Utility Scale Power Generation using Third Generation Photovoltaics based on III-V Semiconductor Technology

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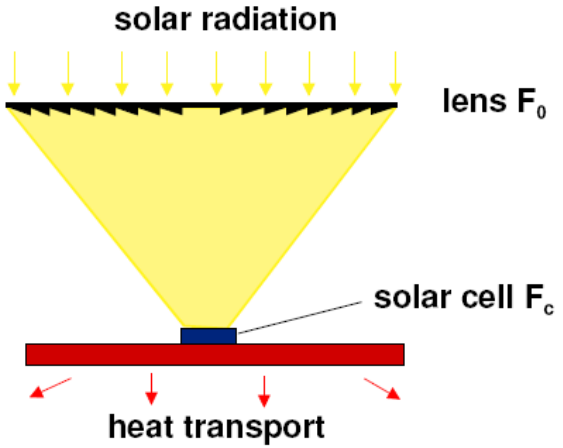
PV Solar Cells – A High Growth Market:

- **Drivers**
  - Environmental concerns driving need for clean and sustainable energy sources
  - Aggressive legislation to achieve environmental targets
  - Economic drivers for alternative energies
- **Technologies**
  - First Generation: Silicon based
    - ~20% efficiency
    - ~$2.5/Wp
  - Second Generation: Thin film
    - <15% efficiency
    - ~$1-$2/Wp
  - Third Generation: GaAs CPV (Concentrator Photovoltaics)
    - >40% efficiency
    - <$1/Wp

What is CPV?

- III-V multi-junction PV cells operated under optical concentration (lenses or mirrors) – mounted on 2-axis solar tracker
- Typically x500-600 suns

- This reduces need for III-V material and increases device performance (reduced cost)

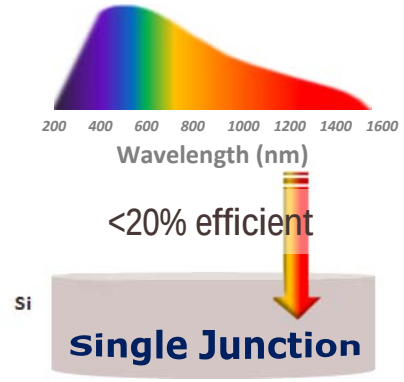


Seven 5-inch Silicon Cells Provide Equal Power to One 1cm² Multi-junction Solar Cell

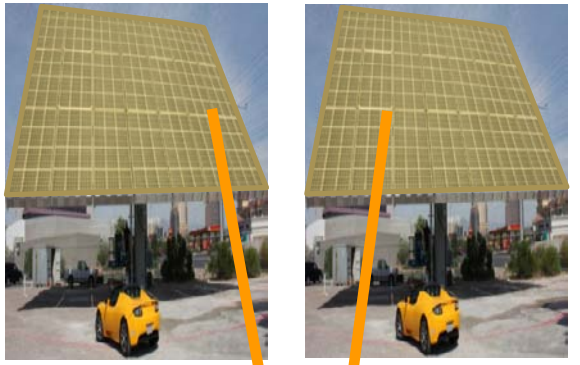
Source: Emcore

Third Generation Solar: Concentrating PV technology.....
significantly reducing solar power generation costs

SILICON



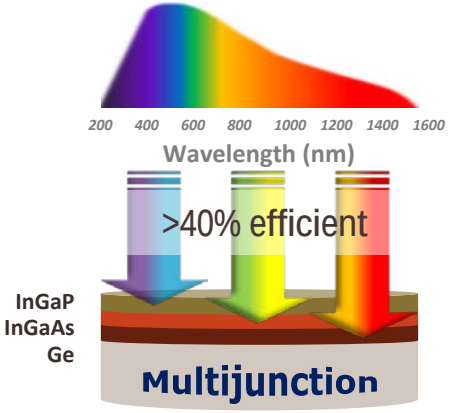
~1000x decrease in semiconductor area for III-V vs. c-Si



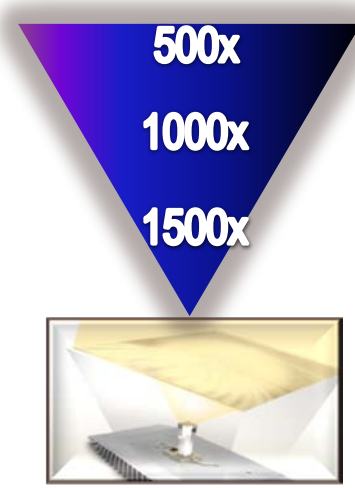
SILICON

COMPOUNDS

High conversion efficiency



High concentration



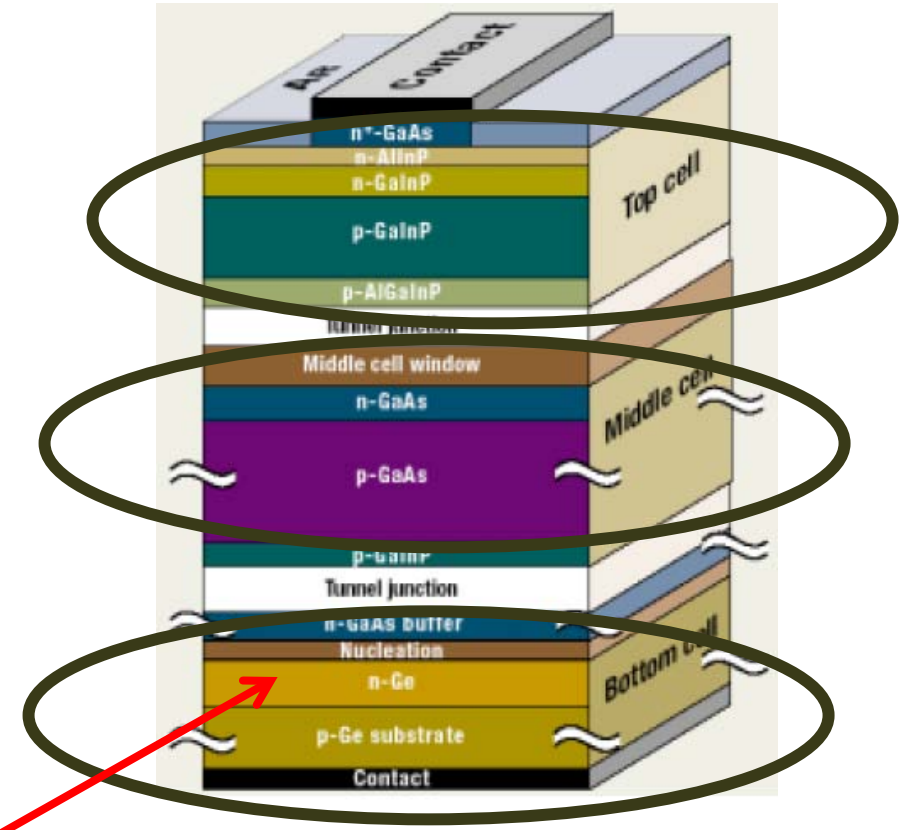
Less material (lower cost)

