CPV Technology Overview
Research and Development

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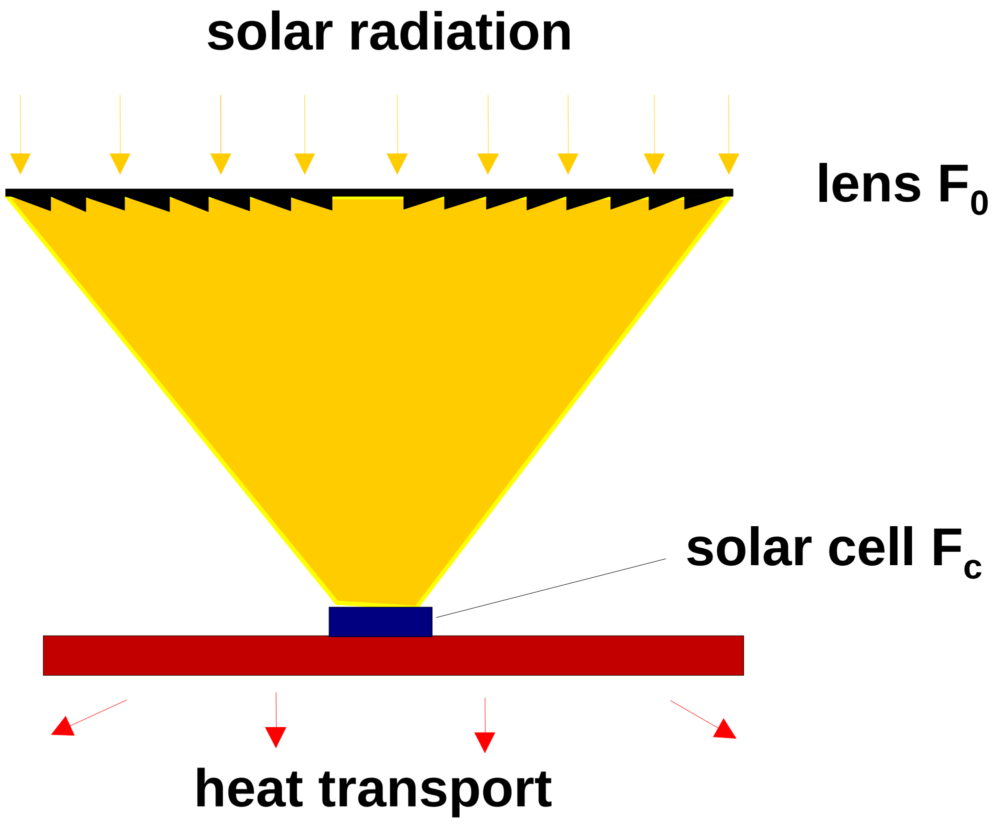
Why Concentration Technologies?
THE Option for Low Cost on €/kWh-level

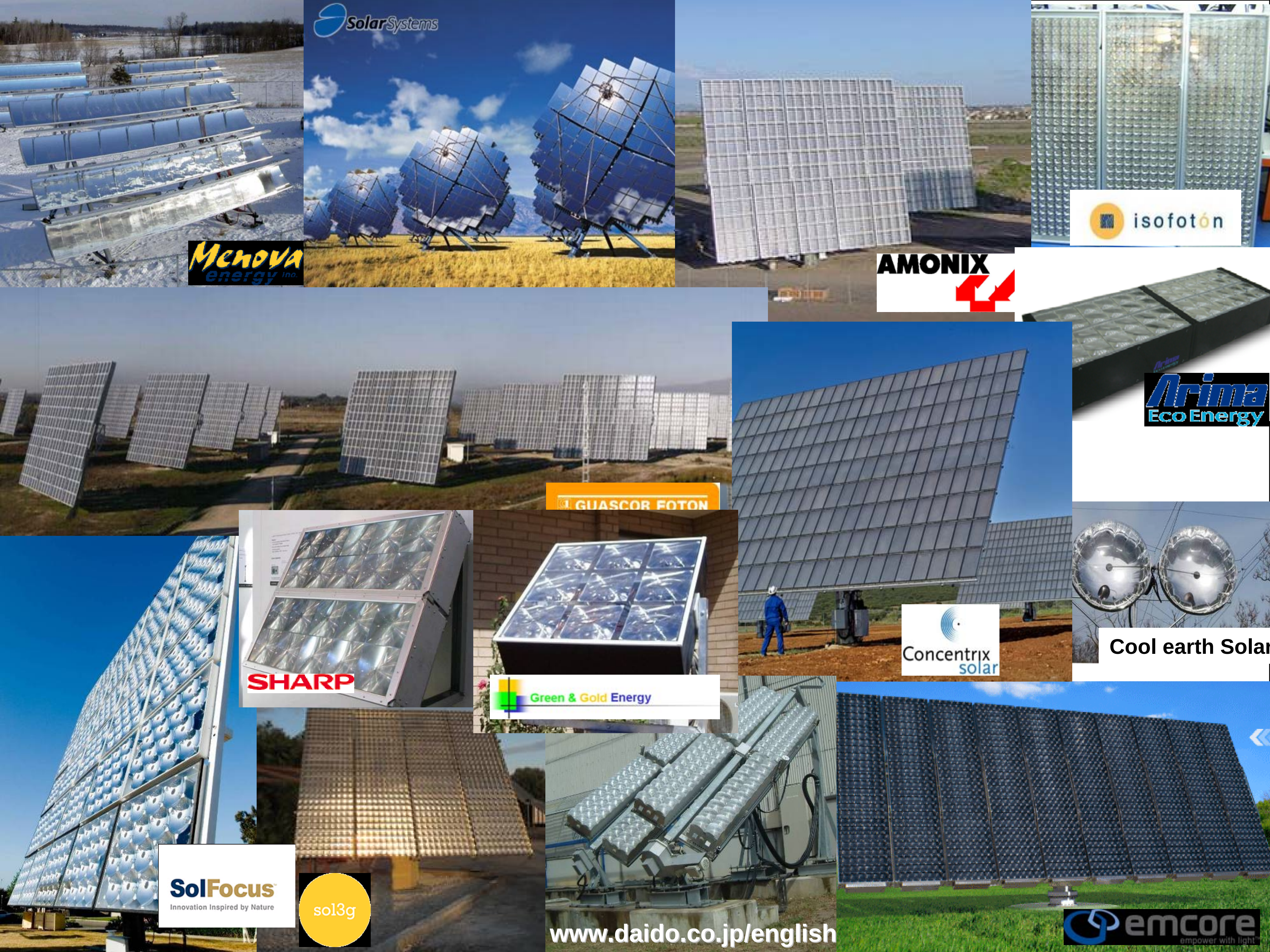
The basic idea and difference to standard PV:

Decouple the area for sunlight collection (F_0) and area for conversion (F_c)

$$C_{geo} = \frac{F_0}{F_c}$$

→ semiconductor (conversion area) is the most **expensive**
→ use a **cheap** optic for collection of the sunlight




Menova energy inc.
Solar Systems
AMONIX
isofotón
Arima Eco Energy
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Green & Gold Energy
Concentrix solar
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SolFocus
Innovation Inspired by Nature
sol3g
www.daido.co.jp/english
emcore
empower with light

CPV – a plurality of system solutions that place Opportunities and Challenges

CPV – Concentrating Photovoltaics
A Trial for Classification

- LCPV – low concentrating photovoltaics

  Concentration factor: 1 < C < 50 [suns*]
  Concentrator cells: mainly modified Si cells
  Tracking: often 1-axis tracking, but also 2-axis

- HCPV – high concentrating photovoltaics
  Concentration factor: C > 300 [suns*]
  Concentrator cells: III-V-based high efficiency multi-junction cells
  Tracking: precise 2-axis

