National Renewable Energy Laboratory
Innovation for Our Energy Future

Solar Technology Overview

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NREL
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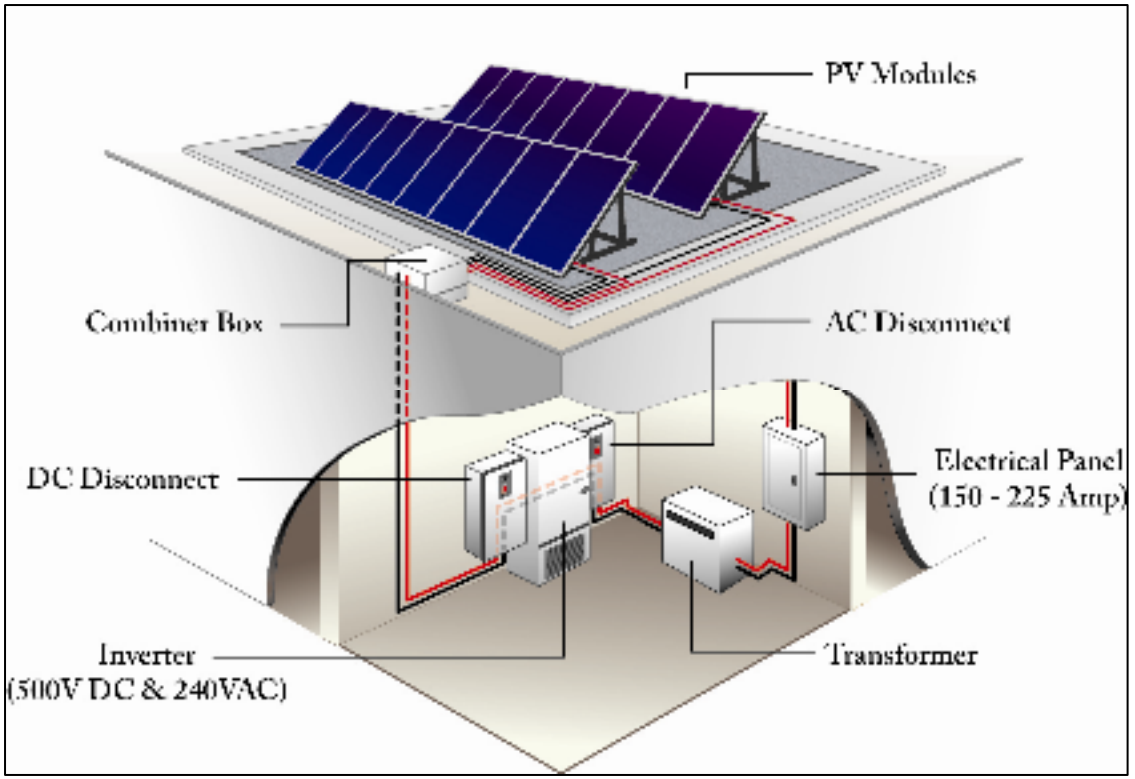
Funded By:
SOLAR AMERICA COMMUNITIES

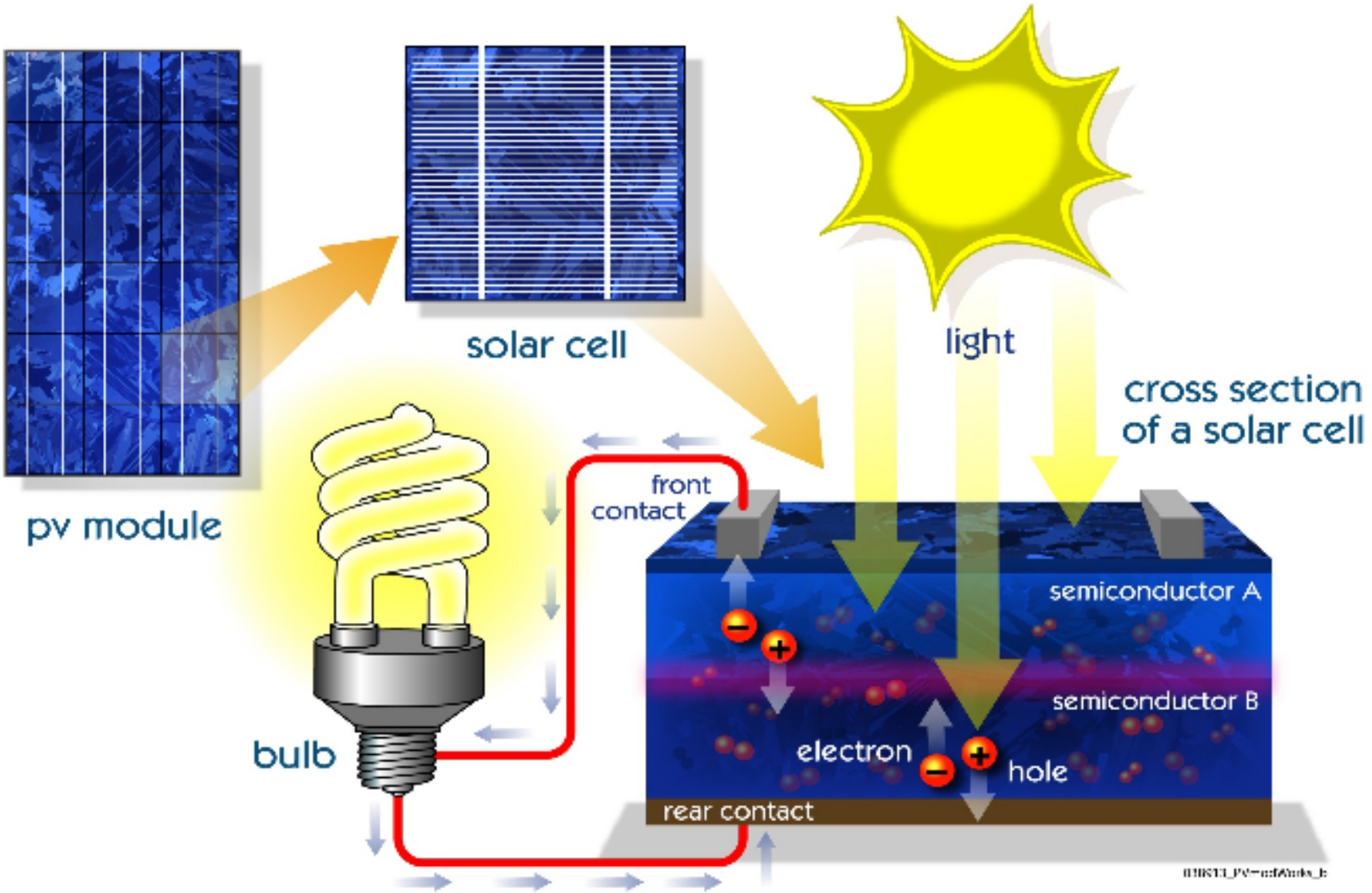
PV Technology Overview

- Direct conversion of sunlight into DC electricity
- DC converted to AC by inverter

