# From Space to Earth:

# CPV – Concentrator Photovoltaics

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Milano, 07 May 2013



released for publication (level 1 of 5)

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# History

## “Telefunkenpark” Heilbronn, Germany

## Company

**for 49 years solar cells from Heilbronn**

AEG · TELEFUNKEN · DASA · ASE · RWE Solar · RWE Space Solar Power GmbH · AZUR SPACE Solar Power GmbH

**Revenue of 40m€ (2012) with 200 people**

**Owned by Generali Group (IT)**

**40% world market share of civil space satellite market**

**Only European manufacturer of triple GaAs solar cells**





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# AZUR SPACE Technical Milestones

**1st generation**
Silicium Photovoltaik – mono and multi crystaline

**1964** First silicon space solar cell 8 % AMO

**1974** First multi-crystalline Si–solar cell (10 cm x 10 cm, 10% AM 1.5) for terrestrial application

**1983** First fully automated terrestrial production line in screen printing technology

**1986** High efficiency Si solar cell (18% AMO, 20% AM 1.5) in production

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**3rd generation**
III-V semiconductor Photovoltaik

**2001** First European triple junction GaAs space solar cell (25% AMO)

**2008** First TJ-GaAs triple junction GaAs space solar cell with 30% efficiency

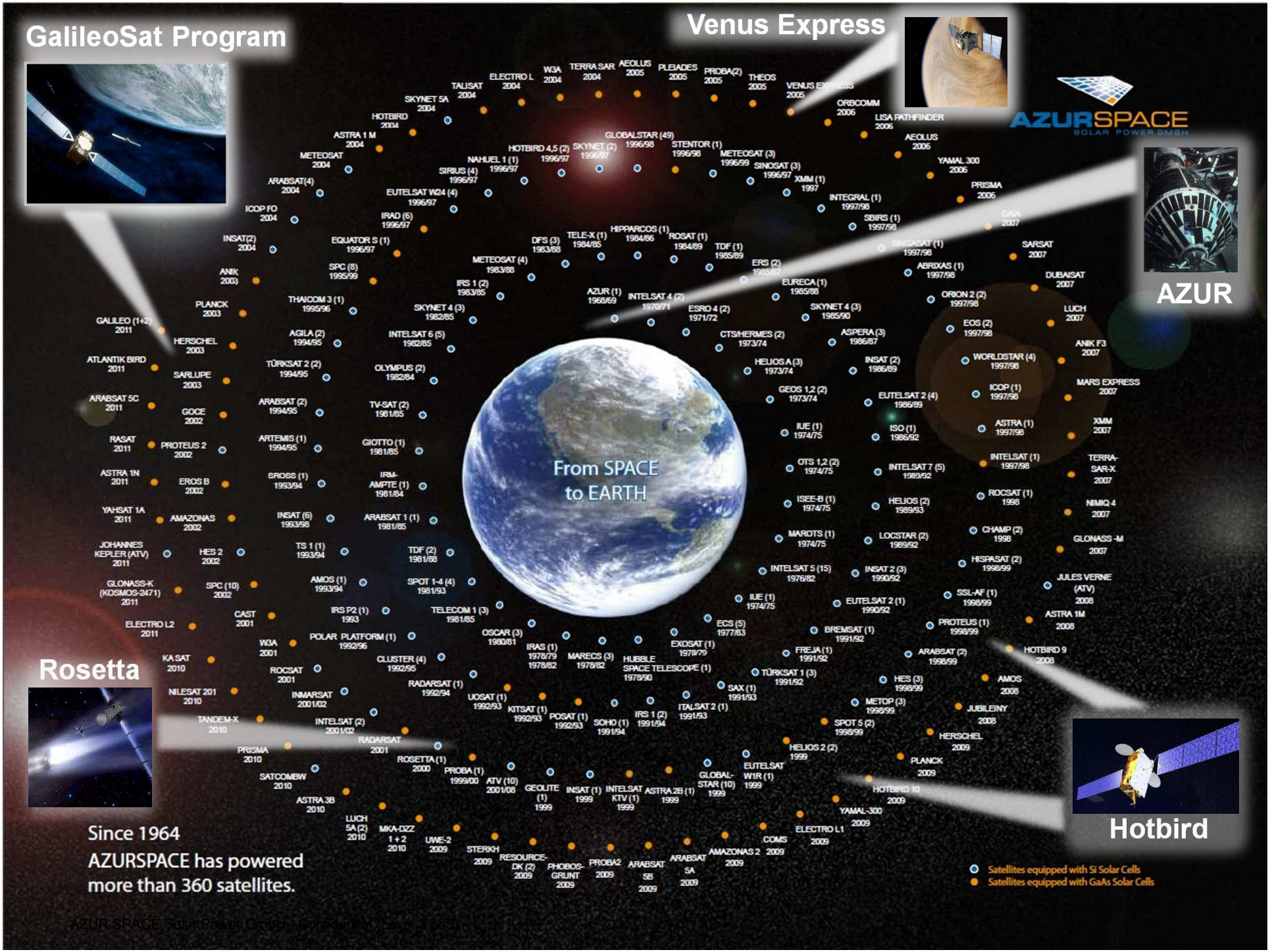
**2009** First terrestrial CPV TJ-GaAs solar cell with 41% efficiency (cooperation with Fraunhofer Institut für Solare Energiesysteme, Freiburg)

