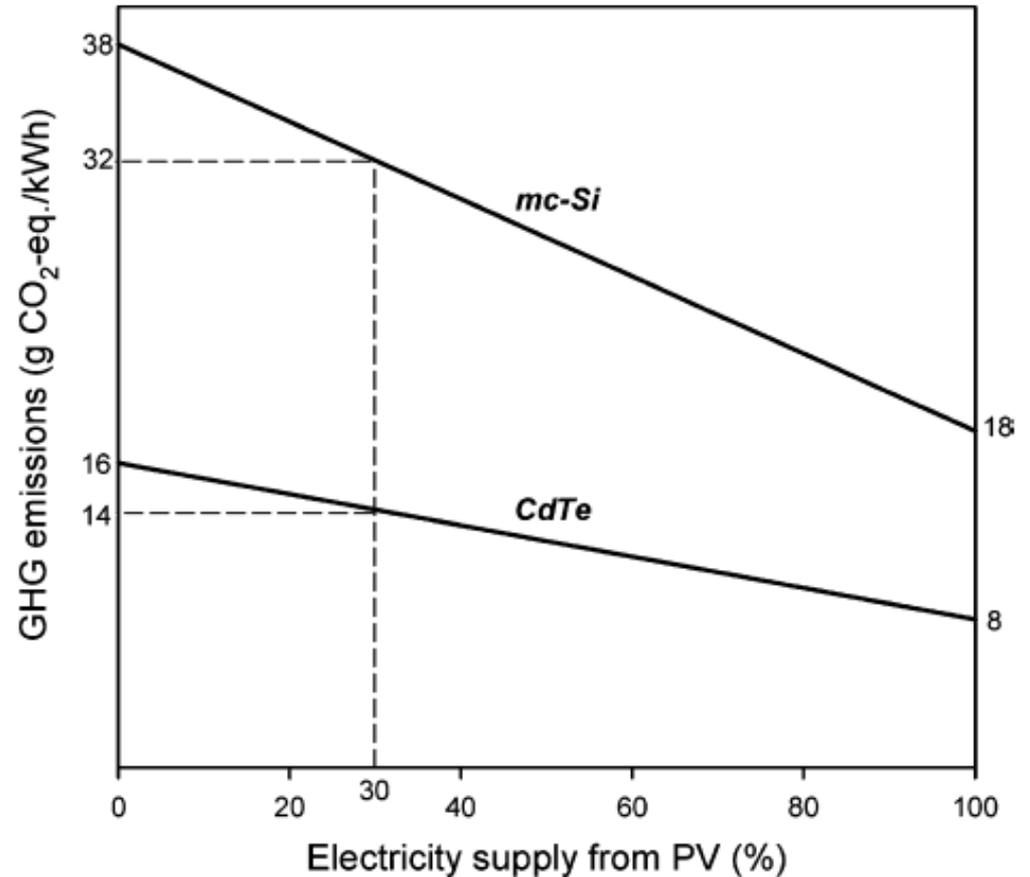


Fthenakis, V. M., et al. "Emissions from Photovoltaic Life Cycles." *Environ. Sci. Technol.* 42, no. 6 (2008): 2168-2174.

FIGURE 2. Life-cycle emissions from silicon and CdTe PV modules. BOS is the Balance of System (i.e., module supports, cabling, and power conditioning). Conditions: ground-mounted systems, Southern European insolation, 1700 kWh/m²/yr, performance ratio of 0.8, and lifetime of 30 years. Case 1: current electricity mixture in Si production—CrystalClear project and Ecoinvent database. Case 2: Union of the Co-ordination of Transmission of Electricity (UCTE) grid mixture and Ecoinvent database. Case 3: U.S. grid mixture and Franklin database.

