PV RESEARCH FOR THE SUPPORT OF EUROPEAN ENERGY TRANSITION

EASAC Workshop, Sept. 19-20, 2013 Stockholm

Institutsleiter: Prof. Goetzberger, Prof. Luther, Prof. Weber

Dr. Frank Dimroth

Fraunhofer Institute for Solar Energy Systems ISE

www.ise.fraunhofer.de

Staff: 1270, 2012 Budget: € 77 million,
Established: 1981

Fraunhofer ISE

50 % of all renewable energy systems in Germany owned by private investors

5 % by big utilities

“It is my hope that this report shocks us into action. Even for those of us already committed to fighting climate change, I hope it causes us to work with much more urgency.”

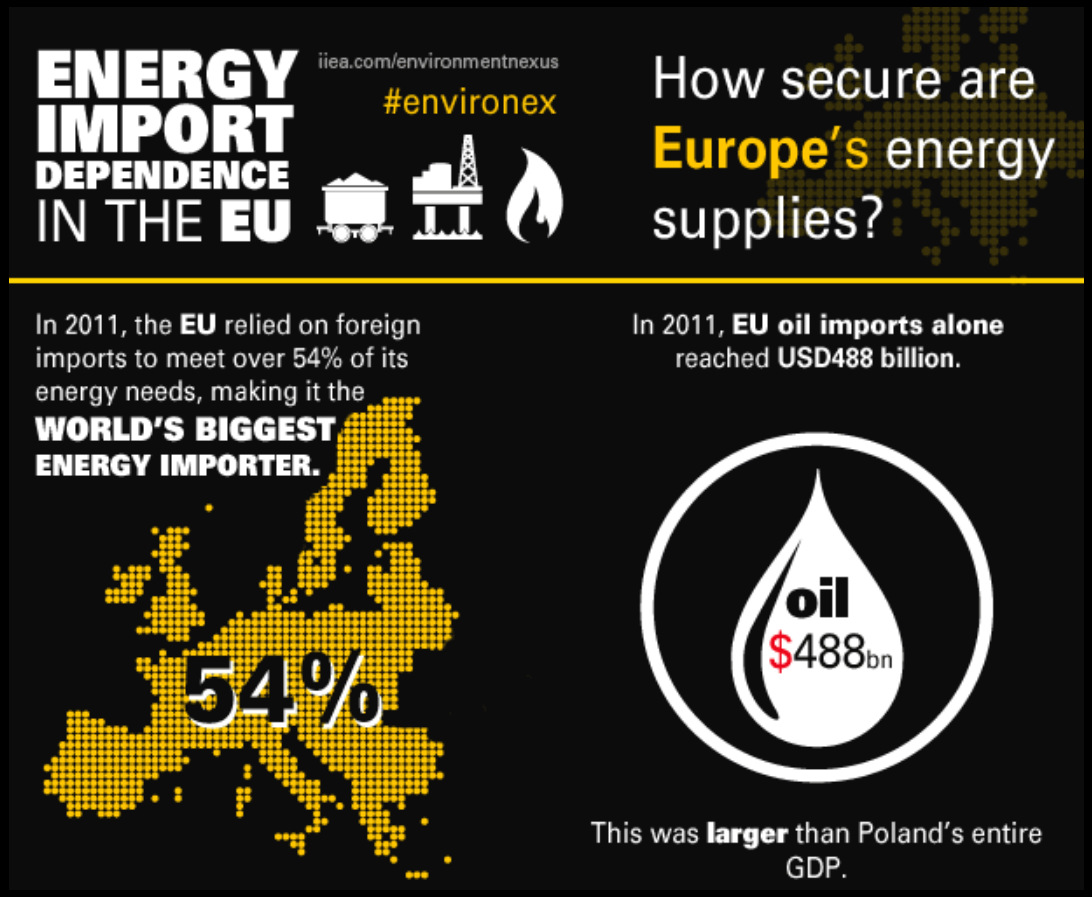
Dr. Jim Yong Kim, President, World Bank Group

World bank report November 2012

“We cannot afford another 20 years of listlessness. We need a rapid expansion in low-carbon energy technologies if we are to avoid a potentially catastrophic warming of the planet, but we must also accelerate the shift away from dirtier fossil fuels.”

Ms. Van der Hoeven, International Energy Agency, April 2013

Situation of European Energy Supply



http://www.iiea.com

Supply risk

> 1.000.000.000 €/day for fuel imports

Climate change

The EU is committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050

http://ec.europa.eu/energy/index_en.htm

Germany will stop nuclear in 2022

Decision about the future of our energy system is made now for the next 30 years

Energiewende

Germany's energy transformation

Energiewende

German plans to cut carbon emissions with renewable energy are ambitious, but they are also risky

Jul 28th 2012 | BERLIN AND NIEBÜLL | From the print edition

"THE quieter the evening, the more you hear it," says Wilfried Bockholt, mayor of Niebüll in North Friesland. He mimics the sound of a 55-metre-long rotor whirling round a windmill's mast. He is a driving force behind the "citizens' wind park", but he has mixed feelings. A region famed for broad horizons is now jagged with white spires. "They alter the landscape completely," he laments.

A new dawn

North Friesland's wind boom is part of Germany's *Energiewende* (energy transformation), a plan to shift from nuclear and fossil fuels to renewables. It was dreamed up in the 1980s, became policy in 2000 and sped up after the Fukushima disaster in March 2011. That led Angela Merkel, the chancellor, to scrap her extension of nuclear power (rather than phasing it out by 2022, as previous governments had planned). She ordered the immediate closure of seven reactors. Germany reaffirmed its clean-energy goals—greenhouse-gas emissions are to be cut from 1990 levels by 40% by 2020 and by 80% by 2050—but it must now meet those targets without nuclear power.

The rest of the world watches with wonder, annoyance—and anticipatory Schadenfreude. Rather than stabilising Europe's electricity, Germany plagues neighbours by dumping unpredictable surges of wind and solar power. To many the *Energiewende* is a lunatic gamble with the country's manufacturing prowess. But if it pays off Germany will have created yet another world-beating industry, say the gamblers. Alone among rich countries Germany has "the means and will to achieve a staggering transformation of the energy infrastructure", says Mark Lewis, an analyst at Deutsche Bank.

In this section

Another weak link in the euro zone

Is "Grexit" at hand?

Punk prayer

Energiewende

Old and nasty

Euro EUphemism

Reprints

Risky

Unpredictable power generation

Gamble with the country's economy

Cost, Cost, Cost

More Science before Action

Action supported by Science

Germany

REMod-D

Seversal possible scenarios for 85-100 % renewable heat and electricity

Example of optimized system for 500 TWh electricity demand

247 GW

150 GW

50 GW

Large scale heat storage 500 GWh

Gas heat pumps 27 GW_{th}

Comb. cycle power plts 37 GW

Combined heat and power systems 40 GW

Elec. heat pumps 97 GW_{th}

Total annual cost is in the same range as for today's energy system, once transition has been made and components cost passed their learning curve

http://www.ise.fraunhofer.de/de/daten-zu-erneuerbaren-energien

Studie zu 100% Erneuerbaren Energien in Deutschland

Dr. Hans-Martin Henning / Dipl.-Ing. Andreas Palzer, Fraunhofer ISE (2012)

