Hochkonzentrierende Photovoltaik: Stand der Entwicklung und Perspektiven

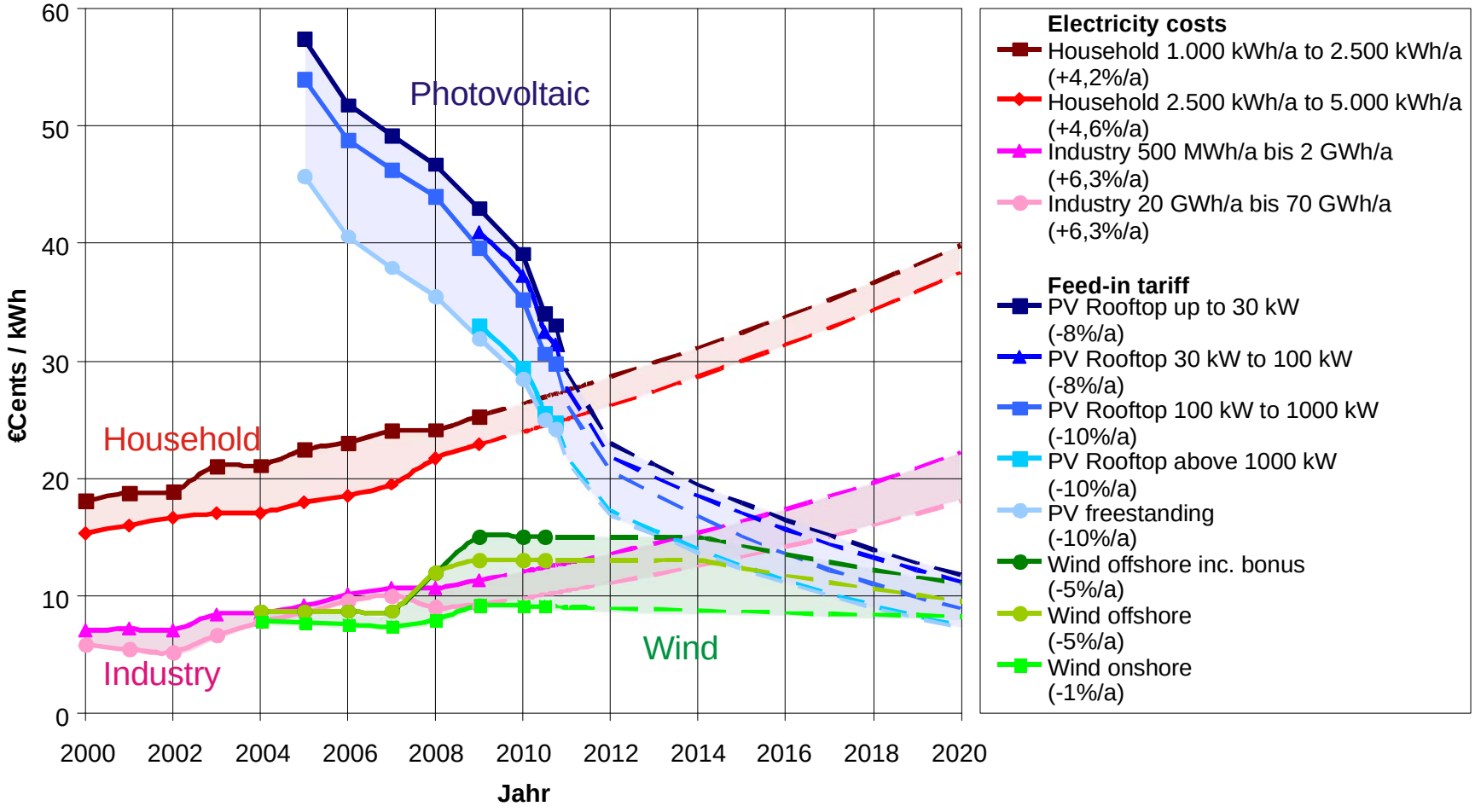
Andreas W. Bett

Fraunhofer Institut für Solare Energiesysteme
ISE, Freiburg, Germany
www.ise.fraunhofer.de

DPG Frühjahrstagung, AK Energie
Dresden, 16. März 2011

Fraunhofer ISE

Electricity Costs and Feed-in Tariff in Germany



Source: B. Burger, “Energiekonzept 2050”, June 2010, FVEE, www.fvee.de, Update of 29.09.2010

Fraunhofer ISE

Photovoltaics

Standard PV and Concentrating PV

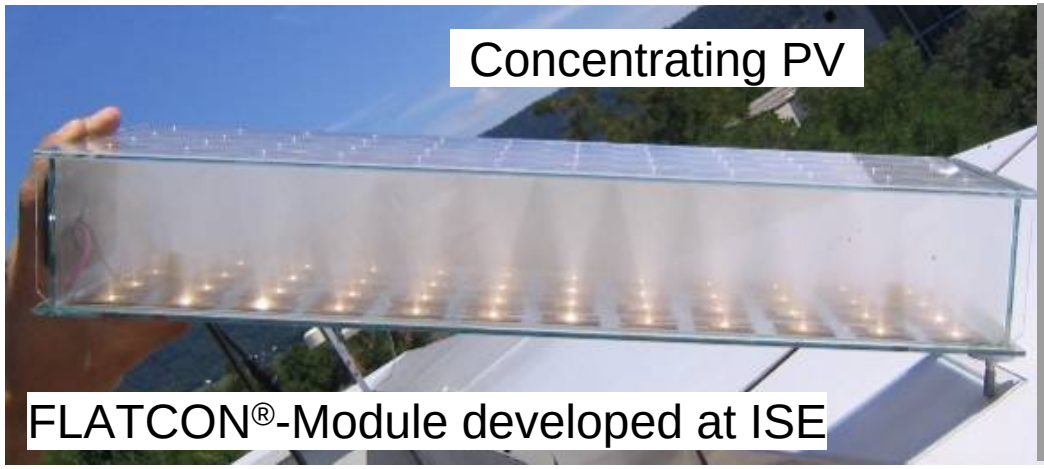
Light collection and conversion is one unit

Fraunhofer ISE

Photovoltaics

Standard PV and Concentrating PV

Light collection and conversion is one unit



Light collection

collection area

separated from

Light conversion

cell area

Concentration Factor = collection / cell area

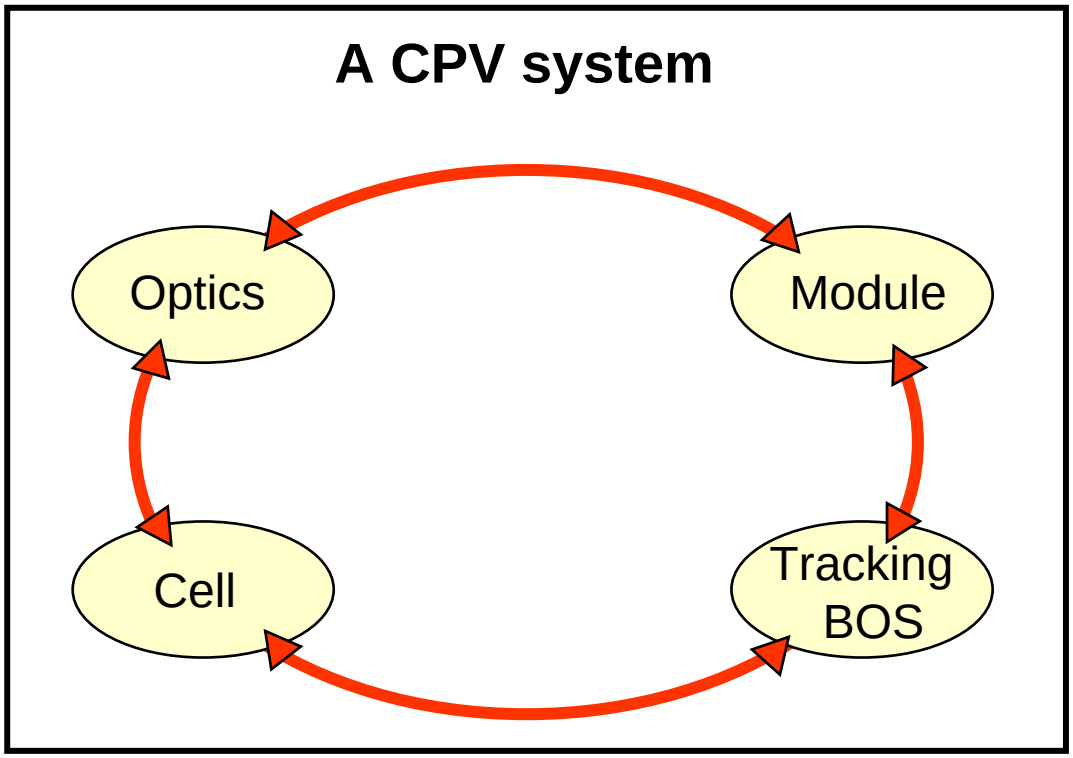
Fraunhofer ISE

The Concentrating PV Technology (CPV)
It is a System Approach

The necessity:

Optimise the system!

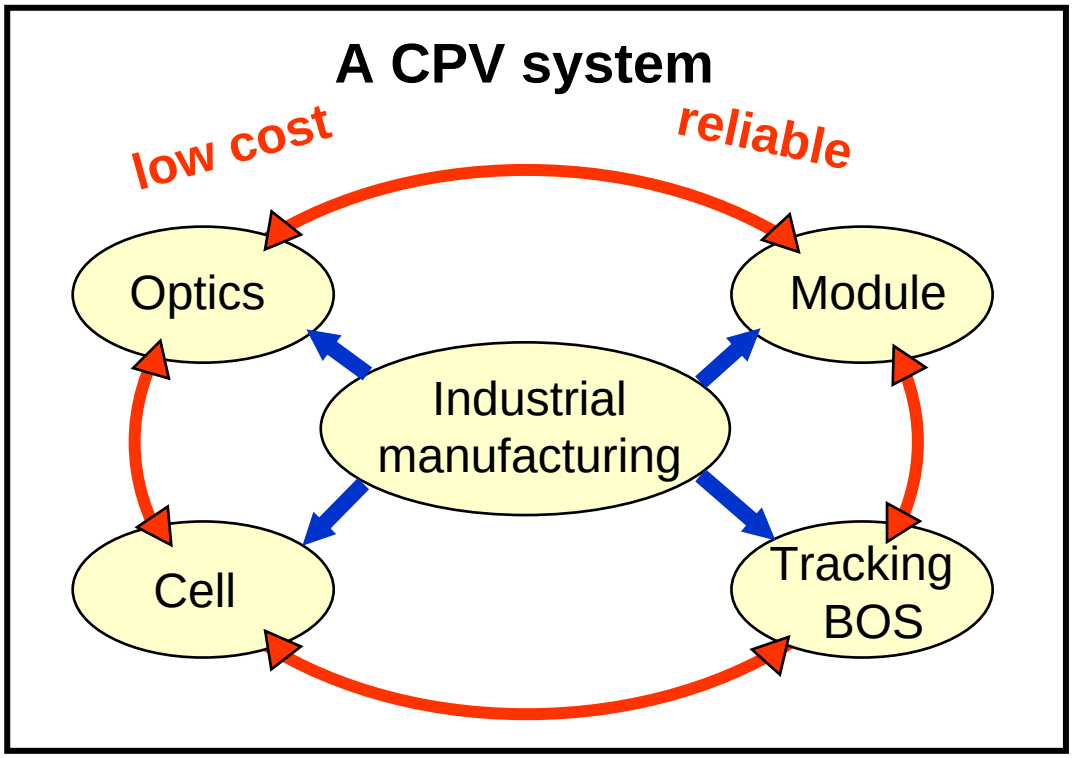
This requires knowledge in different fields (optics, mechanics, semiconductors…)

