# Seeing Solar Energy in a Different Light: Concentrating Photovoltaics (CPV)

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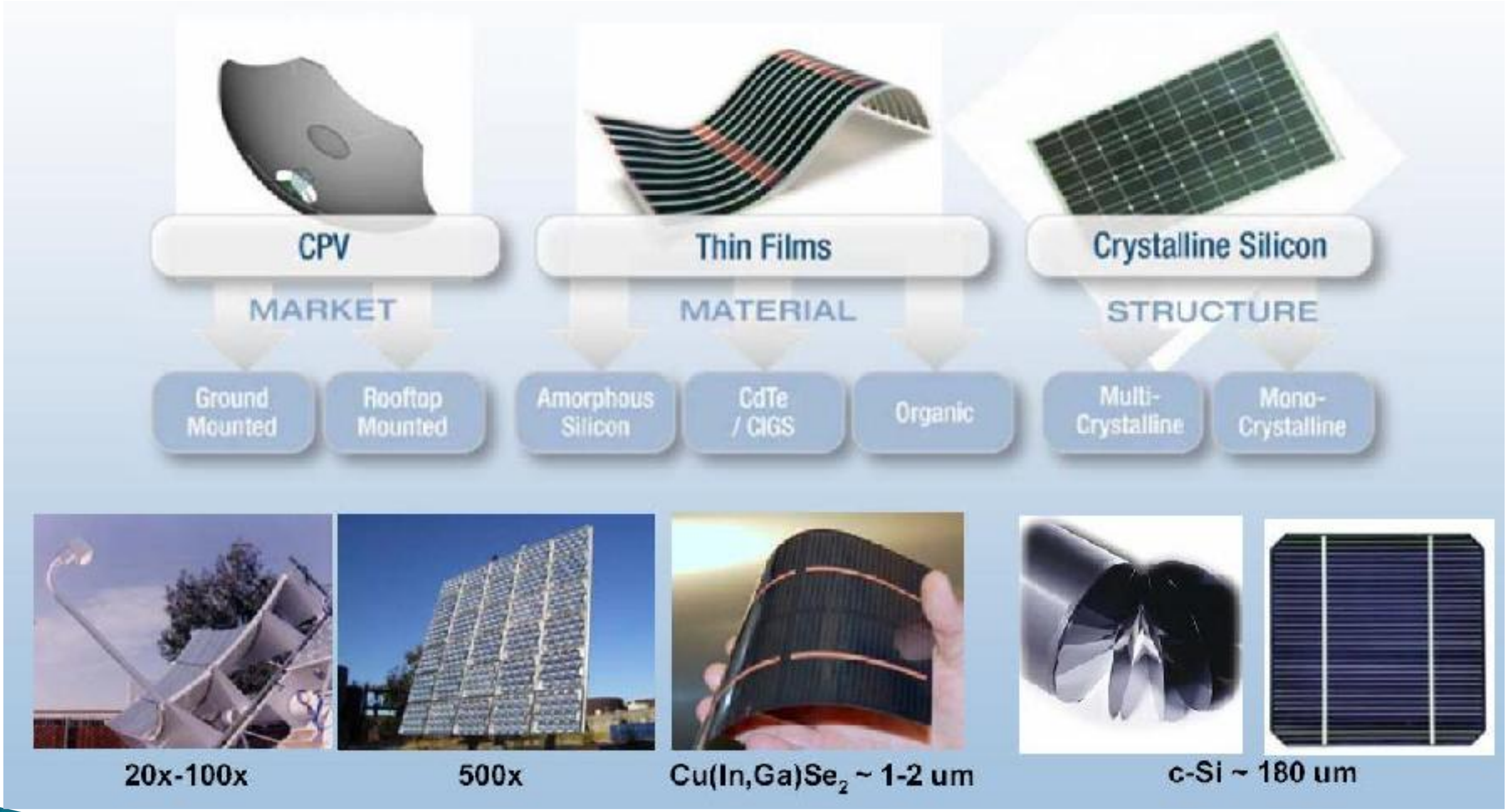
# Photovoltaics:
# 4GW/Yr Industry with 20%+ CAGR

