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Concentrating Photovoltaic Systems

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Concentrating Photovoltaic (CPV) Systems

Why concentrate?

Two different reasons:

- *Replace expensive PV cells by cheaper optical material*
- *Use high efficiency cells*

(Note: Cannot increase solar radiation per area of aperture.)

Concentrating Photovoltaic (CPV) Systems

Why concentrate?

1. **Cost benefit**
   Silicon cells: 150 €/m2
   Lenses: 30 €/m2 (potentially 15 €/m2)
   Mirrors: 15 €/m2
   - But don't lose this cost advantage in the other components!

Concentrating Photovoltaic (CPV) Systems

Why concentrate?

2. Efficiency gain:
Silicon cells: 15% (typical) – 22% (high)
Triple-junction GaAs ('III-V') cells: ~40% (towards 50%)
- Higher efficiency reduces €/Wp of whole system.

But cost:
Silicon cells: 150 €/m2
III-V cells: ~ 50,000 – 35,000 €/m2
(& potential for 15,000 €/m2)
So high concentration (> 500x) needed!

Concentrating Photovoltaic (CPV) Systems

CPV started in 1970s
- Sandia, Martin Marietta, Entech, ...

Dr George Whitfield at the University of Reading worked on CPV back in ~1977

Concentrating Photovoltaic (CPV) Systems

Today there are 4 main CPV incumbents:

- Amonix (US) & Guascor Foton (Spain)
- Solfocus (US)
- Concentrix (Germany)
- Entech (US)

About 10 more companies offer systems, both reflective (mirror) and refractive (lenses).

In total about 80 companies offer, or are developing, CPV.

--- Photo Gallery of some current systems ---

moke and mirrors: Solúcar Energía completed this 1.2 MW 2.2× system near Seville in 2006. It is the largest low-concentration PV plant built since Arco olar's 6 MW 2× plant in California in the 1980s, which was later dismantled.

Solucar
~ 2x

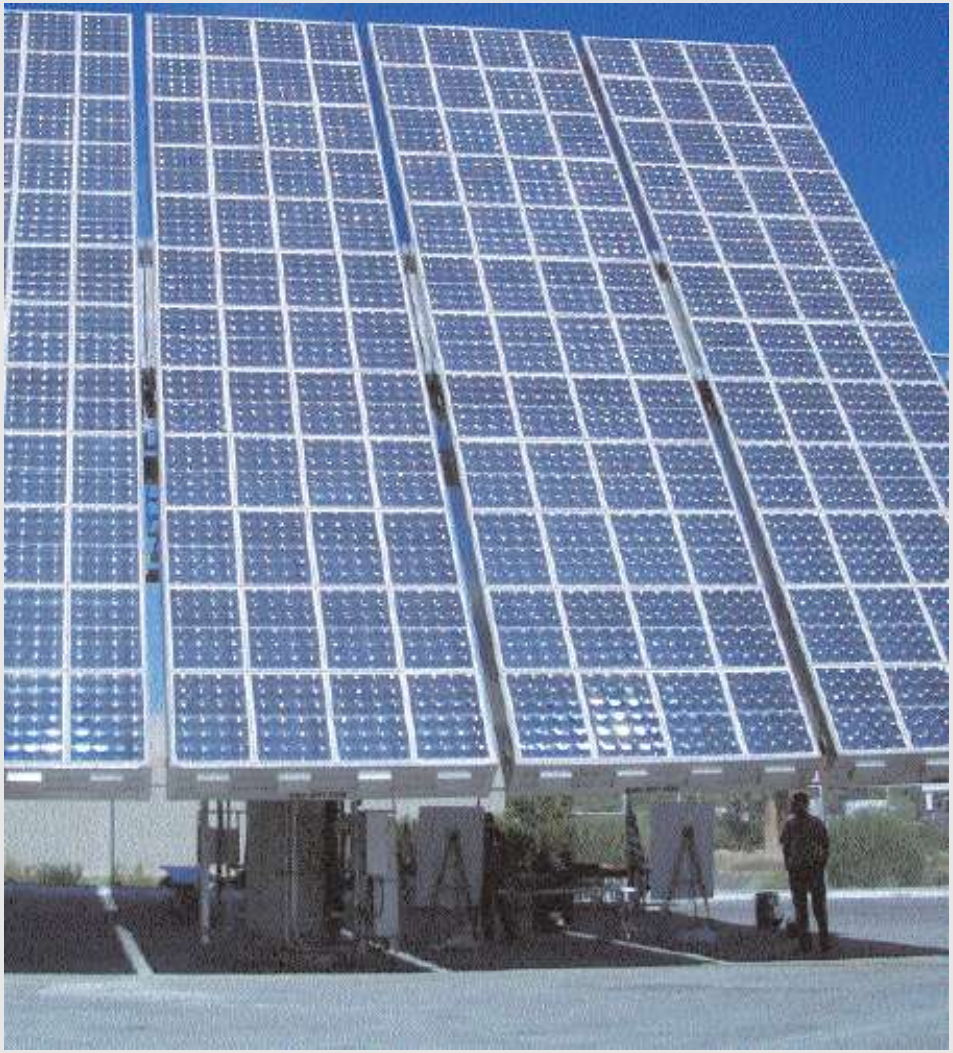
Shanghaied: Part of a 100 kW 3× project completed last year by US-based JX Crystals Inc. at the Shanghai Flower Port. Low-concentration systems account for the majority of CPV installed to date.