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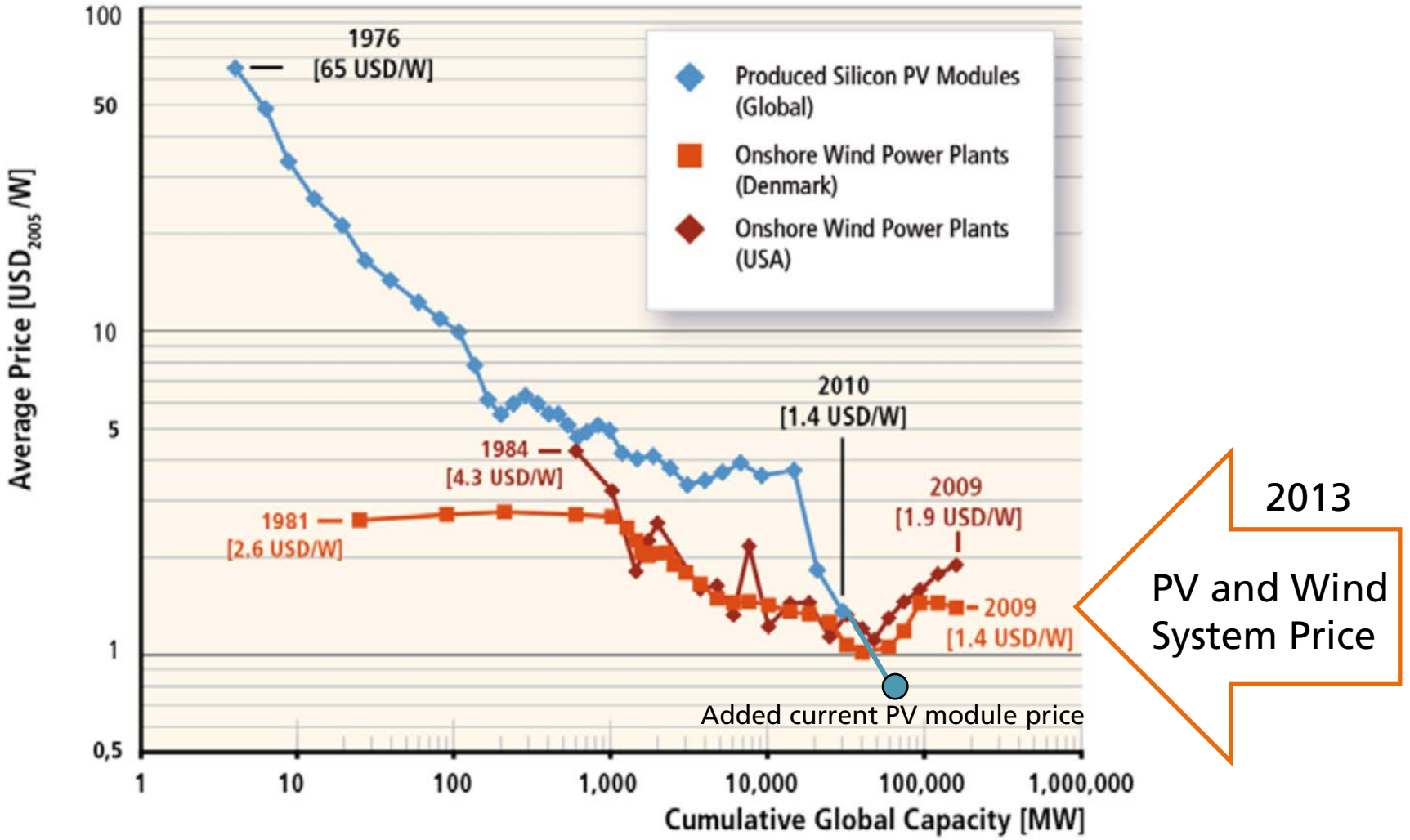
Solar and Wind Power between 8-15 €cent/kWh in D



Intergovernmental Panel on Climate Change (IPCC), Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) www.srren.org

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Photovoltaics: Efficiency and Cost Matters

Thin film & polymers

10 % efficiency

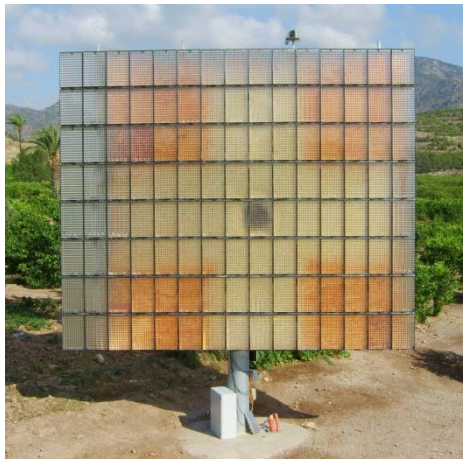
cheap, large areas

Silicon PV

20 % efficiency

efficient, medium cost

CPV



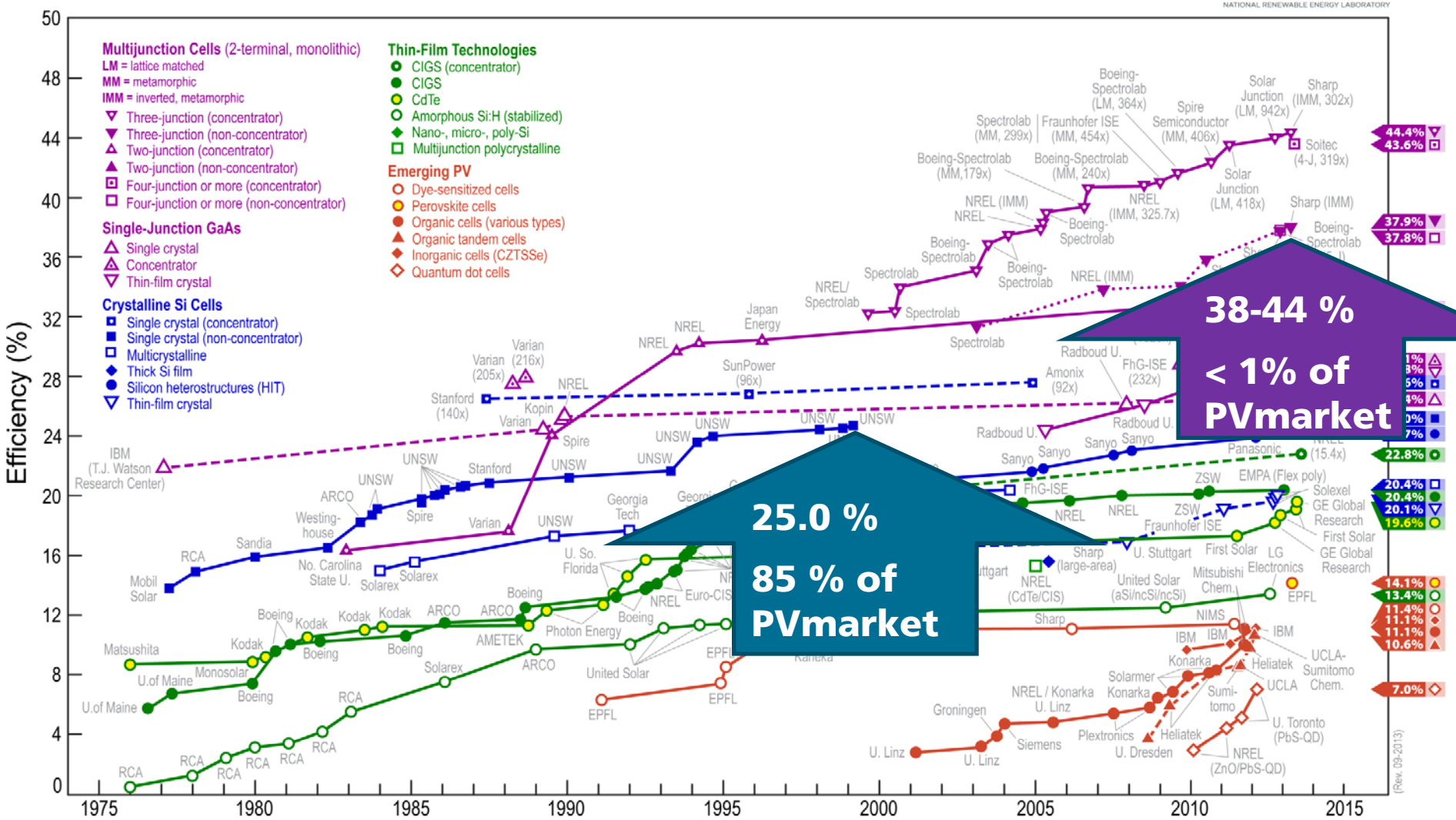
30 % efficiency

highest efficiency

85 % of market → push to higher efficencies

Cost of electricity similar, depending on application

Best Research-Cell Efficiencies



http://www.nrel.gov/ncpv/images/efficiency_chart.jpg

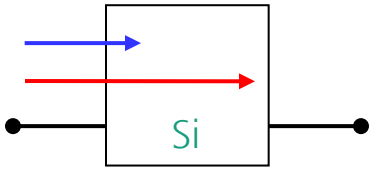
Expected Scientific Achievements in 2030