**2011** CPV wafer with 40.3% average efficiency and 41.5% max. efficiency in production

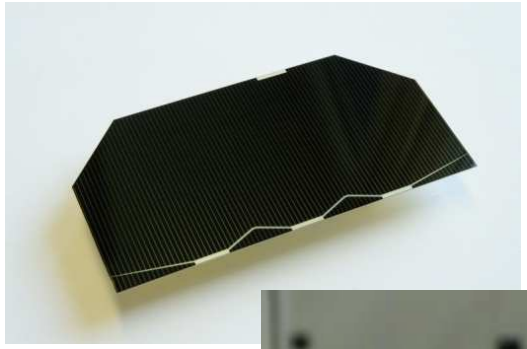
**2012** CPV development wafer with 42.3% average and 43.3% max. efficiency

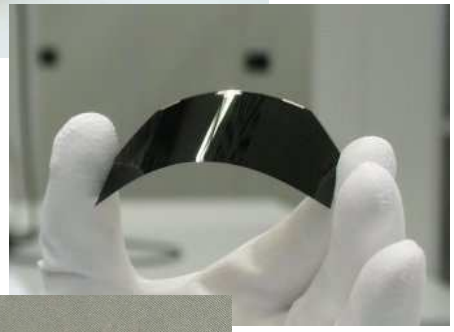
**2012** Best EOL GaAs space solar cell on the market

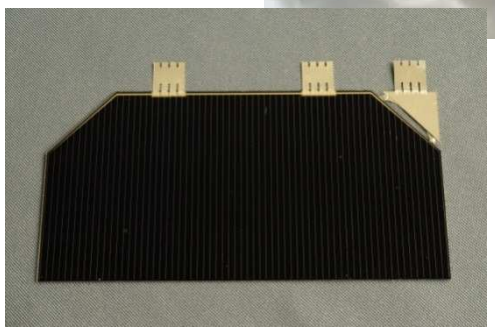
# Solar Cells for Space


GalileoSat Program
Venus Express
AZURSPACE
SOLAR POWER GMBH
AZUR
Rosetta
Hotbird
From SPACE
to EARTH
Since 1964
AZURSPACE has powered
more than 360 satellites.
Satellites equipped with Si Solar Cells
Satellites equipped with GaAs Solar Cells
AZUR SPACE Solar Power GmbH - Confidential (Level 1 of 3)