**Application:** Power Plants and Industrial Facilities | Industrial Rooftops | Residential Rooftops and Small Power Plants



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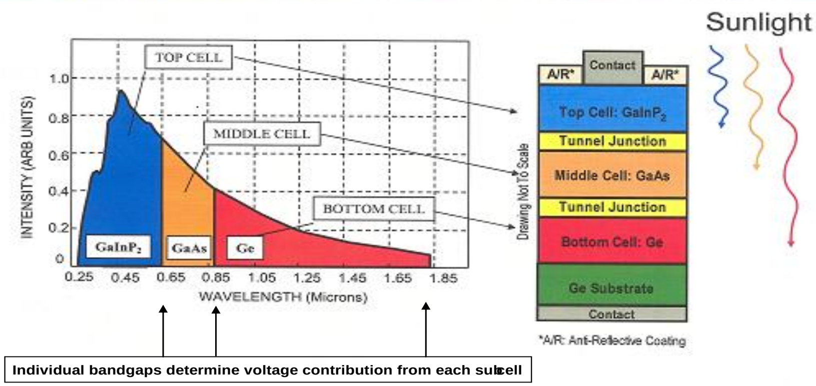
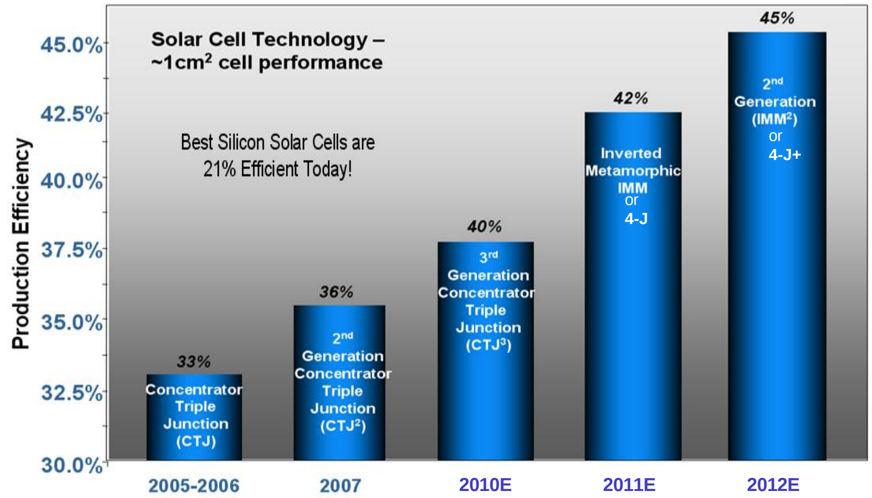
# PV Technology Comparison

| | Advantages | Disadvantages |
|---|---|---|
| **Silicon PV**<br>**Module efficiency approaching 20%+** | • Indirect sunlight acceptable<br>• Operates with or without tracking<br>• Mature, robust technology | • Limited efficiency improvements possible without adding tracking<br>• Significant efficiency loss at high ambient temperatures |
| **Thin Film PV**<br>**Module efficiency approaching 10%+** | • Indirect sunlight acceptable<br>• Potential for lowest cost/kWh<br>• Can be integrated into building materials | • Low efficiency, long term reliability unproven<br>• Requires significant surface area and large support structure<br>• Efficiency loss at high ambient temperatures<br>• Cd/Te approach utilizes scarce, environmentally-challenging materials |
| **High Concentrating Photovoltaics (HCPV)**<br>**Module efficiency >25%** | • Potential for highest module and system efficiency<br>• Good performance in hot climates<br>• Potential for lowest $/kWh/m^2$<br>• Significant efficiency improvement still possible<br>• Highest power delivery during peak loads | • Requires direct sunlight, complex optics and tracking<br>• Optical and tracking losses degrade system efficiency<br>• Generally not cost effective below 100 kW<br>• Long term reliability unproven |
| **Concentrating Solar Thermal (CST)**<br>**Efficiency is configuration-dependent, but could exceed 25%** | • Efficient in large, utility-type installations<br>• Potential to store energy<br>• Not dependent on cell efficiency improvements | • Requires direct sunlight and water for cooling<br>• Capital intensive installation<br>• Remote locations create permitting, land use and transmission line availability challenges<br>• Generally not amenable to distributed power applications |