* 1 sun equals 1000 W/m²

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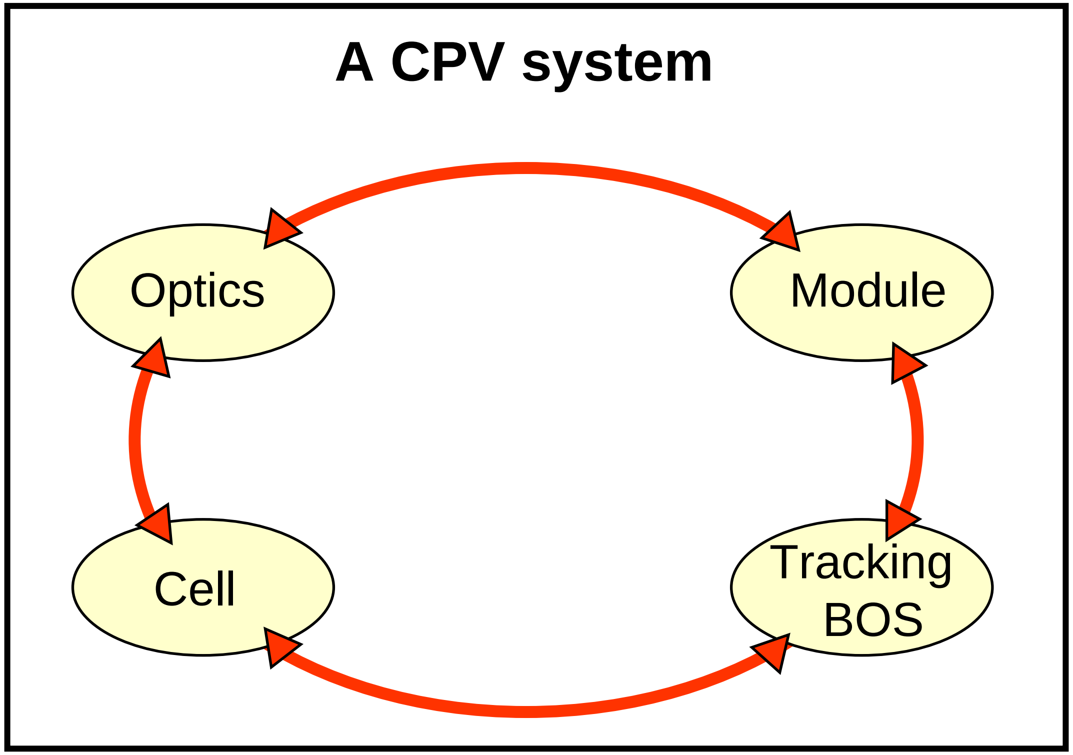
CPV – Concentrating Photovoltaics
A System Approach: the Challenge and the Opportunity

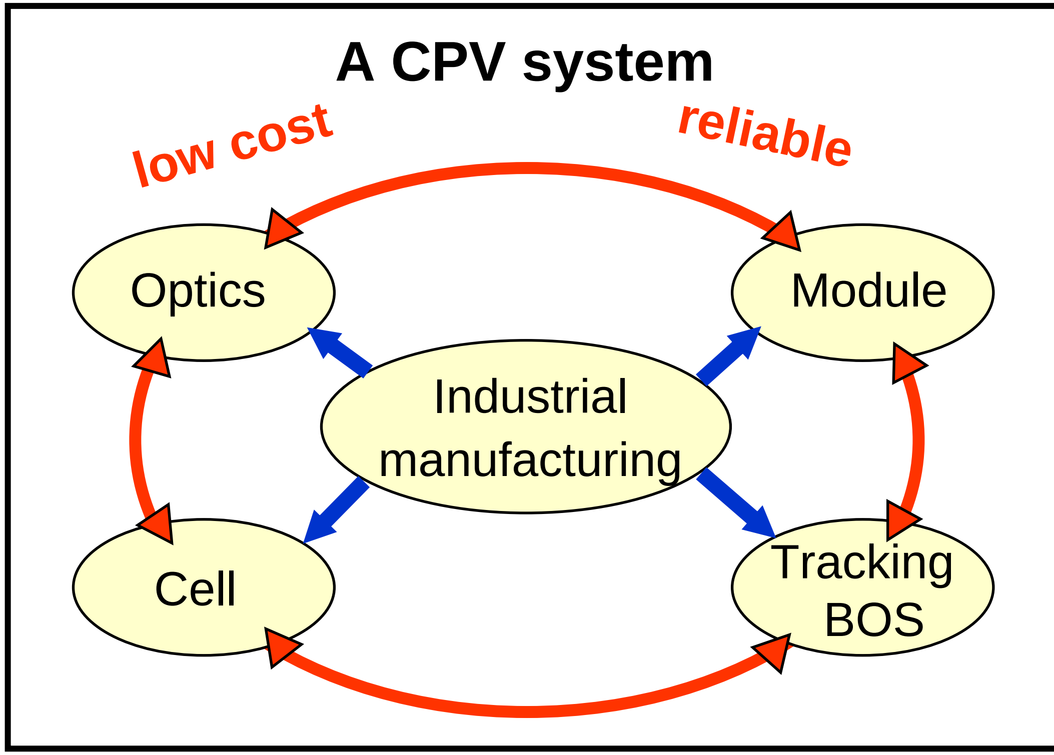
Optimise the system!

This requires knowledge in different fields (optics, mechanics, semiconductors…)



CPV – Concentrating Photovoltaics
R&D Requirements

Optimize through R&D:
- Performance
- Cost
- Reliability
- Manufacturability
- Ease of shipping, installation, alignment, maintenance



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Outline

- Concentrator Solar Cells
- Optics
- Tracking
- Reliability, Testing and Standards
- Energy Payback Time
- CPV System Examples

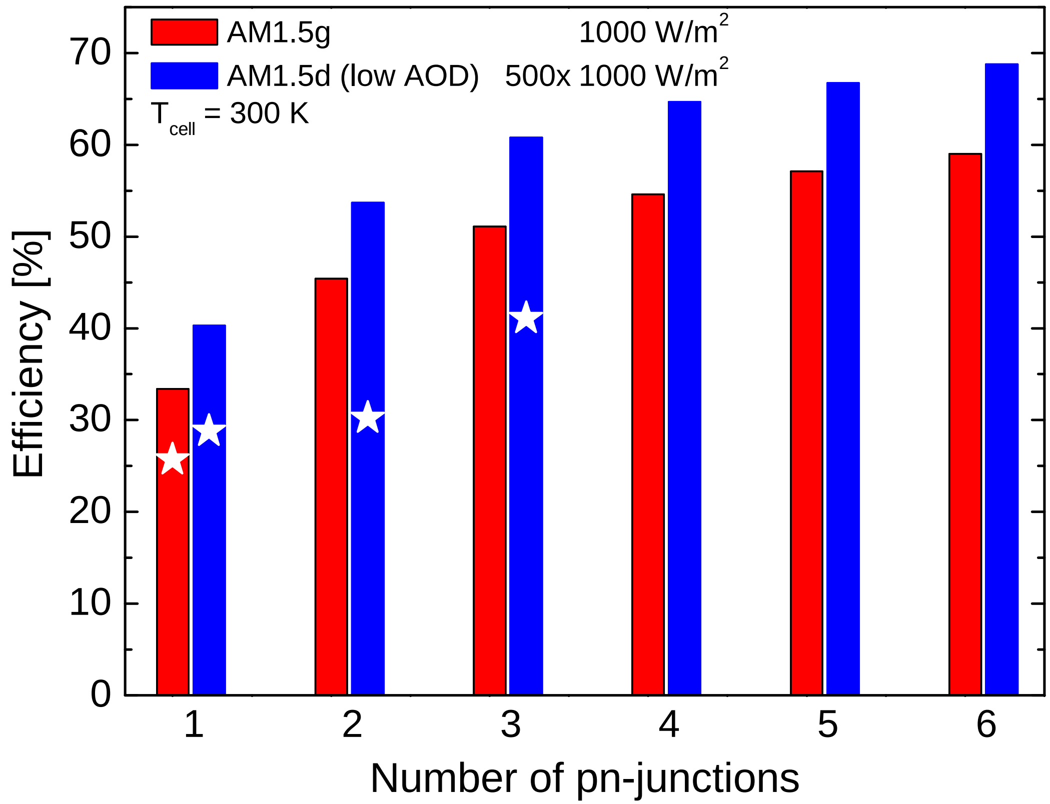
Efficiencies for Solar Cells

Shockley-Queisser Limit – the Theoretical Limit*

- J_{SC} increases linearly with concentration
- V_{OC} increases logarithmically with concentration

$\Rightarrow$ η increases with concentration

$\Rightarrow$ η increases with number of cells



* Note: 75-80 % of the theoretical limit can be practically realised!