1cm² Multi-junction Solar Cell provides as much power as seven 5-inch Silicon Cells

COMPOUNDS

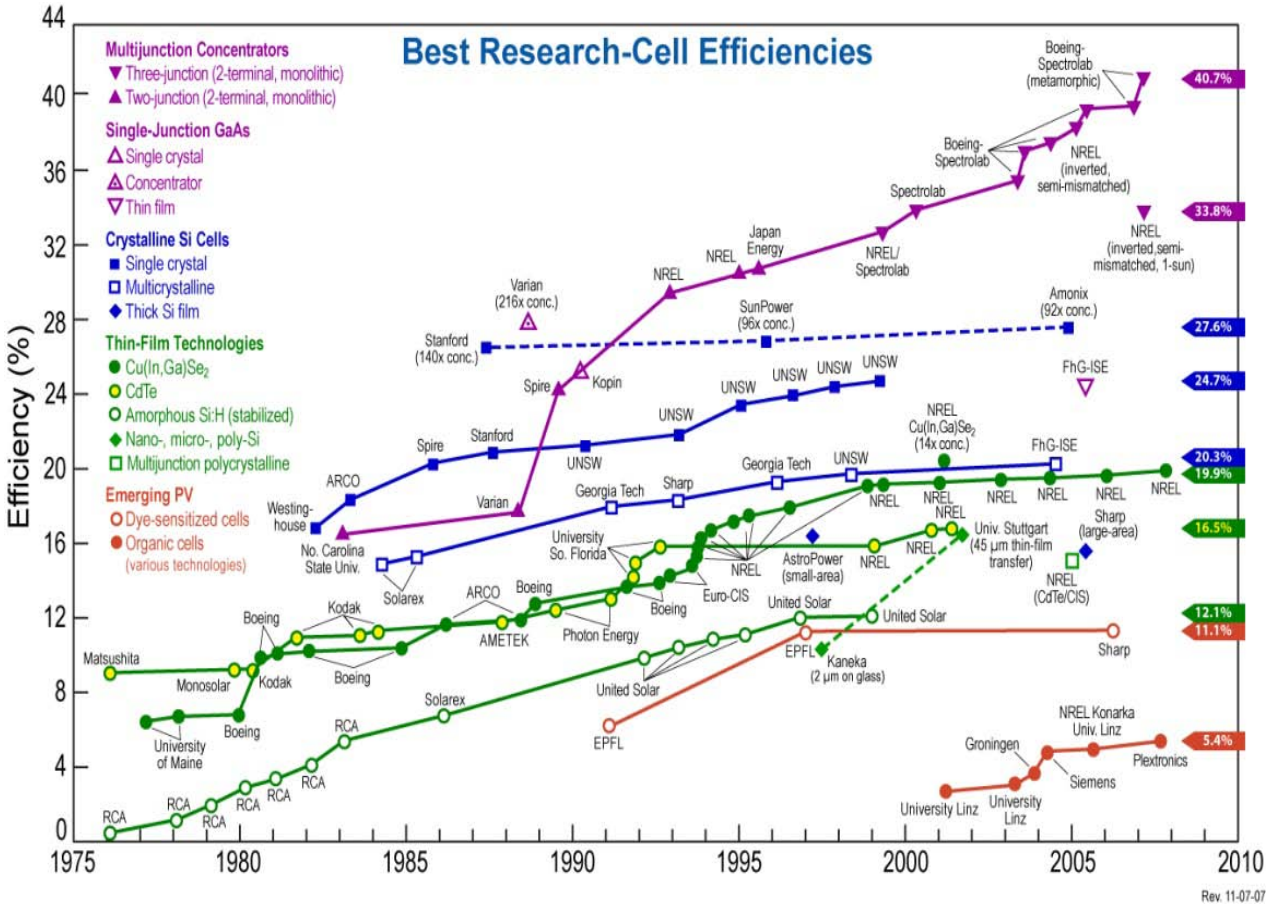
CPV Device Structure:

- Classic triple junction with InGaP, InGaAs, Ge junctions epitaxially grown onto Germanium substrate
  - Lattice matched, 4” wafers (or larger)
  - 2x Tunnel contacts (important)
  - Typically 6-7µm thick
- Ge bottom sub-cell created by Group V diffusion into Ge substrate



PV Solar Cells – A History:

Source: NREL

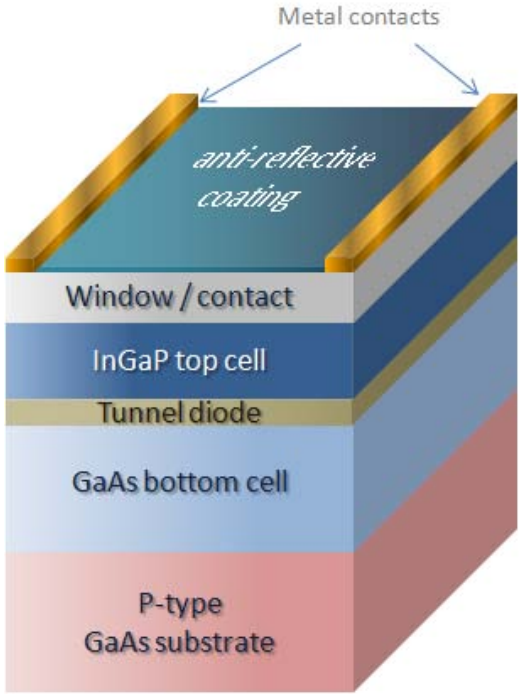


- Multi-Junction cells have by far the highest efficiency and the fastest rate of improvement
- <u>But</u> cost is a major issue – they are very expensive

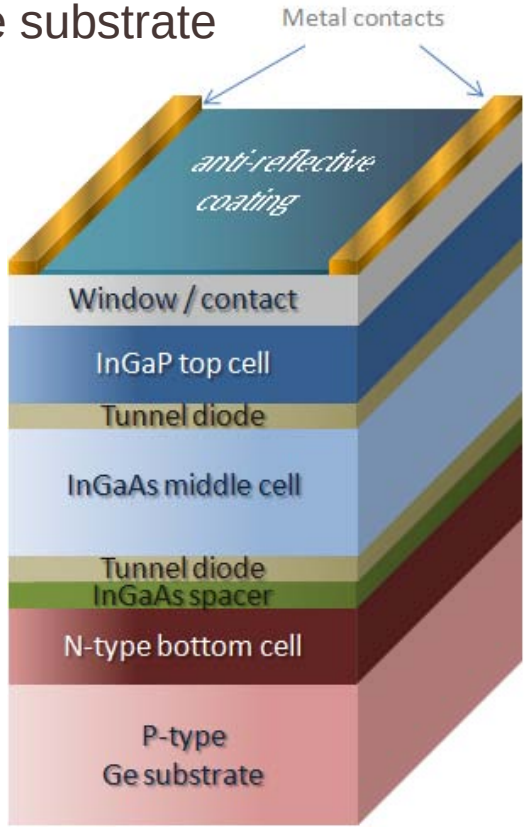
IQE CPV Technology & Capabilities:

Solar Cell Schematic Structures

a) Dual Junction utilising GaAs substrate

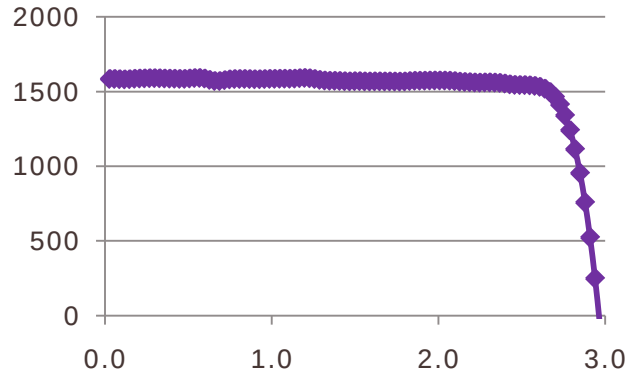


b) Triple Junction utilising Ge substrate

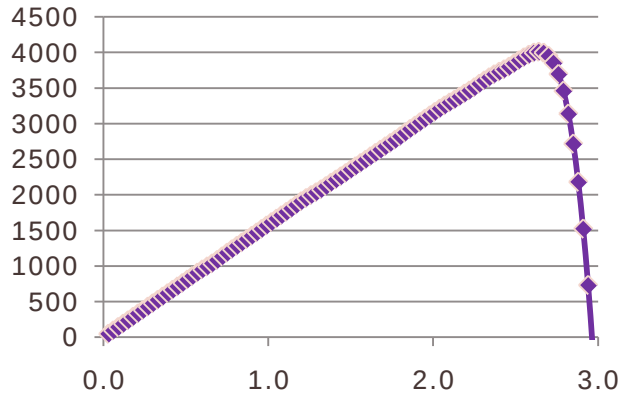


Triple Junction solar cell status:

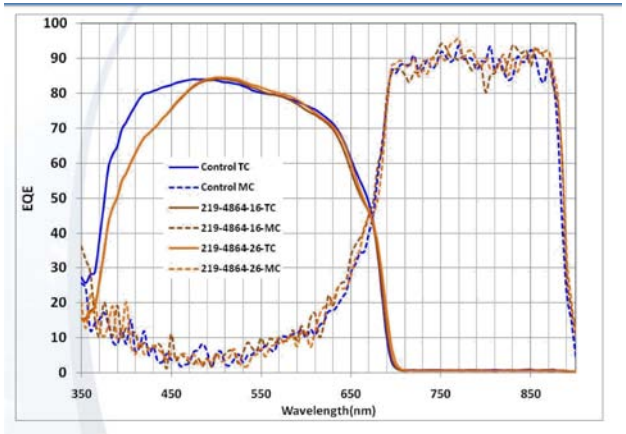
a) Triple junction on Ge multisun I-V curve



b) Triple junction on Ge multisun P-V curve



c) External QE

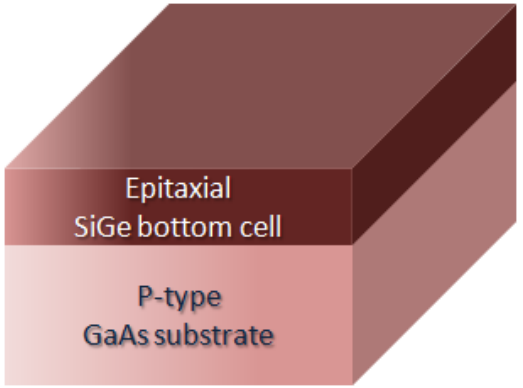


- V_{oc} ~3V, Isc ~1.6A
- Fill Factor ~87%
- Efficiency ~39% at 200 suns
- EQE close to 'benchmark' - Spectrolab
- Customers have IP that add 1-1.5% absolute efficiency