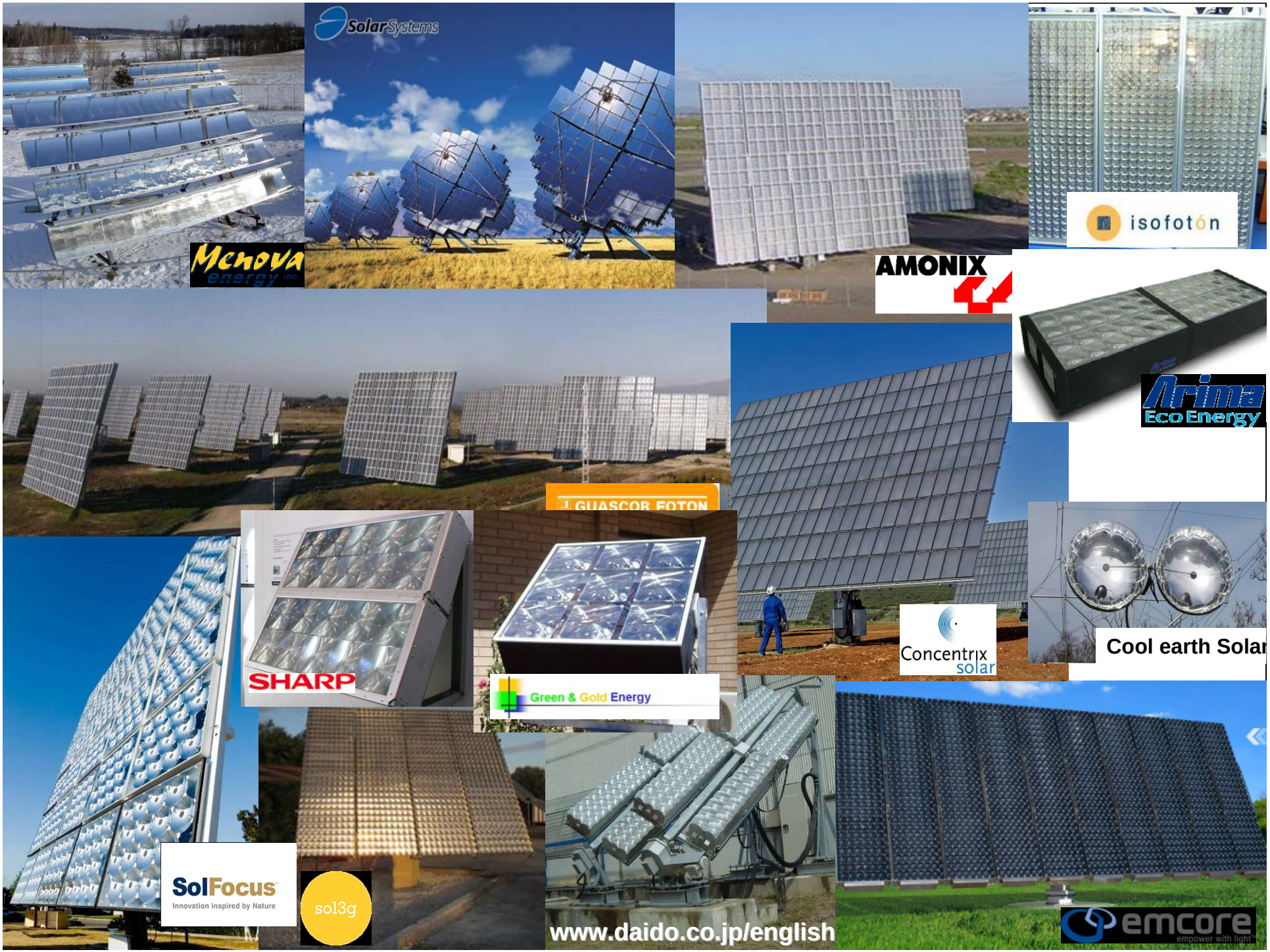


The Concentrating PV Technology (CPV)

There are many technical solutions to realise CPV systems!

→ many companies started their business




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

Classification of CPV Systems
Low and High Concentration

Concentration: < 100
Si-cells
static or one-axis

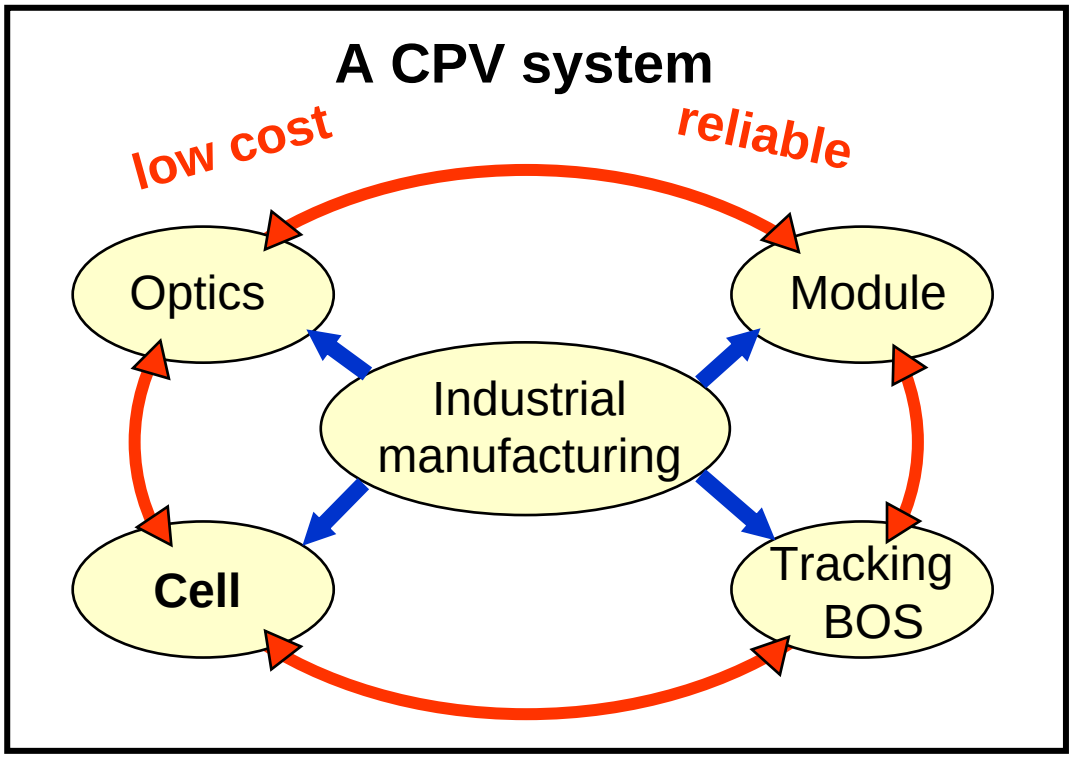
Euclides, Tenerife

Concentration: > 300
III-V-cells
two-axis

FLATCON, FhG ISE / Concentrix

The Concentrating PV Technology (CPV)

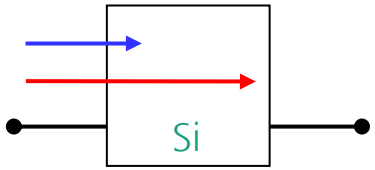
Cell

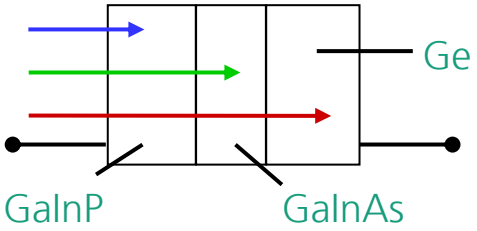


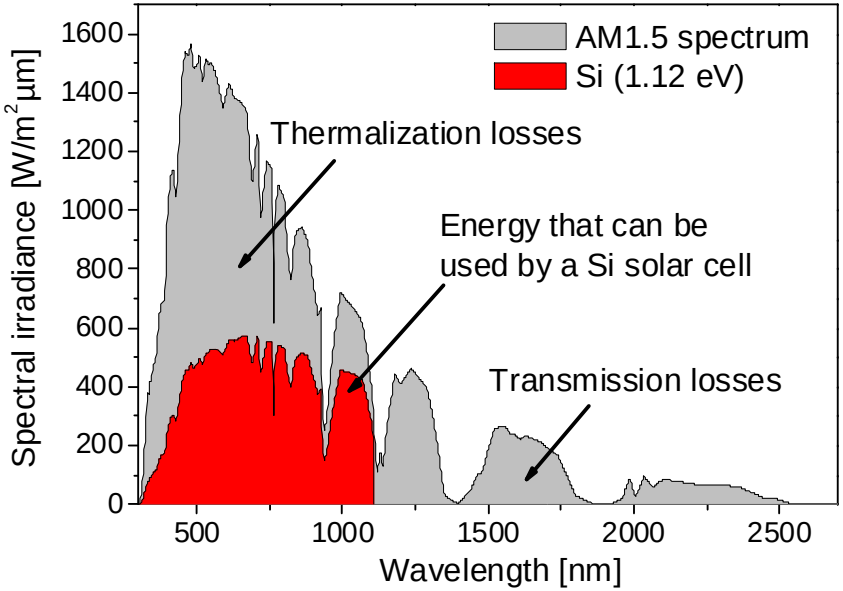
Fraunhofer ISE

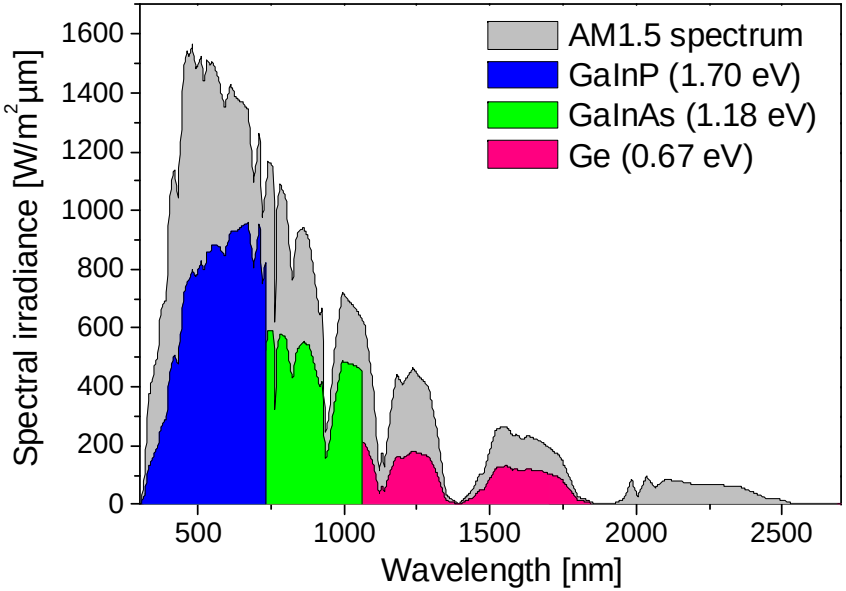
Why Multi-Junction Solar Cells?