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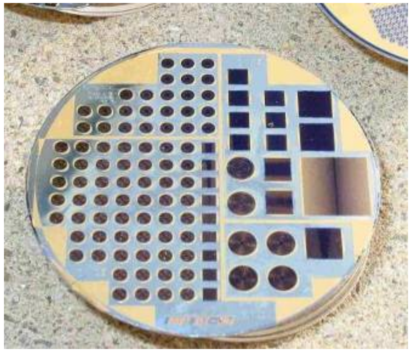
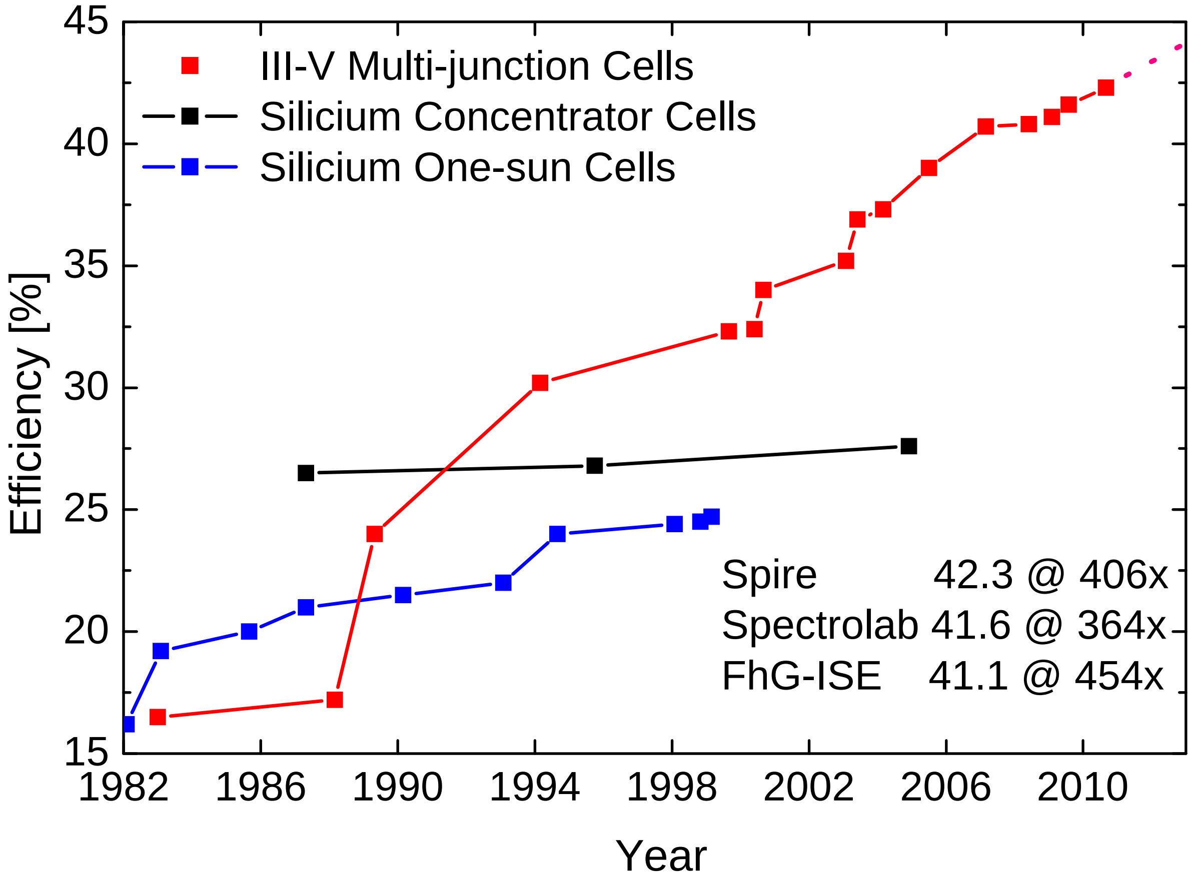
Concentrator Solar Cells
Development of Performances versus Time

independently confirmed efficiency values only

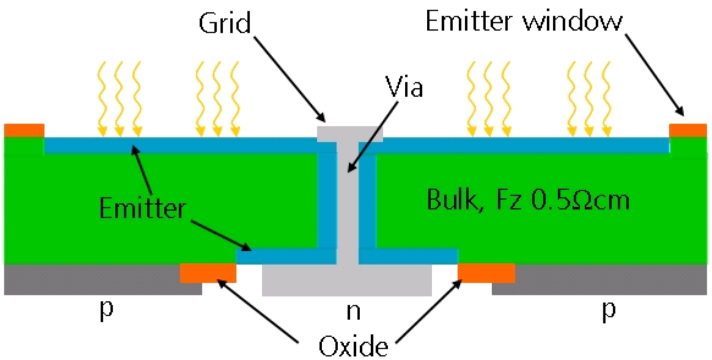
Note
no unique concentrator cell design
→ custom designed