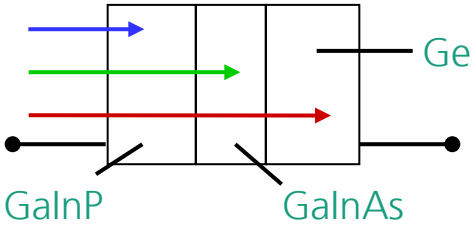
We will …

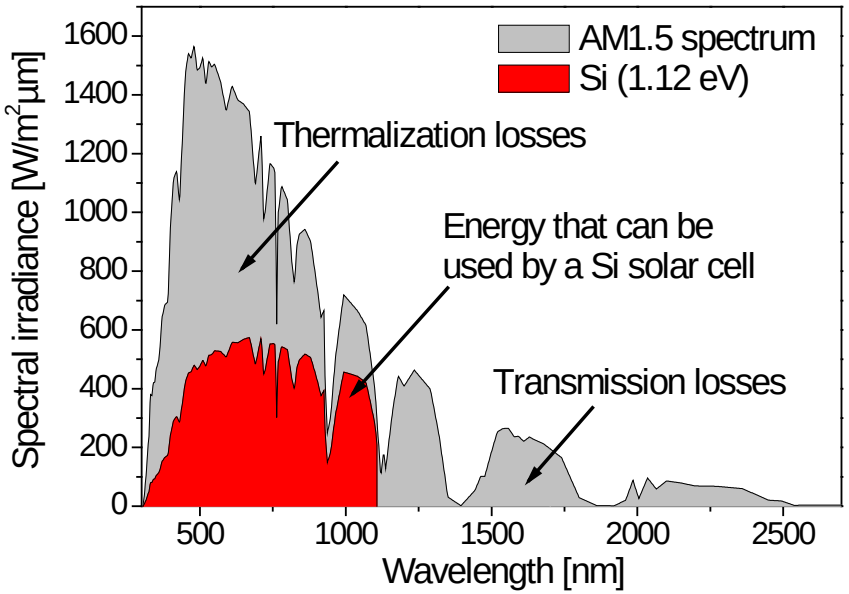
- develop solutions to provide 50 % efficiency with III-V multi-junction solar cells under concentration, concentrator will allow us to meet cost targets
- find technologies to significantly reduce maufacturing costs of III-V cells through large area eitaxy and thin layer lift-off
- combine the III-V multi-junction technology with Si photovoltaics to increase efficiency to 30 % at 1-sun
- Extended lifetime of PV products, which significantly lowers cent/kWh

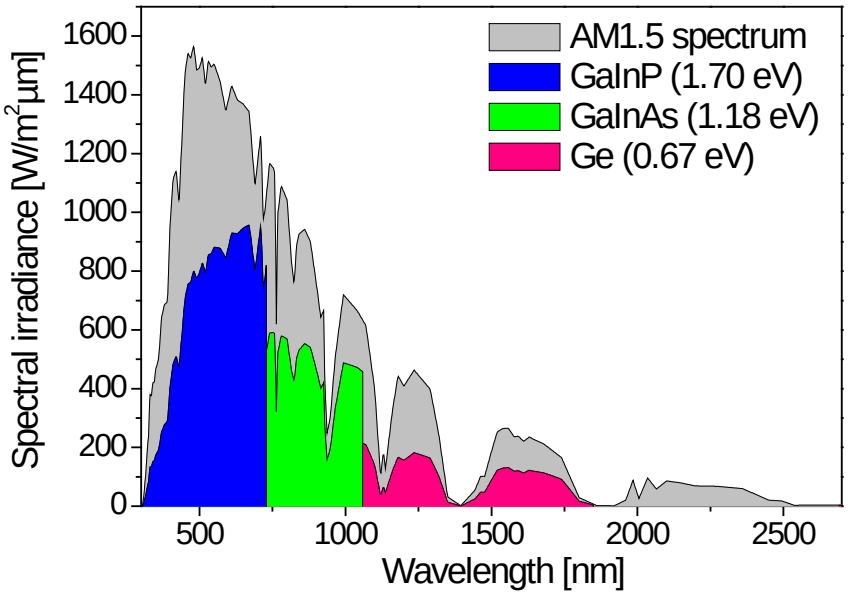
Multi-Junction Solar Cells

Efficiency increases with number of stacked pn-junctions









Excellent material quality is more important than optimum bandgaps

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Improved current matching

+ 15 %

GaInP 1.7 eV
GaInAs 1.1 eV
Metamorphic
Ge 0.7 eV

+ 10 %

41 % Fraunhofer ISE

In 2009

Lattice matched 4-junction

AZURSPACE SOLAR POWER GMBH

GaInP 1.9 eV
GaInAs 1.4 eV
GaInNAs 1.0 eV
Ge 0.7 eV

Ultra-thin lift-off devices

GaInP 1.8 eV
GaInAs 1.4 eV
Ge 0.7 eV

substrate removal

cea leti

Lower cost III-V Solar cells on Si

Bonding

GaInP 1.9 eV
GaInAs 1.4 eV
Si 1.1 eV

GaInP 1.9 eV
GaInAs 1.4 eV
Metamorphic
Si 1.1 eV

HZB Helmholtz Zentrum Berlin

Philipps Universität Marburg

GaAsP 1.9 eV
InAsP 0.9 eV
Si

LUND nano LAB

4-junction with Semiconductor Bonding

+ 15 %

GaAs substrate lift-off

Bonding

GaInP 1.9 eV
GaInAs 1.4 eV
GaInAs 1.0 eV
Metamorphic
Ge 0.7 eV

GaAs substrate lift-off

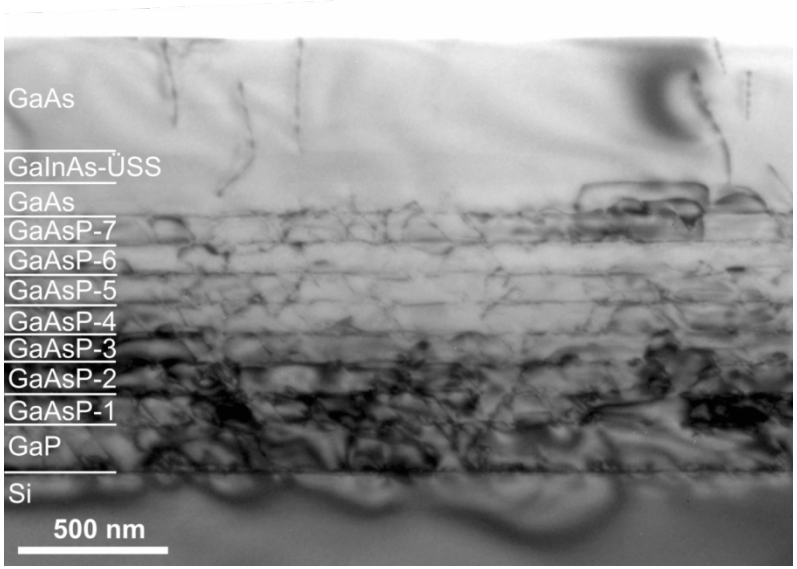
GaInP 1.9 eV
GaAs1.4 eV
GaInAsP 1.0 eV
GaInAs 0.7 eV
InP

Inverted metamorphic Devices

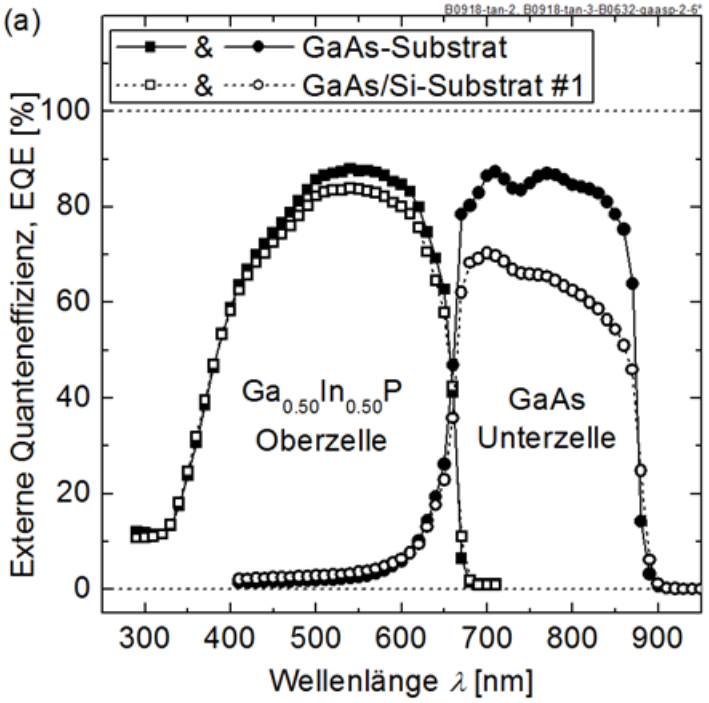
GaAs substrate lift-off

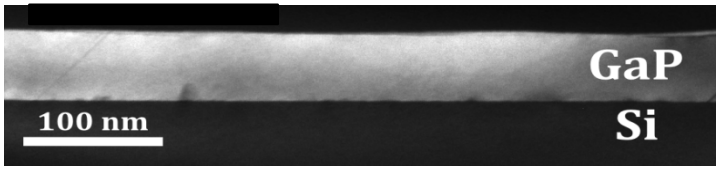
GaInP 1.9 eV
GaInAs 1.4 eV
Metamorphic
GaInAs 1.0 eV
Metamorphic
GaInAs 0.7 eV