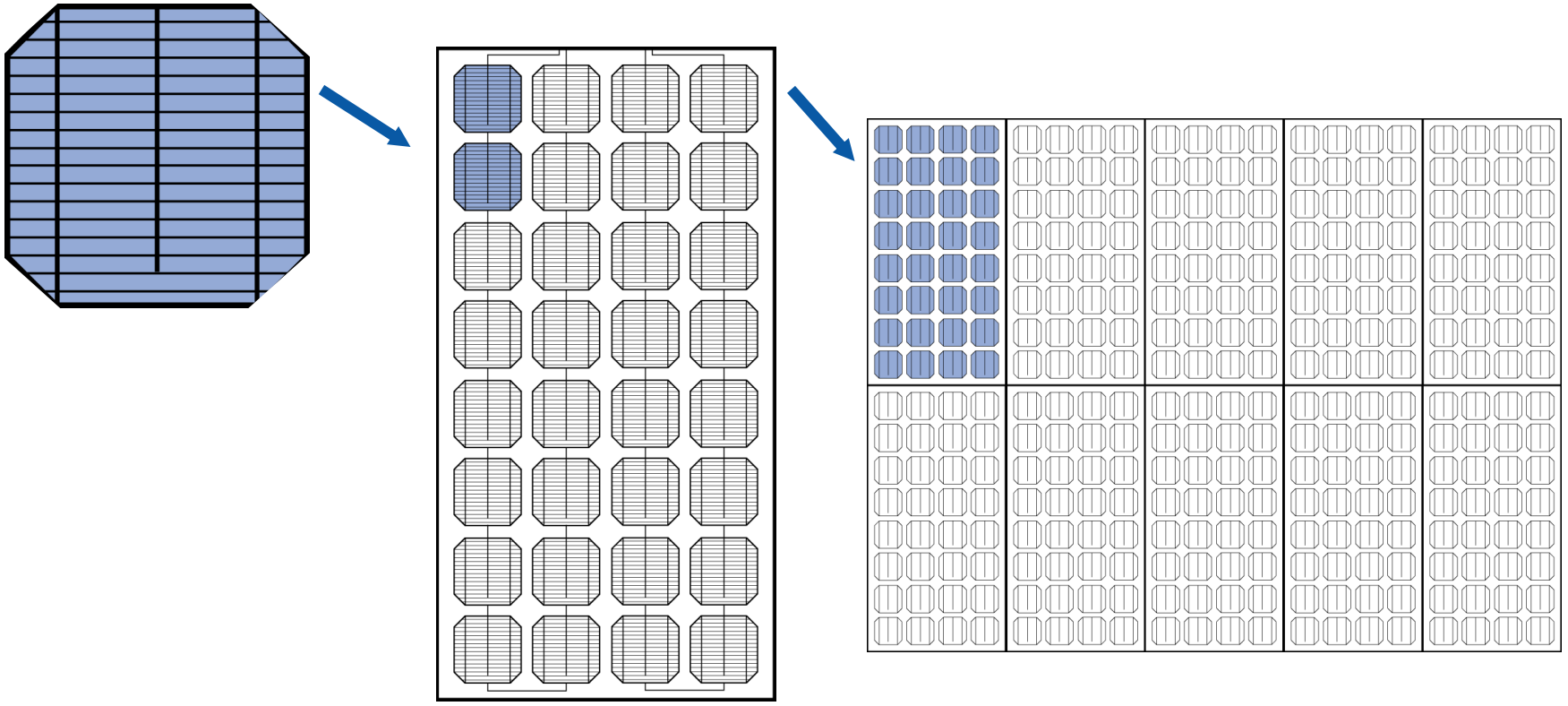


- Solid-state electronics, no-moving parts
- High reliability, warranties of 20 years or more
- PV modules are wired in series and parallel to meet voltage and current requirements

Solar Cell Operation



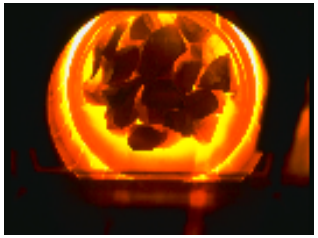
PV is *Modular*

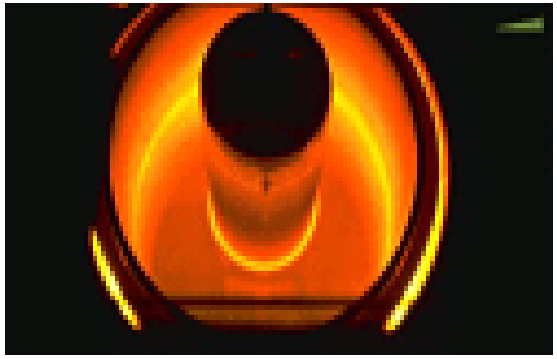


Cells are assembled into ***Modules***... and modules into arrays.

PV Manufacturing

Single Crystal





Multi-Crystal

Thin Film

Efficiency of Different Types of PV

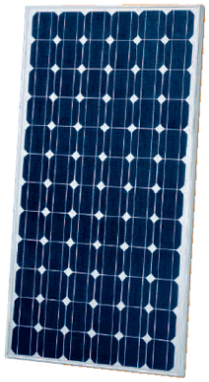
Year	Crystalline Silicon			Thin-Film Silicon		Concentrator Silicon
	Single-Crystal	Cast	Ribbon	Amorphous Silicon	Other	
2007	17	14	12	8	12	35
2008	19	14	13	8	12	34
2009	20	14	13	8	12	38

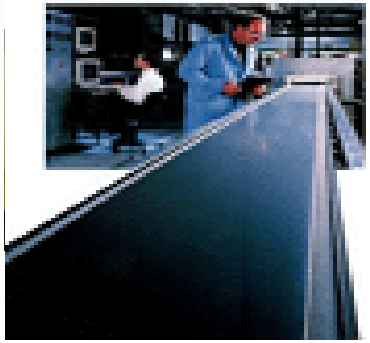
Source: U.S. Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Photovoltaics Types

PV Cell Types

Single Crystal * Multi-Crystal * Thin Film * Cadmium Telluride * CIGS





Efficiencies:

14 to 23% 13 to 17% 6 to 11% 10% to 11% 12% to 14%

PV Manufacturers
(Partial list)

Crystal Silicon
Kyocera
LDK Solar
LG
Mitsubishi
Q - Cells
Sanyo
SolarFun Power
SolarWorld
Solon
SunPower
SunTech
Trina Solar
Yingli Solar

a - Si
ENN Solar
Moser Baer
Sharp
SunFilm
SunWell
Uni - Solar

CdTe
Abound Solar
First Solar
GE

CIGS
Ascent Solar
Global Solar
MiaSole
Solibro
SoloPower

Flat Plate PV Systems

Arizona Public Service, Prescott, AZ

Dangling Rope Marina, Glen Canyon National Recreation Area, UT

Alamosa PV System, Alamosa, CO

5 – 10 acres per MW for PV systems

Land can be left as is or graded

Ground Mounted - NREL PV Project in CO

- 720 kW (1200 MWh) single-axis tracking, ~ 5 acres
- 20-year PPA contract (utilizing Western)
- 20-year easement
- RECs sold to Xcel Energy for RPS solar set-aside (20 year contract)
- PPA price equal to or less than utility electricity prices (based on EIA projections)
- Operational December 2008
- Additional PV projects installed include 1.2 MW single axis tracking at NREL NWTC, 100 kW roof mount and RSF PV

Total Area required for PV

- Varies by technology, tilt, and location
- Roof Mount - sloped roof, flush-mounted power densities of 11 DC-W/ Sq Ft crystalline
- Flat roof, slope panel = 8 DC-W/ Sq Ft
- Ground Mount:

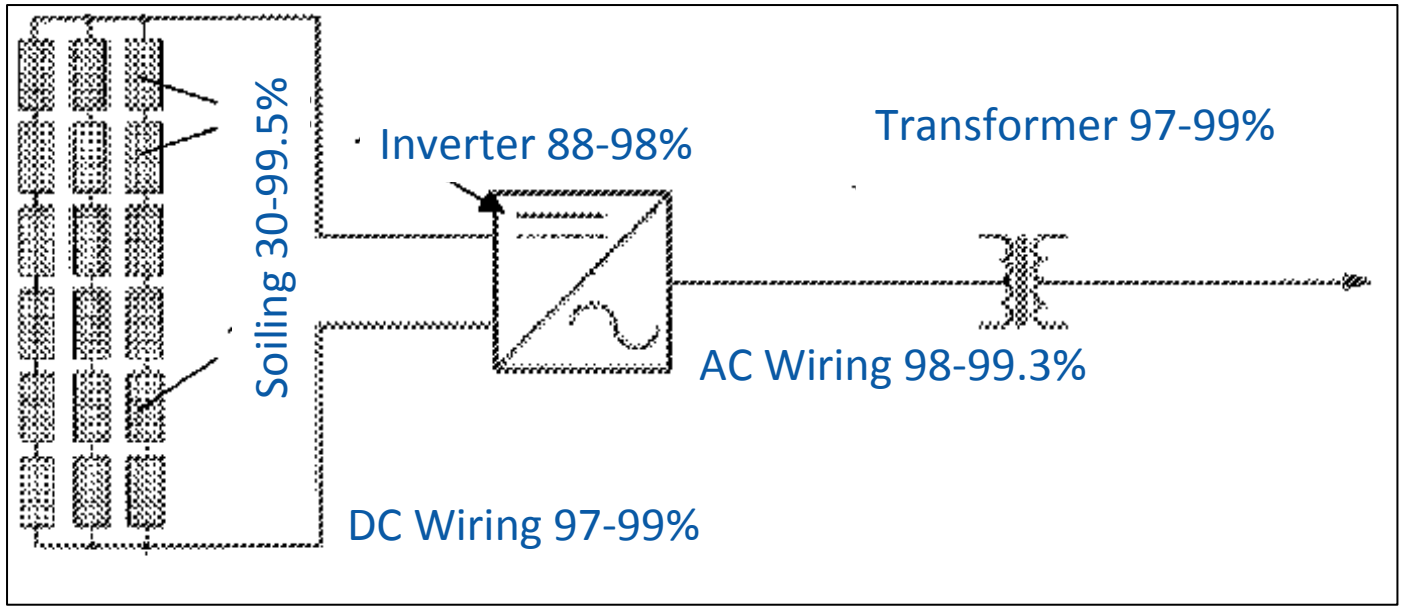
System Type	Fixed Tilt Energy Density (DC-W/ft^2)	Single Axis Tracking Energy Density (DC-W/ft^2)
Crystalline Silicon	4	3.3
Thin Film	3.3	2.7
Hybrid High Efficiency	4.8	3.9

“Balance of System” Efficiency 60-82%

Module Efficiency 6-20%

Diodes and Connections 99-99.7%

I and V Mismatch 97-99.7%



Inverter

Xantrex PV150 Inverter, Tuscon Electric Power

Manufacturers:

(Partial list)

Advanced Energy
Diehls AKO Stiftung & Co.
Elettronica Santerno
Fronius International Gmbh
GE Energy
Ingeteam
KACO
Kostal Industrie Elektrik
Mitsubishi Electric
Power - One
Refu Elektronik
Satcon
Siemens
SMA Technology AG
Sputnik
Xantrex

Converts Direct Current (DC) to Alternating Current (AC)

Priorities: Where to Install Solar

1. On the "Built Environment" where unshaded – size to capacity (pipes & wires) and load (kWh & thermal)
   a. **On existing building roofs that have an expected life of at least 15 more years and can accept added load. Reduces solar load on building. NEPA categorical exclusion.**
   b. On ALL new buildings – all new building should be "solar ready", see http://www.nrel.gov/docs/fy10osti/46078.pdf
   c. Over parking areas, pedestrian paths, etc. – energy generation and nice amenity.
2. On compromised lands such as landfills & brownfields.
   a. Saves green fields for nature.
3. IF installed on green fields minimize site disturbance, plant native low height vegetation as needed.

Roof Characteristics

Ideal – Install PV on new roof, require 25 year roof warranty W/ PV installed (PV comes with 25 year warranty).

Acceptable – Install PV on roof with at least a 15 year expected life.

Roof MUST be able to accept added weight and wind load of PV – Typically 2 lbs/square ft.

Do not install PV on lightweight roofs such as mobile homes or on roofs in poor condition.

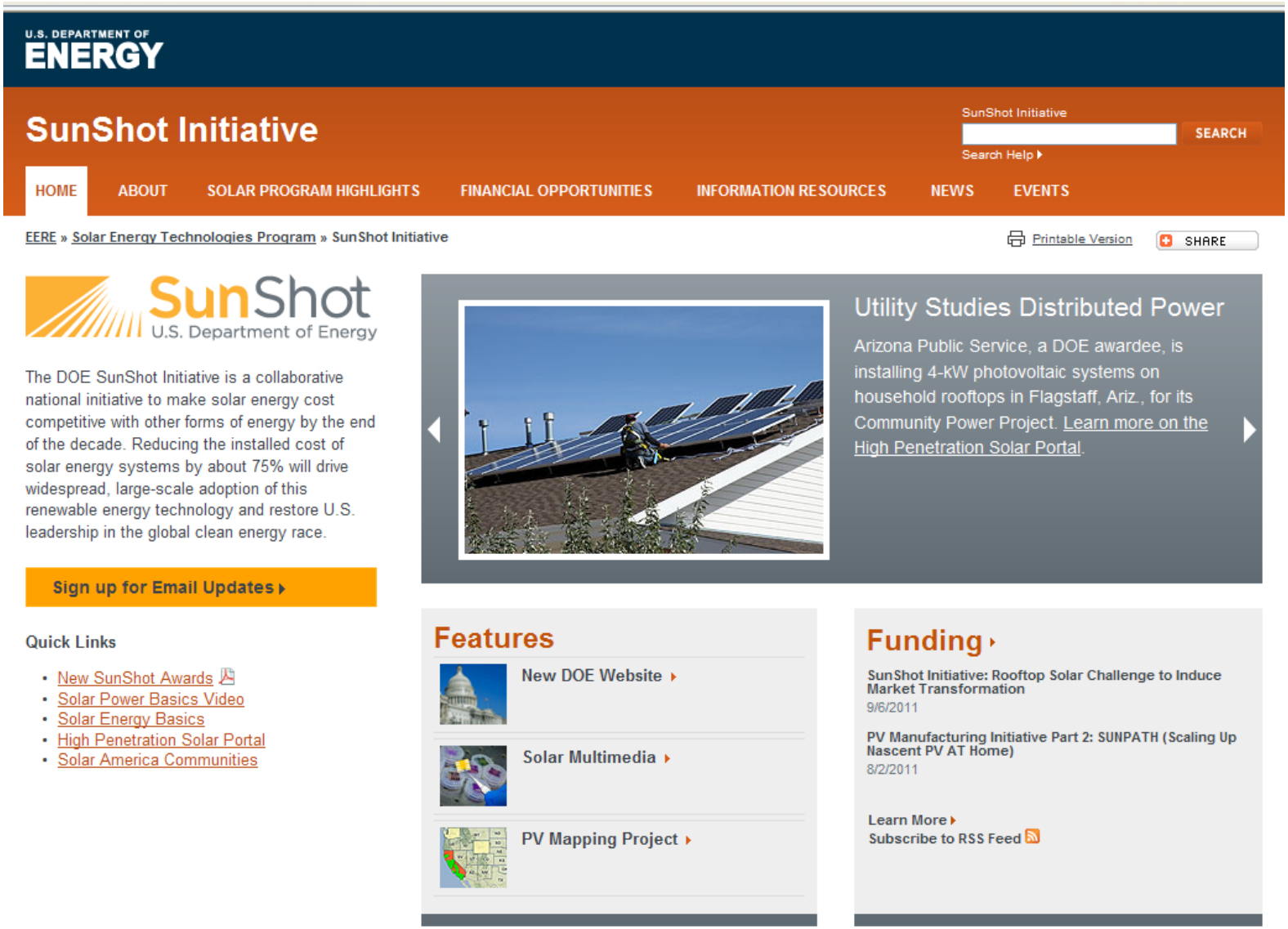
Costs

- Use PERFORMANCE SPECS (kWh/year) not specific manufacture or kW.
- Provide clear requirements and evaluation criteria
- Costs depend on:
  - Size – bigger is better:
  - Balance of system costs including structures, inverters, electrical and interconnection.
- Lowest cost is direct roof attachment such as standing seam metal roof – Installed approx. $5/Wdc for 100kW
- Ballasted or racks – add $0.3/W
- Ground mount fixed tilt – add $0.35/W
- Single axis tracking (over 300 kW) – add $0.7/W
- Carports – add $0.6/W
- High efficiency modules (GT 17%) add $0.5 - $1/W