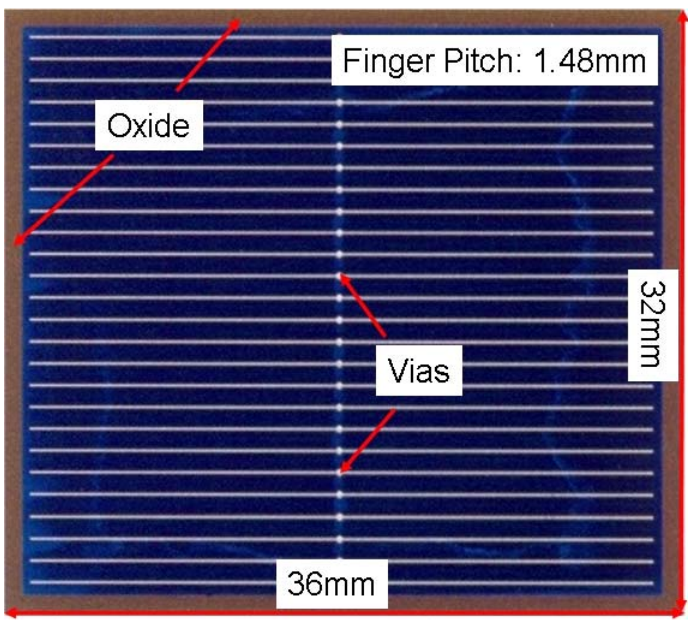


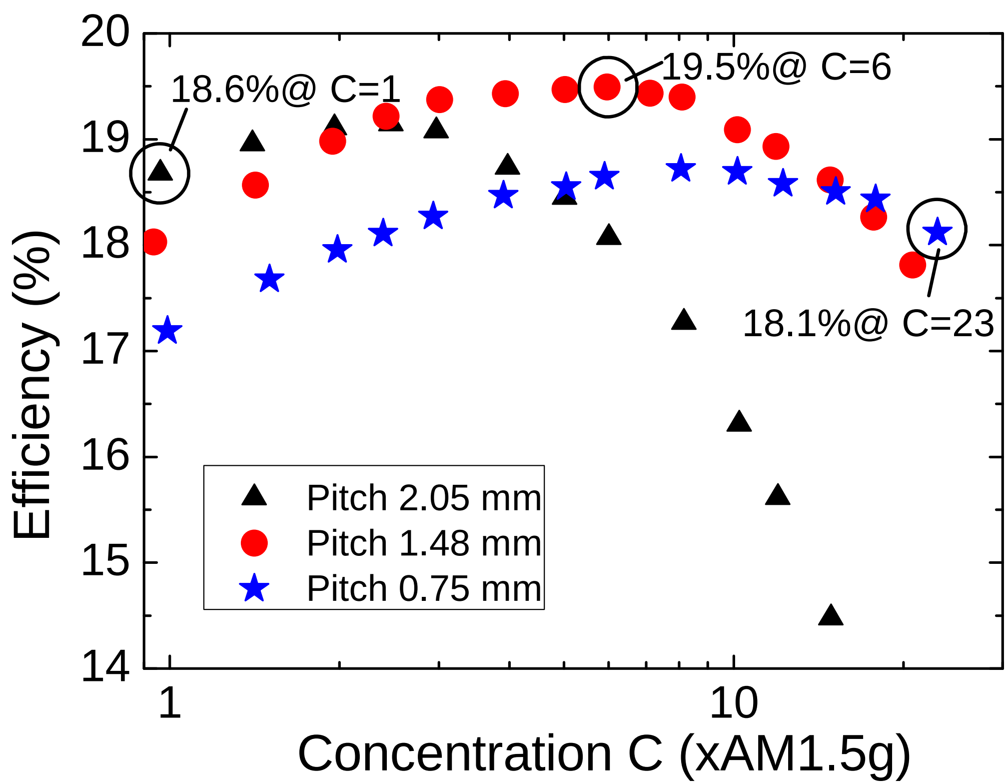


Si Concentrator Solar Cells

An Example for R&D: Industrial feasible C-MWT Cells







Si Concentrator Solar Cells
Industrial Availability

- SunPower sold Si CPV cells off the shelf a decade ago, but made a business decision to stop
- Some companies use one-sun Si solar cells (only for very low concentration)
- NaREC is currently the primary company which includes concentrator Si PV cell in their business model
- PVTEC of Fraunhofer ISE offers pilot sampling

⇒ *Supply of Silicon concentrator cells remains a problem for this segment of the community*

III-V-based Triple-Junction Solar Cell

The Industrial Standard Today

- 19 layers
- doping levels:

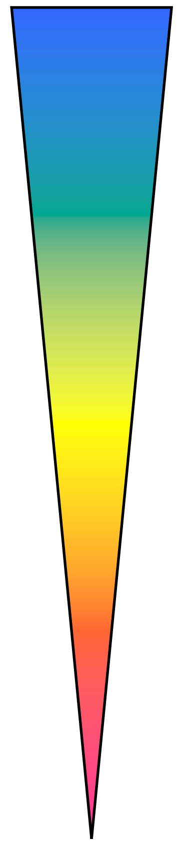
  $5*10^{16} – 2*10^{20}$ cm^{-3}
- thicknesses:

  0.02 – 4.0 µm
- layer compositions:

  binary – quaternary

  As/P hetero-interfaces

→ Efficiency in production:
36 % - 39 %



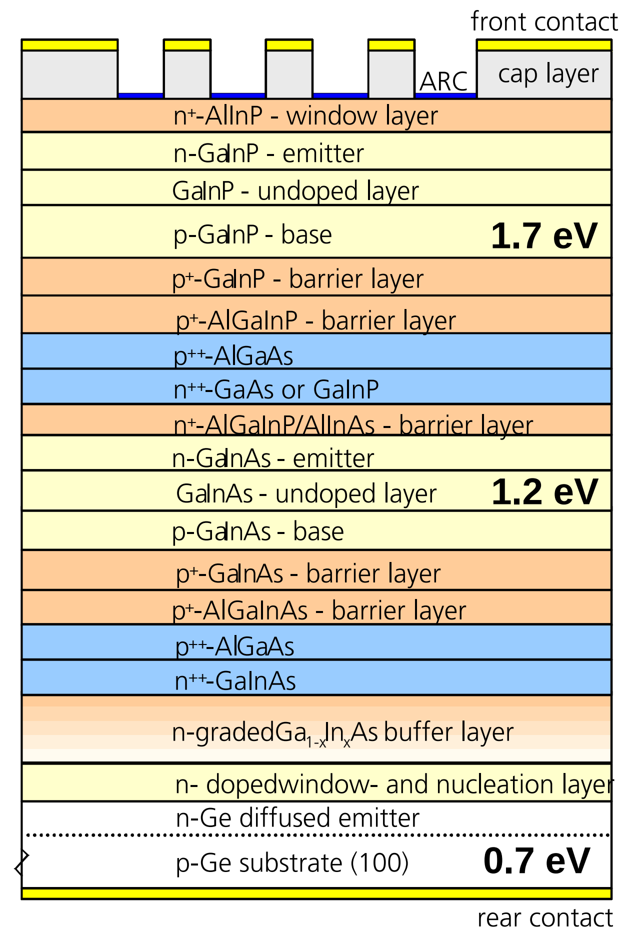
GaInP

tunnel diode

GaInAs

tunnel diode

Ge



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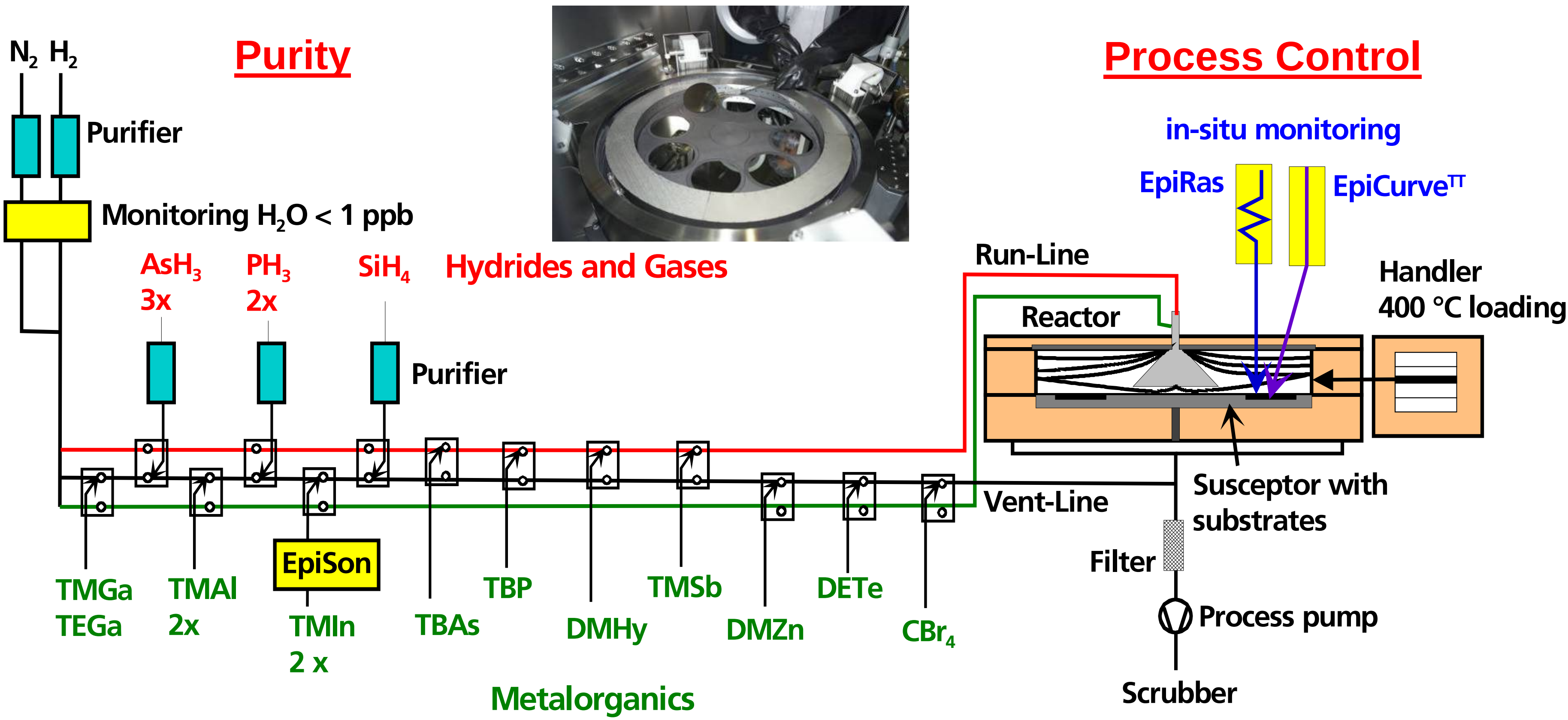
III-V-based Triple-Junction Solar Cells