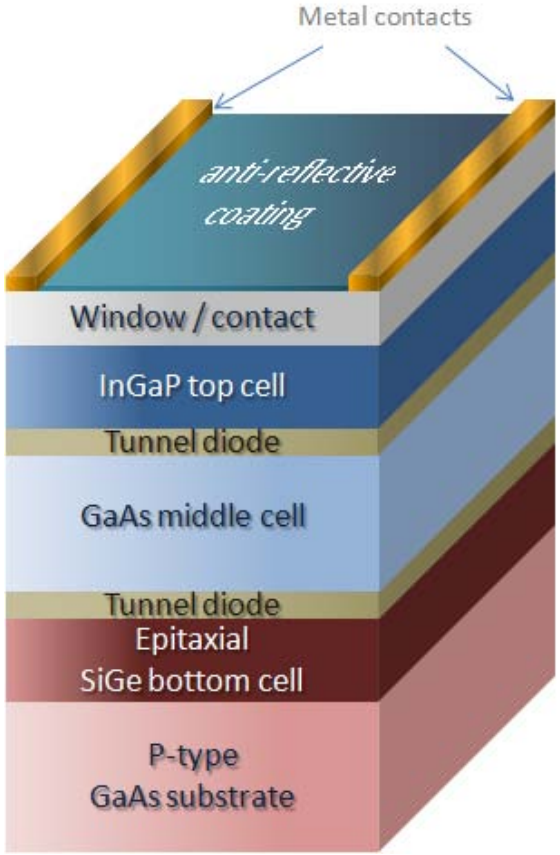
Triple Junction Solar Cell with epitaxial SiGe bottom cell:

Schematic:

(IQE Patent pending)



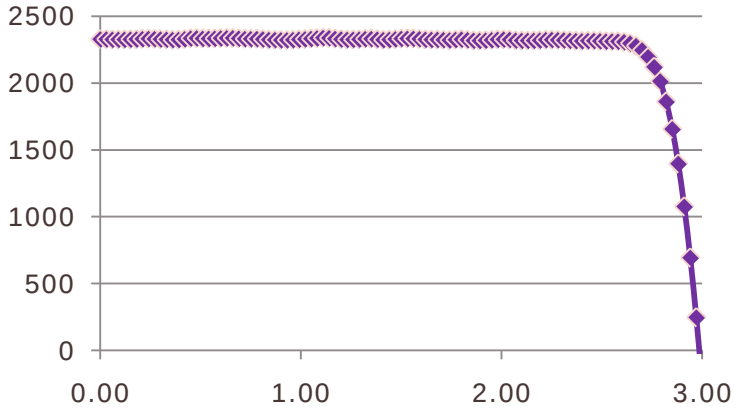
a) SiGe grown lattice matched onto GaAs substrate – growth by CVD at IQE Silicon



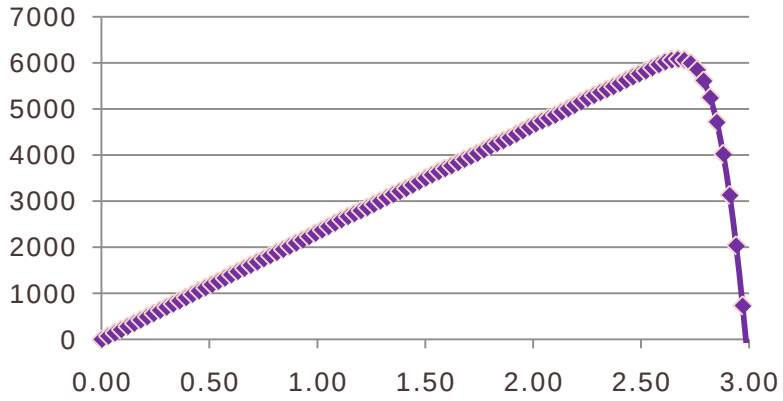
b) Subsequent III-V overgrowth by MOCVD to define solar cell

Triple Junction Solar cell utilising epi SiGe on GaAs:

a) Multisun I-V curve

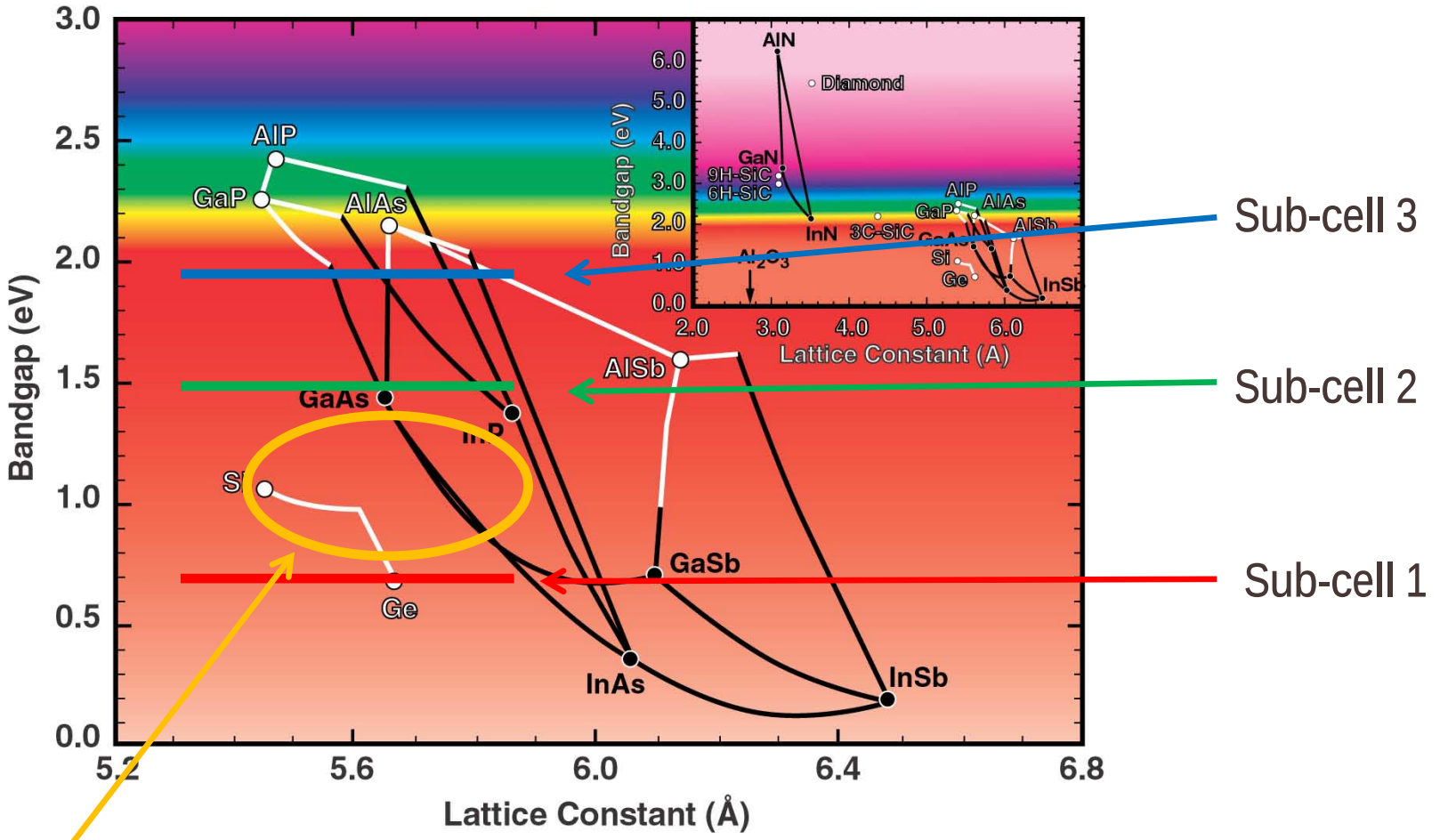


b) Multisun P-V curve



- First ever triple junction solar device utilising SiGe bottom cell
- Increased V_{oc} compared with TJ on Ge (Larger bandgap of SiGe)
- Good device performance - >6W Pmax at ~x200 suns , Fill Factor ~90%
- Already demonstrated on 6” diameter substrates
- Equivalent performance to 3J on Ge (~38% multi-sun efficiency)
- Improved device performance and substrate removal investigation

Lattice-matched multi-junction cells:



Lack of lattice matched, ~1.0eV material limits higher device performance

Novel CPV Device concepts:

Improved Cell Efficiency:

- Band structure Engineering – Quantum Wells, Quantum Dots
- Novel Materials – InGaAsN, SiGeSn

Cost Reduction:

- Substrate re-use
- III-V on Silicon

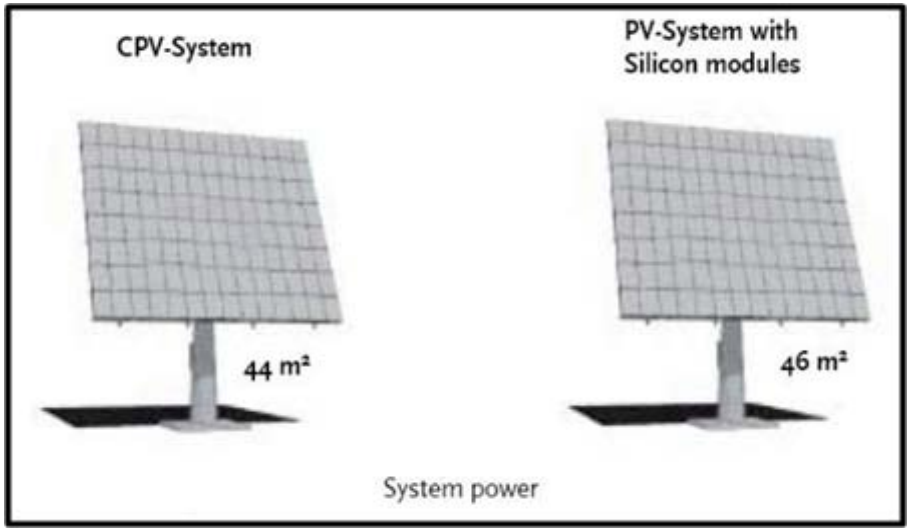
Summary of CPV advantages:

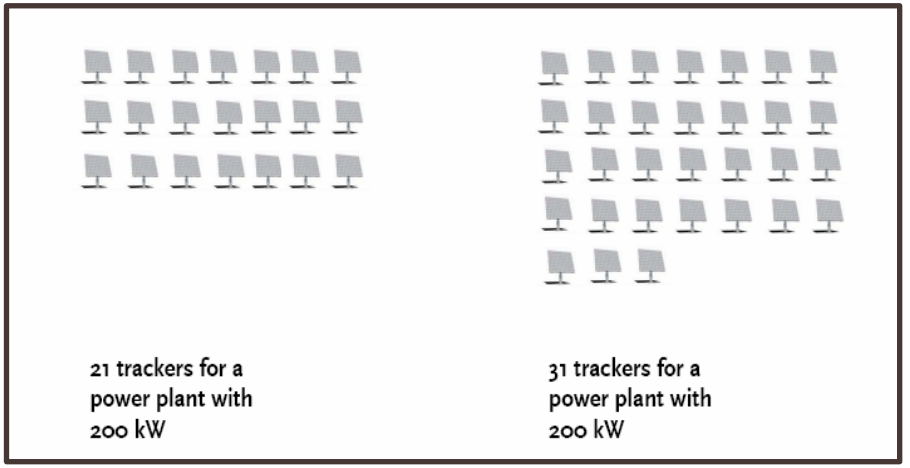
Highest efficiency solar convertor

- More power output per M^2
- Optics concentrate sunlight onto cells at levels equivalent of up to 1500 suns
- Only CPV III-V triple junction solar cells maintain performance at normal operating temperatures (70°C)