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LCA Outputs: Sensitivity to Energy Inputs

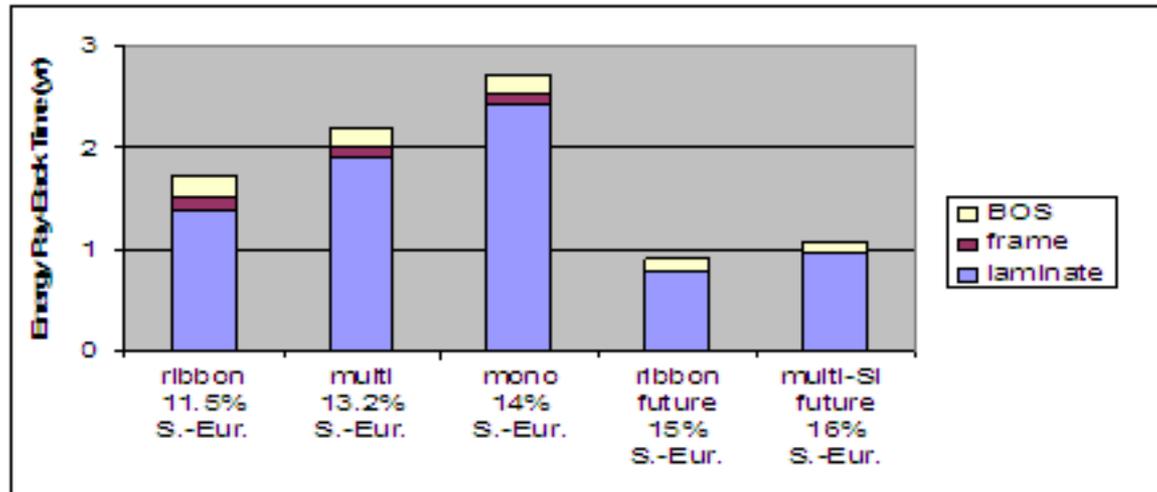
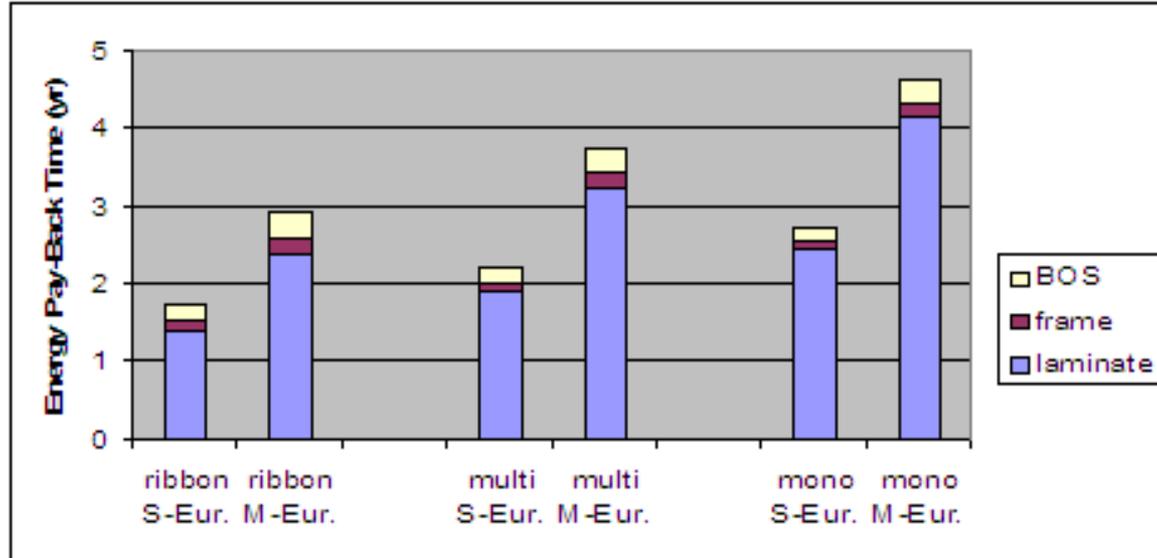


Fthenakis, V. M., et al. "Emissions from Photovoltaic Life Cycles." *Environ. Sci. Technol.* 42, no. 6 (2008): 2168-2174.

FIGURE 6. Greenhouse gas emissions profile for PV modules when using a PV breeder that supplies electricity for PV production. Insolation of 1700 kWh/m²/yr, performance ratio of 0.8, and lifetime of 30 yrs are assumed. BOS is not included. In 2005, the total (100%) electricity corresponded to 250 kWh/m² for mc-Si and 59 kWh/m² for CdTe PV.