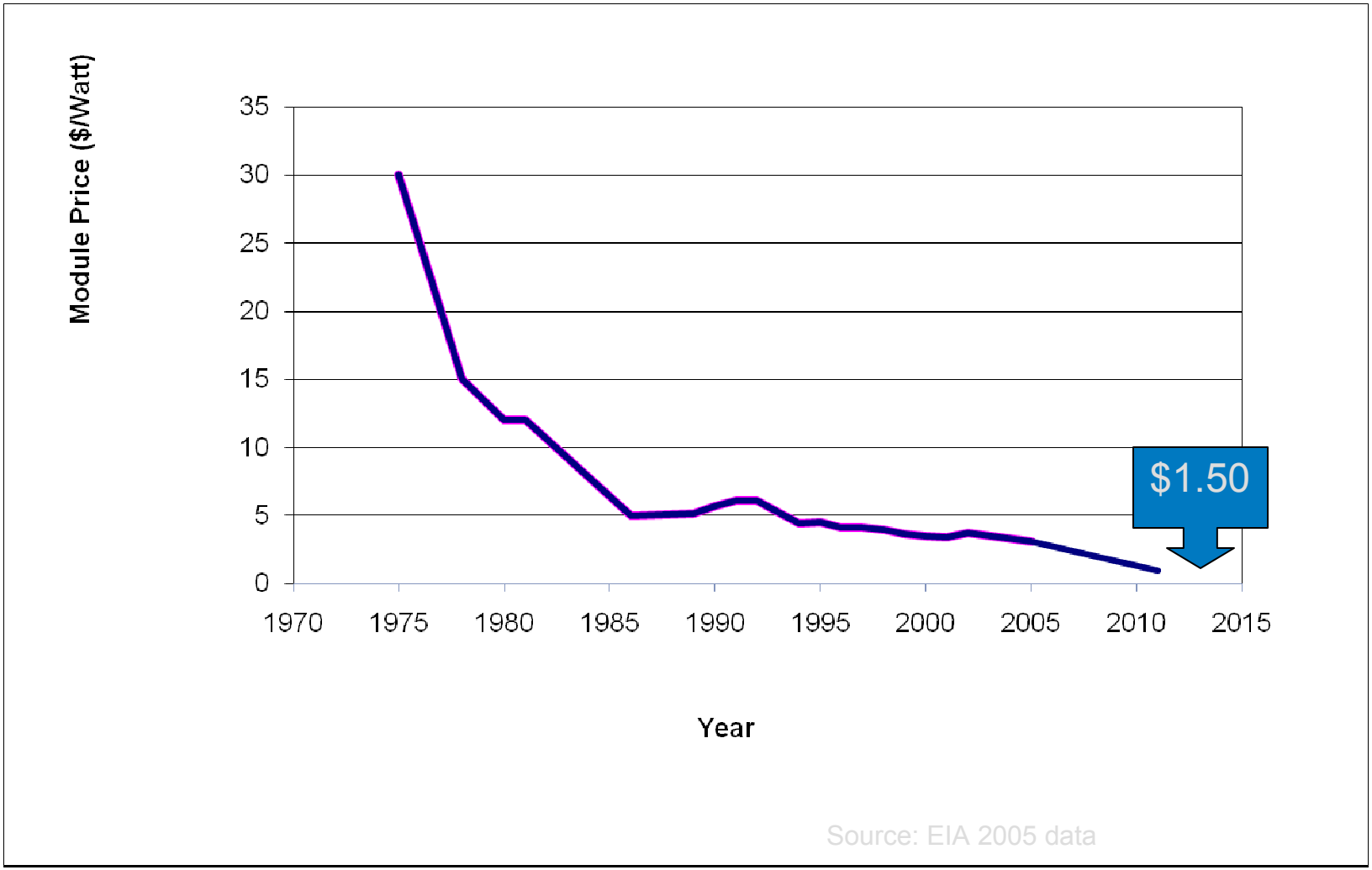
Panel Warranty and Lifetime

- UL listed
- IEC 61215 Silicon
- IEC 61646 Thin film
  - Performance
  - Thermal cycling: tests panel under 200 freeze/thaw cycles
  - Hail test
- Majority of panel failures identified in first few years