JX Crystals – 3x

Skyline Solar - Linear mirror system ~ 10x

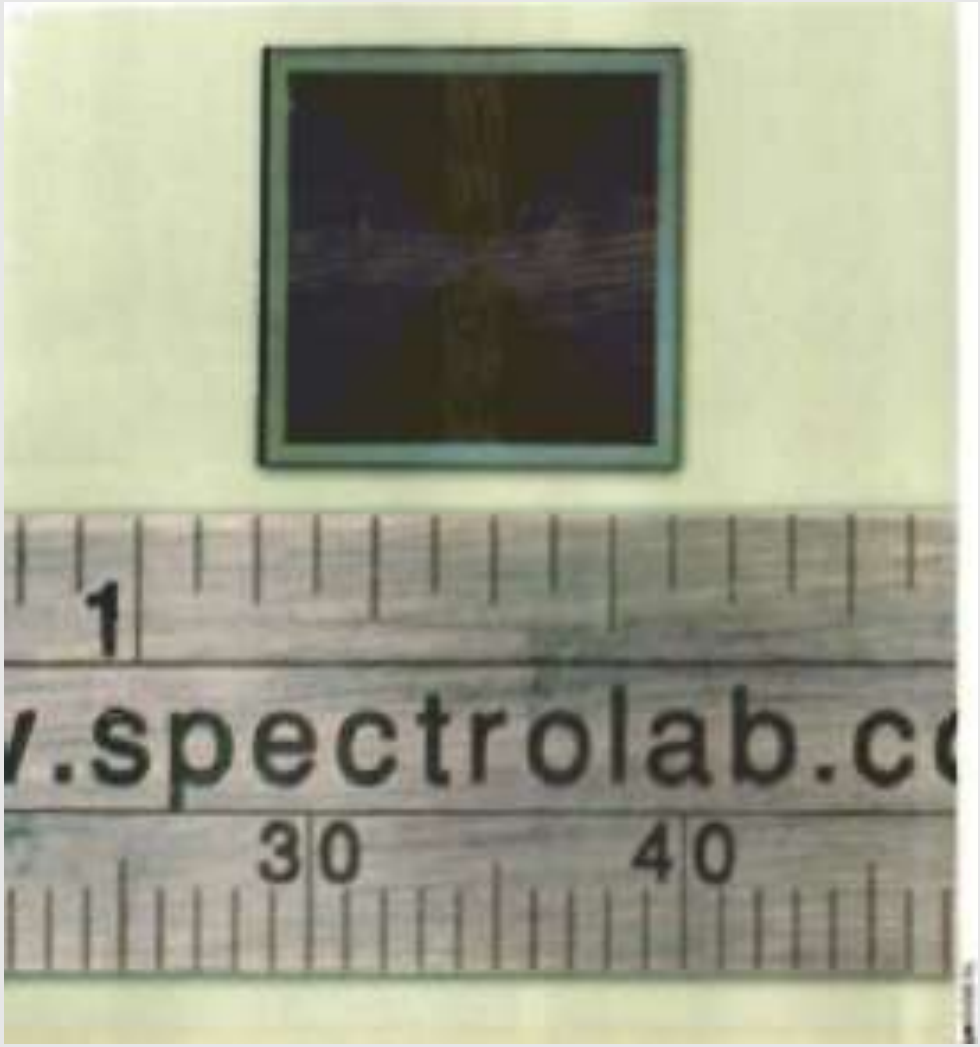
HelioDynamics – Linear Fresnel mirror PV / Thermal hybrid – 10x, 16x.