# Silicon and CPV Cell Comparison




Projected Production CPV Cell Efficiencies




- Silicon cells only capture a portion of the solar spectrum from approximately 500 to 1000 nm
- CPV cells employ three compound semiconductors connected in series to capture solar spectrum from approximately 300 to 1600 nm
- CPV's three junction structure makes better use of energy available in the solar spectrum: typical CPV cell efficiency 28% to 31% (non-concentrated illumination) compared to 18% to 21% for Si cells
- Under 1000X concentration, a 1 $cm^2$ CPV cell can furnish >25W equivalent to the power delivered by at least 10 5-inch Si solar cells

- Optics and tracking requirements add volume to the CPV system decreasing its $W/m^2$ advantage at the system level
- Comparison of delivered power for current 30 $m^2$ system:
  - Approximately 4kWp (Si, one-axis tracking)
  - Approximately 5.5kWp (CPV, two-axis tracking)
- CPV system requires about 30% less land area than one-axis tracking Si system to deliver the same amount of peak power

Source: Fraunhofer Institute, Spectrolab

# CPV Technology Tradeoffs

| Typical CPV cell performance for various cell sizes and concentrations | | | |
|---|---|---|---|
| CPV cell active area | Estimated cells per 100 mm wafer | Concentration ratio | Estimated cell efficiency at 25°C |
| 1 mm x 1mm | 3000 | 1000 | >38% |
| 7.5 mm x 7.5 mm | <100 | 1000 | >36% |
| 10 mm x 10mm | 50 | 1000 | >35% |
| 9.2 mm x 9.2 mm | 60 | 590 | >37% |
| 10 mm x 10 mm | 50 | 500 | >36% |

**Larger cells, lower concentration:**

- Generally larger illumination area per 100 mm wafer because less volume is lost to wire bonding
- Larger illumination area yields more power per 100 mm wafer, but also poorer heat dissipation
- Much lower cell yield per 100 mm wafer; requires stringent fabrication processes to ensure high yields
- Less stringent optical specifications required to illuminate larger aperture cells

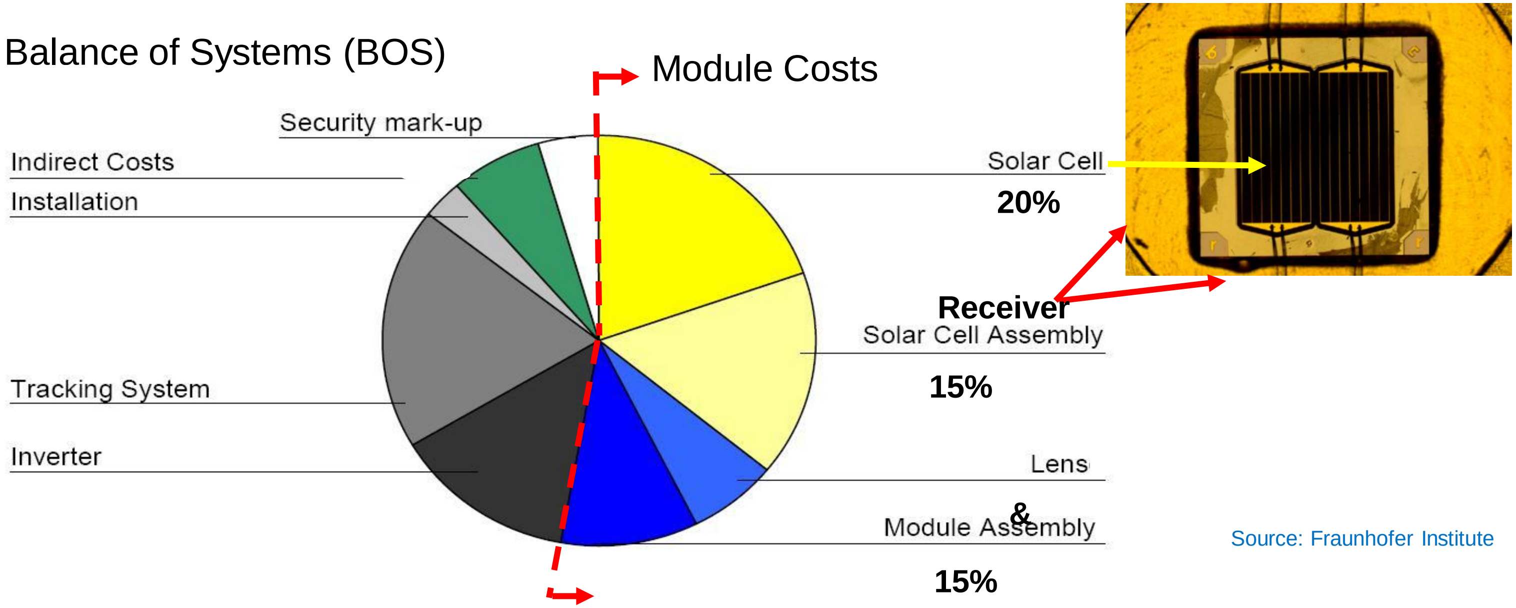
**Smaller cells, higher concentration:**