# 3G30C Triple Space Solar Cell







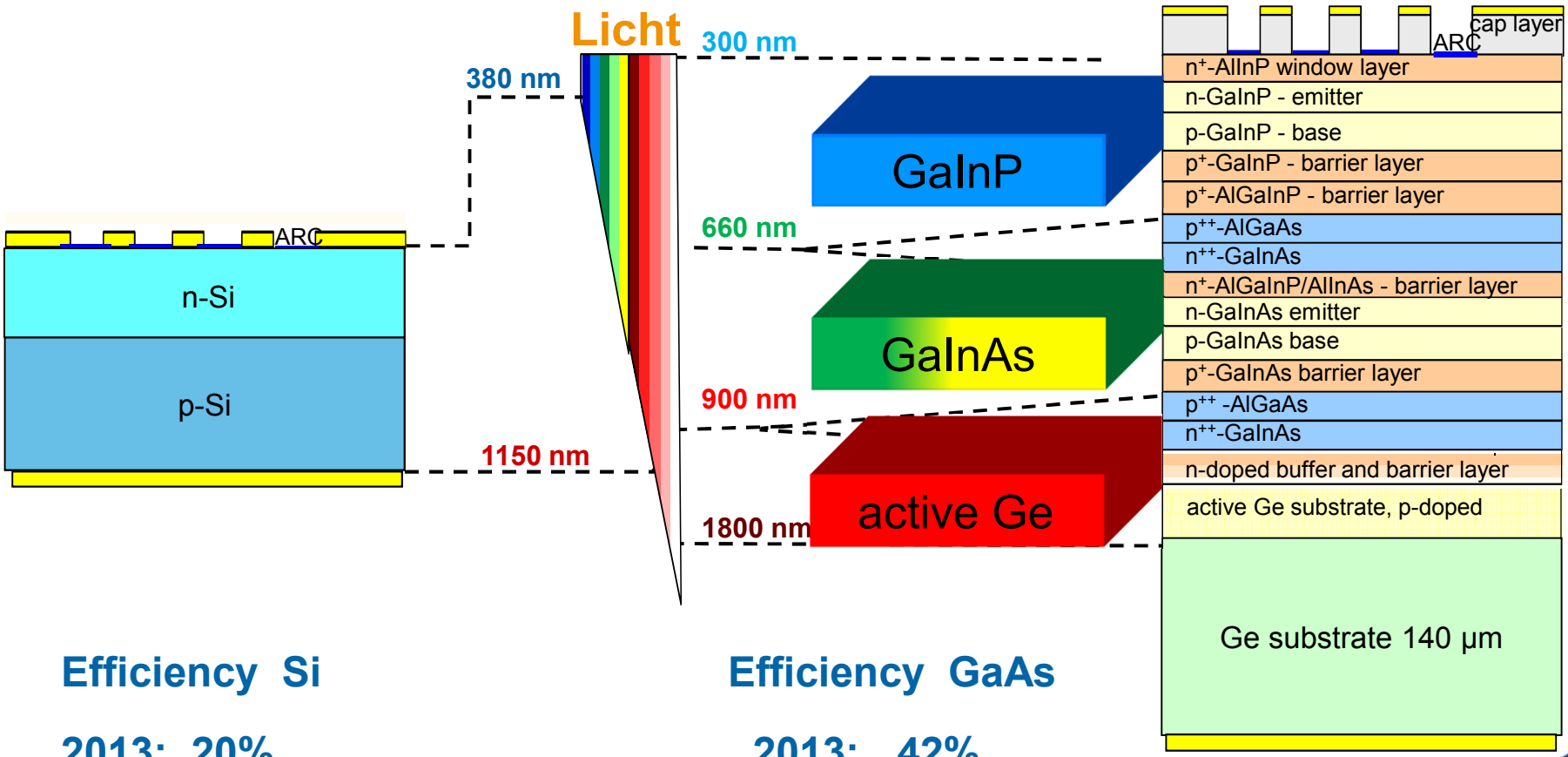
- Solar cells with 4 × 8, 8 × 8, 6 × 12 $cm^2$ cell size
- Ultra-thin cells
- Solar cell assemblies with bypass diode

| Cell type | **3G30** (AZUR SPACE) | **Competitor A** | **Competitor B** |
|---|---|---|---|
| **Begin-of-life efficiency** [1] | **29,8 %** | 29,5% | 29,5% |
| **End-of-life efficiency** after 15 years in GEO orbit [1,2] | **28,1%** [3] | 26,6% | 26,6% |

[1] - *at 1353 W/$m^2$, 28 ° C*
[2] - *equivalent to 5E14 1 MeV $e^-/cm^2$ fluence*
[3] – *AZUR patent pending*