Amonix - Was silicon at 350x; now III-V



Guascor Foton

- 400x;
- silicon, now III-V?

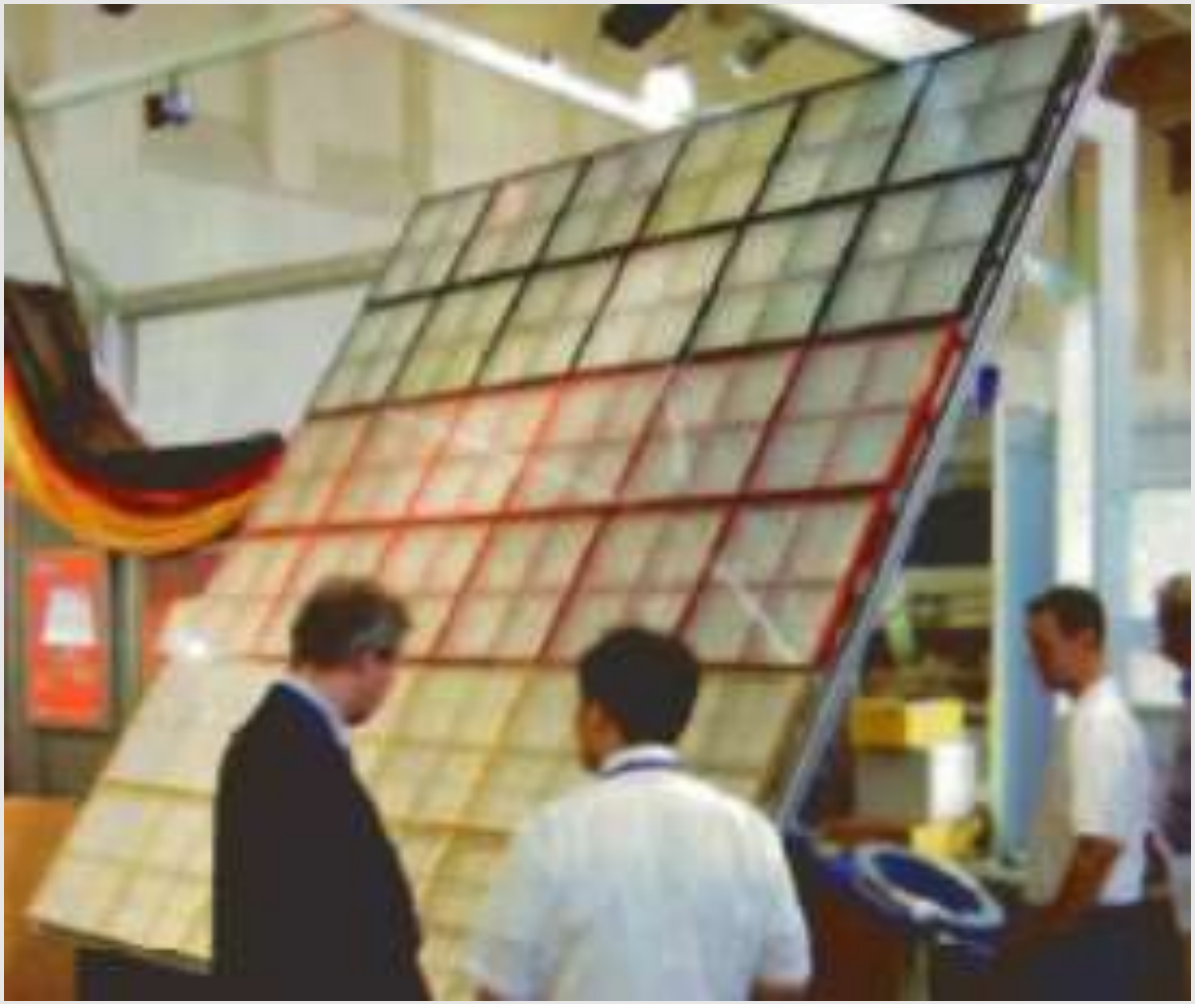


Spectrolab 10 x 10 mm triple-junction III-V cell

550-suns CPV system at Inuyama, Japan.
DAIDO STEEL

World's highest efficiency CPV system – Daido Steel, Japan

Manufacturing line for Concentrix



CPV panels can be thin – Solar Tech

Emcore – Ver. 2
~ 500x

Artist’s impression of large carousel CPV system - Greenvolts

Solar Systems Pty. (Australia)
- **was silicon, now III-V**
- **recent change of ownership**