Reduce the Thermalisation and Transmission Losses!
Increase the Efficiency!









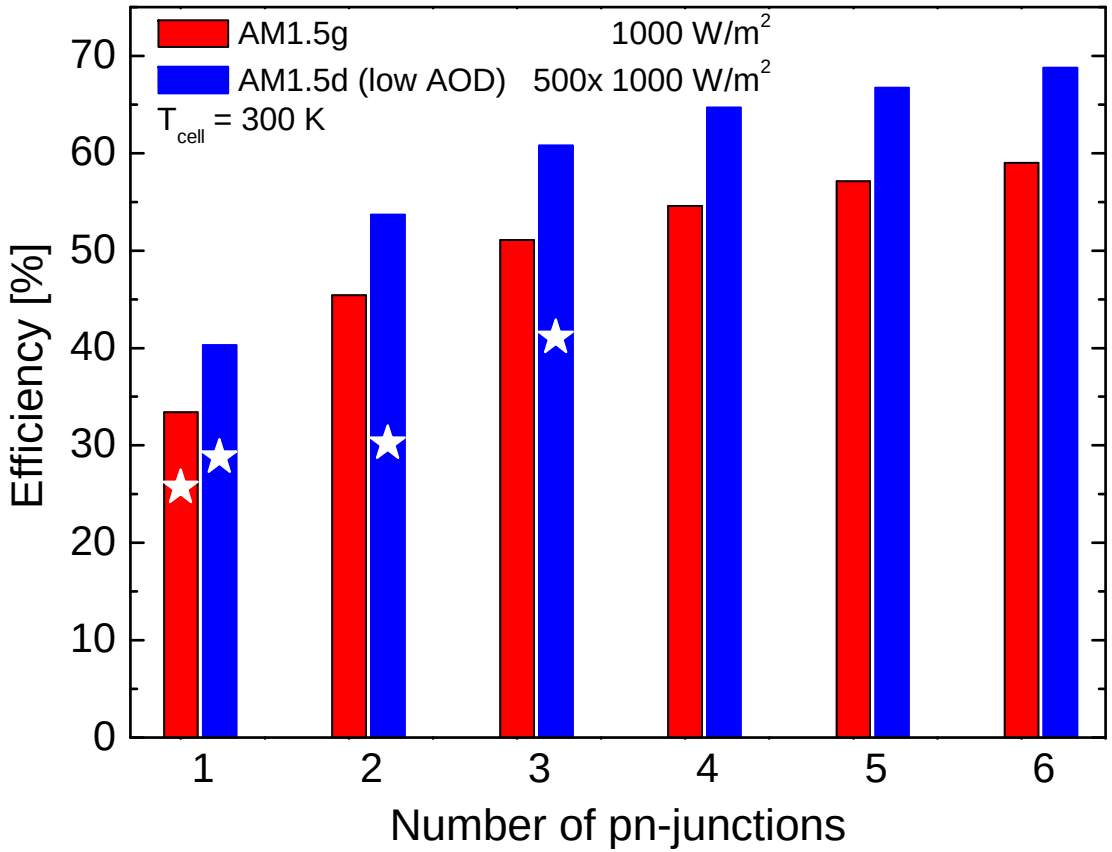
Fraunhofer ISE

Why Multi-Junction Concentrator Solar Cells?
Shockley-Queisser Limit for Solar Cells

⇒ η increases with number of cells

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

⇒ η increases with concentration



Fraunhofer ISE

III-V-based Triple-Junction Solar Cell

The Structure

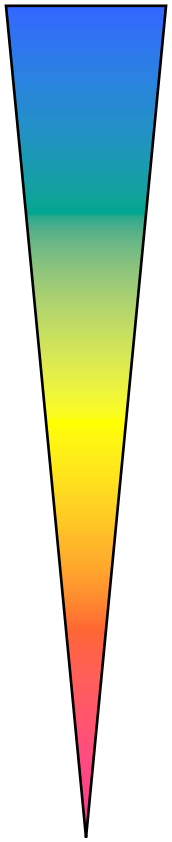
- 19 layers
- doping levels:

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

  0.02 – 4.0 µm
- layer compositions:

  binary – quaternary

  As/P hetero-interfaces



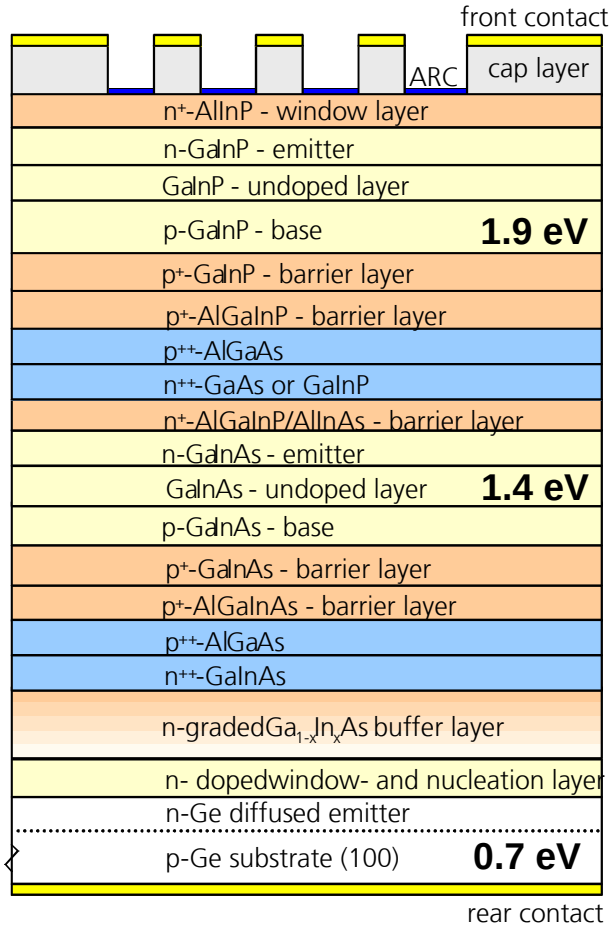
GaInP

tunnel diode

GaInAs

tunnel diode

Ge

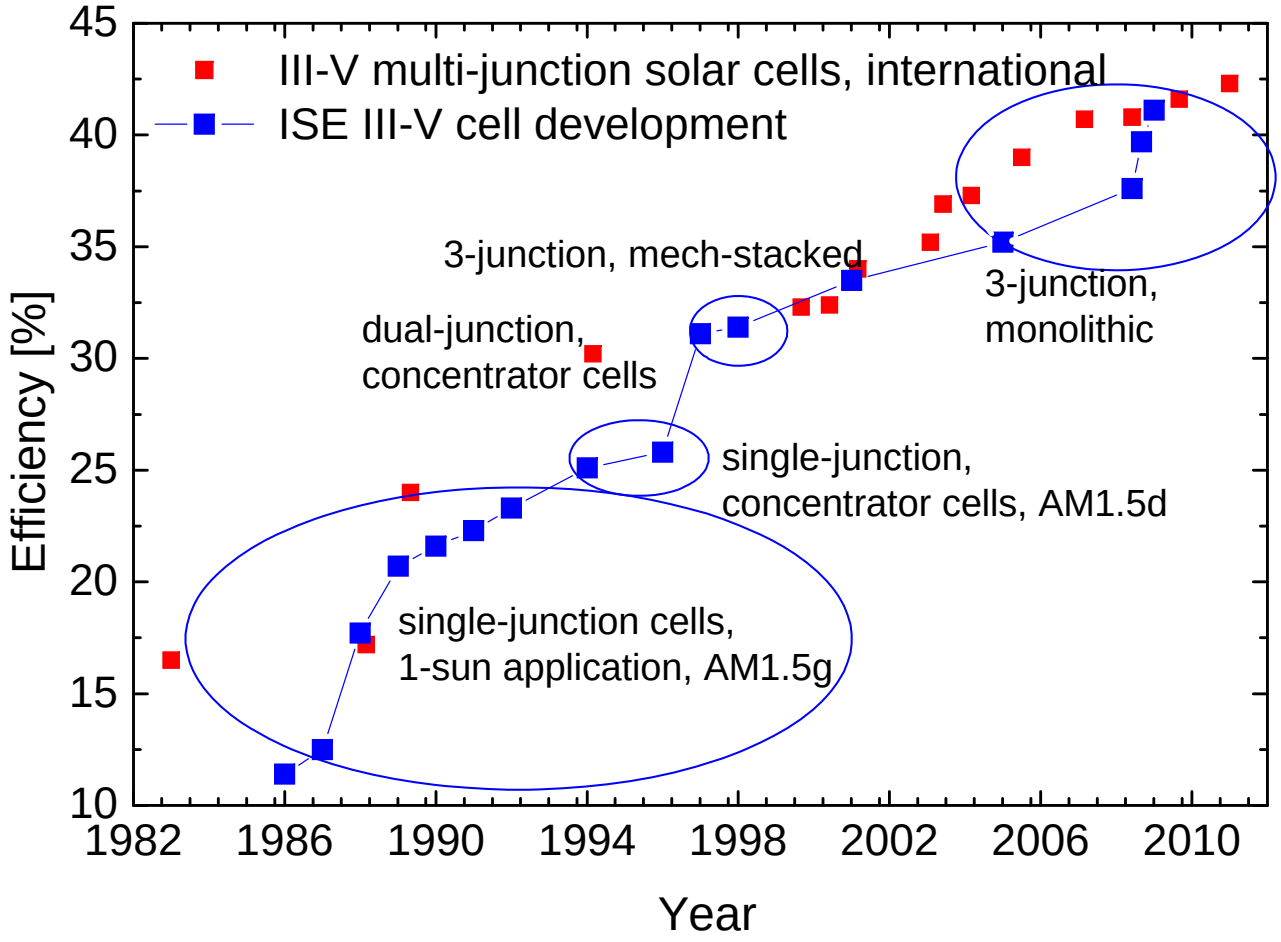


AZURSPACE SOLAR POWER GMBH

Fraunhofer ISE

Terrestrial Concentrator Solar Cells

Development of III-V-based Solar Cell Efficiencies

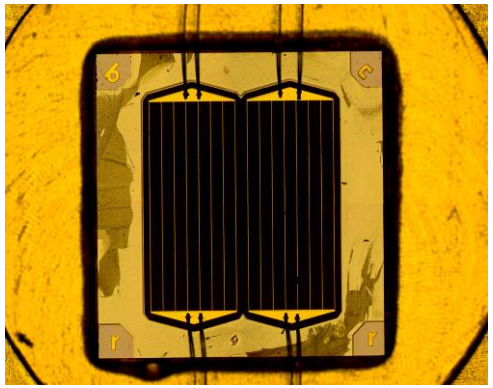


Fraunhofer ISE

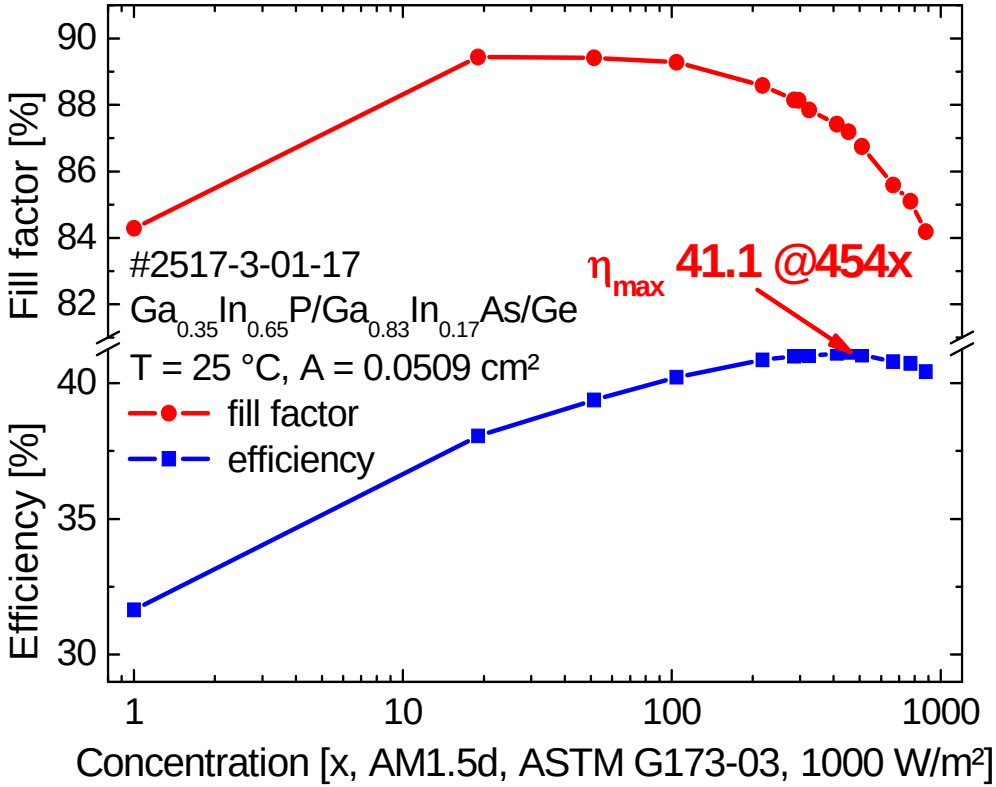
Metamorphic Triple-Junction Solar Cell at ISE

η= 41.1 % @ C = 454

η = 40.4 % @ C = 880



A=0.0509 cm²

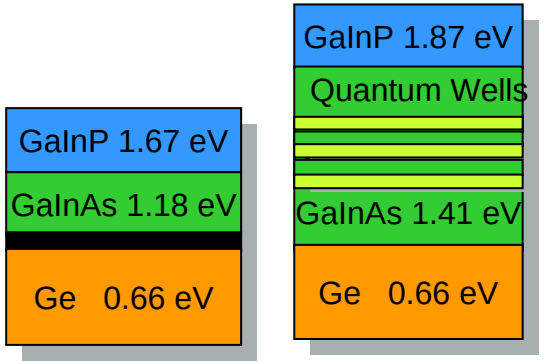


W.Guter et al., Applied Physics Letters 94, 223504 (2009)