# ❑ Terrestrial Concentrator Photovoltaics (CPV)

# Si and GaAs Solar Cells




**Efficiency Si**

**2013: 20%**

**2020: 24%**

**Efficiency GaAs**

**2013: 42%**

**2020: 50%**

# Solar Cell Processes

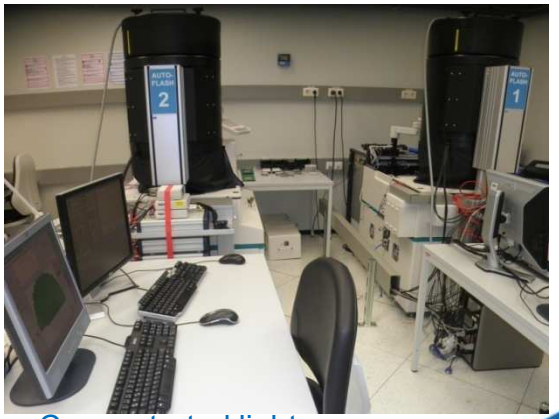
Epitaxy Reactors

Photolithographie Processes

Evaporation Processes

Dicing Processes

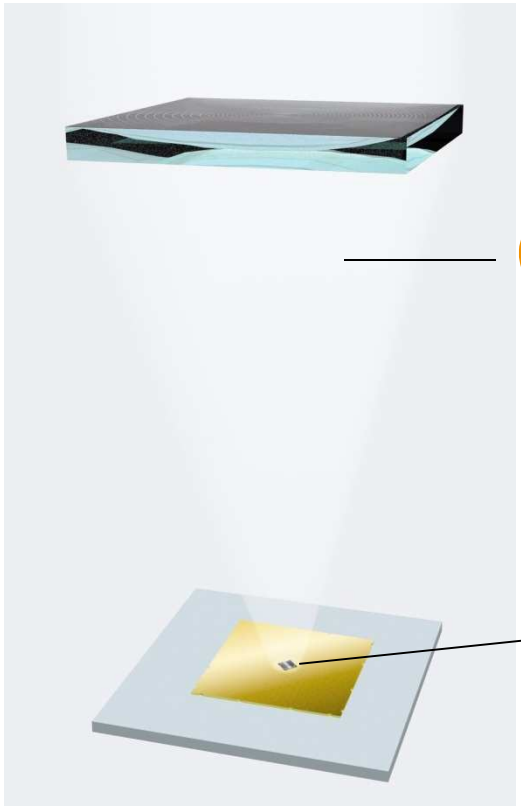
Chemical Processes



Concentrated light measurement

# Principle of Concentrating PV (CPV)

Substitution of expensive semiconductor material by cheap optics




50% cell efficiency until year 2020

**Efficiency is the key driver for cost reduction**

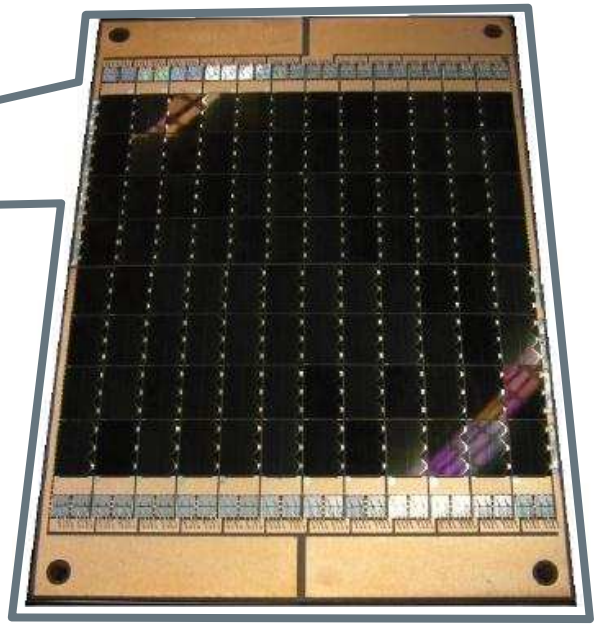
# Examples CPV Power Plants in Europe


Seville (Spain)


Puertollano (Spain)

| Location | Size | in operation since... |
|---|---|---|
| Seville, Spain | 100kWp | 2008 |
| Puertollano, Spain | 500kWp | 2008 |
| Altomonte, Italy | 6 kWp | 2008 |
| Bernin, France | 6 kWp | 2010 |
| AbuDhabi, Emirates | 100 kWp | 2010 |
| Sede Boqer, Israel | 6 kWp | 2010 |
| El Natrun (near Cairo), Egypt | 30 kWp | 2010 |

# CHP Combined Heat and Power Systems

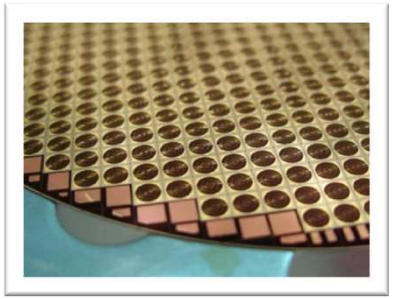



Dense array of solar cells on a heat sink with active cooling

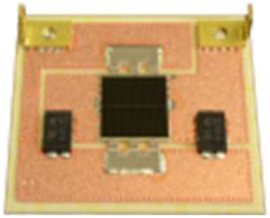
32m$^2$ parabolic dishes: **7.5 kW$_{elect.}$ + 17.4 kW$_{therm.}$**

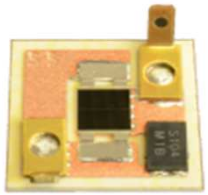
# CPV solar cells and subsystems for all over the world

**CPV solar cells on wafer or bare cells, 38% to 42% efficiency, depending on design and measurement condition**

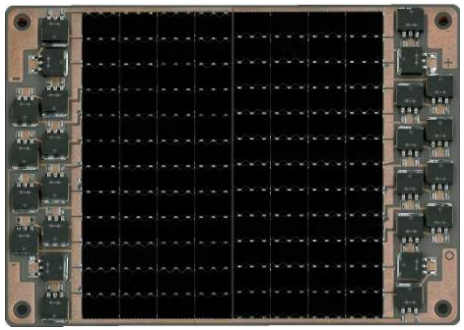


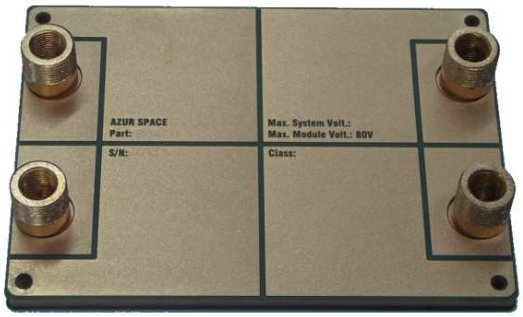
**CPV solar cells on ceramic board (EFA* – Enhanced Fresnel Assembly)**