The Whitfield Solar CPV Collector

- Point-focus Fresnel lenses
- No secondary
- Laser-grooved buried-contact silicon cells, 70x
- Closed-loop 2-axis tracking, tilt & roll

R&D History

EC-funded: ***EUCLIDES; Small-PV; CPV Manufacturing***

- Laser-grooved buried-contact cells good to ~30 suns
- Easy modification of high-volume 1-sun cell line
- Hence cost (per unit area): ~ Only 1-sun cell cost +10% !
- Small-aperture for the *individual optical component* reduces material required for passive heat-sinking; and for rigidity (self-weight bending).
- Hence: Infinitely-small optical aperture = zero material.
- Design & manufacturing to achieve CPV at €1/Wp

BP & U. of Ferrara, & UK DTI funded:

- LGBC cells good to 100-suns!

Hence: Cells at ~€5cents/Wp or less (of the €1/Wp goal)

LUCENT - Improve efficy. LGBC cells, ~18% at 100-suns

Design Principles

Whitfield Solar Ltd.; University of Reading ‘spin-out’, 2004

Design Principles:

- **‘One-sun’ high-volume cells modified for concentration**
- **70x onto illuminated spot (= 50 suns) to reduce cell cost**
- **Point-focus to offer adequate concentration**
- **2-axis tracking to reduce manufacturing / pointing precision**
- **Small optical aperture elements to reduce material for heat-sinking and avoid self-weight bending**
- **Stop at 100 x 100 mm, to reduce component count and avoid necessity of robot manufacture**
- **Flat, f-no. ~1 Fresnels - not high efficiency, but easy to make and good acceptance angle**
- **V-trough housing to give heat sink area ~2x aperture**
- **Digital closed-loop tracking. 'Works straight out of the box’**

Initial Development

- 2004 – 2007: Initial Component & Prototype Testing
  - UK & University of Cartagena
  Reported at CPV-4 Conference, El Escorial, Spain.

- 2008: Design for Manufacture

Design for Manufacture

UK Design company, FE modelling, DFMEA analysis

- Lenses: Hot-pressed PMMA
- Cells: With no BP Saturn line, now NaREC
- Cell lay-down: Industrial silicon chip process, & conformal coat
- Troughs: pressed, injection moulded end-caps
- Tracker:
  - Insolation monitoring
  - Sensor & motor control accuracy ±0.1º
  - Power-monitoring alignment optimisation
  - Communications
  - Asymmetric speed for sun tracking
  - 1 or 2 axis; Range of motor V & A