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LCA Outputs: Energy Payback



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“State-of-the-art photovoltaic systems have Energy Pay Back Times as low as 1.7 years.” *ECN News*, 15 May 2006.

LCA Outputs: Energy Payback

	Consumed energy of PV module	
	Standard	Recycled
Silicon production	7,55 kWh/wafer	-
Solar cell production	0,65 kWh/wafer	0,65 kWh/wafer
Module production	1,12 kWh/wafer	1,12 kWh/wafer
Recycling at end of life	-	0,4 kWh/wafer
Total	9,32 kWh/wafer 0,129 kWh/kWh _{Gen}	2,17 kWh/wafer 0,030 kWh/kWh _{Gen}

Table 3: Energy content of a module using virgin wafers and a module using recycled wafers

Great study, but old data (2000).

	Standard	Recycled
Energy input	9,32 kWh/wafer or 4,26 kWh/Wp	2,17 kWh/wafer 0,99 kWh/Wp
Energy pay back time		
Sunny regions	2,58 years	0,6 years
Continental regions	4,92 years	1.14 years

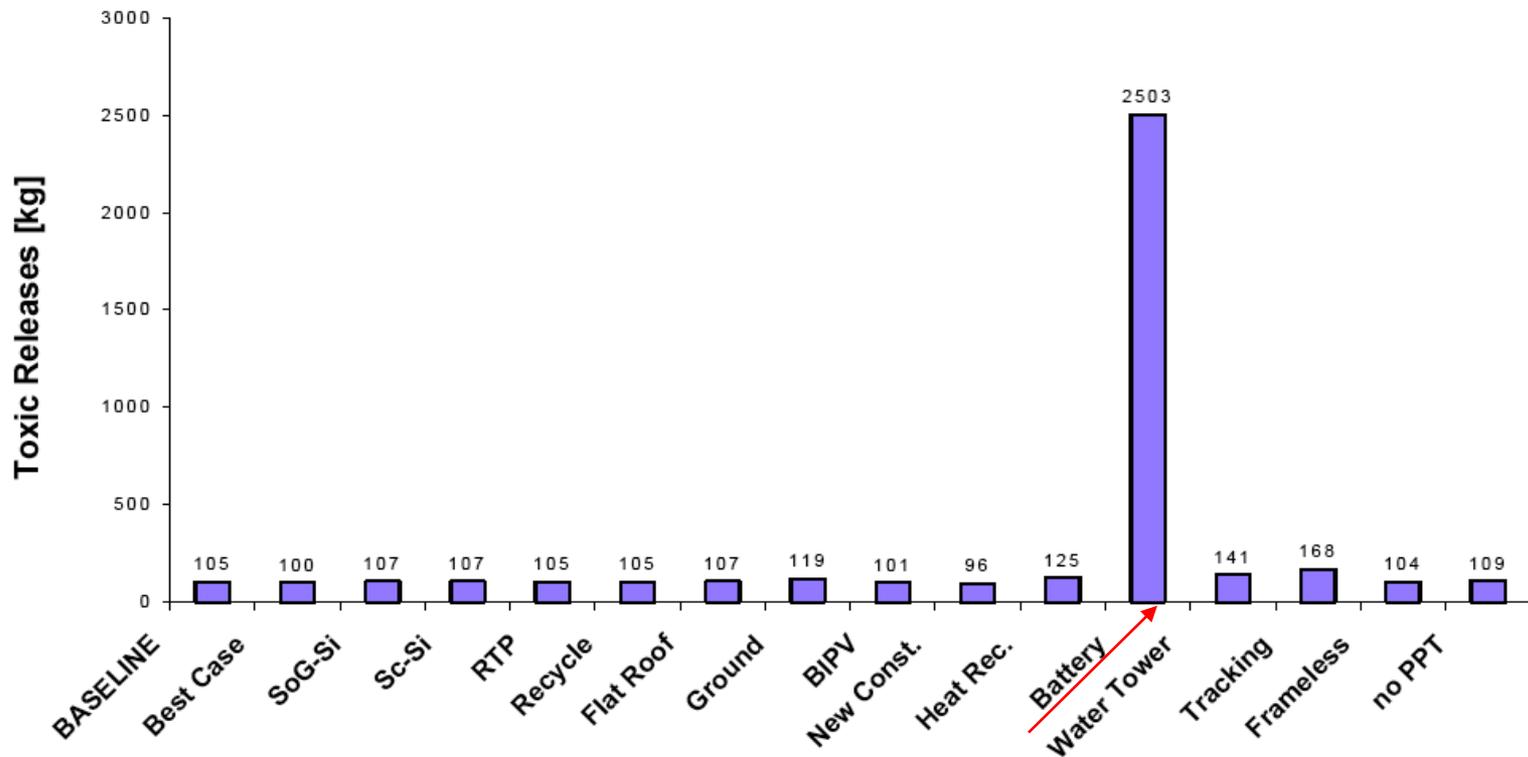
Table 4: Energy pay back time for a module using virgin wafers and a module using recycled wafers