SunShot Initiative http://www1.eere.energy.gov/solar/sunshot/

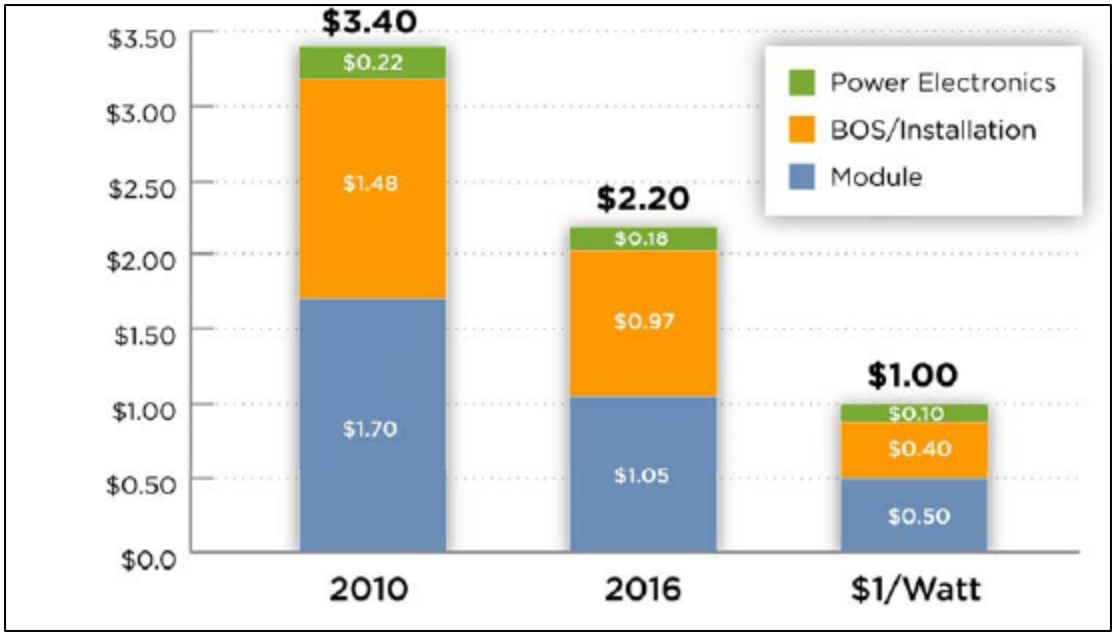


Price of PV Modules

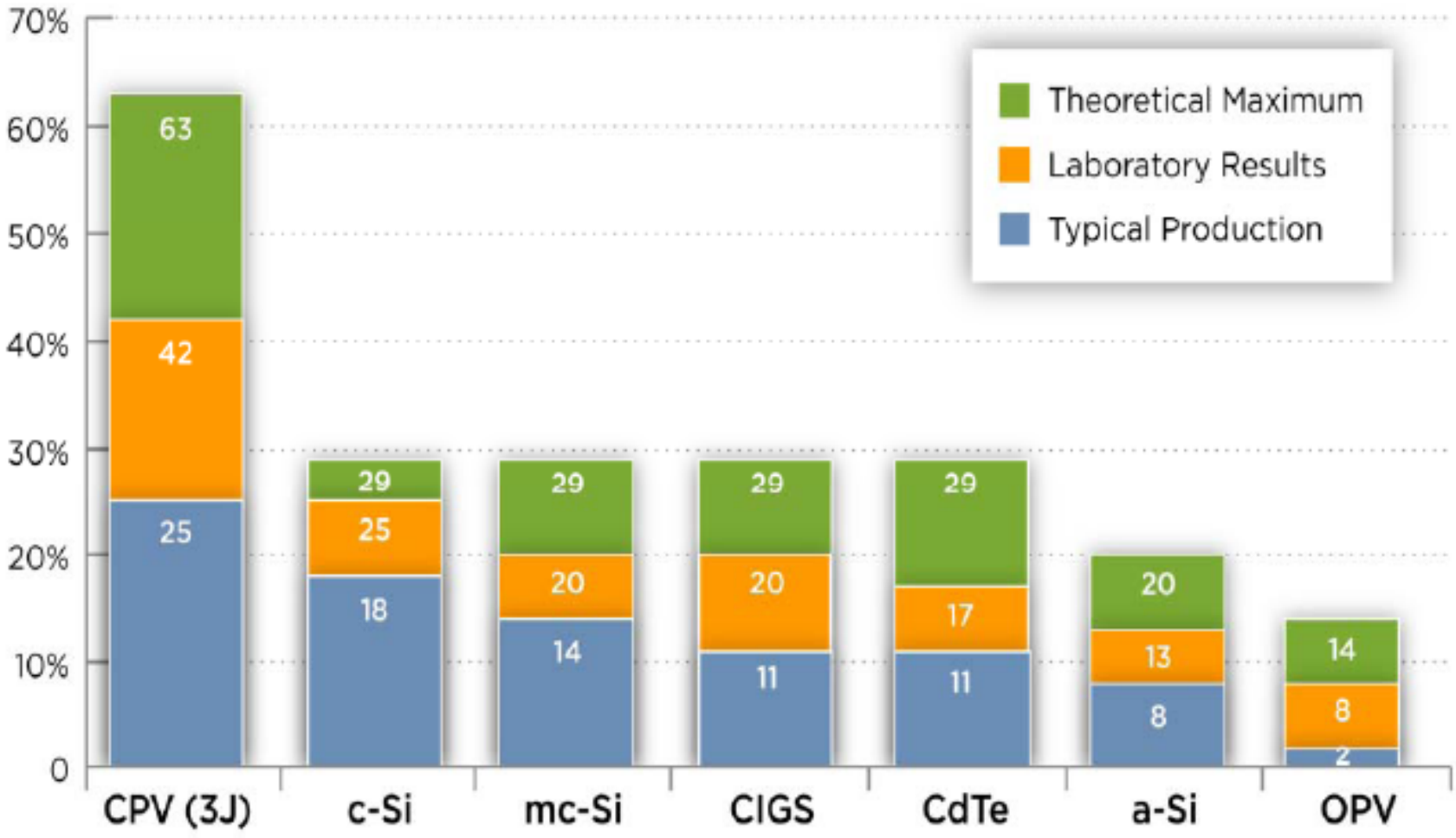


Three Part Cost Reduction Strategy

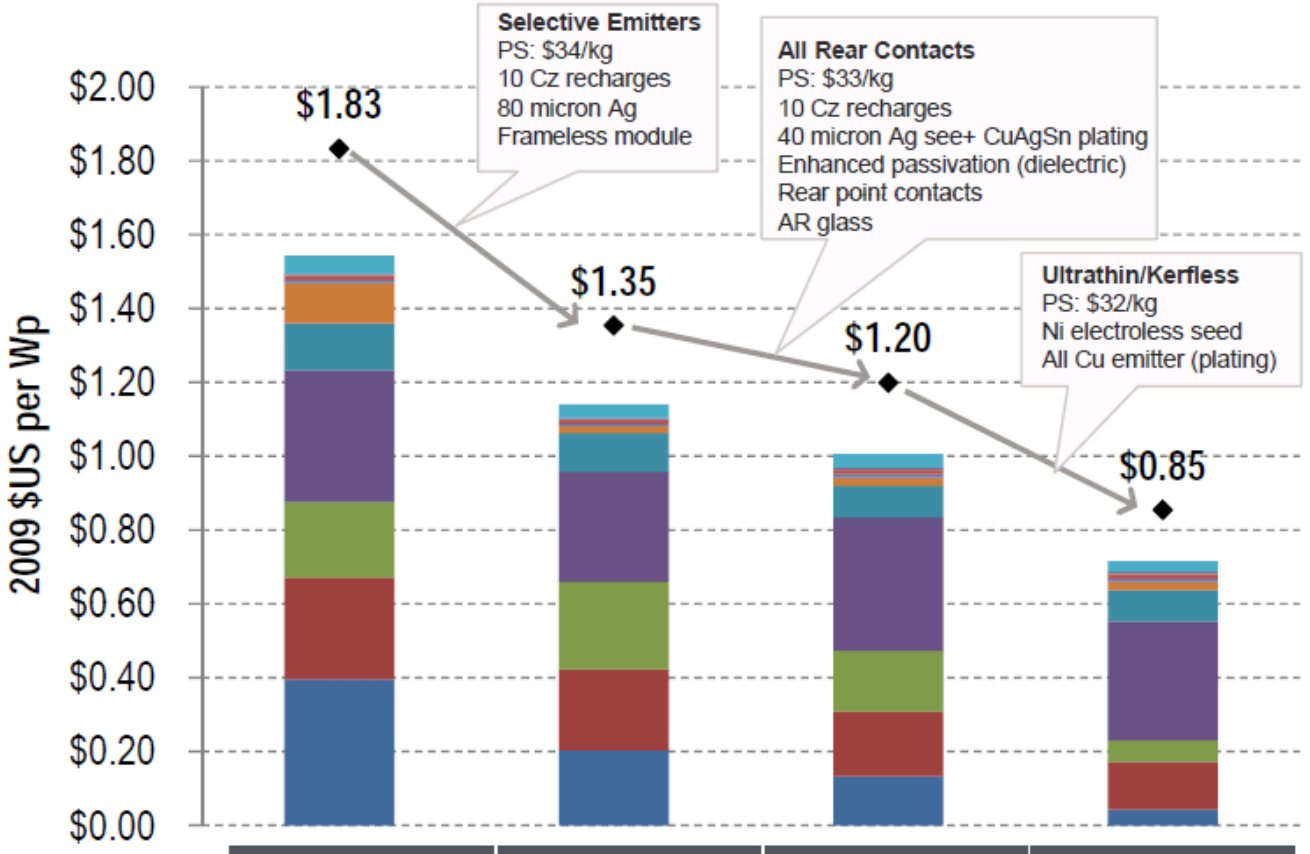
- Panel costs (goal is $50 cents/watt)
- Power electronics cost
- Balance of Systems Cost
  - Installation
  - Permitting
  - Financing
  - Other