**CPV solar cells on water cooling unit (ADAM* – Advanced Dense Array Module)**

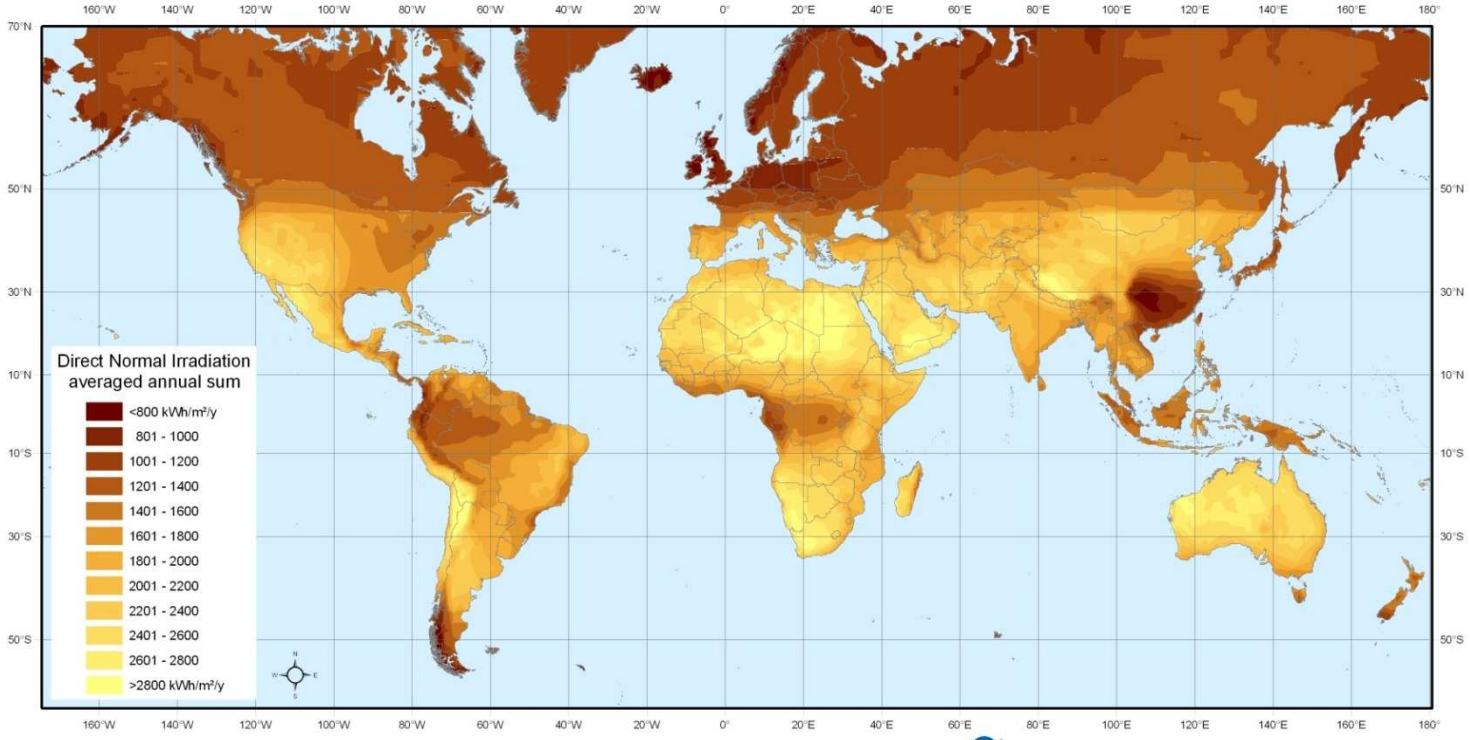





*) Registered trademark of AZUR

# Optimal CPV condition: high DNI regions

energy output vs. daytime

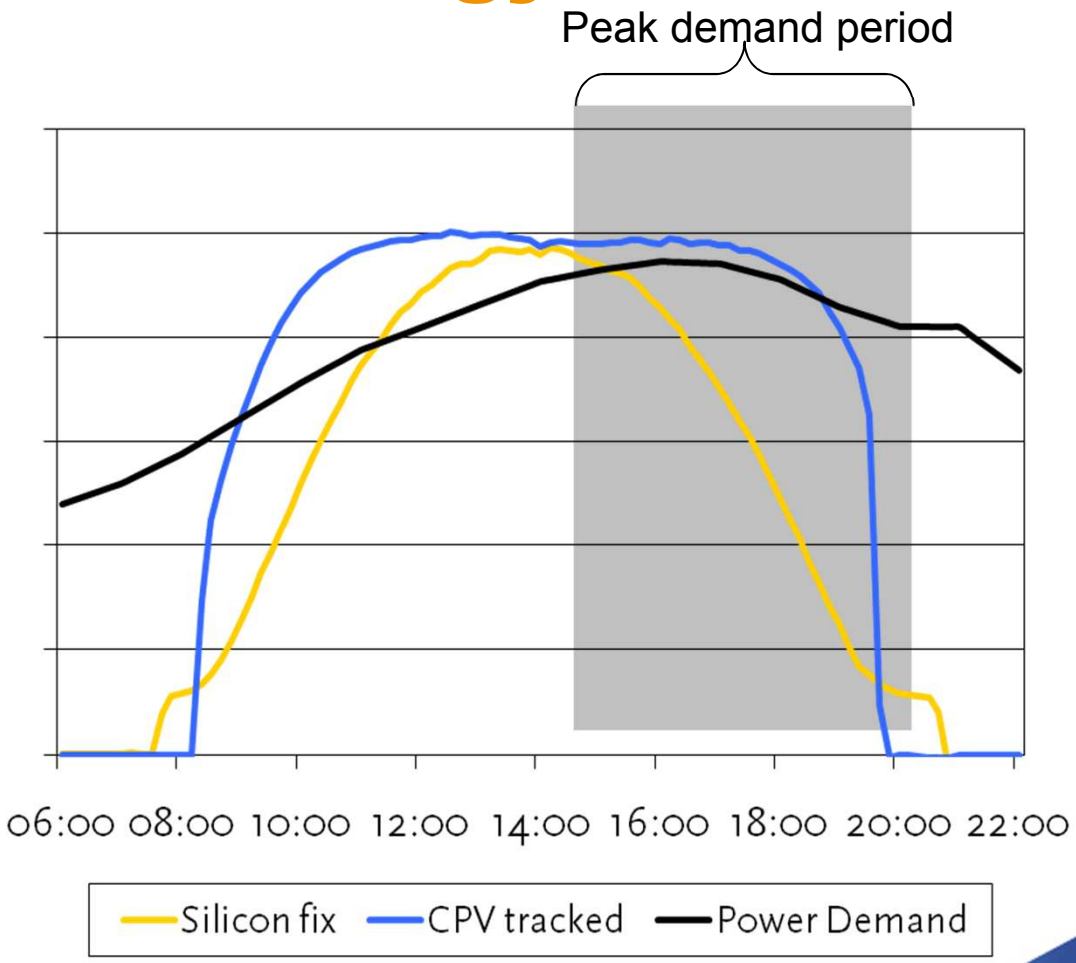



Data based on SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(http://eosweb.larc.nasa.gov/sse/)

**Advantages for economically weak but sunny regions in south of Europe, MENA states etc.**

# CPV - Consistent Energy Production

CPV matches very well with peak demand in sunny regions




Notes: power curve of Californian grid 6 Aug 2008, production curves in Seville 1 May 2008
Sources: California Independent System Operator, Concentrix Solar, Abengoa Solar

# Solar Cell Efficiency and Cost Leverage Factor are Key

$$\frac{\text{System Cost} \downarrow}{\text{Power} \uparrow} = \frac{\text{Cost (Steel, Glass, Cell)} \downarrow}{\text{Efficiency} \uparrow * \text{DNI}}$$