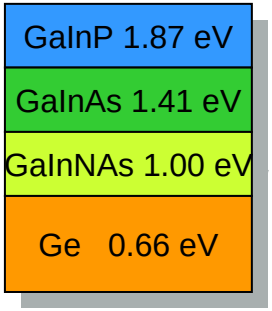
Fraunhofer ISE

Advanced III-V Solar Cell Concepts
Under Investigation at Fraunhofer ISE

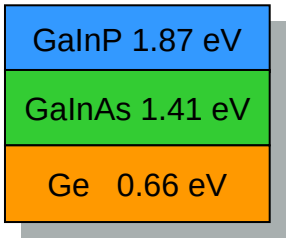
Improved current matching



More junctions

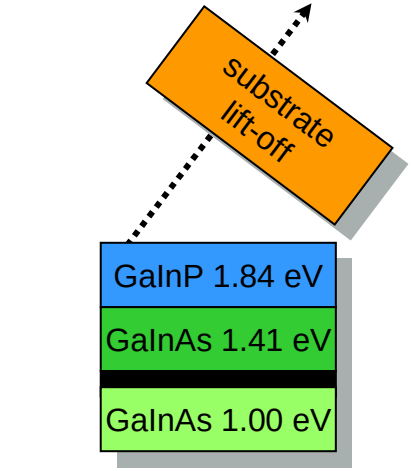


Industry Standard

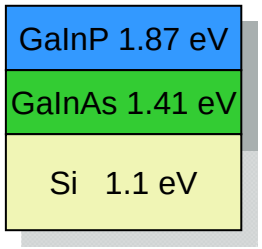


in production:
36-39 % AM1.5d
28-30 % AM0

Inverted metamorphic



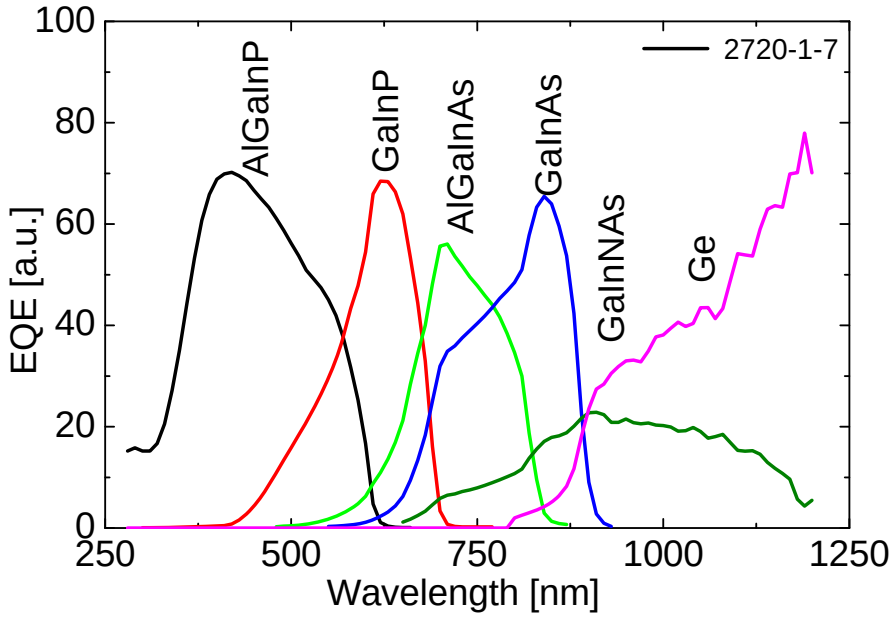
III-V on Si solar cells

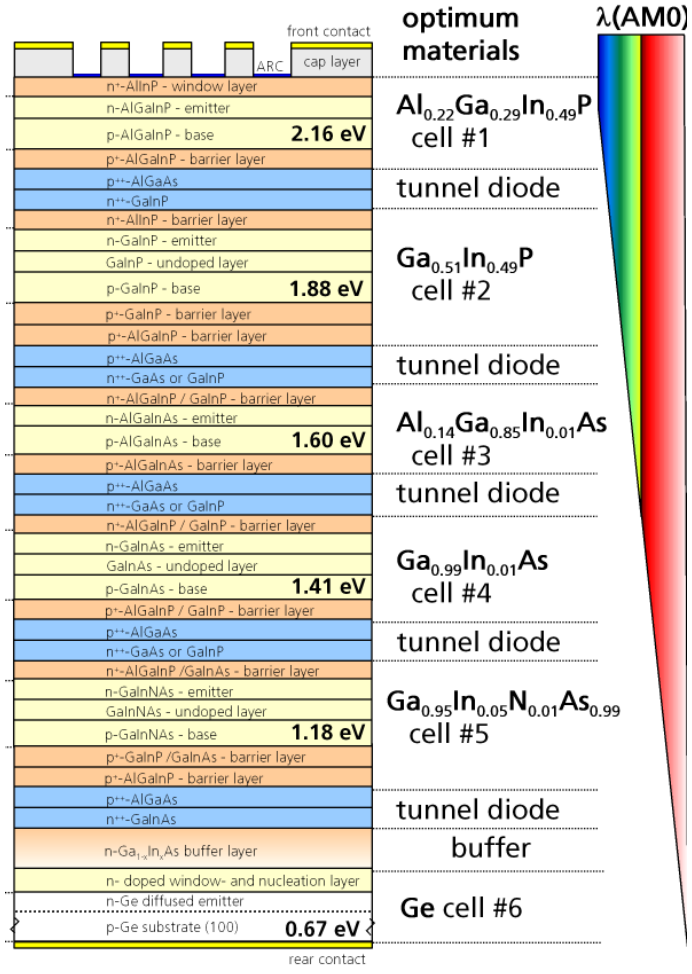


First 6-Junction Solar Cells Realized

Highly complex structure

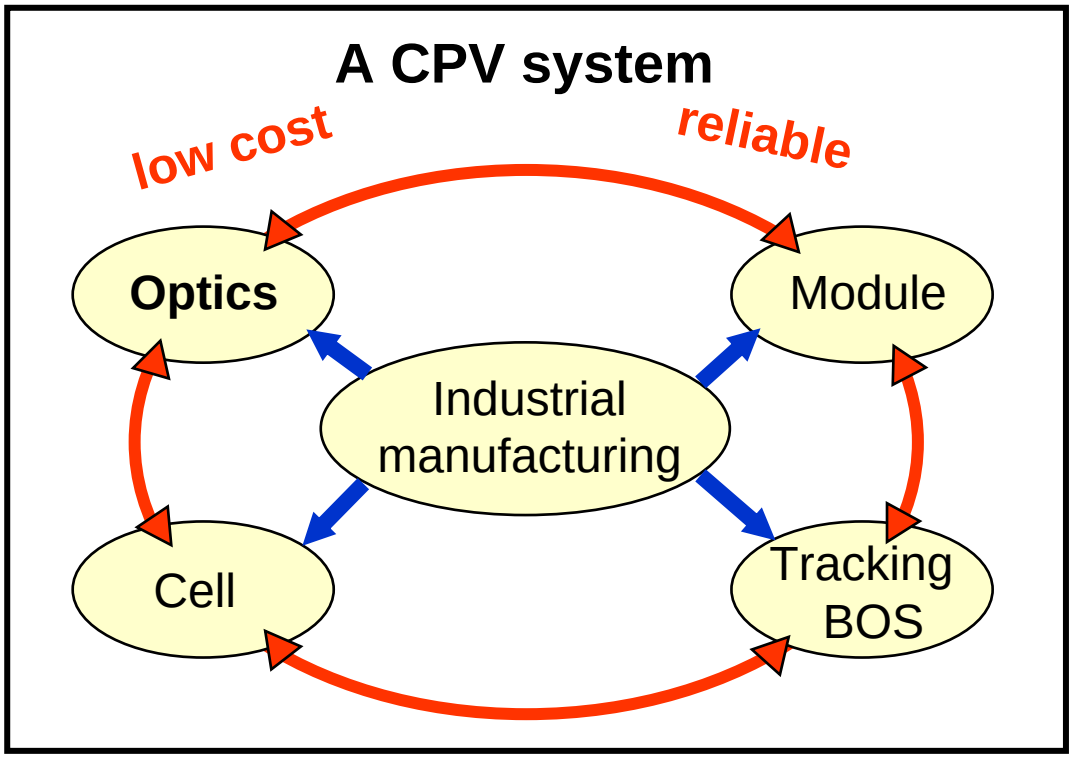
V_{oc} = 5.4V



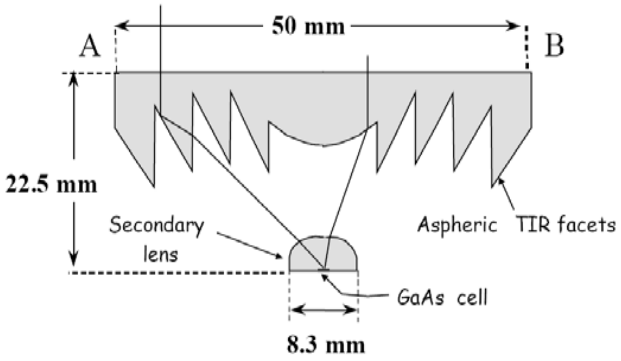


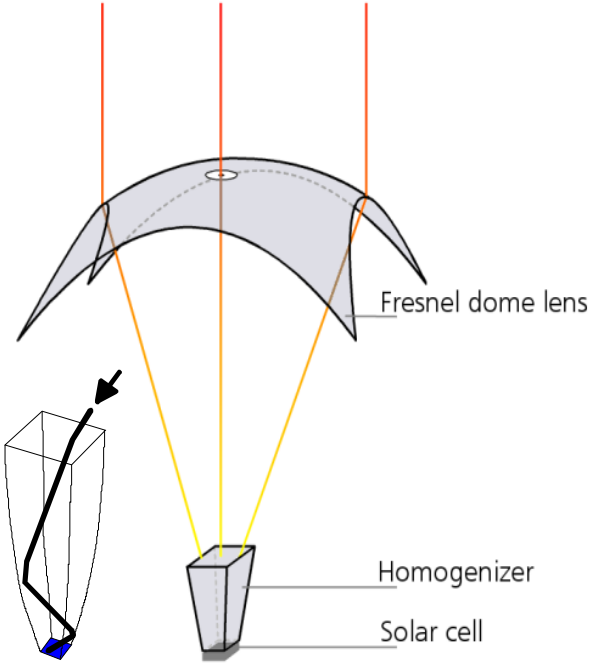
Fraunhofer ISE

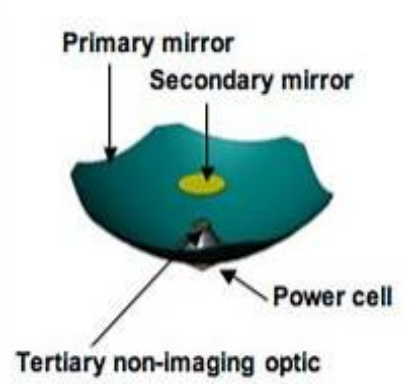
The Concentrating PV Technology (CPV)
Optics

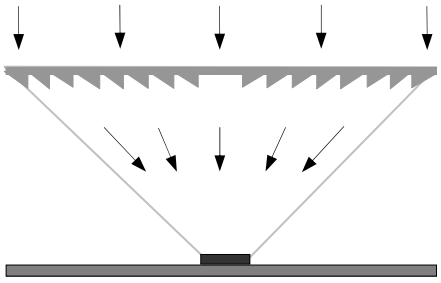


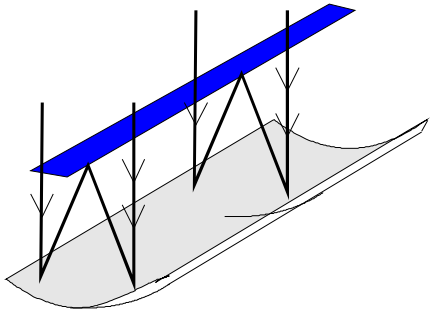
Examples of Concentrating Elements
A Plurality of Designs









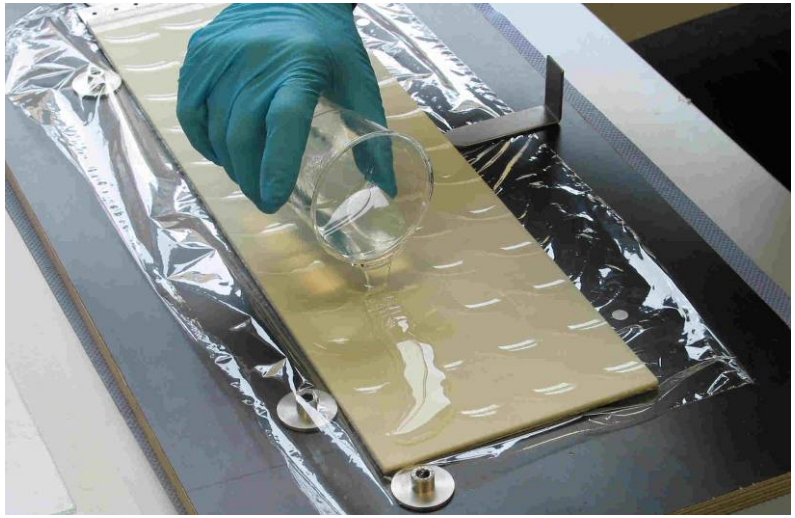


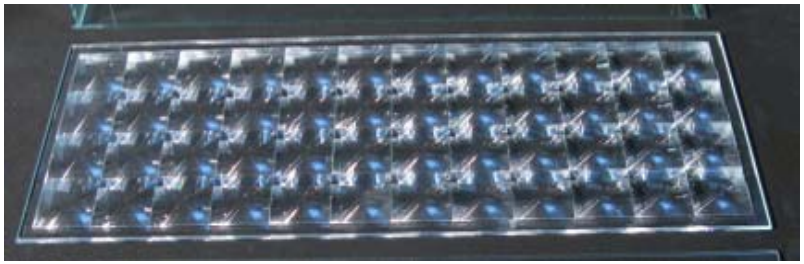
Development goals: high optical efficiencies and homogenous illumination of the cells

Fraunhofer ISE

Manufacturing Fresnel Lenses at ISE
Development of the Silicone-on-Glass Technology

48 lenses are formed in a 0.2 mm thin Silicone film on a glass superstrate





Fraunhofer ISE

Nothing is perfect….

Peak and averaged System Efficiency are influenced by…..

- Chromatic aberration
- Stray light from primary optics
- Circumsolar irradiation
- Assembly accuracy
- ……

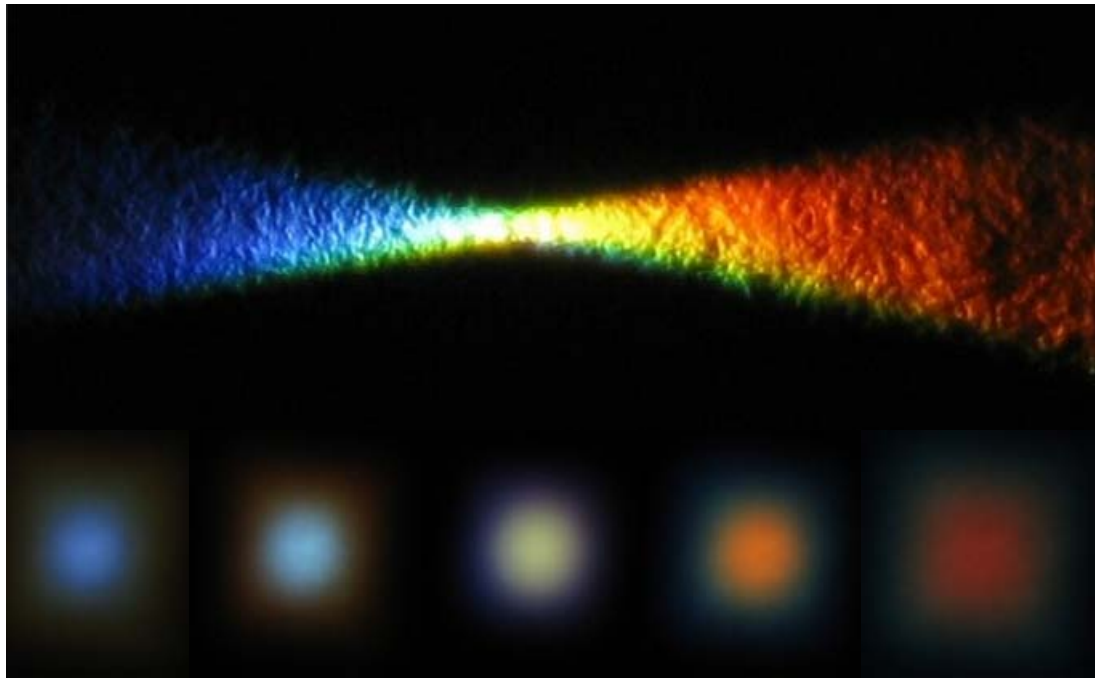
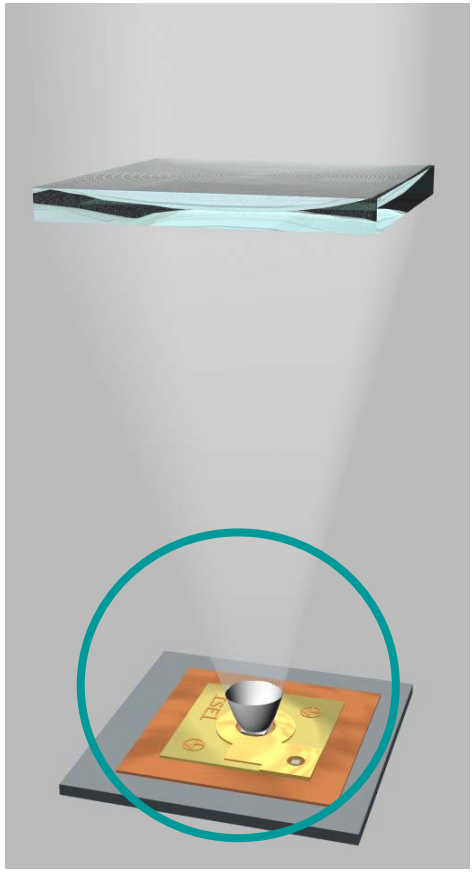
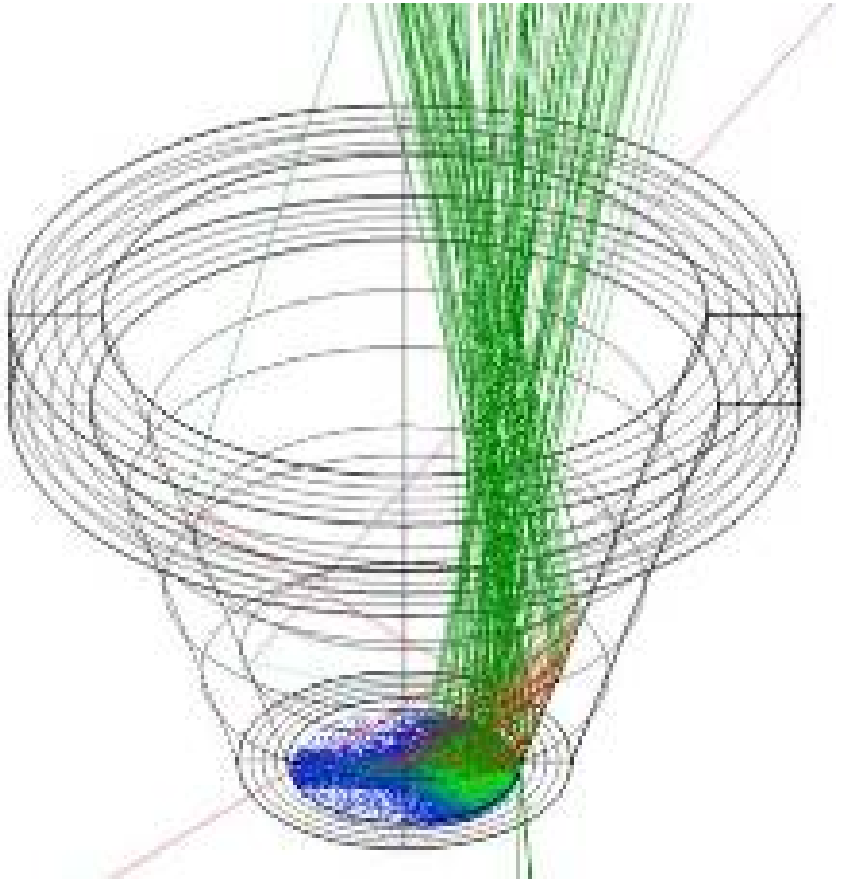