Growth Technology as for LED and LASER Structures!

MOVPE (metal organic vapor phase epitaxy)

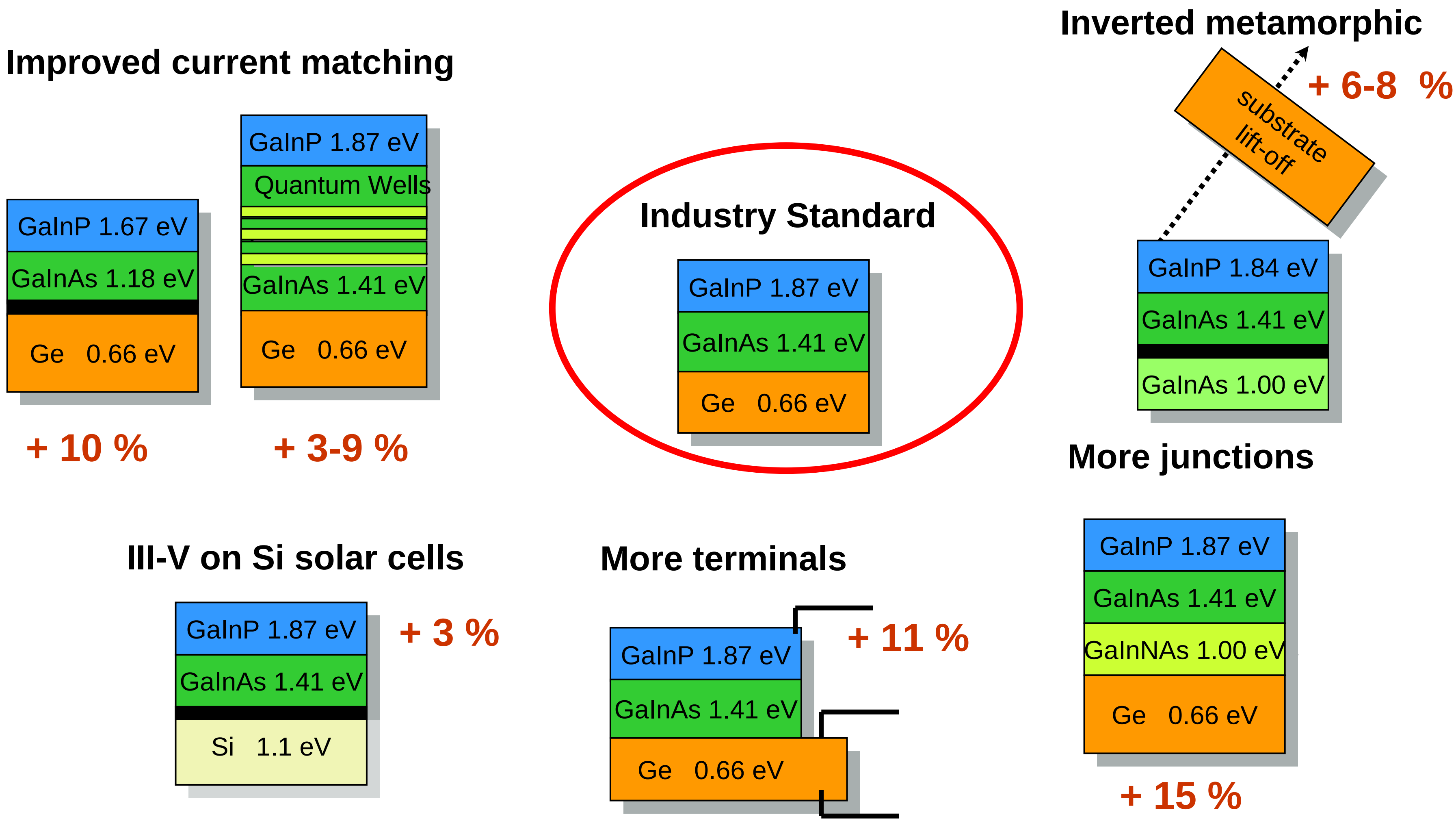


III-V-based Triple-junction Solar Cells

Industrial Availability – No ISSUE!

Company Name/Web Link	Location	Comment
Arima	Taipei, Taiwan	Reported achieving >40% cells.
Azur Space (RWE)	Heilbronn, Germany	Reported 36% efficiency; custom designs available.
CESI	Milano, Italy	Datasheet reports efficiency >30%.
Compound Solar Technology	Hsinchu Science Park, Taiwan	Website shows I-V curve with 33.4% efficiency
Cyrium	Ottawa, Canada	Datasheet describes typical > 39% cells
Emcore	Albuquerque, NM, USA	Datasheet describes typical 39% cells and receivers at ~500 suns.
Epistar	Hsinchu, Taiwan	Multi-junction cells in development
IQE	Cardiff, Wales, UK	Has demonstrated state-of-the-art efficiencies
JDSU	Milpitas, CA, USA	Advertises multi-junction concentrator cells on website
Microlink Devices	Niles, IL, USA	Multi-junction cells removed from substrate in development
Quantasol	Kingston upon Thames, Surrey, UK	Multi-junction cells with quantum wells
RFMD	Greensboro, NC, USA	Multi-junction cells in development
Sharp	Japan	Has demonstrated high efficiencies, but has not indicated plans for commercialization outside of supplying cells for its own CPV systems.
Solar Junction	San Jose, CA, USA	Is approaching 40%.
Spectrolab	Sylmar, CA, USA	Datasheet describes minimum average 36% cells and cell assemblies at 50 W/cm^2. Will ship 35 MW in 2009, and plan to ship 100 MW in 2010 (@500X).
Spire (Bandwidth)	Boston, MA, USA	Announced achievement of 42.3% efficiency.
VPEC	Ping-jen city, Taiwan	Multi-junction cells in development

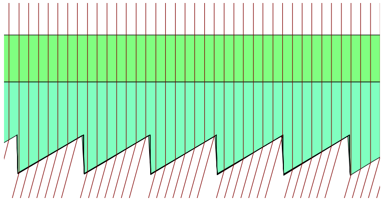
What´s Next?
R&D for Cost Savings and better Performances
Energy Harvesting Efficiency for El Arenosillo, Spain