GaInP/GaAs Solar Cell on Si



TEM: University of Kiel, preparation ⊥ step edges

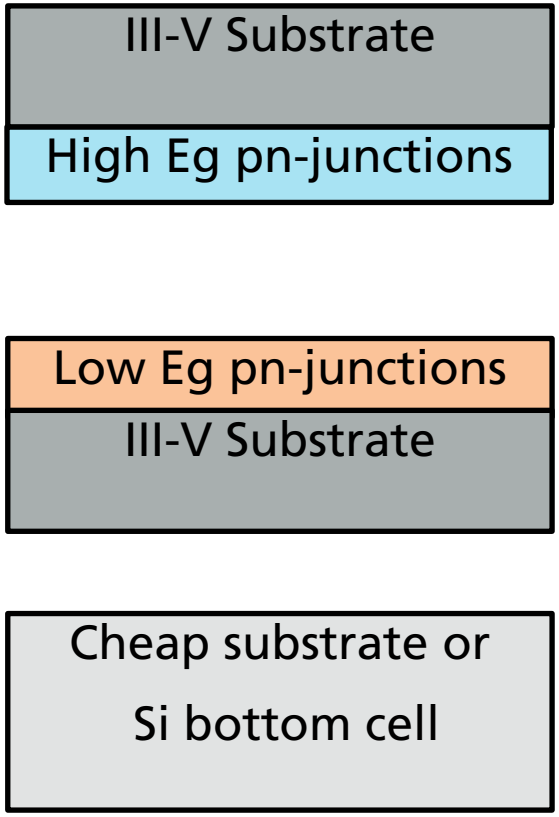




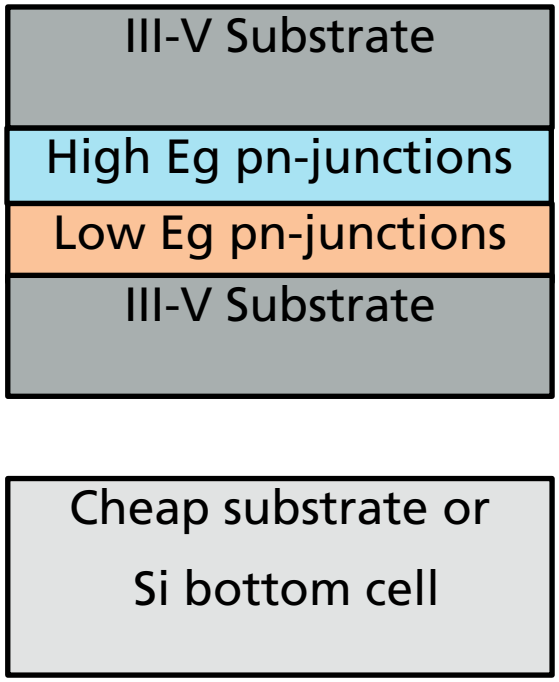
Nucleation with low anti-phase domain density

Substrat	J_{SC} [mA/cm²]	V_{OC} [V]	FF [%]	η [%]
GaAs	13.15	2.45	84.2	27.1
GaAs/Si #1	11.20	1.94	75.3	16.4