PV Panel – Increase Efficiency and Reduce Manufacturing



Monocrystalline Silicon PV Module Manufacturing



2010	Technology Group 1	Technology Group 2	Technology Group 3
180 µm wafer 140 µm kerf	160 µm wafer 120 µm kerf **Selective emitters**	120 µm wafer 90 µm kerf **All rear contacts**	80 µm wafer kerfless **Ultrathin, kerfless, all rear contacts**
14.4% modules	**17.3% modules**	**21.5% modules**	**21.5% modules**

*Source: NREL draft

CIGS Efficiency Improvement Opportunities

	Short Circuit Current (mA/cm²)	Open Circuit Voltage (volts/cell)	Fill Factor	Efficiency (percent)
Practical Potential+	30.0 - 39.0	0.75 - 0.95	0.83	25.0
Best laboratory cell	35.4	0.74	0.78	20.3
Commercial cells*	30 (32.5)	0.60 (0.69)	0.70 (0.73)	13 (16.3)

$$\eta = J_{sc} \cdot V_{oc} \cdot FF / (1000 W/m^2)$$

J_{sc} opportunities

Action	Potential Current Increase (mA/cm²)	Technical Risk	Pathways
Reduce CdS window layer thickness	1.5	Medium	Develop 20 nm thick continuous CdS layer without shunting.
Larger band gap junction partner	2.5	Medium	Replace CdS (e.g. 2.5 eV) with wide bandgap emitter (i.e., ZnS (3.1 eV))
Improved TCO	1.5	Medium	Develop TCO with high conductivity, transparency, environmental stability (i.e., a-InZnO)
Improved monolithic integration	1	Low	Reduce line width of laser/mechanical scribing
Minimize reflection off CIG surface	1.5	Medium	Develop a suitable low cost anti-reflection coating

V_{OC} opportunities

Action	Potential Voltage Increase (V)	Technical Risk	Pathways
Improve the absorber carrier lifetime and concentration	0.05	Medium	Implement in-situ quality control at minimal additional cost
Increase the Ga/In ratio in CIGS by a factor of 2 to 3	0.1	Medium	Increase CIGS deposition temperature via higher temperature glass substrates or alternative stable substrates.

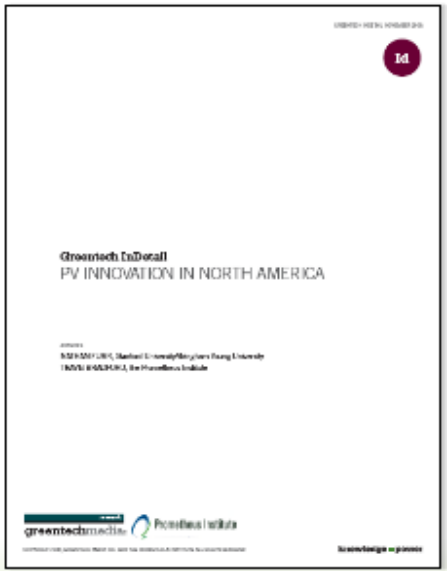
FF opportunities

Action	Potential FF Increase	Technical Risk	Pathways
Reduce contact resistance	0.07	Low	Improved TCO and contact grid combination
Reduce parasitic leakage current	0.10	Low	Improve the density, phase, and crystallinity of the absorber

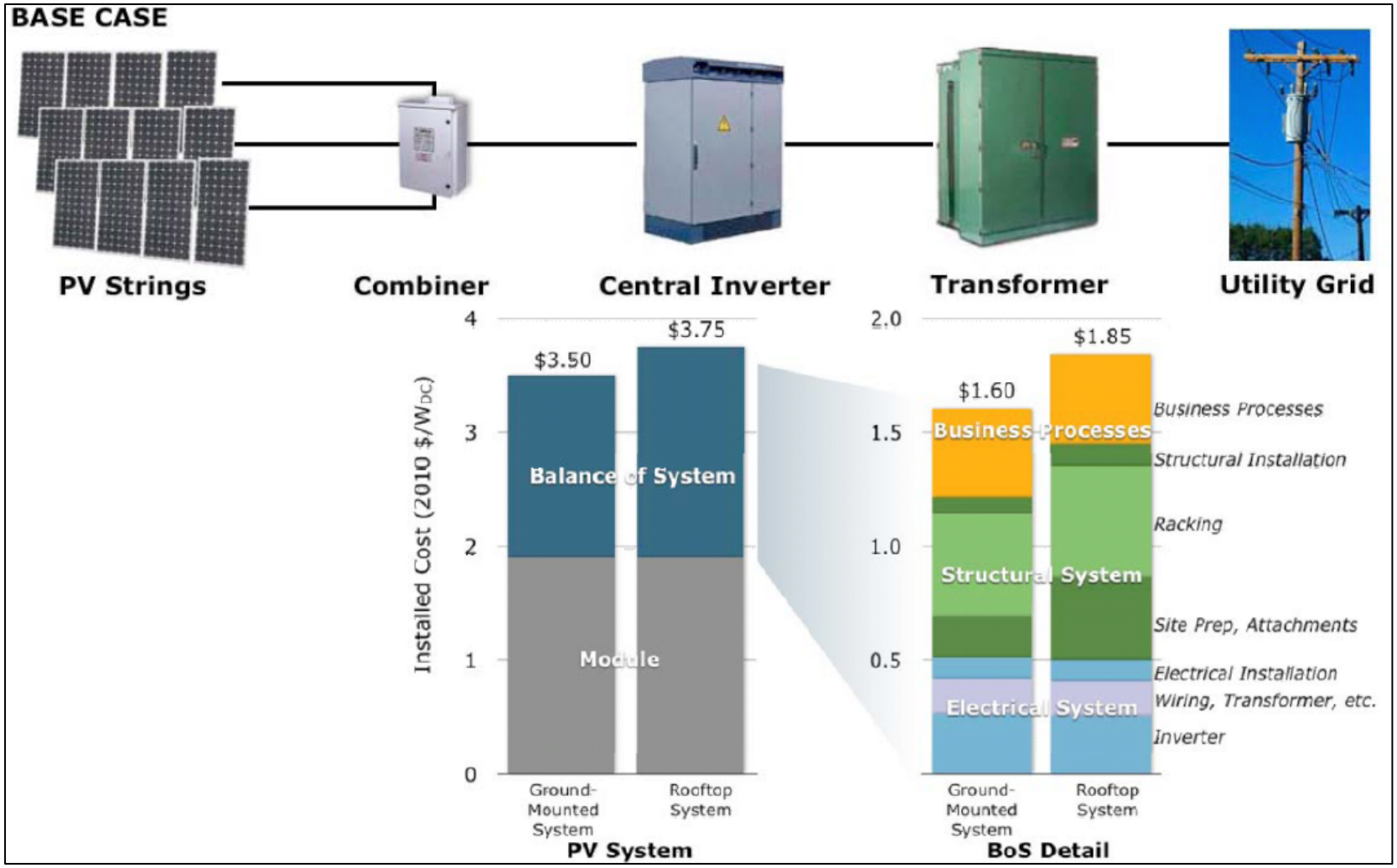
**Source: NREL draft*

PV Panel Innovations

- Silicon
  - SunPower
  - Sanyo Bi-Facial
- Thin-Film
  - *First Solar*
  - *Abound*
  - Ascent Solar
  - Dow Chemical Power House



Power Electronics



Power Electronics

Barrier	Solution
Low volume leads to higher first cost per watt than centralized inverters	Need tens of millions of units
Packaging cost = 25% of first cost	Reduce packaging cost with component integration
Reduce assembly costs components (includes magnetics, gate drivers, power switches)	• High-temperature integrated circuits • High and low voltage electronics on same substrate • Integrated high frequency magnetics