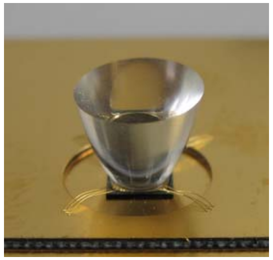
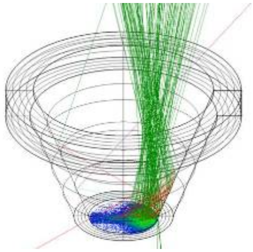
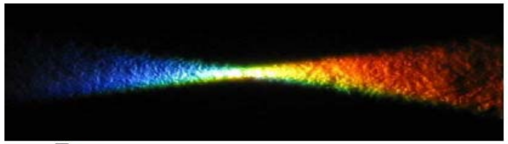
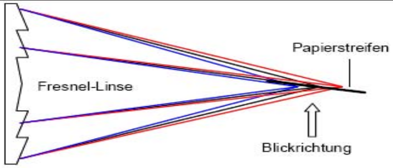


Optics –
a Playground for Creativity

Optics
Design Considerations

- Refractive vs reflective
- Add secondary to increase acceptance angle?
- Small vs large elements
- Planar (Fresnel) vs shaped (domed) elements
- Acrylic vs silicone-on-glass vs many other materials
- Short vs long focal length (f number)
- Point focus (MJ CPV?) vs line focus (Si CPV?)
- Filled (solid) optics vs transmission through air
- Use of wave guides
- Use of luminescence for concentration



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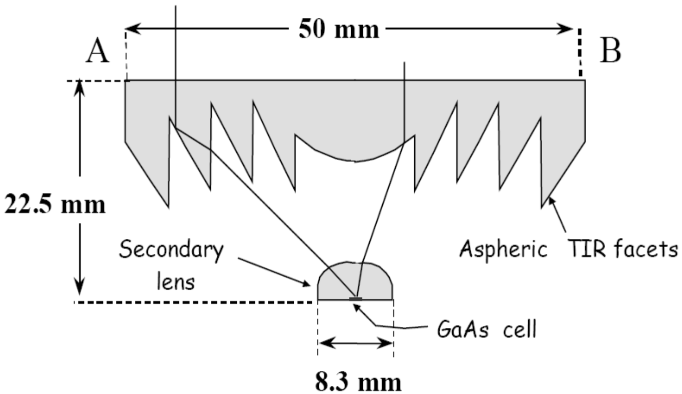
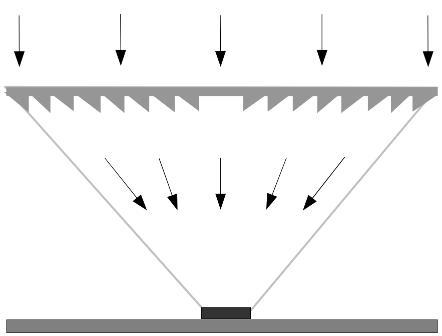
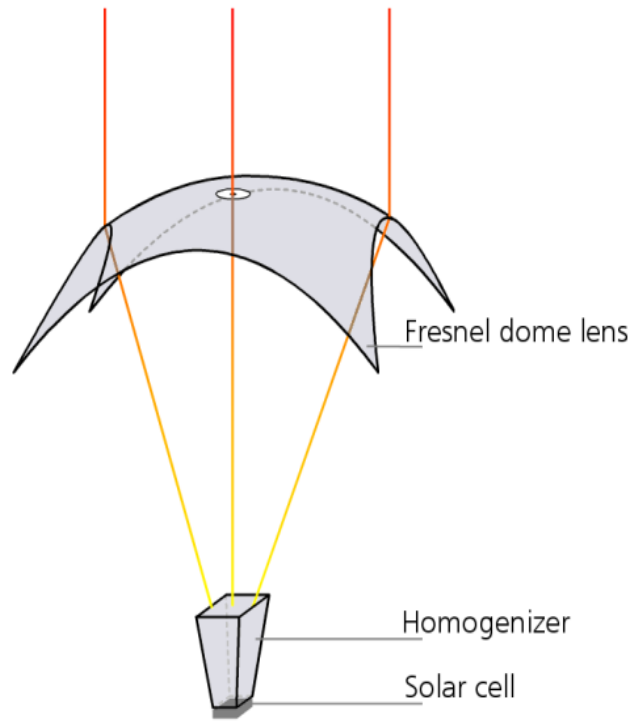
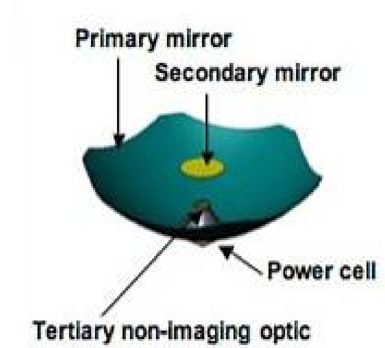
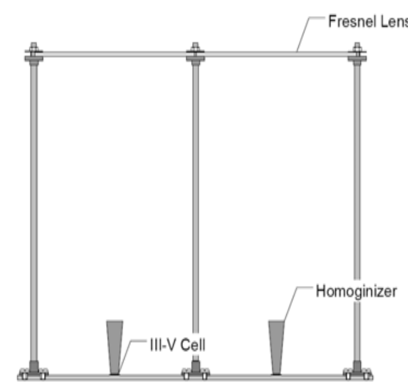
Examples of Concentrating Elements









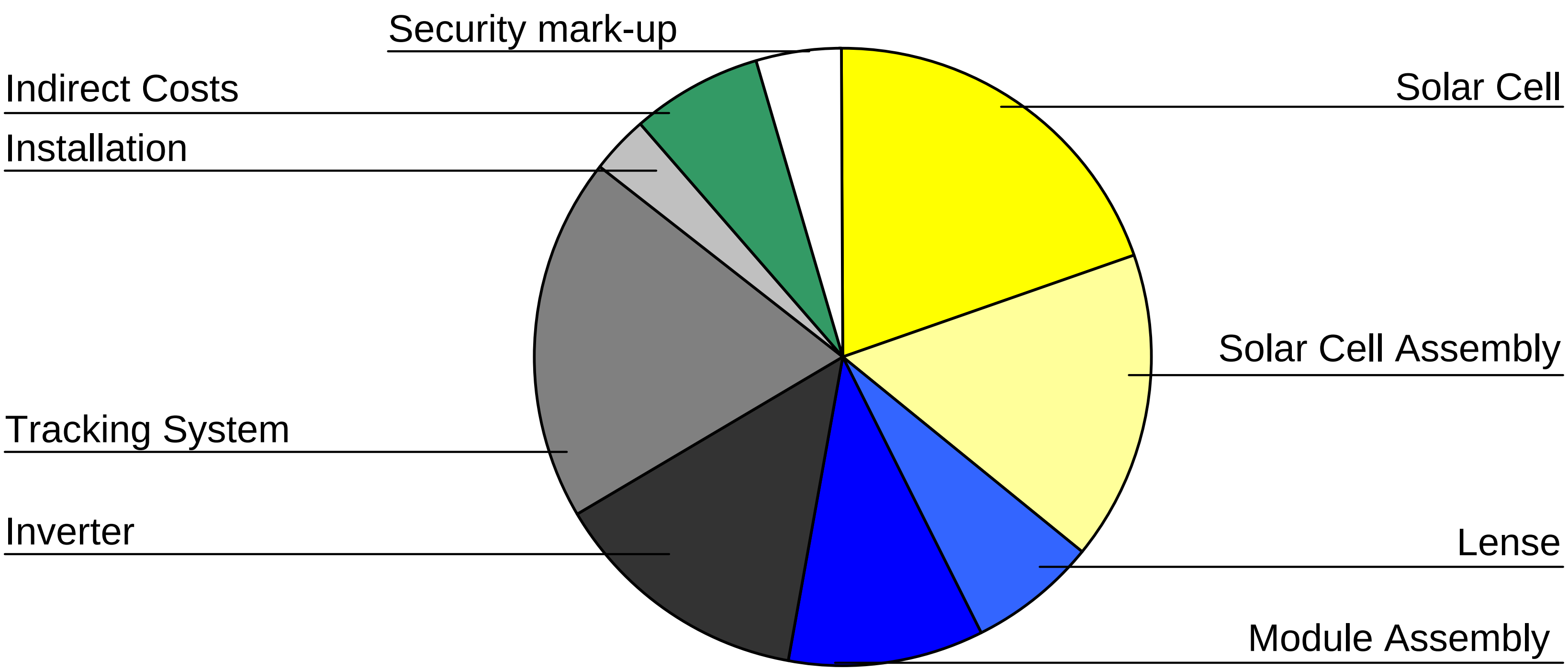


Sources: UPM, Daido Steel, Fraunhofer ISE, Sol3G, Solfocus

Trackers and BOS –
high-tec or low-tec?
But: with Cost Impact!