Photo visualize the chromatic aberration of a Fresnel lens

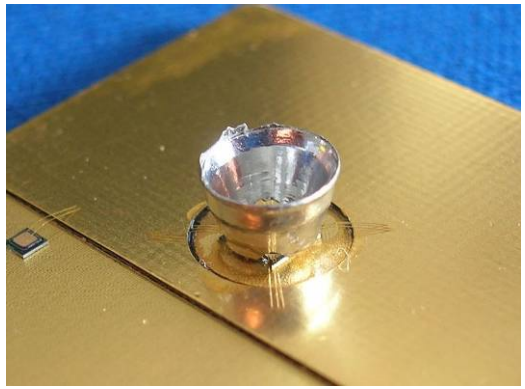
Improvements by use of Secondary Optics

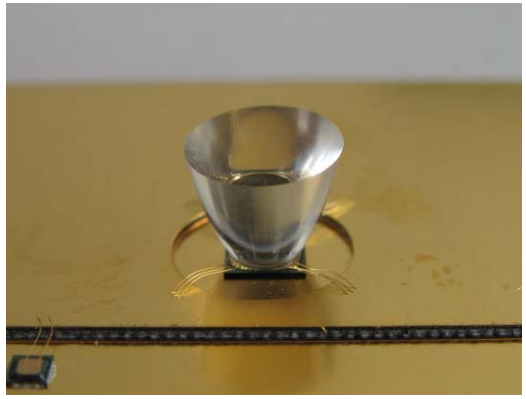




Fraunhofer ISE

Secondaries: First Prototypes





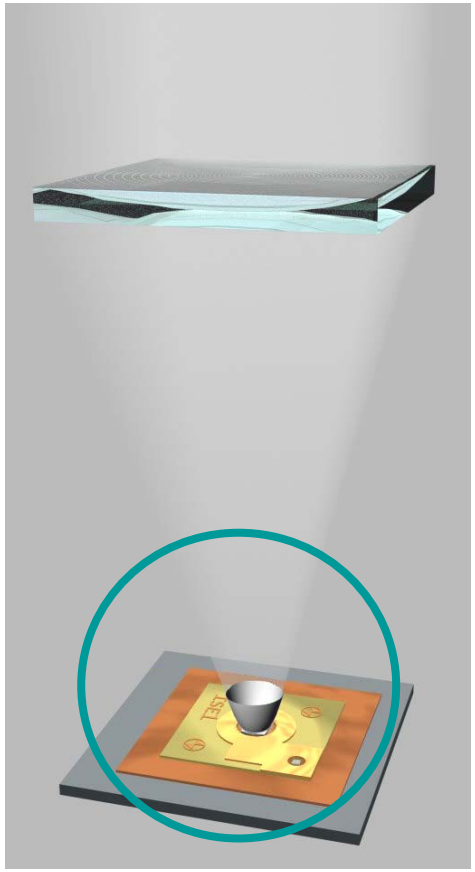
Reflective Secondaries

- Material choices: metal-coated polymer, aluminium, stainless steel
- Surface: Al, Ag, with protective coating
- Shape: conical, parabolic, combinations

Solid (Refractive) Secondaries

- Material choices: glass, silicone, polymer
- Shapes: compound parabolic, conical lens/aspheric, combinations