Next Generation III-V Multi-Junction Technology

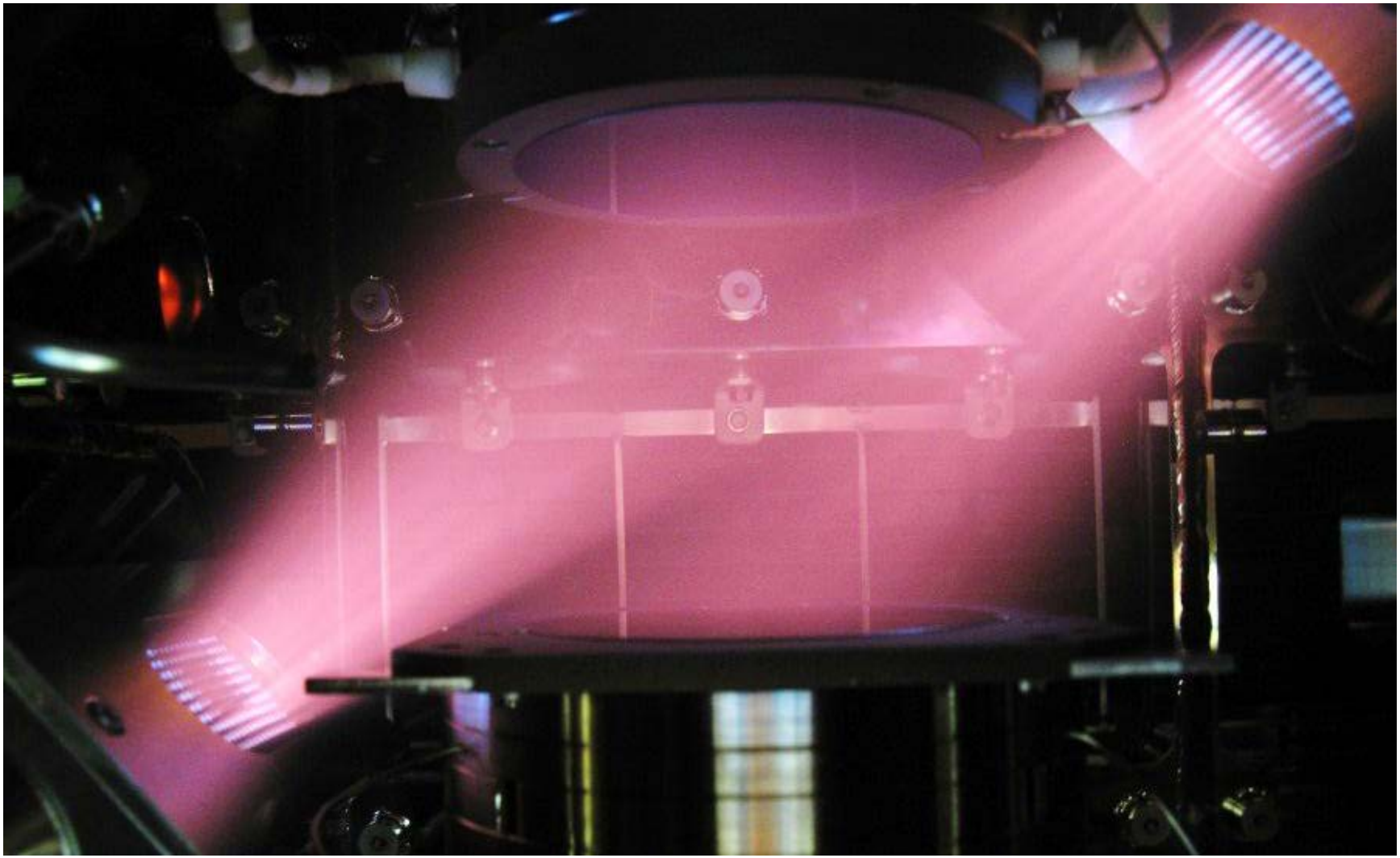


Next Generation III-V Multi-Junction Technology



Wafer Bonding

Plasma Beam Activated Wafer Bonding



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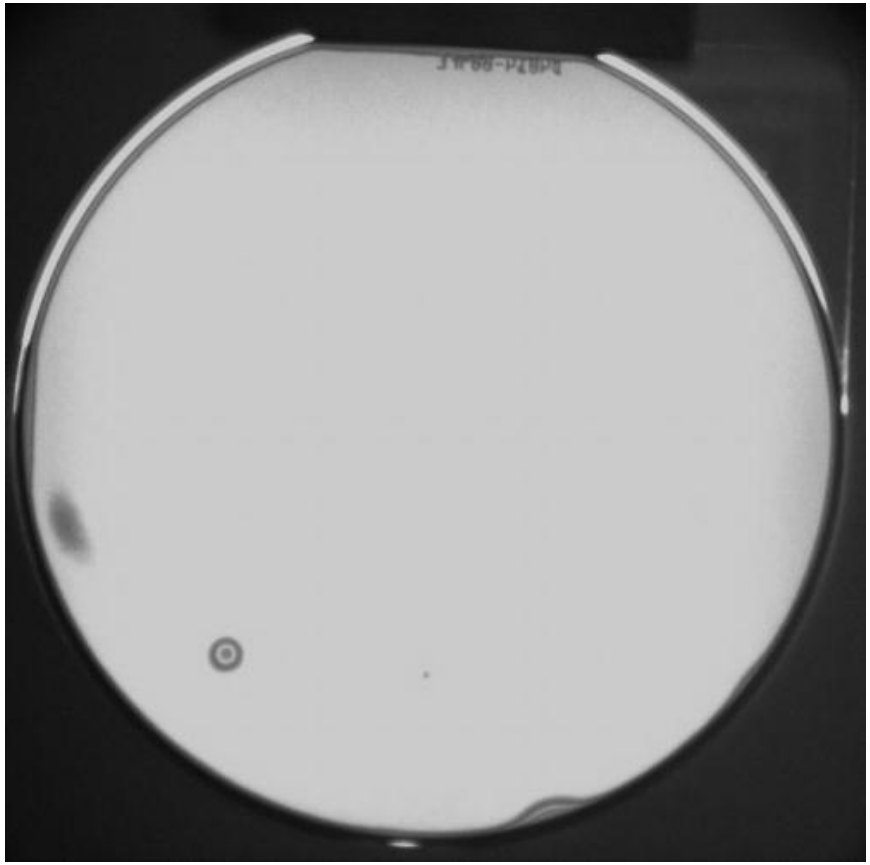
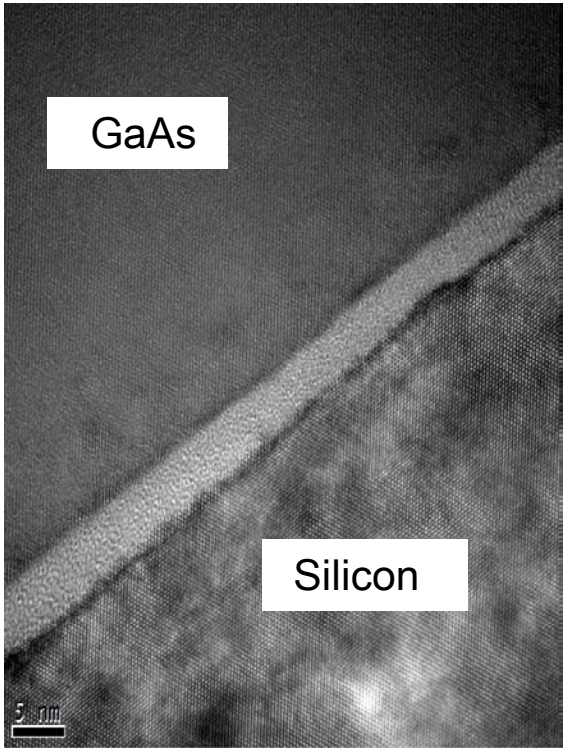
Optimized Bonding Conditions between GaAs and Si



IR transmission of bonded GaAs-Si wafers

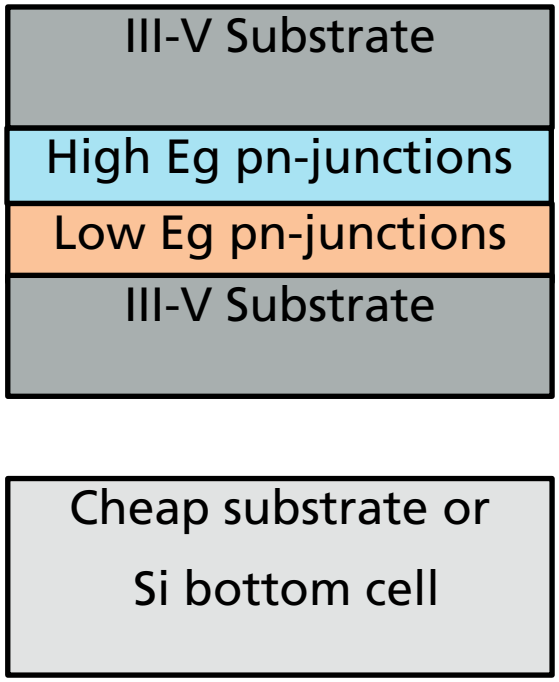
HRTEM-image of Si/GaAs interface



→ 4 nm thick amorphous layer

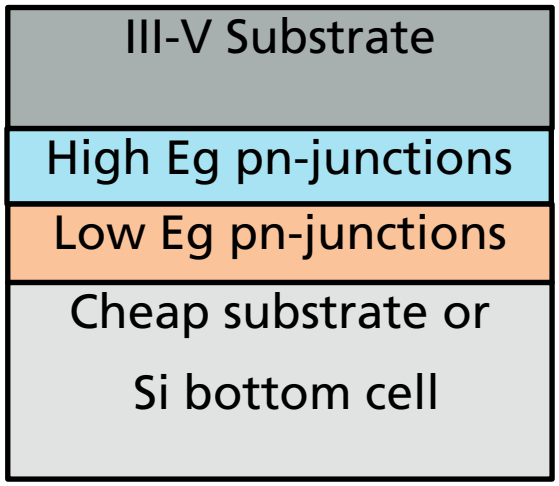
High Resolution TEM Image, Bright Field, Zone Axis Si, Universität Kiel, Group Prof. Dr. Jäger, 2011

Next Generation III-V Multi-Junction Technology



III-V substrate lift-off and recycling

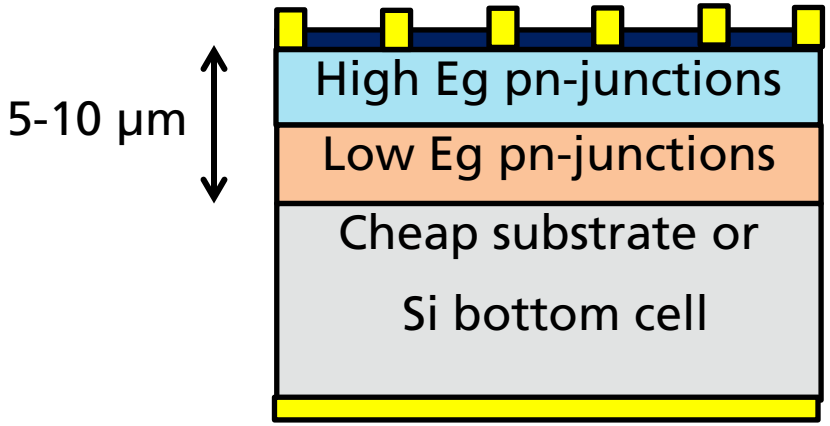
Next Generation III-V Multi-Junction Technology



III-V substrate lift-off and recycling

Bonding to new substrate

Next Generation III-V Multi-Junction Technology

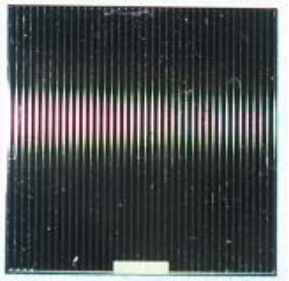


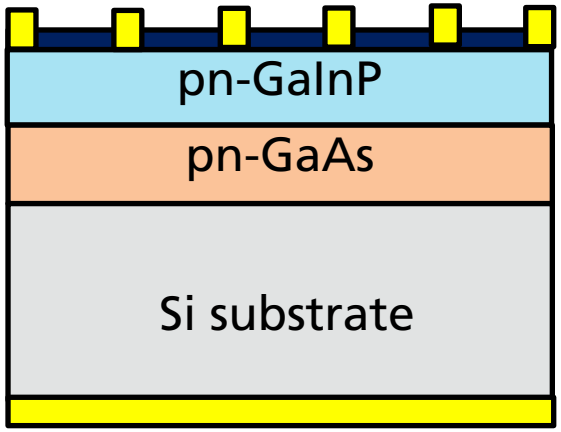
Processing of solar cell contacts and ARC