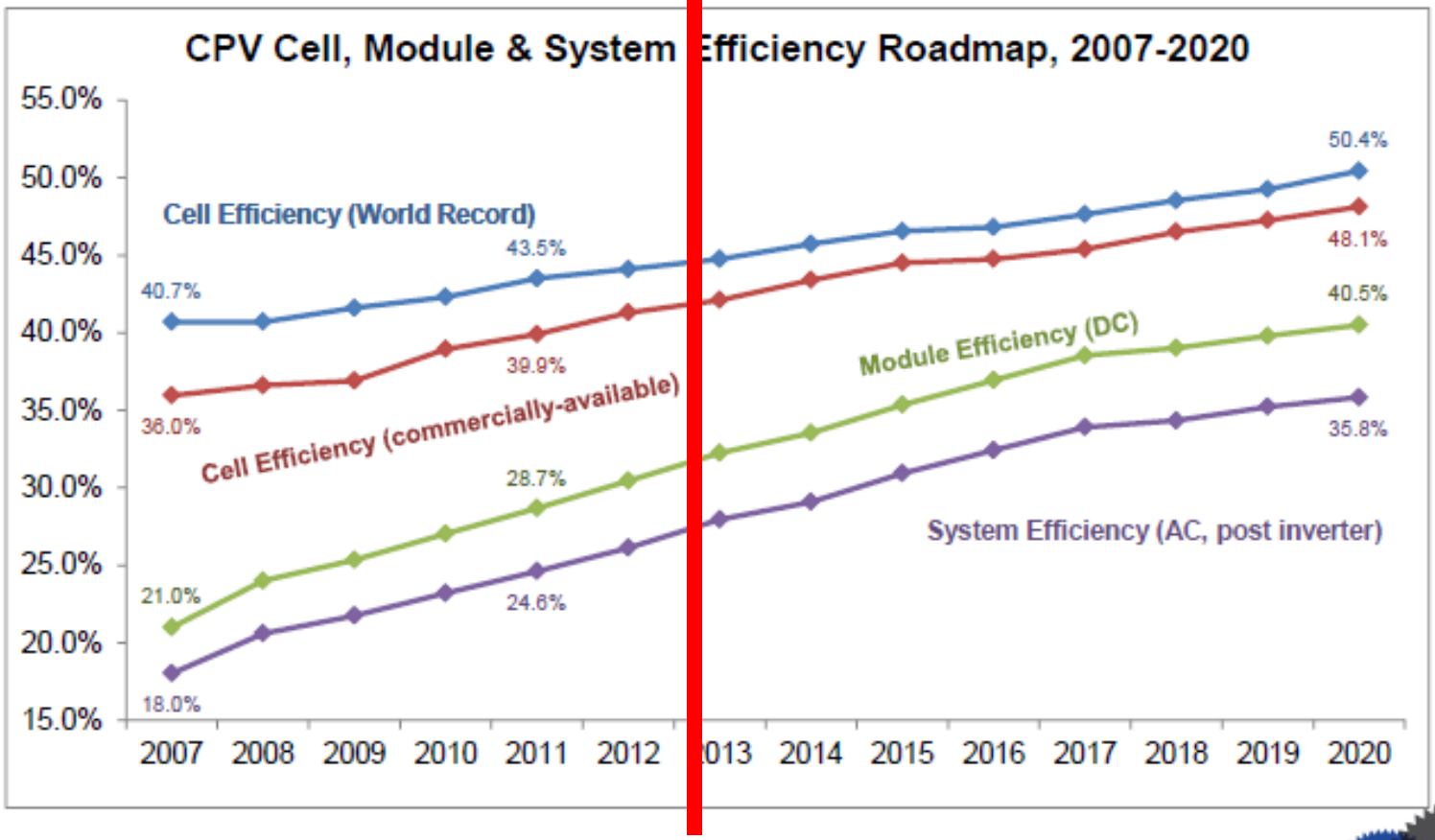
$$\frac{\text{Cost} \downarrow}{\text{kWh} \uparrow} = \text{LCOE}^{1} \downarrow$$