CPV System Cost Analysis

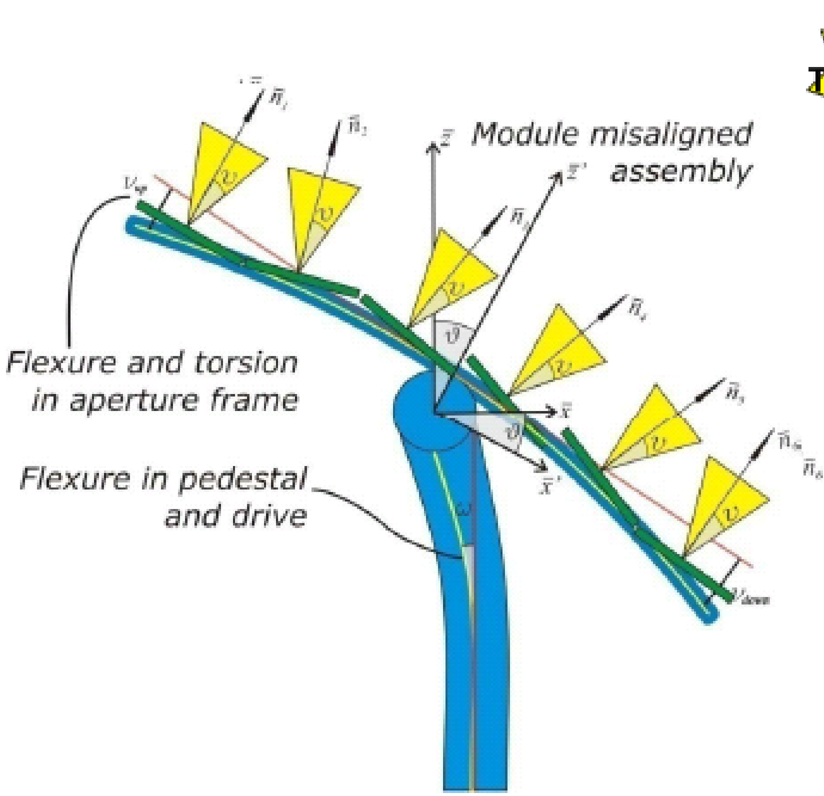
One third of the Cost for Tracker and BOS



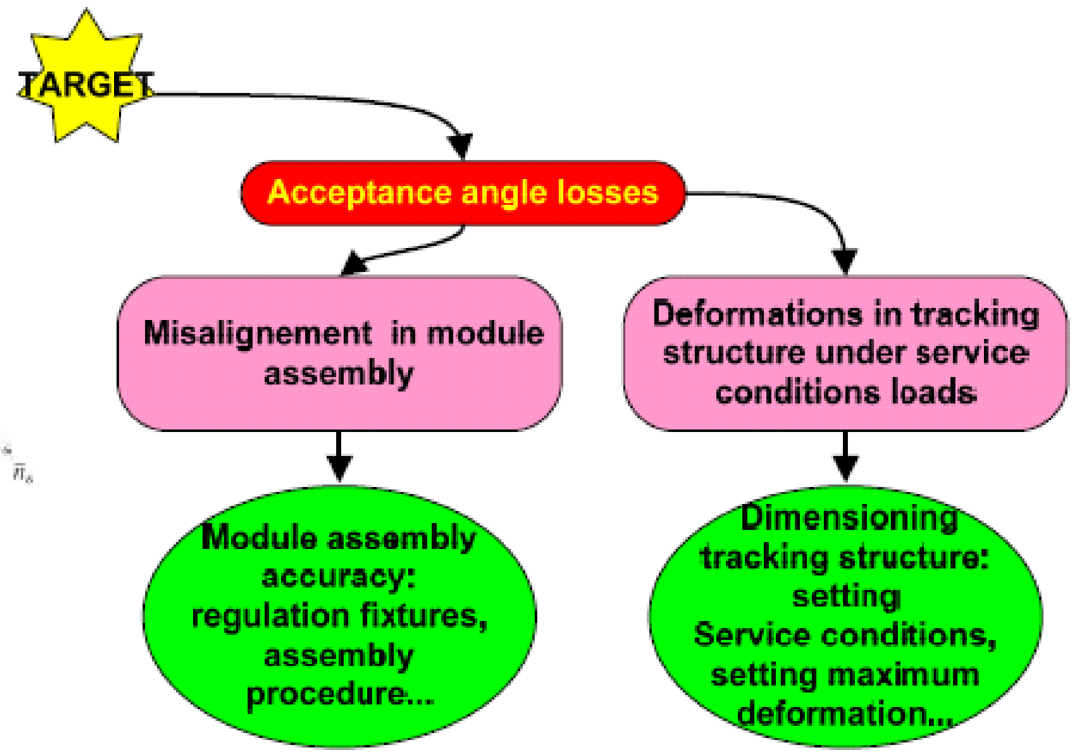
Ref: Lerchenmüller et al, 3rd Solar Concentrator Conference, Arizona, 2005

Trackers

A Need for Accuracy!



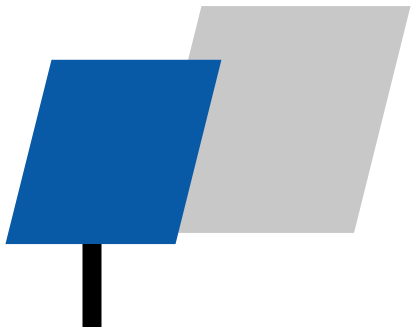
Side view diagram of a 2ax. pedestal tracker with flat CPV modules (green) each with its acceptance angle cone (yellow)



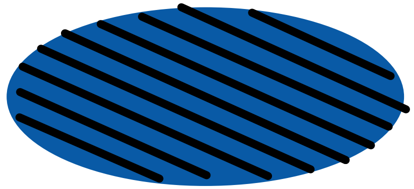
Picture courtesy: I. Luque-Heredia, Spain

Trackers
Make your Choice!