Trough components

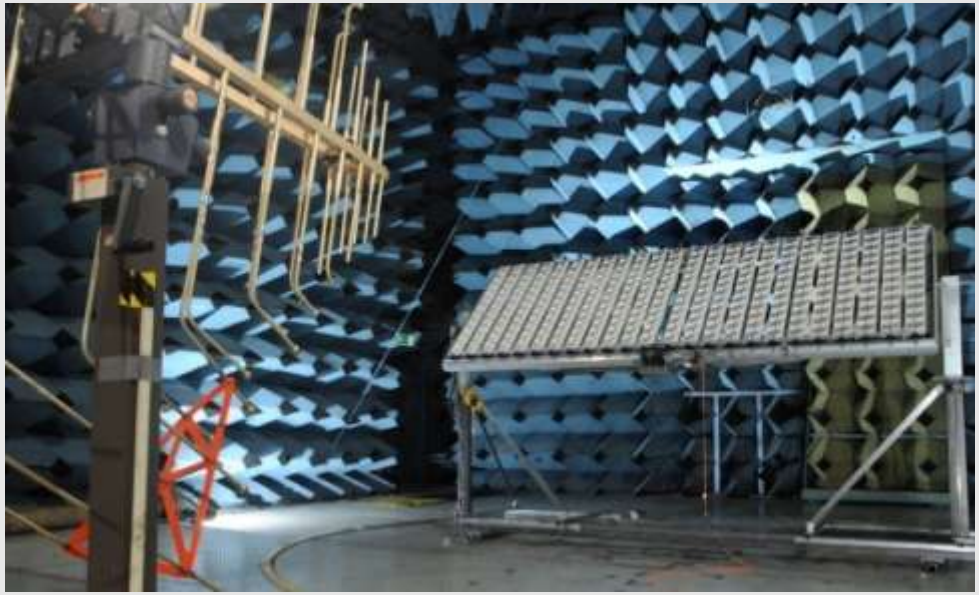
Silicon cells

Wide Guard Band for

- Relative expansion
- Lens anomalies
- Tracking accuracy
- Tolerance stack-up

Validation Testing

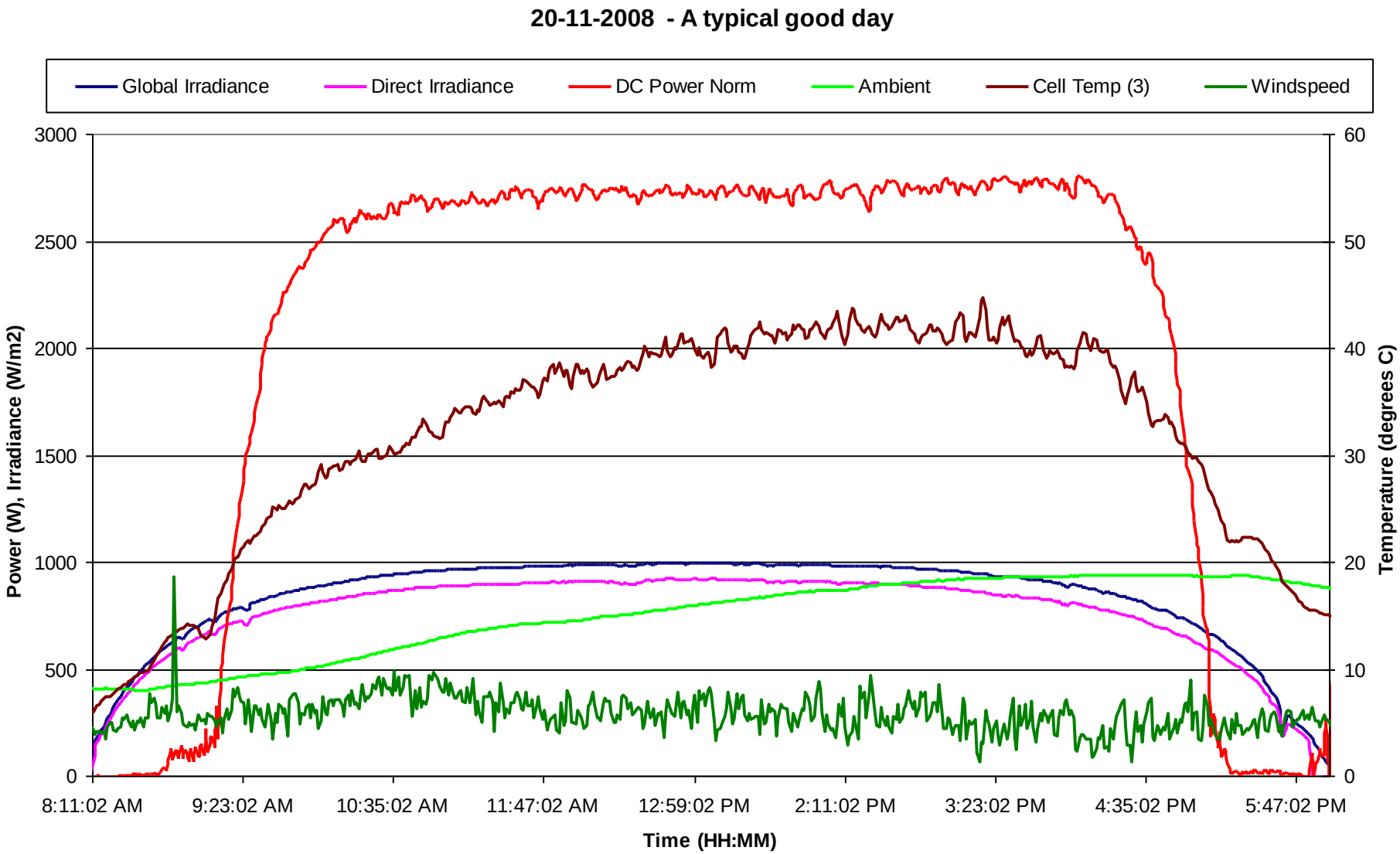
- Rigorous repetitive testing (environmental and durability)
- IEC 62108 pre-qualification tests
- Wind loading tests using full-scale automotive facility up to 120kph
- EMC sign-off
- Extended life UV exposure tests
- Corrosion (salt spray/mist)
- Water and dust ingress to IP65
- Tracking accuracy
- Electrical safety