- Smaller cells have better heat dissipation, permitting higher concentration levels
- Accurate optical illumination is essential to ensure that only the active cell area is illuminated
- Much higher cell yield per 100 mm wafer, but also higher die levels costs for testing and sorting
- Module interconnection costs and resistance effects become significant for smaller cell sizes

Source: Spectrolab

# CPV Value Chain

## Estimated System Costs for 20 MW Production Line




Source: Fraunhofer Institute

- Balance of System costs represent about 50% of current CPV system installed cost
- CPV cell efficiency improvements, larger wafer sizes, improved module interconnection techniques could reduce module costs to 30 to 35% of system costs
- Keys to success of CPV include achieving 30% or better AC system efficiencies, mass producible, lightweight module designs, and lower cost tracking systems

# Strategic Analysis

## Strengths

- Potential for best $/kWh/m² of any solar PV technology
- Can be used for utility or distributed power applications
- Performs better than silicon and thin film PV at higher ambient temperatures
- Enjoys about 30% land usage advantage over one-axis tracking silicon systems

## Weaknesses

- Requires direct sunlight, concentrating optics and two-axis tracking of the sun
- No standardization of cell or module designs to date preventing volume-related cost reductions
- About 18 to 24 months of field operation to date; long-term reliability must be proven
- Relatively large solar panels require assembly at installation site or careful transportation planning

## Opportunities

- Could have installed cost advantage over silicon PV for industrial park and commercial applications between 100 kW and 50 MW
- Module designs accommodate simple cell replacement providing an easy upgrade path to higher cell and system efficiencies
- Combined CPV and thermal system could provide electricity and heating from same system maximizing conversion efficiencies

## Threats

- Silicon PV systems are proven and incorporating tracking capability to increase system efficiency
- CST systems will likely capture solar utility market above 50 MW
- Utility-type CPV installations should be co-located with existing power generation plants to avoid need for new transmission lines

# Summary

## Concentrating Photovoltaics (CPV) offer intriguing benefits:

- Lowest potential $/kWh/m$^2$ capability of any solar PV technology
- Amenable to centralized utility applications and distributed industrial power applications
- Significant headroom for improved cell and system efficiencies
- Small efficiency degradation at high ambient temperatures

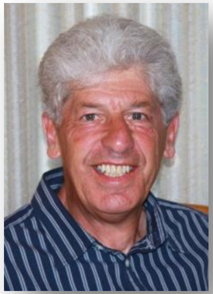
## CPV has hurdles to overcome:

- Balance of systems (i.e., trackers, inverters, installation) represent 50% or more of total installed cost
- No standardization to date on cell or optics configurations inhibits volume-related cost savings
- No major system integrator has endorsed the technology for volume deployments
- Project funding has been limited due to immaturity of technology and a lack of long-term operational performance data

# How Will the Transition Evolve?

RevGen Group can provide important insights on these key questions:

- Can CPV successfully compete on performance and price with silicon and thin film PV?
- In what applications and markets can CPV be successful?
- What technology and operational improvements are key to CPV's success?
- Who are the most likely winners in the CPV competition?
- How can some of the unique advantages of CPV be exploited for a market advantage?



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