- Pedestal vs distributed support
- One axis (for Si CPV?) vs two axis
- Small (individually tracked) vs large elements
- Height
- Circular (carousel: rotate & roll) vs linear (tilt & roll)
- Planar mounting vs staggered mounting
- Open- vs closed-loop tracking control
- Hydraulic vs direct drive



pedestal



carousel

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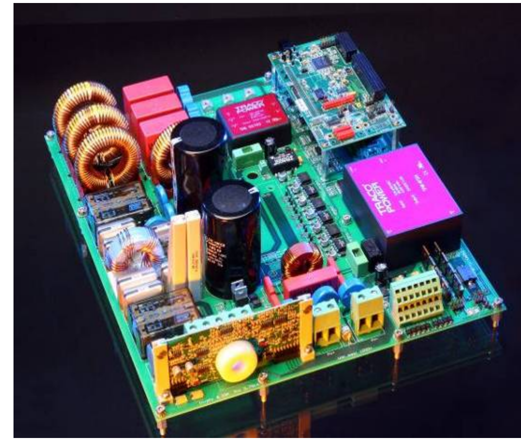
Power Electronics for CPV Applications

- Requirements for CPV inverters:
  - High efficiency, also at nominal power
  - High DC voltage (no DC/DC converter, no transformer)
  - Fast and accurate MPP Tracker (high fill factor)
  - High operating temperature ($T_{amb.}$ > 50 °C)



- Requirements for CPV tracking units:
  - High position accuracy (typ. 0,1° to 1°)
  - No weather sensitivity (wind, clouds, 2nd irr. sources)
  - Robustness and overload capability

- Requirement for both: Reliability and cost effective

Reliability, Testing and Standards
A Key for Bankability

Reliability
An important Challenge!

Reports of reliability issues include:

- Trackers
- Inverters, data acquisition, etc.
- Longevity may be limited by optics, thermal control of cells, dirt getting into the light path
- Only a handful of companies have > 10 y experience in the field
- Most companies are aggressively applying accelerated testing

→ Most companies are considering “design for reliability” from the start

→ Convincing banks of long-term reliability is key hurdle to growth

Reliability and Testing

- Standards for flat plate PV established
- IEC62108: Concentrator photovoltaic (CPV) modules and assemblies

  - Design qualification and type approval

Climate chamber at Fraunhofer ISE

CPV modules in a heat cycling test

International Standards Efforts
For CPV

IEC TC82 WG7 current projects:

- Power Rating
- Safety
- Energy Rating
- Tracker specification
- Acceptance test

UL

- Safety

Power Rating
Order out of Chaos

In the past, companies chose rating conditions:

- Irradiance: 850, 900, or 1000 W/m^2 ?
- Temperature: 25°C cell or 20°C ambient ?

→ affects €/W, performance ratio, and other metrics

IEC WG7 committee has now tentatively chosen:

Irradiance: 900 W/m^2

Test condition:	**Operating condition:**
25°C cell	20°C ambient
(same as flat plate)	(like California's rating)

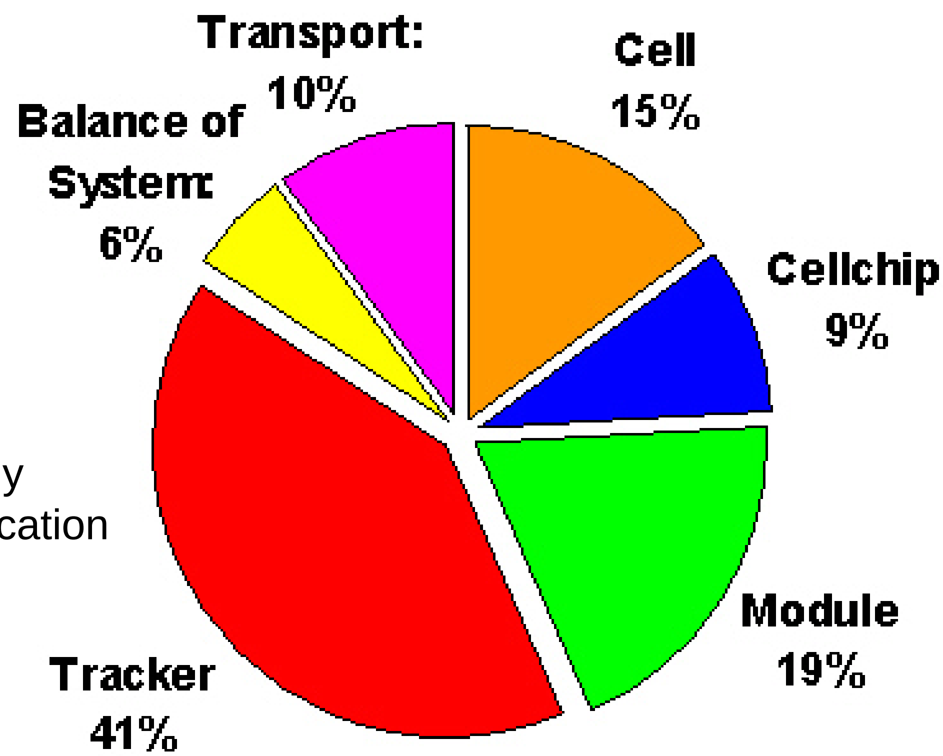
Energy Pay Back Time

A Case Study

Study on Energy Payback Time for a FLATCON® System
CPV is a Green Energy!

<u>Central outcome</u>:
less than 1 y!!
depending on the site.

Percentage of energy demand during fabrication



Ref: Peharz et al, Prog PV Res and Appl., 2005, **13**, 627

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Examples for CPV Systems

Examples for III-V based Concentrator Systems
AMONIX, CA, USA

- C ~ 500x
- Fresnel lens
- Up to 70 kW/pedestal
- Installed:

  ~ 14 MW Si-based

  ~ 2 MW MJ

  > 40 MW in progress
- Production capacity 30 MW/y (plans to expand)

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Examples for III-V based Concentrator Systems
Concentrix Solar, Germany

- C ~ 385x
- Fresnel lens
- 6/12/22 kW pedestal
- Glass/glass construction
- Installed:

  ~ 2 MW on sun

  > 1 MW in progress
- Production capacity 25 MW/y

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Examples for III-V based Concentrator Systems
EMCORE, New Mexico, USA

- C > 1000x
- Fresnel lens
- Tilt & Roll
- Installed > 1 MW of design on pedestal

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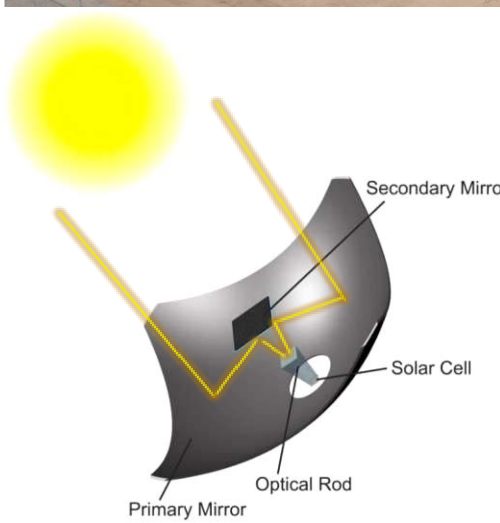
Examples for III-V based Concentrator Systems
Solfocus, California, USA

- C ~ 650 X
- Multiple reflections within glass
- ~9 kW/pedestal
- Installed:

  ~ 2 MW on sun

  > 10 MW in progress

- Production capacity 50 MW/y



Example for Low Concentration System
Skyline Solar, California, USA

- Linear focus
- Reflective optics aimed at opposite side
- C ~ 10x
- Si cells

- ~ 150 kW on sun
- Mirrors shaped in automotive factory

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Example for Co-generation System
Zenith Solar, Israel

- C ~ 800x
- Dense Array with MJC and actively cooled
- ~ 100 kW_{el} + 200 kW_{therm} on sun
- Production starts

Summary

- Many options for optics, trackers, and cells to consider in CPV system development
- High-efficiency multi-unction cells enable high-concentration CPV; while low-X CPV reduces use of silicon
- Module efficiencies of 30% are enabling
- Convergence of product development & market emergence provides growth opportunity

Please visit CPV-7 in April, Las Vegas 2011

http://www.cpv-7.org

Thanks you very much for your attention!

Fraunhofer Institute for Solar Energy Systems ISE

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National Renewable Energy Laboratory
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