Lowest £/kWh by:

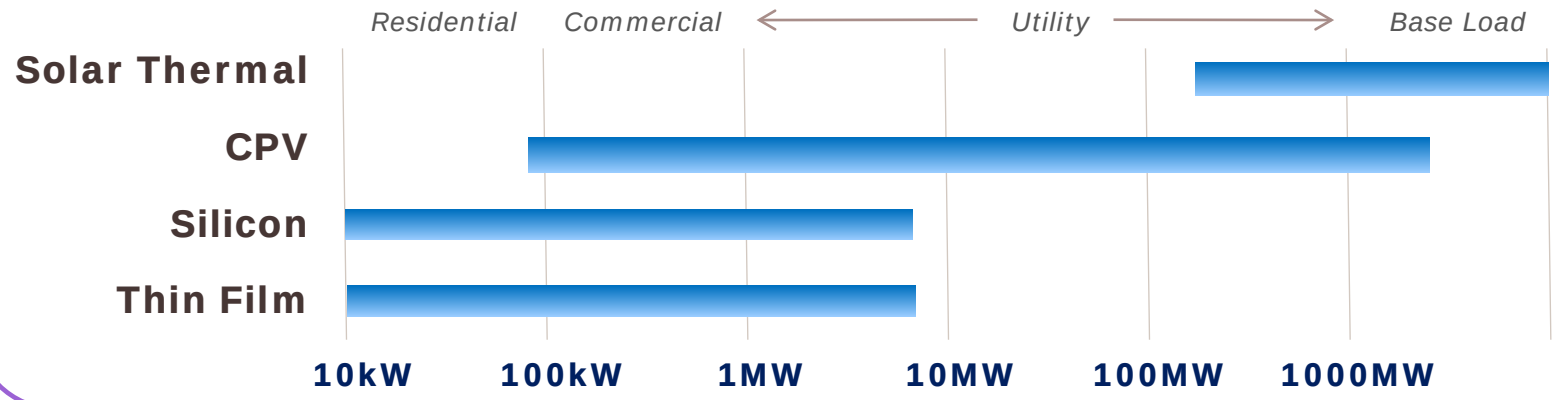
- Increasing cell efficiency
- Reducing cell cost
  - Precision optics & alignment
  - Optimised tracking of the sun
  - Cost reduced trackers
  - Ensures cost of electrical energy from solar CPV will converge on that from fossil fuels



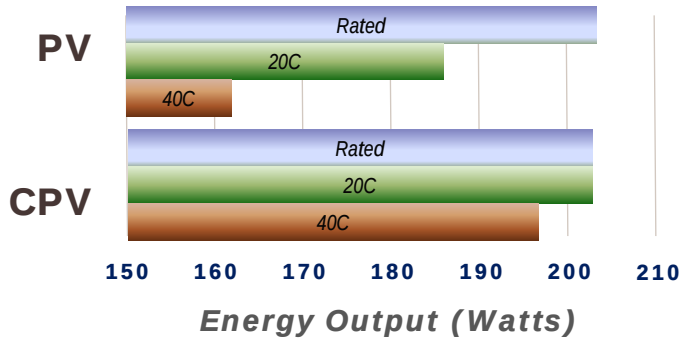


Competitive advantages of CPV:

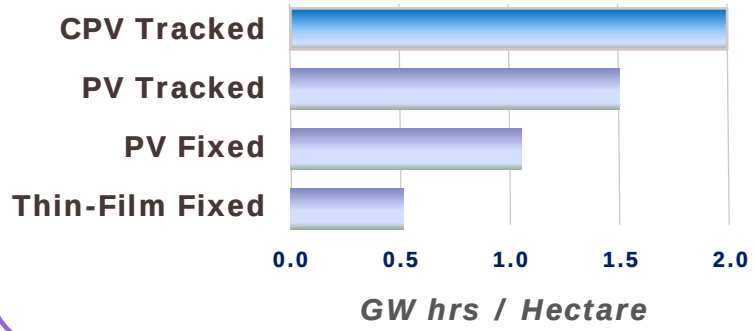
Available across all levels of system integration