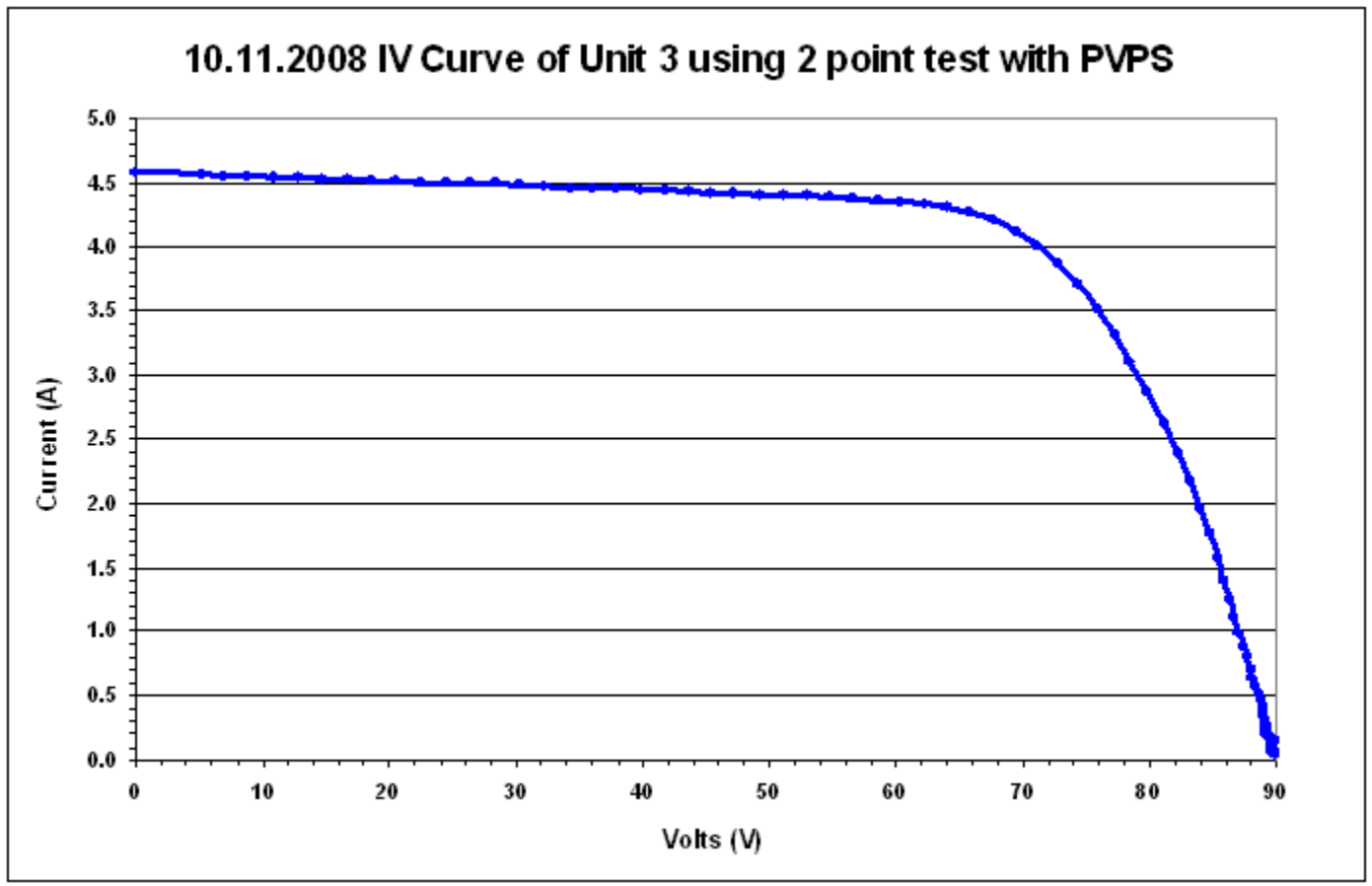
Early Wind-tunnel Test

Testing of production collectors in Spain since September 2008

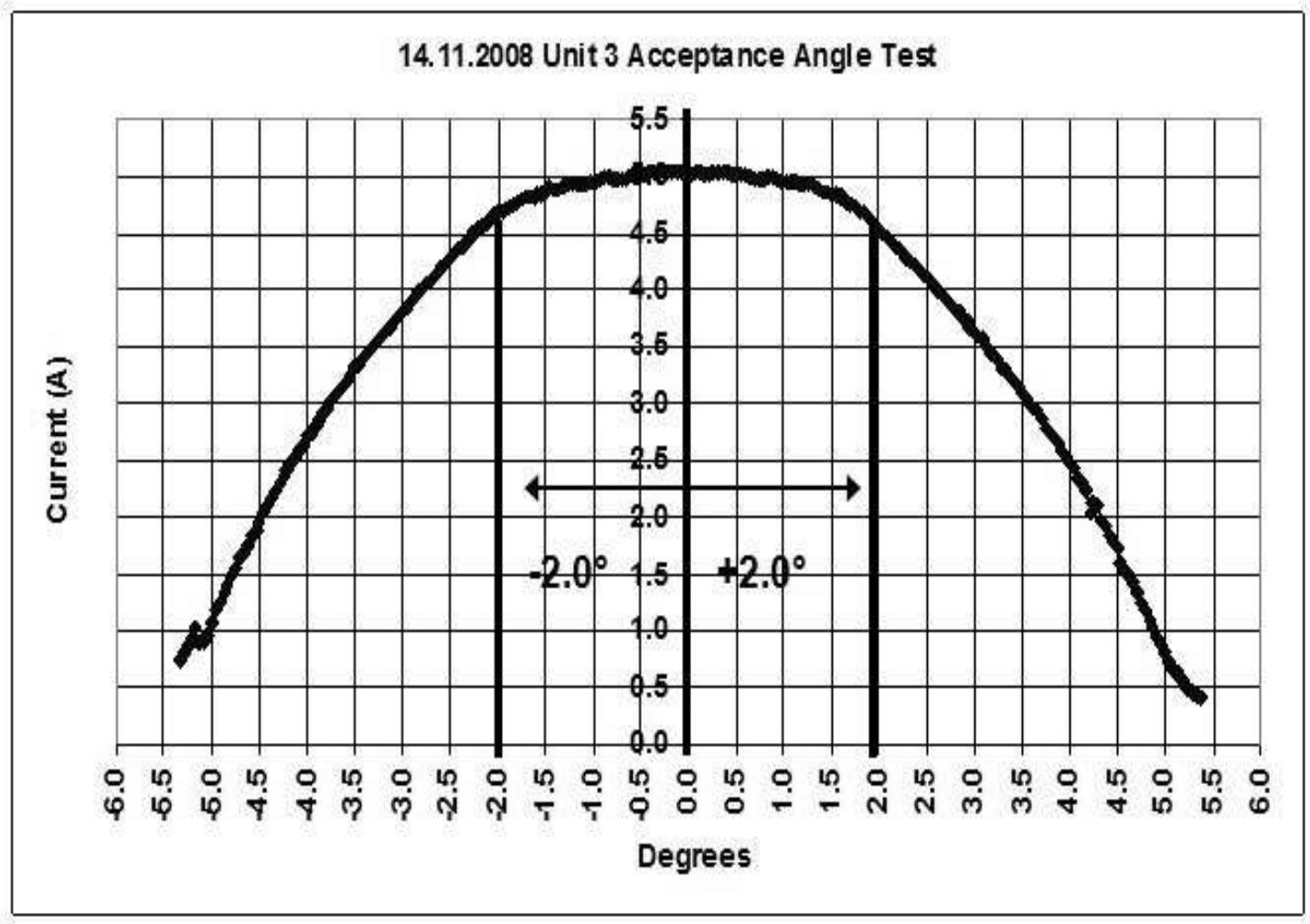
Check of Data Acquisition