Experiment: FLATCON® with/without Secondary Optics

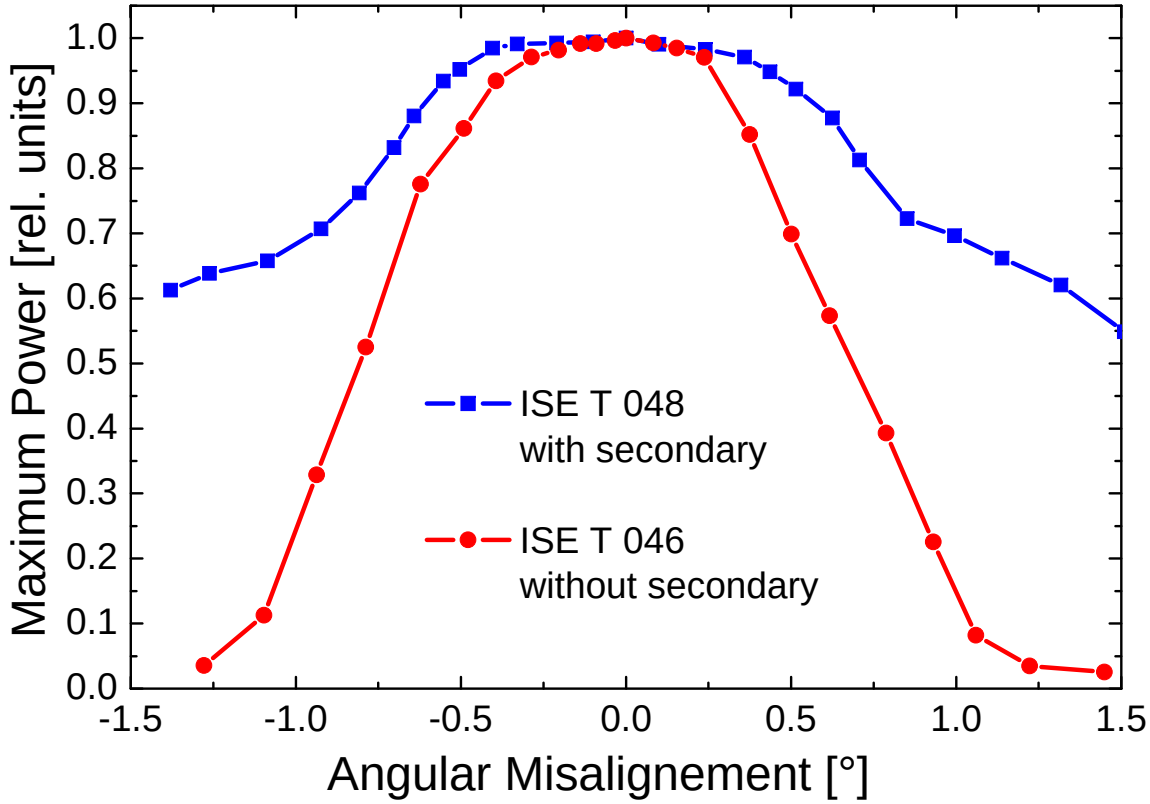


Fraunhofer ISE

FLATCON® Test Module: Indoor Measurement

Modules with/without Secondary Optics

- Acceptance angle measurement show the benefit of the secondary optics



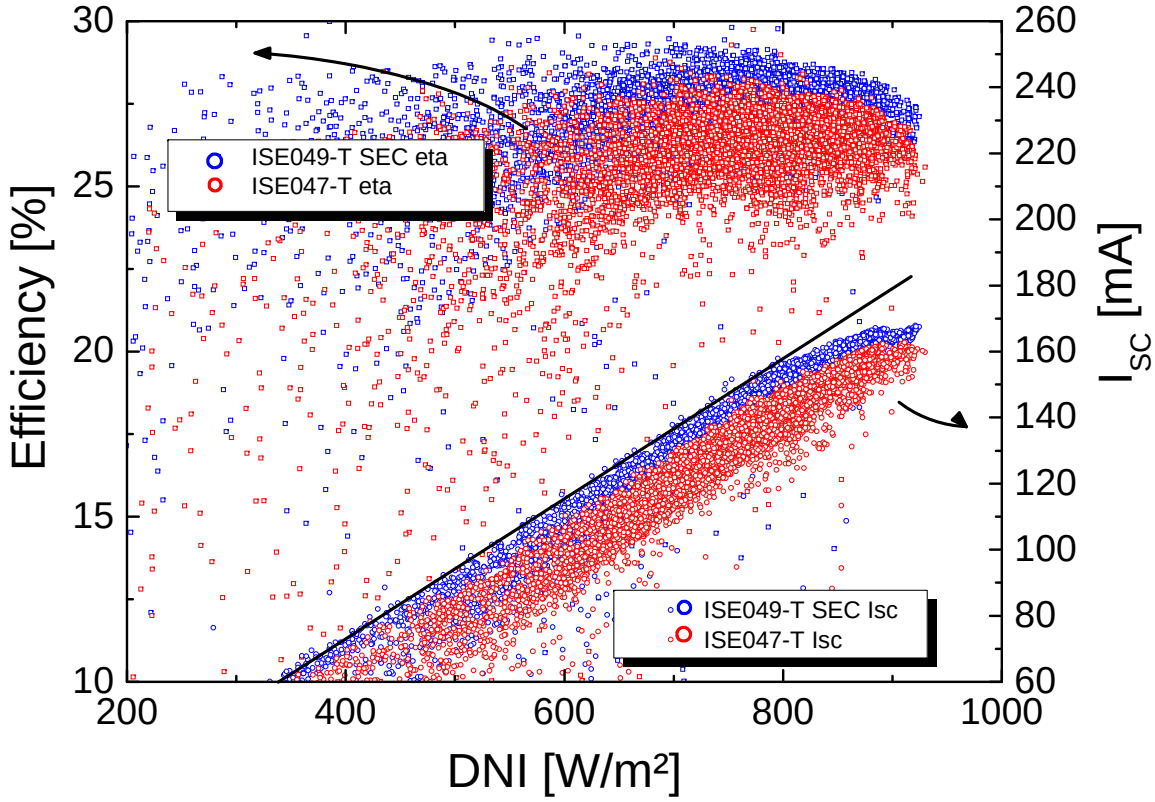
Fraunhofer ISE

FLATCON® Test Module: Long-Term Comparison

Modules with/without Secondary Optics

Measurement period:
May 5th 2008 –
Sept. 30th 2008
~ 6200 measurements

→ Better I_{sc} and η for module with secondary optics



Fraunhofer ISE

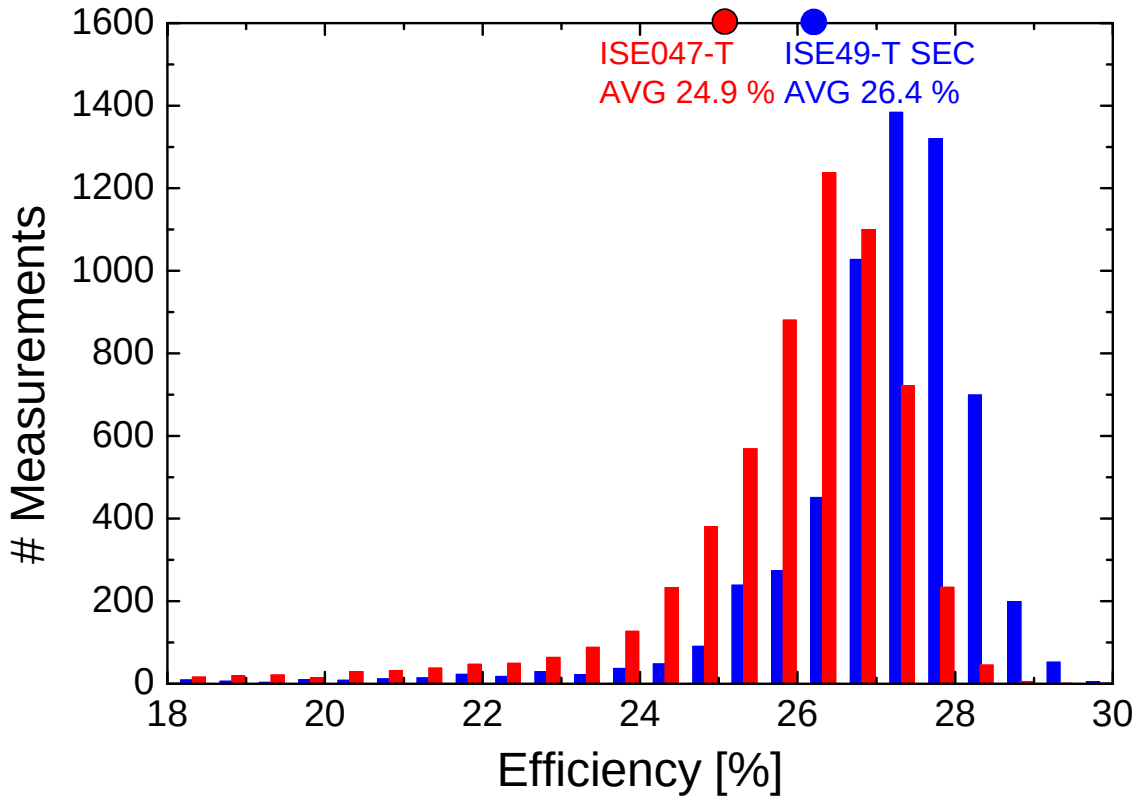
FLATCON® Test Module: Long term Comparison

Modules with/without Secondary Optics

Avg. cell efficiency:
ISE049-T SEC : 34.0 %
ISE047-T : 33.7 %

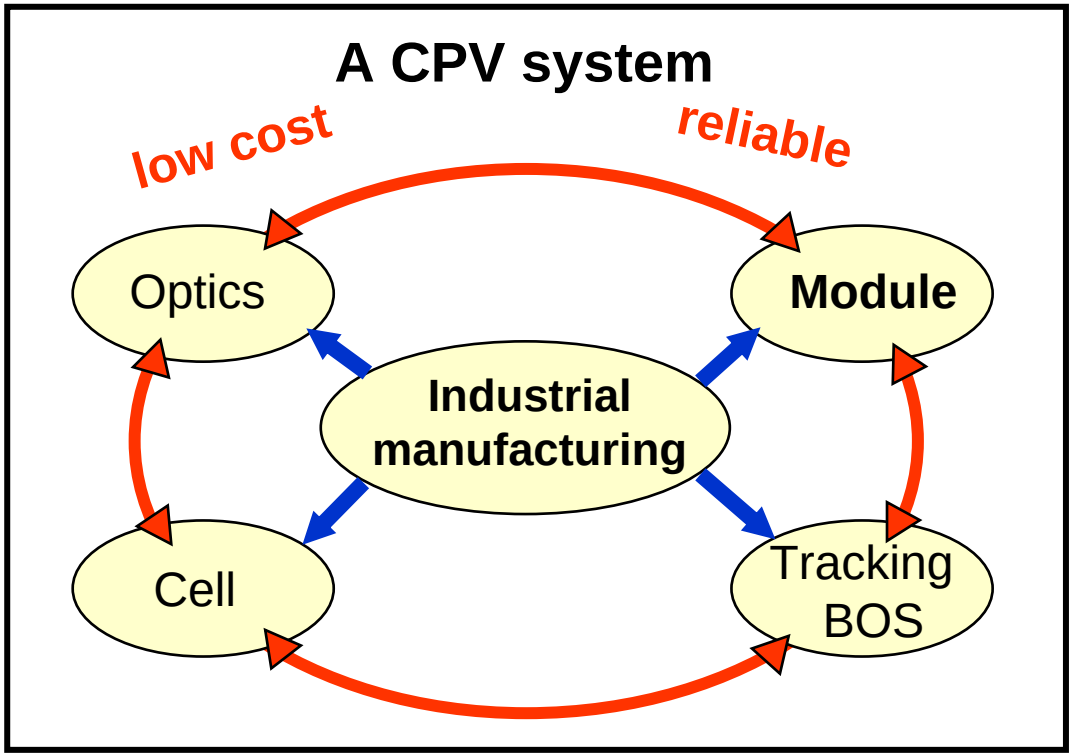
Avg. module efficiency:
ISE049-T SEC: 26.4 %
ISE047-T : 24.9 %

→ $\Delta\eta$ >1.3 $\%_{abs.}$ in avg.!



Fraunhofer ISE

The Concentrating PV Technology (CPV)
Module, Manufacturing and System



Module and Process Development for CPV
Concentrator Technology & Evaluation Center

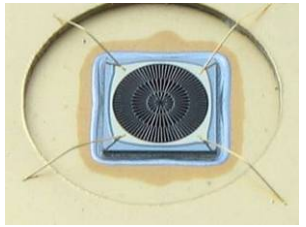
- Development of sub-assemblies and modules based on the “Design for Manufacturing” philosophy
- Industrial-type equipment for development of high volume processes:
  - die bonding
  - reflow process
  - Heavy- & thin-wire bonding

ConTEC - Concentrator Technology & Evaluation Center

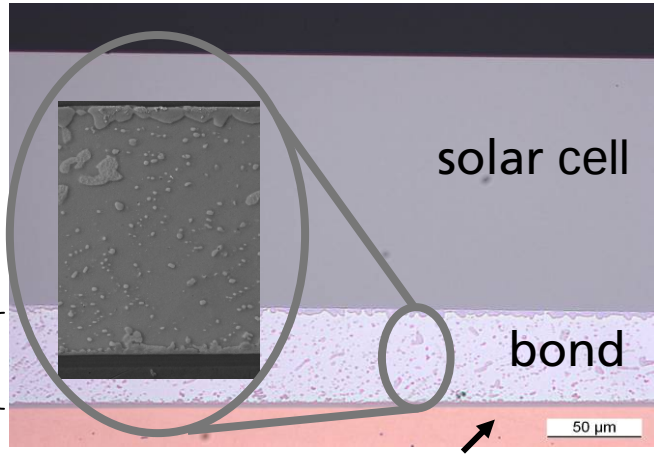
Assessment of Reliability

- Investigations on sub-components and module components
- Front contact:
  E.g. ultrasonic bonding with Au and Al wires
- Back contact:
  e.g. soldering or electrically conductive adhesives
- Accelerated ageing

front contact → wire bond



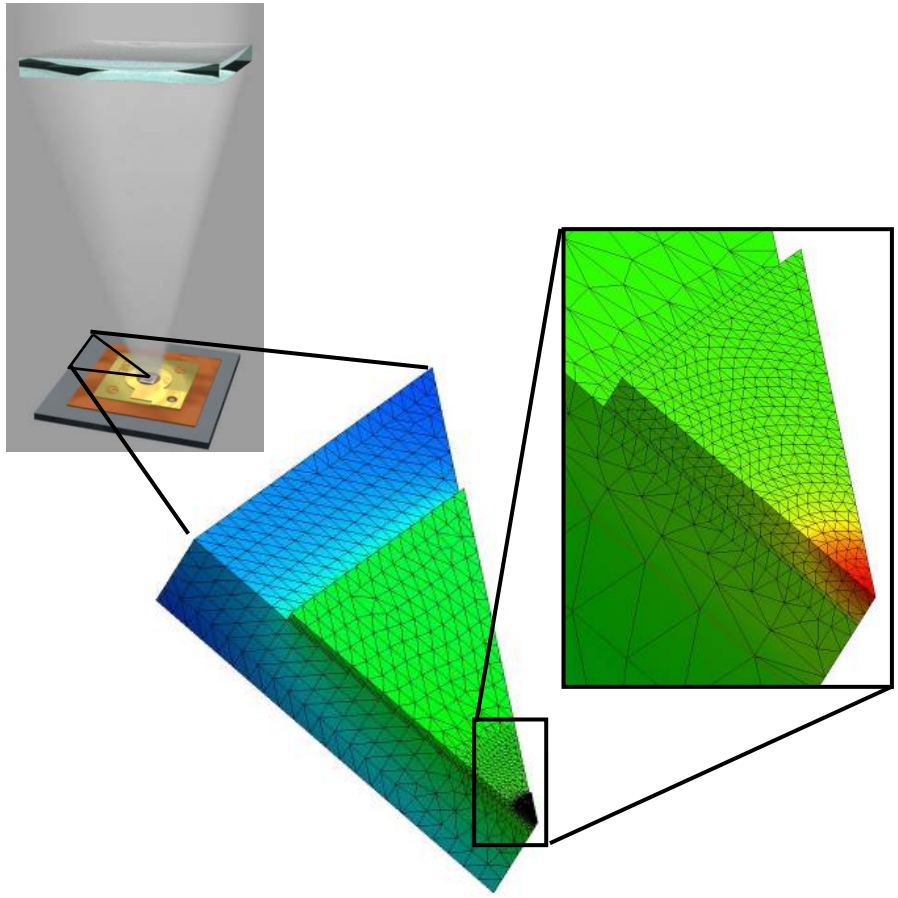
back contact



Fraunhofer ISE

Module Development
Thermal and Mechanical FEM-Simulation

- Boundary conditions in CPV-Systems:
  Handling of energy densities >100 W/cm² is necessary
- Simulation of temperature distributions allows for:
  - Estimation of temperature in the components, thermal expansion and mechanical stability
  - Optimization of the design e.g. heat spreaders
  - Comparison to in- and outdoor measurements