[1] LCOE = levelized cost of energy

Cell costs are 15 -20% of overall CPV system‘s cost

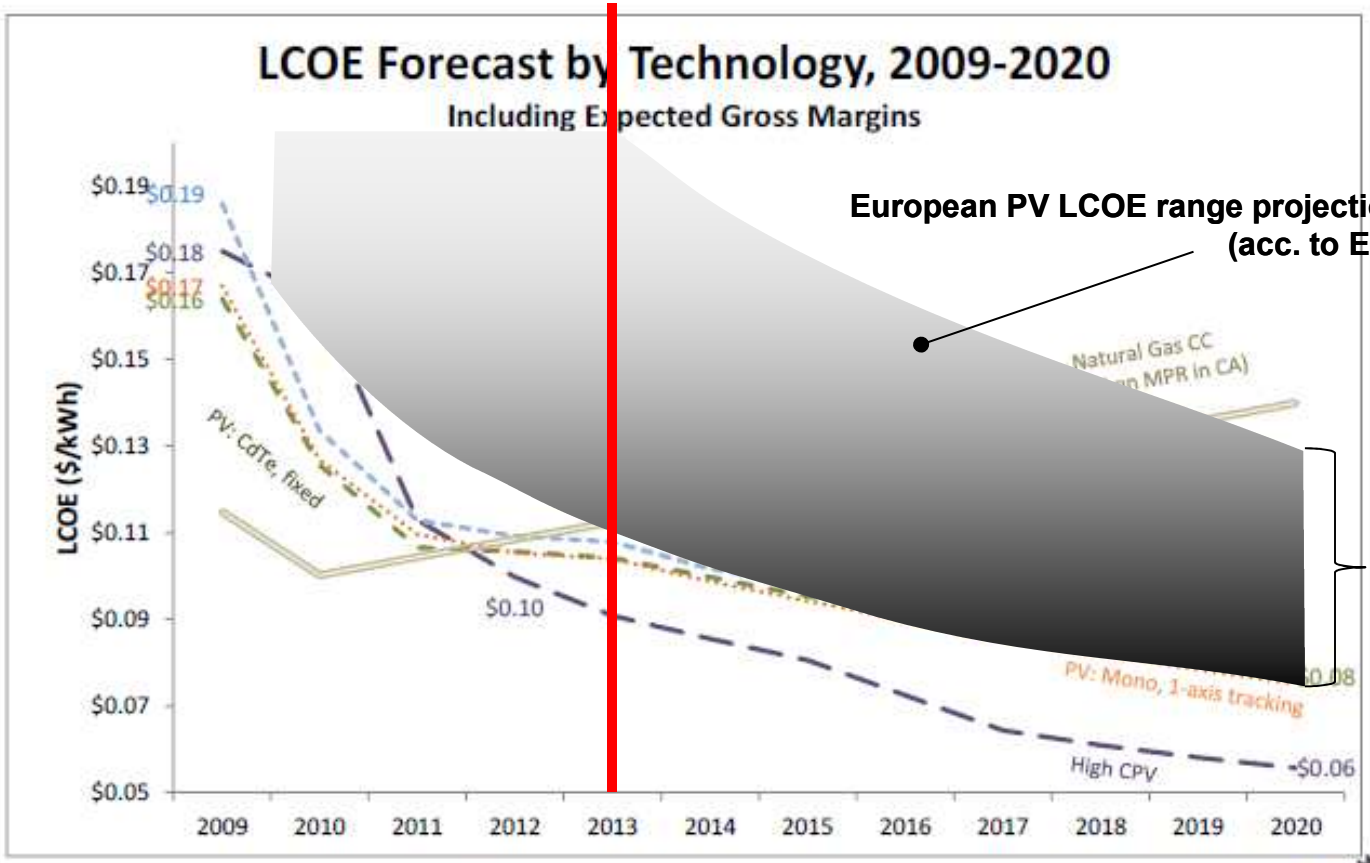
**Cell efficiency and cell cost have a leverage effect of factor 5-7 on overall CPV system cost**

# CPV Consortium Study



# CPV Consortium Study

## Lowest LCOE at high DNI

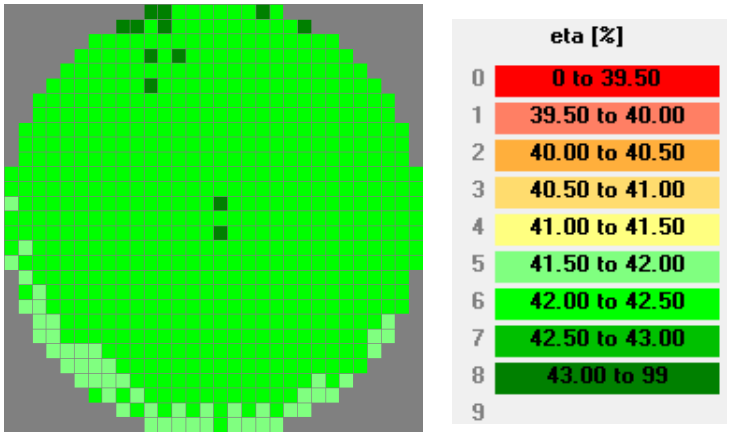



LCOE calculation for a sample 20 MW plant in Phoenix, AZ with a DNI of 6.9 kWh/m^2/day

# AZUR Solar Cell Technology Roadmap

## (*500x, AM1.5d, 25° C*)

| Cell Type | Average Efficiency (500x) | Availability |
|---|---|---|
| 3C40 | 40 % | since 2010 |
| 3C42 | 42 % | 2013 |
| 4C44 | 44 % | 2014 |
| 4C45 | 45 % | 2015 |




**3C42**
wafer avg = 42.3 %@500x
hero cell = **43.3 %**@500x

# ❑ Conclusion

# Conclusion for Competitive CPV Electricity without Subsidies in EU

- Demo CPV solar power plants
- Industrialisation („Death Valley“) with competitive implementation of whole industrial value chain in Europe
- Further R&D (cell and system improvements, cost reduction)
- AZUR 2013: 90 MW CPV solar cells ($\eta$=42%)
  AC electricity cost 10 €ct / kWh

  2020: 3000 MW CPV solar cells ($\eta$=50%)
  AC electricity cost 5 €ct / kWh

# Thank you very much for your kind attention!