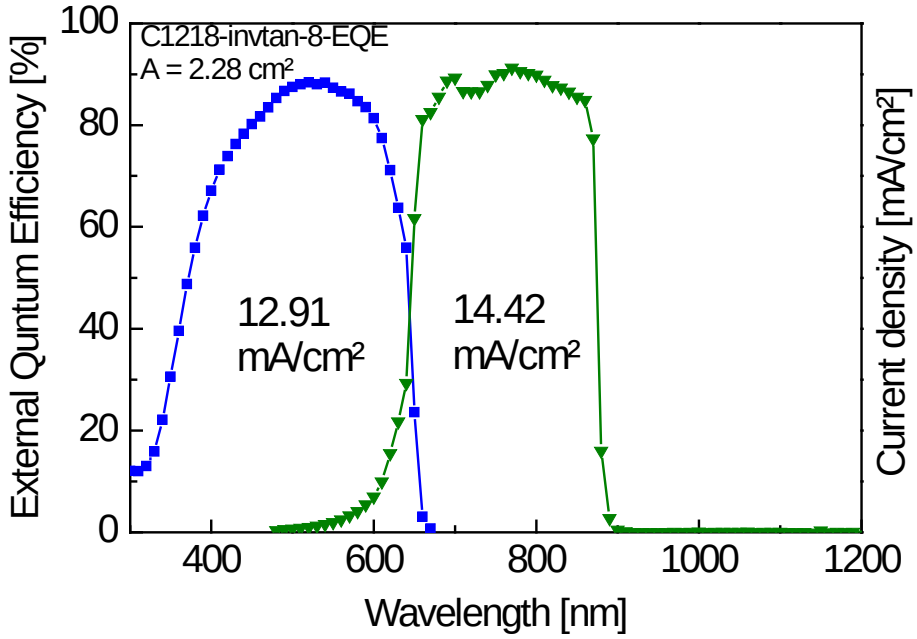
GaInP/GaAs Dual-Junction Solar Cell Result on Si

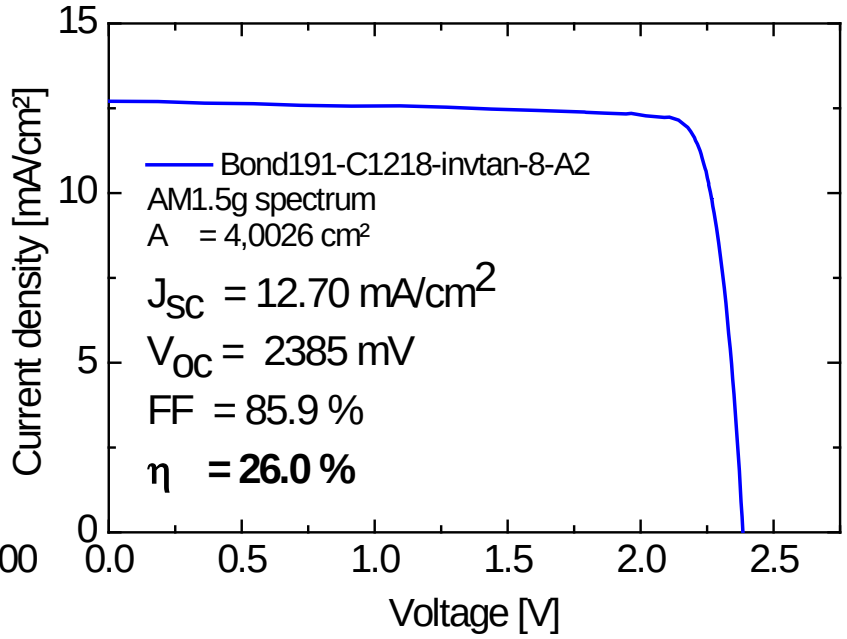
Tandem solar cell on Si with
26.0 % AM1.5g efficiency

A = 4 cm²









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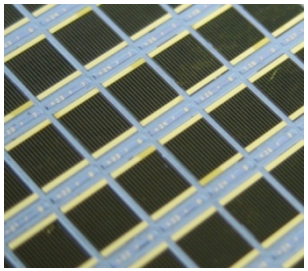
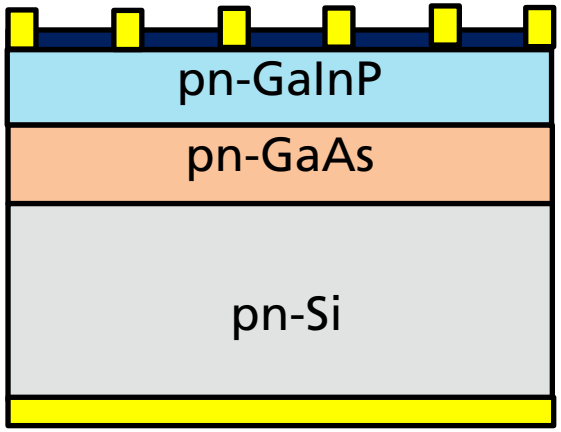
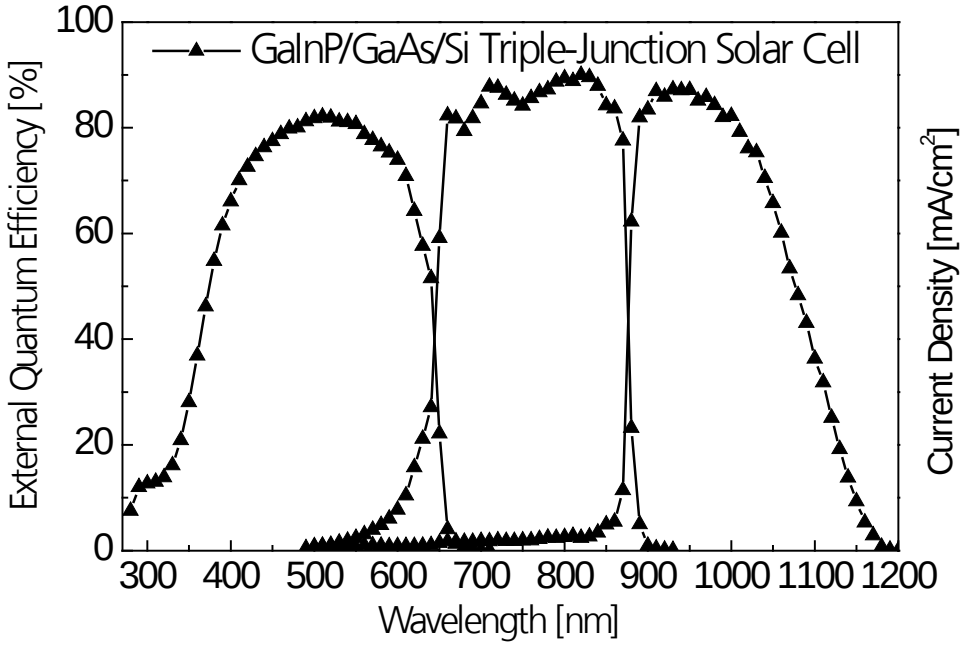
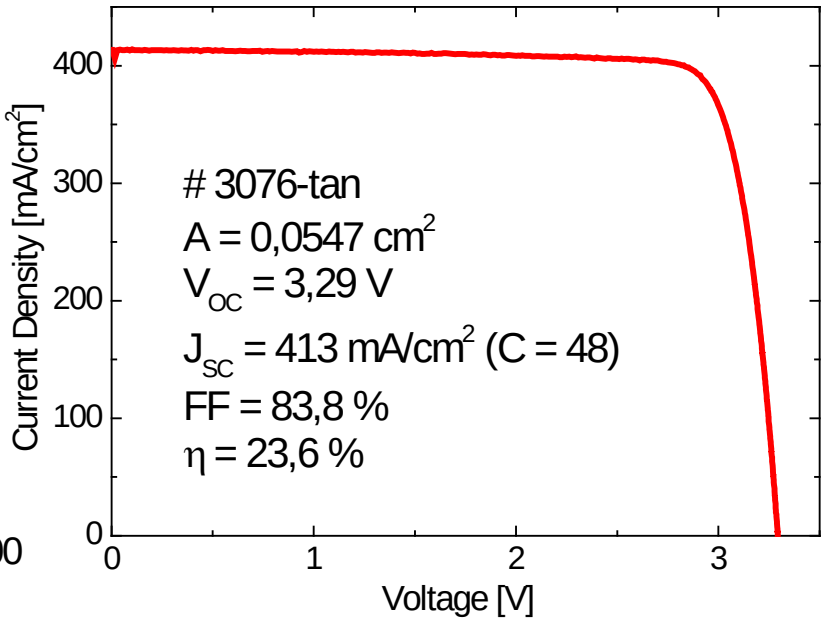
GaInP/GaAs//Si Triple-Junction Cell Result