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L. Frisson *et al.* "Recent Improvements in Industrial PV Module Recycling." *16th European PV Solar Energy Conference*, Glasgow, UK (2000)

LCA Outputs: Toxic Releases

Batteries: Add financial cost, environmental impact.



Technology Choices for the PV Industry: A Comparative Life Cycle Environmental Impact Perspective.

T. Williams, S. Boyd, T. Buonassisi, Proc. 21st EU-PVSEC (Barcelona, Spain, 2005)

LCA Outputs: Toxic Releases

Cadmium: Topic of controversy!

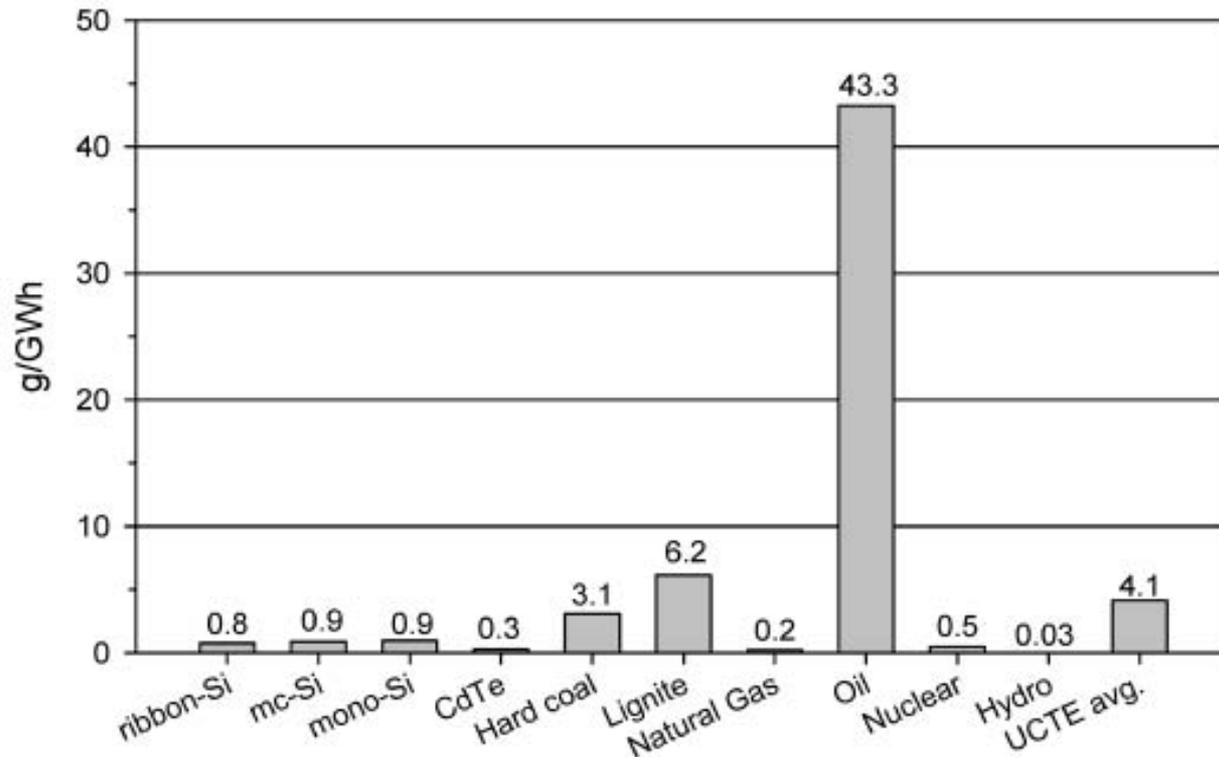


FIGURE 3. Life-cycle atmospheric Cd emissions for PV systems from electricity and fuel consumption, normalized for a Southern Europe average insolation of 1700 kWh/m²/yr, performance ratio of 0.8, and lifetime of 30 yrs. Ground-mounted BOS (18) is assumed for all PV systems; comparisons with other electricity generation options.