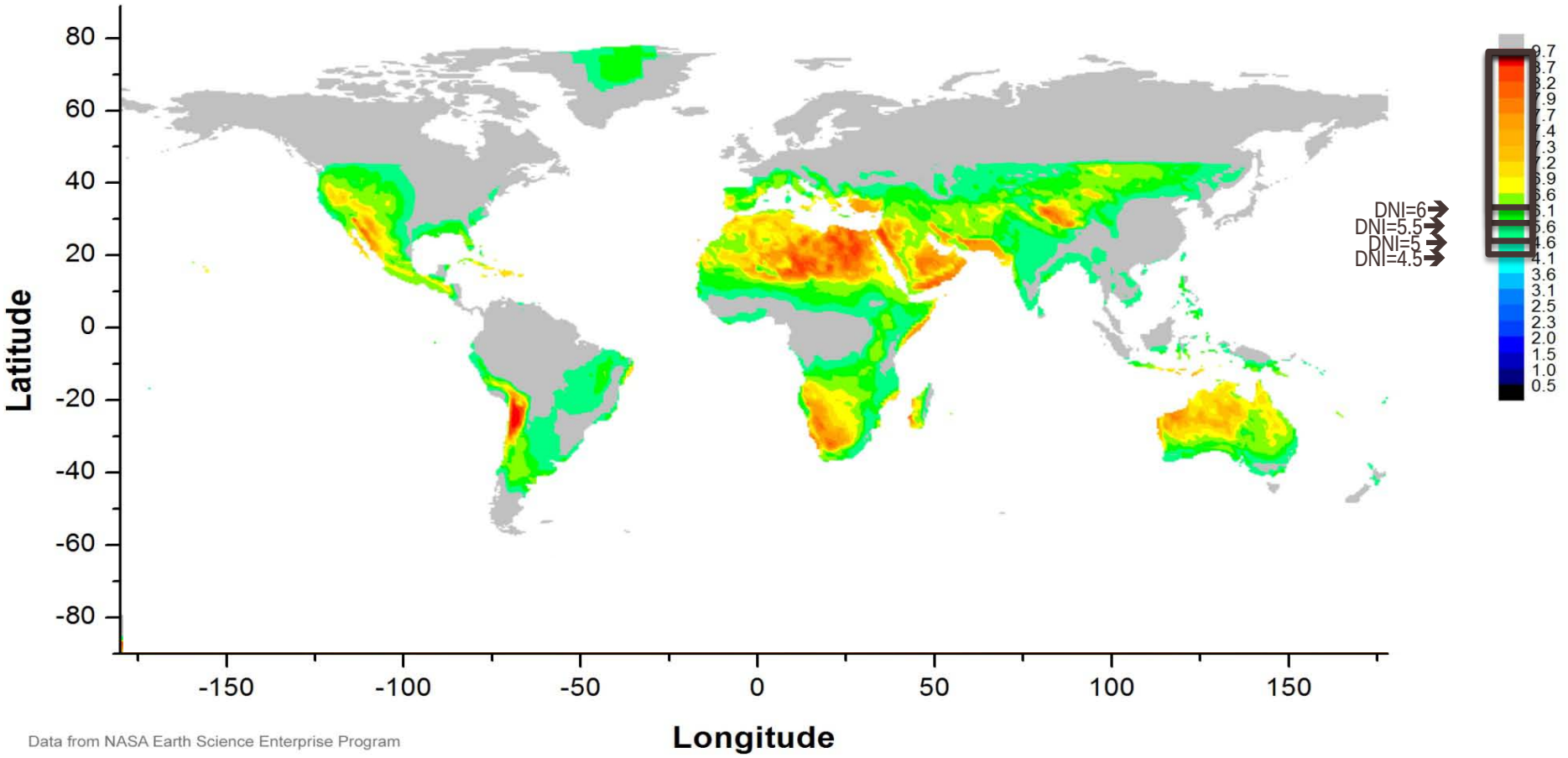
Best solution for hot climates



Highest Energy Density



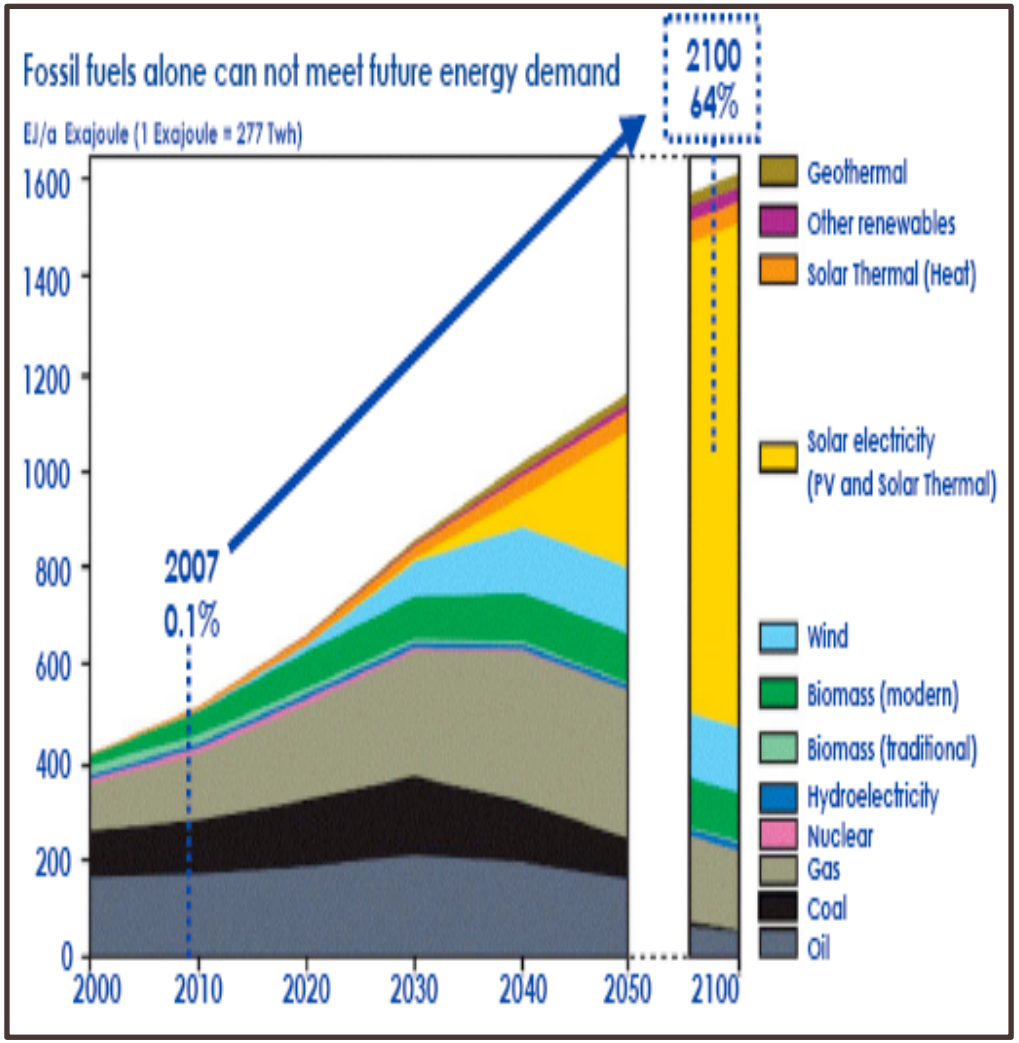
Improved solar system performance and/or lower cost expands the global LCOE parity region