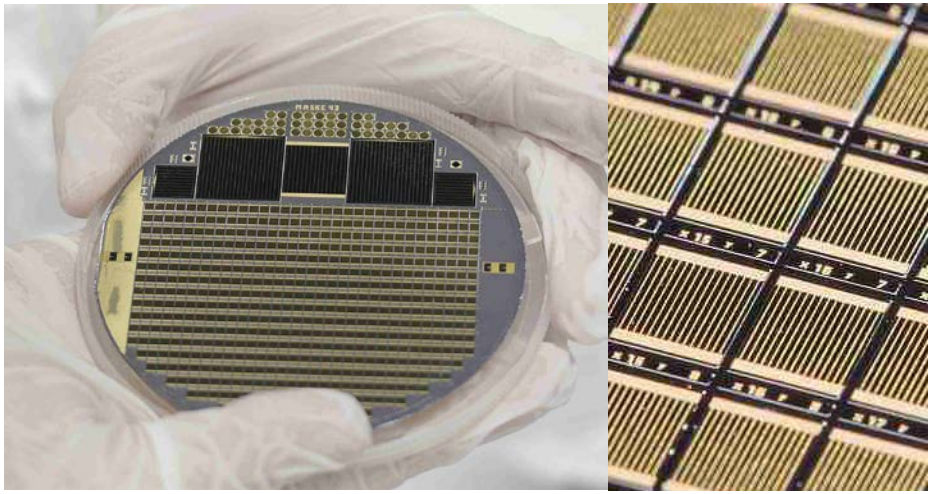


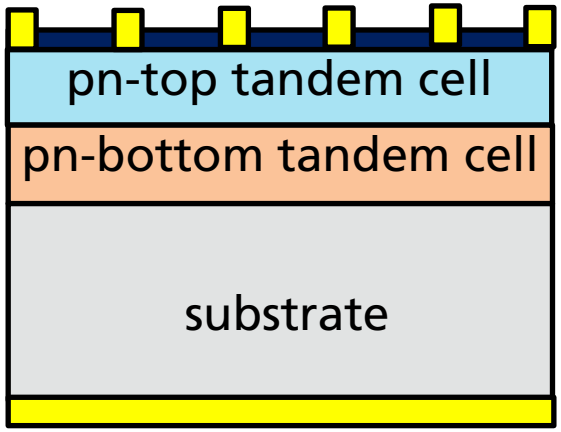


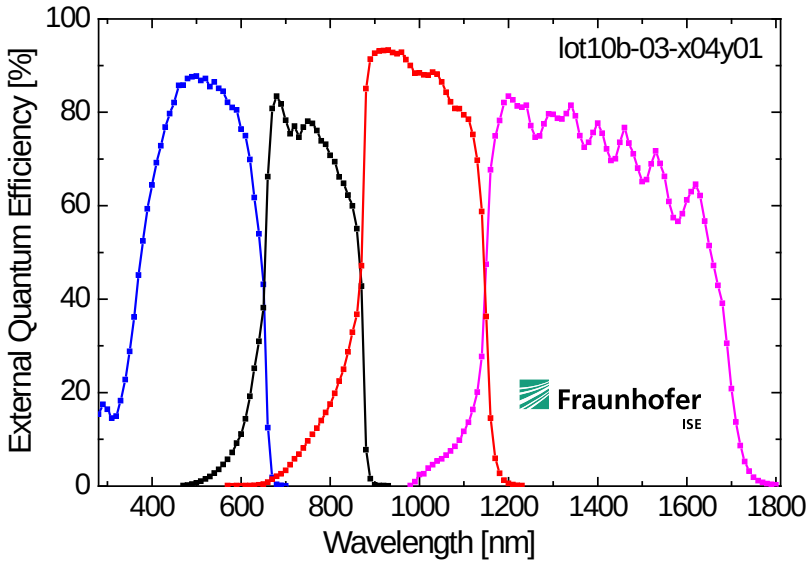


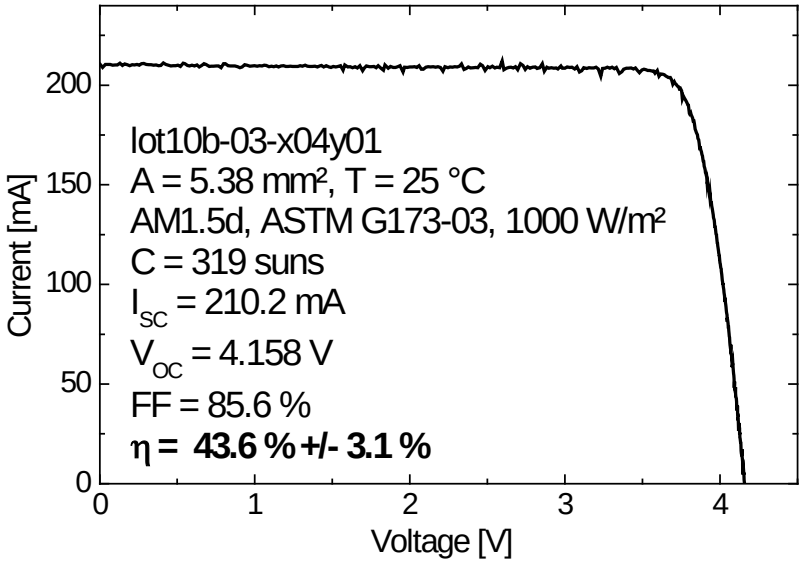
K. Derendorf et al., IEEE J. of PV, DOI 10.1109/JPHOTOV.2013.2273097 (2013)

43.6 % Efficiency for Wafer-Bonded 4-Junction Solar Cell





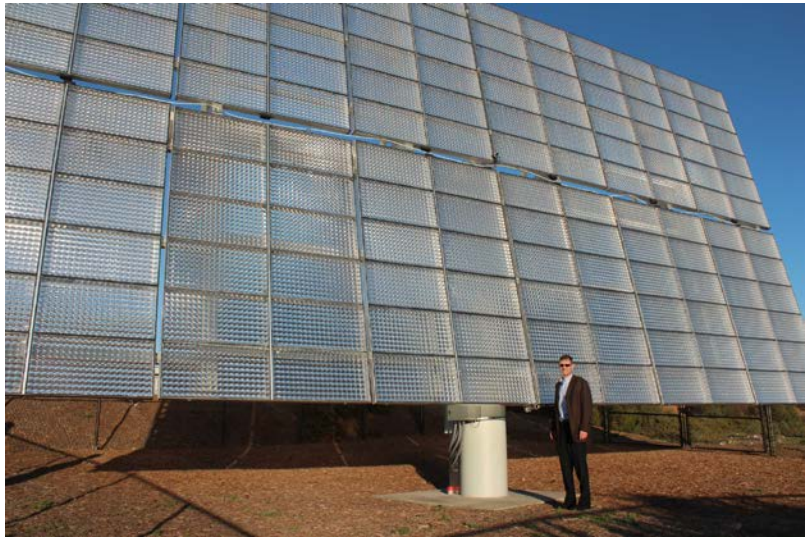




Soitec HZB Helmholtz Zentrum Berlin cea leti Fraunhofer ISE

SOITEC Solar CPV Systems

25-27 % system efficiency
with 39 % solar cells



SOITEC 1 MW, New Mexico

Soitec

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Solar Hydrogen Production with 18 % Efficiency But no Feed-In Tariff for Hydrogen