Power Electronics

Barrier	Solution
Small volume production	• Economies of scale in production (~2000 units per year → 15¢/watt from 20¢/watt) • Leverage technology in other industries (e.g, motor drives already at 10 ¢/watt)
Magnetics components represent 30% of the inverter cost	Higher switching frequency could reduce by 80% the cost of passive (magnetics) components; resulting in a reduction of 3-4¢/watt
Need to reduce dead-on-arrival rate in particular; estimated to be 75% of inverter failures.	Self commissioning systems (like motors); will reduce need for skilled technical labor and will reduce human error leading to out of the box failure.
Solder joint failure due to thermal cycling of IGBT (5-10 year life)	Sintered packages (increase 25 – 30 year life)

Power Electronics Innovations

- Inverters
  - String Inverters
  - Micro-Inverters
  - Central Inverters
- Power Electronics
  - Solar Edge
  - Solar Magic
  - Tigo
  - DC-Combiner boxes

Power Electronics Innovation

- Reduces module and BOS costs
  - Module integrated converters mitigate variability
  - Streamlined site engineering and installation
  - AC modules for low cost (labor, wiring, permitting) install
  - Light weight central inverters (rooftop, no slab, crane, etc)

Balance of Systems:

- Three elements
  - Design innovations
  - Mechanics and materials
  - Installation approaches and automation

Automation

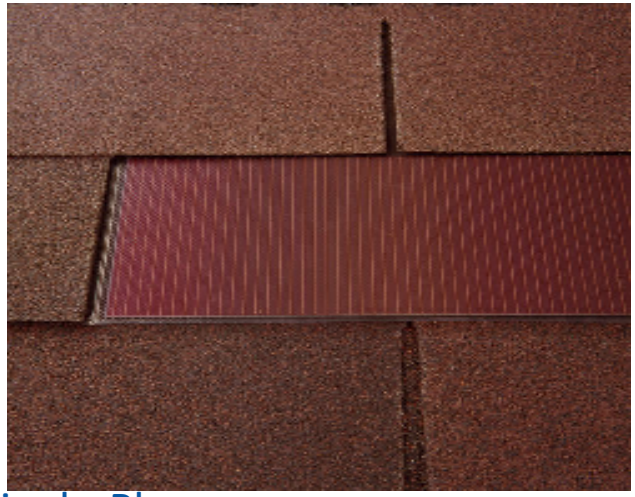
Plug and Play with BIPV

Wiring, Frameworks, Mechanics

Building-Integrated Photovoltaics

Glazing

Shingles



Standing Seam

Baseline – RE = 0

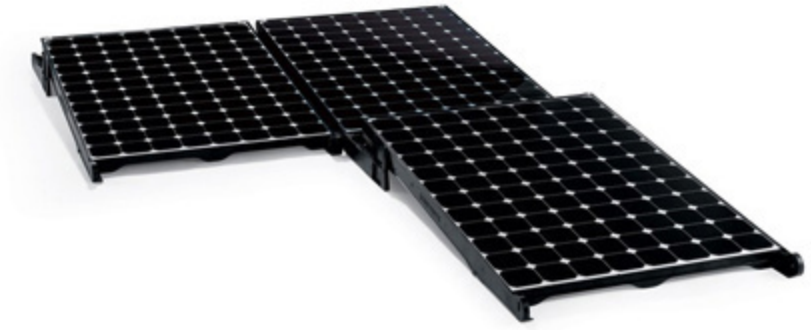
Baseline – RE = 0

Single-Ply

Roof-integrated photovoltiacs

Interesting Products

- Sun Power T-5
- Self grounding modules
- Standing seam roof with S-5 clip

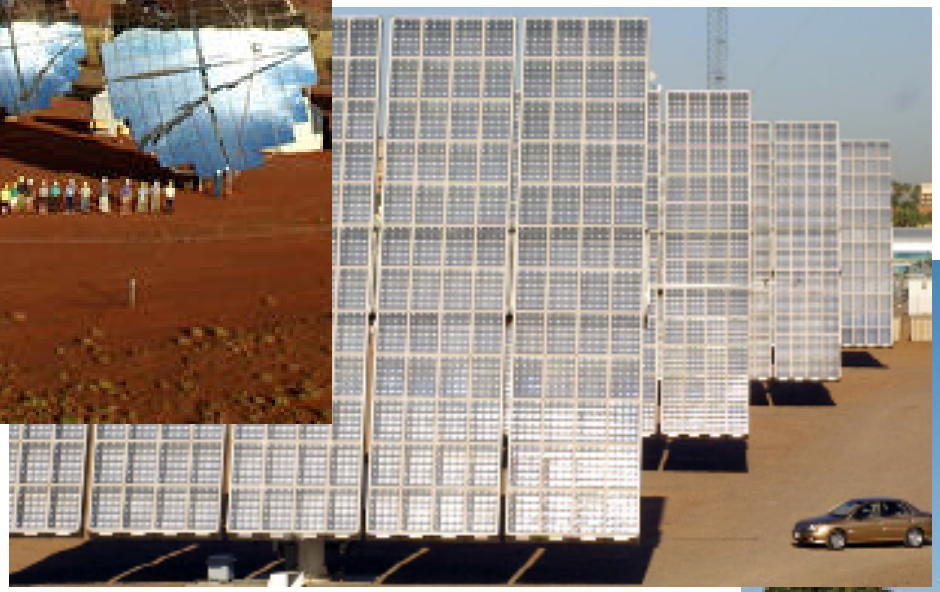


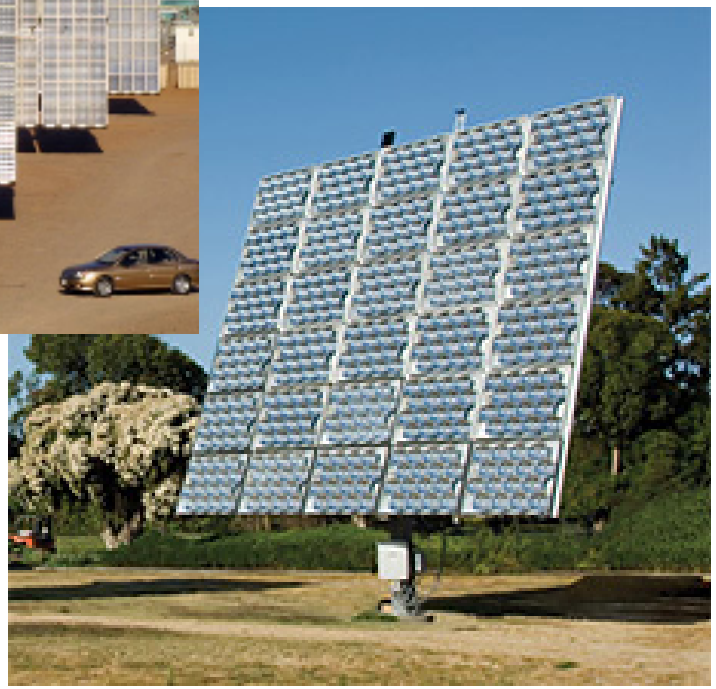
Research Support Facility – A Net Zero Office Building