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Fthenakis, V. M., et al. "Emissions from Photovoltaic Life Cycles." *Environ. Sci. Technol.* 42, no. 6 (2008): 2168-2174.

LCA Bottom Line

LCAs indicate that current PV technology:

- Emits 90-96% less CO₂/kWh than coal.
- Has a 1-5 year energy payback.
- Has little differences between PV technologies.

PV Module Recycling

- Required by law in some places for certain types of modules (e.g., First Solar modules in Germany).
- Industry-wide groups promote best practices.
- Necessary to develop for when the industry reaches steady-state (while growth rate is positive, the volume of new panels swamps out those being recycled).

Tuesday, 16:30 - 18:00

Commercial-Scale Recycling of Photovoltaic Modules

L. Krueger*, A. Meader, K. Squires
First Solar, Inc.
*Corresponding author



In line with extended producer responsibility First Solar has developed and implemented the industry's first prefunded Module Collection and Recycling Program. This program:

- Provides for the collection and recycling of modules at any time, at no additional charge
- Prevents waste management issues for future generations
- Maximizes the recovery of valuable materials for use in new solar modules or other new products

First Solar's Module Collection and Recycling Program is helping to minimize any adverse environmental impacts associated with PV systems, allowing First Solar to make a significant contribution to the challenges of achieving energy independence and combating climate change.

First Solar's Module Recycling Process results in a 90% overall recycling rate, including:

- ~95% recycling of semiconductor material for use in new modules
- ~90% recycling of glass for use in new glass products



Aspiration System
This aspiration system is used for dust control in all of the parts of the recycling process and is equipped with one million and high efficiency particulate air filters (HEPA) which are 99.99% efficient. Collected dust and fibers are disposed of in an environmentally safe manner.

Collection
First Solar provides online resources for customers to request a collection service. Once all First Solar modules are collected, they are transported to a recycling facility and loaded on trucks for a 400-mile haul.

Shredder
The modules are reduced in size in a shredder to create a smaller size for easier handling. The shredder also has large rollers to break the modules into large pieces.

Hammermill
In this step, the hammermill reduces the glass substrate into small particles. The hammermill is equipped with a hammer to break the glass into small pieces.

Film Removal
The semiconductor films are physically removed from the glass substrate in a series of steps. The film is then washed and dried to remove any remaining material.

Solid-Liquid Separation
The glass is washed with water to remove any remaining semiconductor material. The water is then separated from the glass.

Precipitation
The semiconductor material is precipitated from the water. The precipitate is then washed and dried to remove any remaining water.

Dewatering
The semiconductor material is dewatered to remove any remaining water. The dewatered material is then washed and dried to remove any remaining water.

Metal-Rich Filter Cake
The metal-rich filter cake is a byproduct of the recycling process. It is used in a variety of applications, including as a feedstock for the production of new solar modules.

Clean Glass
The clean glass is a byproduct of the recycling process. It is used in a variety of applications, including as a feedstock for the production of new solar modules.

Glass-Laminate Material
The glass-laminate material is a byproduct of the recycling process. It is used in a variety of applications, including as a feedstock for the production of new solar modules.

Glass Rinsing
The glass is rinsed to remove any remaining semiconductor material. The rinsed glass is then washed and dried to remove any remaining water.

	Maximum Achieved Capacity	Total Volume Recycled (Through August 2009)
Facility 1 (PBG)	105 tons/week	2360 tons
Facility 2 (PBG)	70 tons/week	3140 tons
Facility 3-4 (P&M)	155 tons/week	5380 tons
Total Combined	330 tons/week	10880 tons



Visual presentation by First Solar at the 2009 EU-PVSEC

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