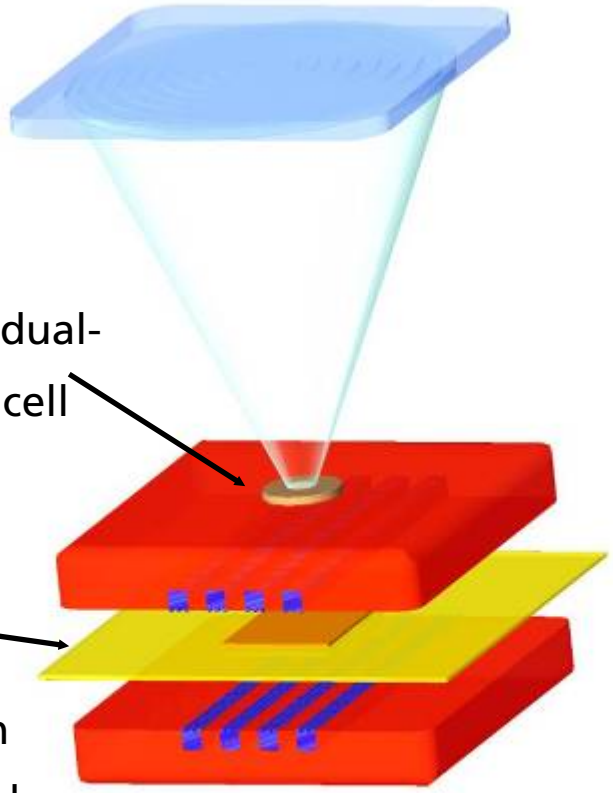
Fresnel lens

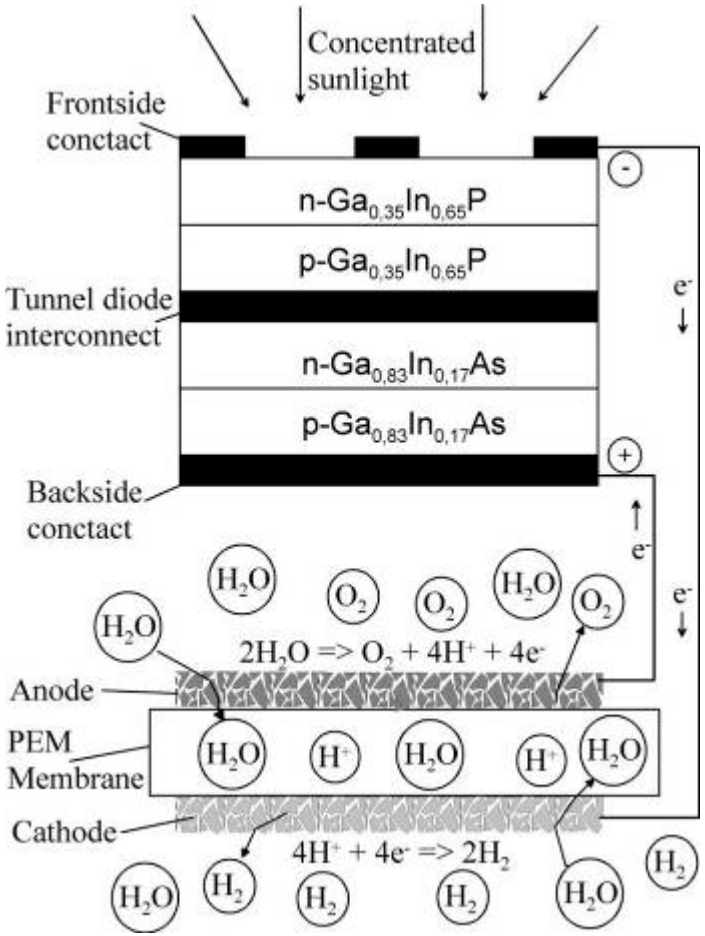
C = 500

GaInP/GaInAs dual-junction solar cell

polymer membrane

titanium with H_2O flow field





G. Peharz et al., Int. Journal of Hydrogen Energy 32 (2007)

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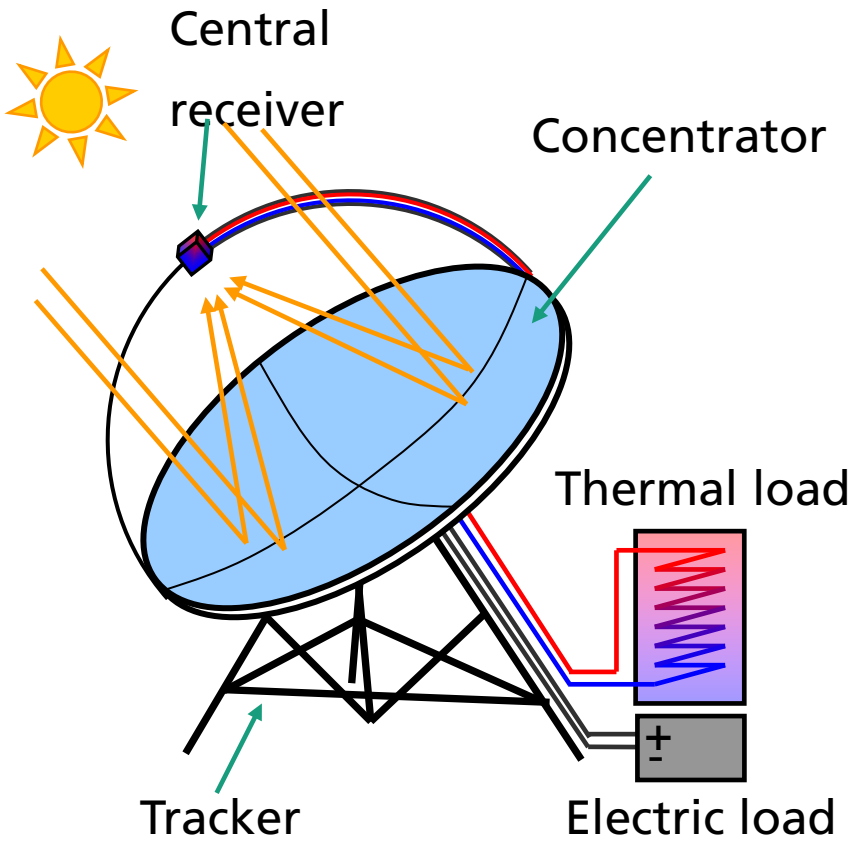
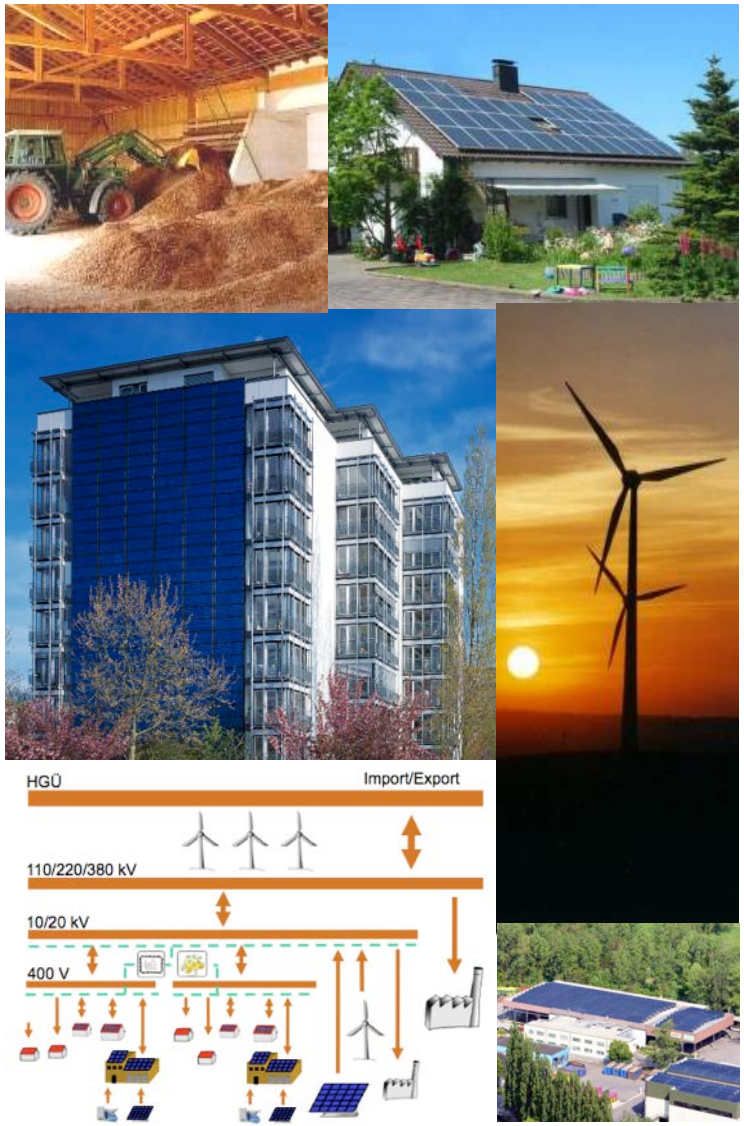
Co-Generation of Heat and Electricity
Central Receiver System + Thermal Application (CPVT)

- Active cooling delivers usable heat
- High temperatures up to 150°C
- Diverse applications
  - Industrial process heating
  - Solar desalination + solar cooling



Conclusions

- Science will support lowering costs, increasing reliability and efficiency of renewable energy systems
- Si is a wonderful photovoltaic material and will have a bright future, especially in combination with new technologies like III-Vs or organics to enhance efficiency
- The „Energiewende“ can not wait for scientific breakthroughs



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Thank you for your attention!