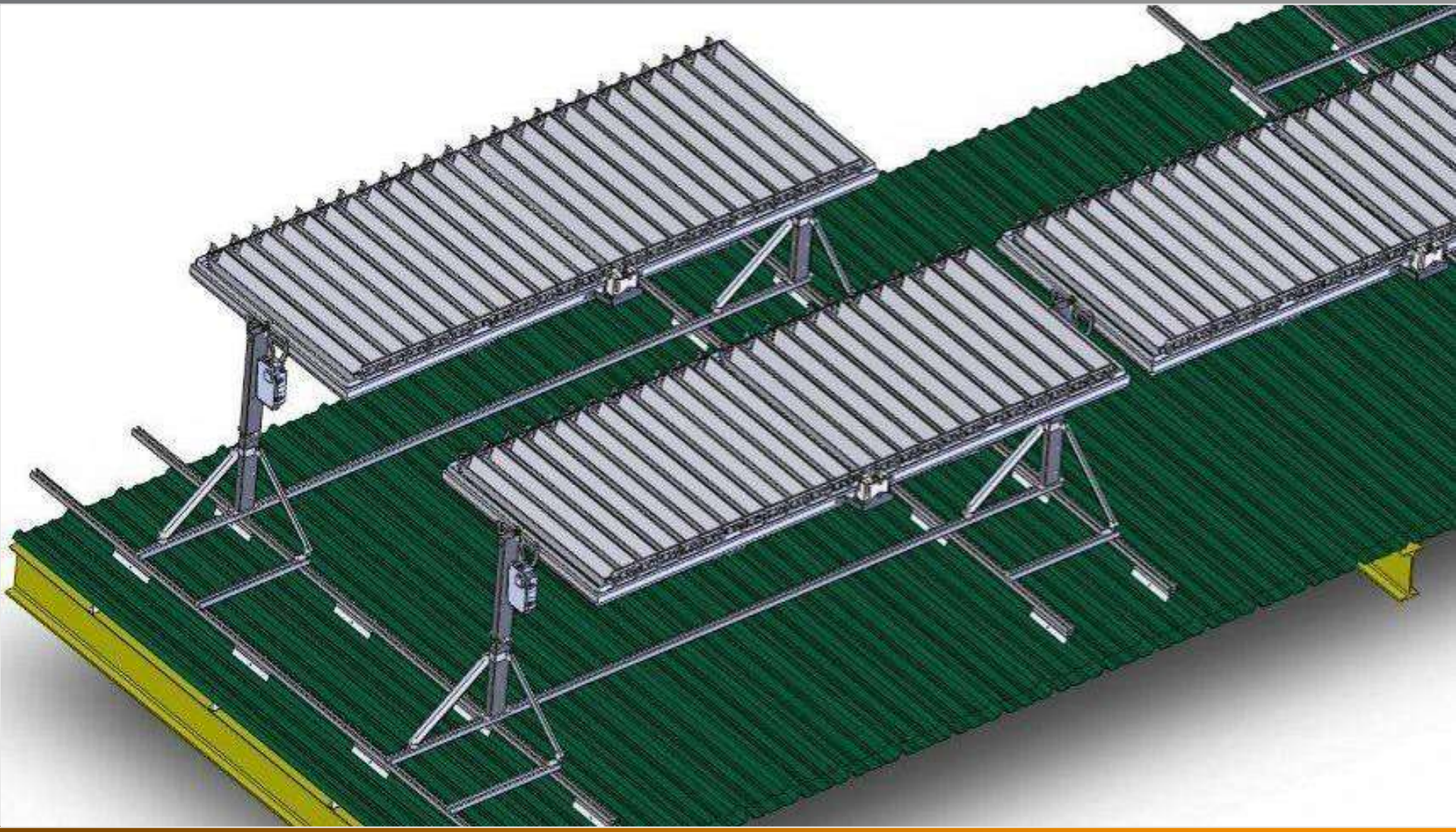
Typical unit I/V curve



Acceptance Angle



Rooftop solutions also



Advantages of CPV

Lower cost
Essential for high-efficiency cells.

Efficiency: Drives to grid-parity
Raises power per unit area

Capital cost: ~20%/Wp of standard PV module factory; less of a thin-film factory.

“The fastest way to Terrawatts”