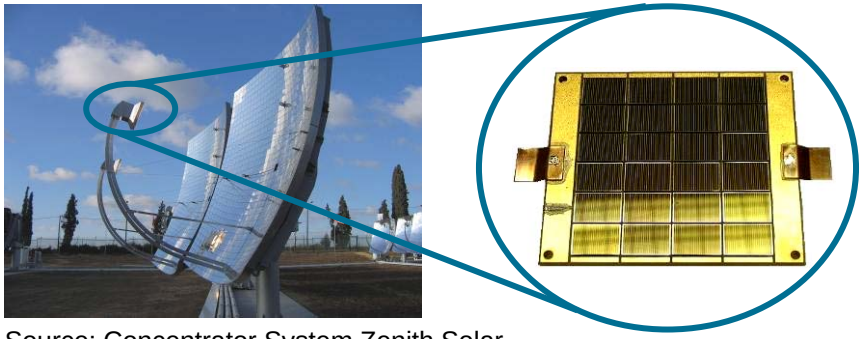
ConTEC - Concentrator Technology & Evaluation Center

Module Development for High Concentrator Systems

For Point Focus Systems

- Fresnel lens as primary optics
- Geometrical concentration factors 350 - 500x
- Passive cooling of the heat sink

FLATCON®
Fresnel **L**ens **A**ll-Glass **T**andem Cell **Con**centrator



Source: Concentrator System Zenith Solar

For Central Receiver

- Optics: mirror
- Concentration factors 500 to >1000
- Dense array receiver
- Active cooling → use of thermal energy

Fraunhofer ISE

Co-generation of Electricity and Heat
Total System Efficiency > 70 %

Solar dish-based CPV system using MIM cells developed at ISE.
Zenith Solar launched the first systems , April 2009, Kibbutz Yavne, Israel

ZENITHSOLAR

Fraunhofer ISE

CPV Power Stations

100 kW Units in Puertollano and Seville in Spain
1 MW in USA, 150 MW in USA (planned)

Puertollano La Nava 1
100 kW_{nom}
grid connected end of
September 2008

Casaquemada
100 kW_{nom}
grid connected end of
September 2008

Averaged AC-System
Efficiency > 22 %, max > 25 %

Concentrix solar

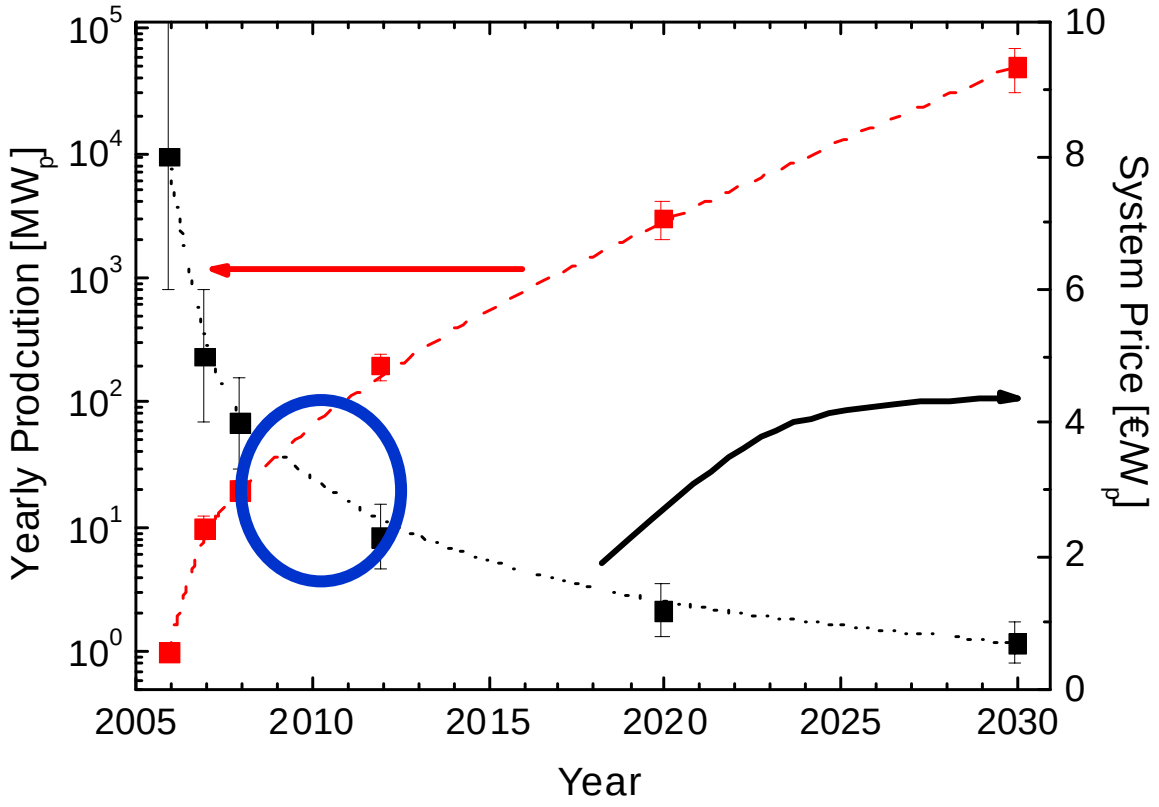
Fraunhofer ISE

The Promise of CPV in the Future

Price and Market

CPV is at the „starting“ point

Threat:
- bankability
Opportunities:
- CAPEX
- land use

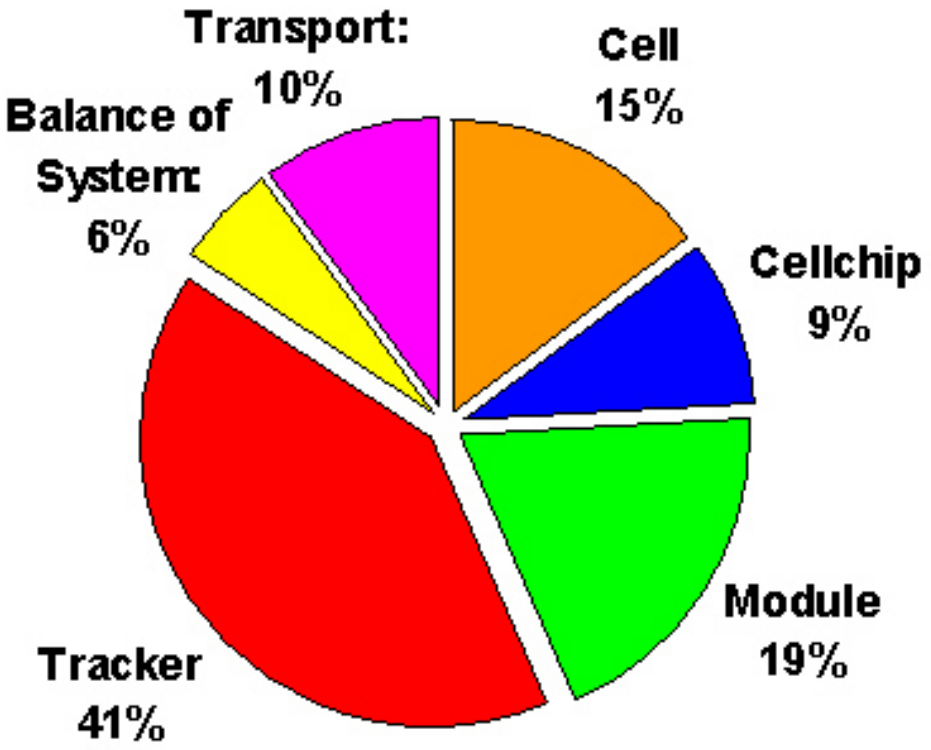


Source:
http://www.eupvplatform.org/fileadmin/Documents/PVPT_SRA_Complete_070604.pdf

Fraunhofer ISE

High Concentration PV is GREEN

Energy-Pay-Back-Time
for FLATCON® systems
8-16 months
depending on the site



Ref: G. Peharz et al, PIP, 2005, 13, p. 627-634

Fraunhofer ISE

Conclusions

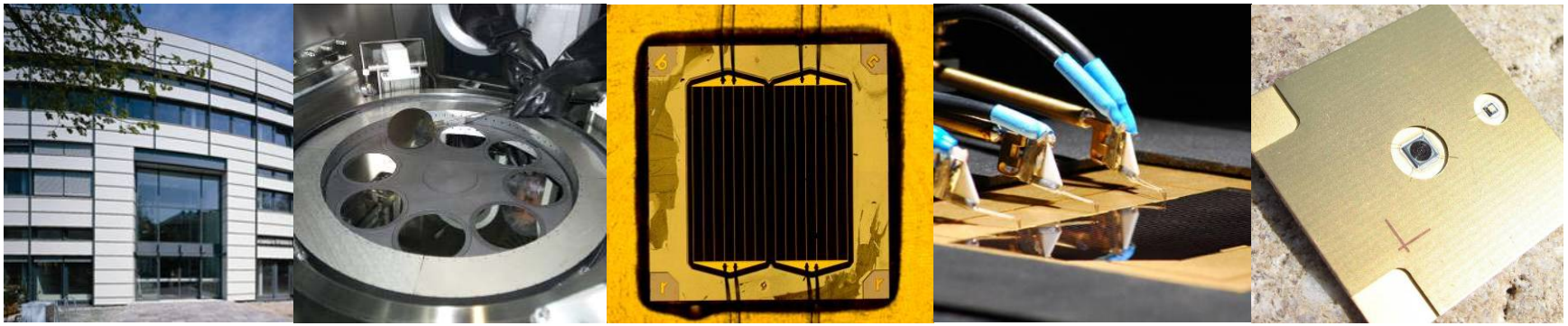
- CPV systems offer a wide range of promising designs
- III-V-based multi-junction solar cells exceed the 42 % efficiency margin
- CPV power plants achieved an AC-operating efficiency of 25 %
- CPV shows great promise for cost-efficient and green energy production

We acknowledge the important contributions of all our collaborators, as well as financial support by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Federal Ministry of Education and Research

Thank you for your attention!



Fraunhofer Institute for Solar Energy Systems ISE

Dr. Andreas Bett

www.ise.fraunhofer.de
www.III-V.de
andreas.bett@ise.fraunhofer.de

Fraunhofer ISE