Concentrating PV Systems

Reflective

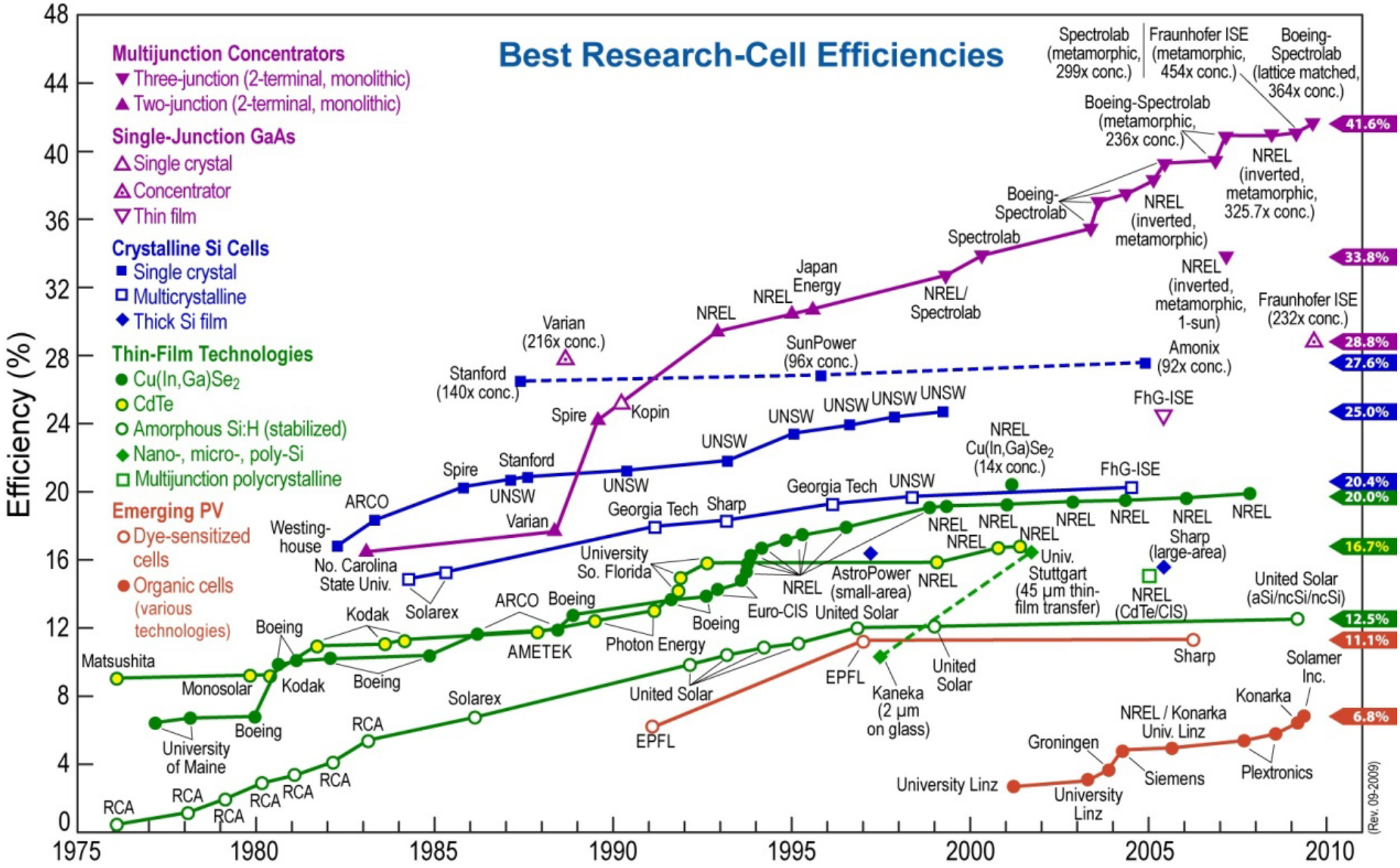
Refractive





Reflective + optical rod

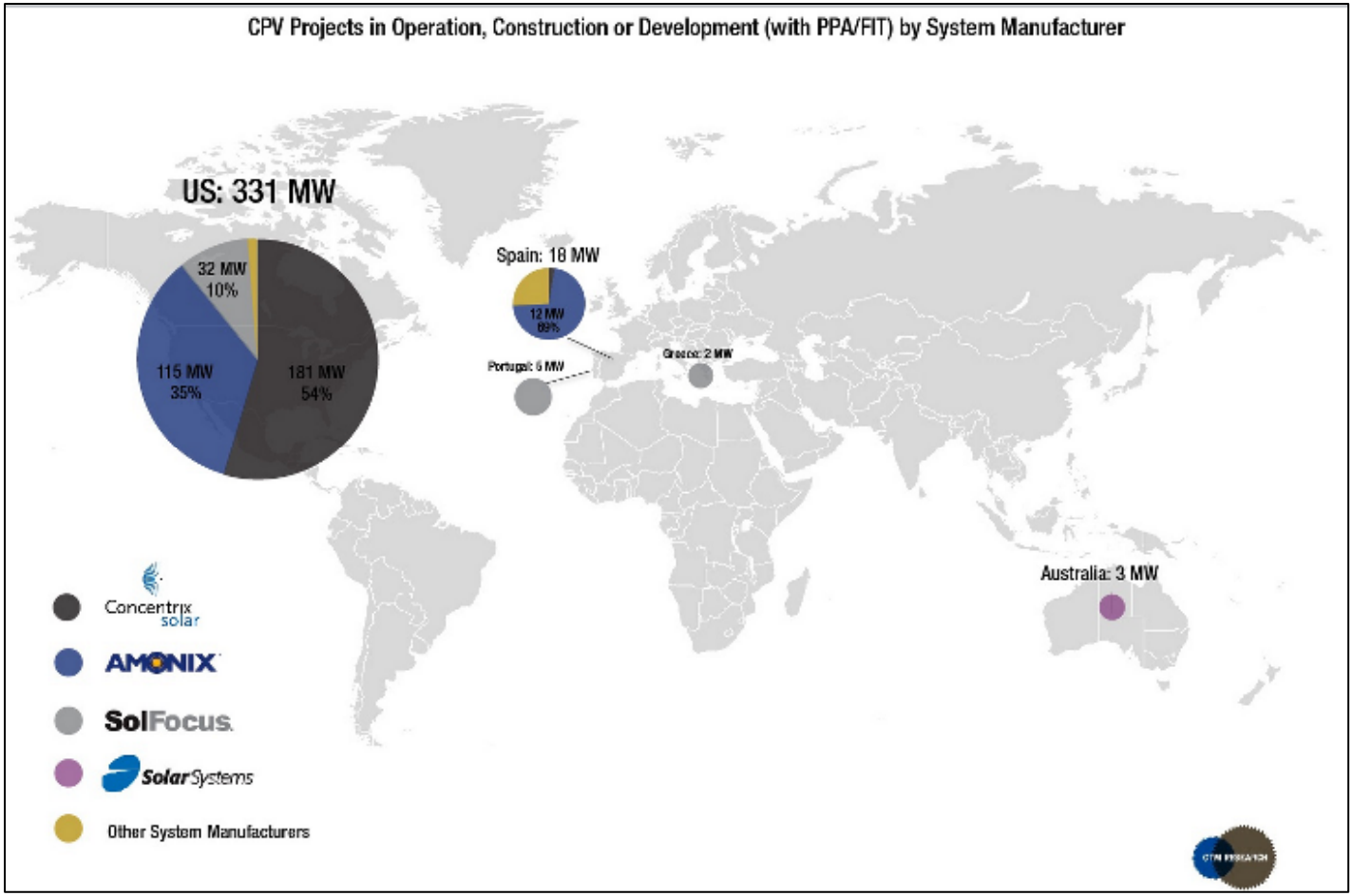
PV Cell Efficiencies



Concentrating PV Market

Concentrating PV

Aminox
Solfocus
Concentrix
Emcore



http://www.greentechmedia.com/content/images/reports/cpv-atlas-2.jpg

Alamosa CO Case Study

Concentrating PV

Received $90 million loan guarantee

30 MW CPV

Won on LCOE over traditional PV

- Multi Junction PV
- Concentrating Optics
- Two Axis Tracking
- 40% efficiencies

Solar TAC http://www.solartac.org/Default.aspx

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