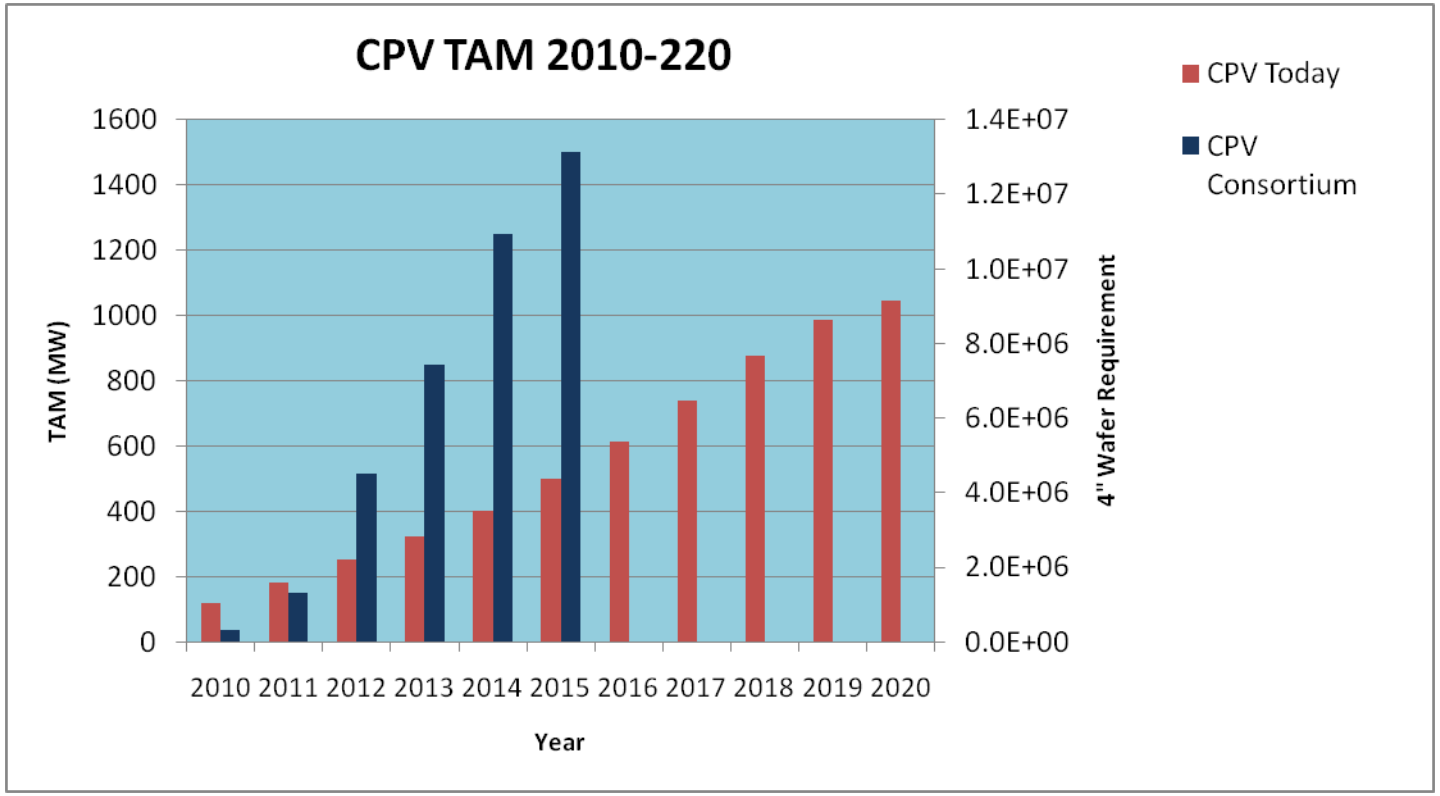
* LCOE – Levelised Cost of Energy

Rapid growth in CPV installations

- Drivers
  - Environmental concerns driving need for clean and sustainable energy sources
  - Aggressive legislation to achieve environmental targets
  - Economic drivers for alternative energies
- Number of CPV installations forecast to grow rapidly as a result of:
  - Multi-junction Compound Semiconductor cells used in space for over 20 years; proven long-term reliability
  - Field test data over 12 to 15 months shows total power output within 3% of predicted levels
  - with proven field test data, utility companies now engaging in major projects.



Immediate Market Opportunity:



Total epiwafer market in excess of 1 Million wafers/yr by 2013 (4” equivalent)

CPV solar: IQE at Inception of the emerging supply chain

Epi Foundry

Chip Suppliers & Chip Foundries

10-15 in total

Systems

40-50 in total

Space

emcore | SPECTROLAB A BOEING COMPANY

emcore | SPECTROLAB A BOEING COMPANY | azur solar

CESI | emcore | SPECTROLAB A BOEING COMPANY | Concentrix solar

Terrestrial

IQE

Engaged with and designed into leading CPV suppliers

VPEC

Cyrium Technologies | WIN SEMICONDUCTORS | QuantaSol | JDSU | AWSC | spire Semiconductor | MTPV | SOLAPOINT | RoseStreet Labs Energy | Solar Junction

greenvolts | SHARP | sol3g | SolFocus Innovation Inspired by Nature | Arima Eco Energy | sunrgi | circadian solar POWER WITH PURPOSE | Panasonic | coolearth | Guascor Foton | ENTECH SOLAR | Soliant Energizing commercial rooftops | AMONIX Powering our Future | ENFOCUS ENGINEERING | isofotón | WhitfieldSolar | SolarTec International AG

Summary:

- Multi-junction CPV technology has the greatest potential to deliver lowest cost electricity
- Tracked, High DNI areas and utility scale
- Offers highest efficiency conversion of sunlight to electricity
- Offers greatest opportunity for significant cost reduction
- Novel device architectures offer route to higher efficiencies & lower cost
- IQE is ideally placed at the leading edge with state of the art performance and IP for improved devices

Thank You