

Progress in High Efficiency Terrestrial Concentrator Solar Cells

R.K. Jones, P. Hebert, P. Pien, R.R. King, D. Bhusari, R.
Brandt, O. Al Taher, C. Fetzer, J. Ermer

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Spectrolab Overview

- **Established in 1956**
 - 53 years in the solar business
- **Acquired by Hughes in 1975**
- **Acquired by Boeing in 2000**
 - Wholly owned subsidiary
 - Merchant supplier to aerospace industry
 - Processed wafers, cells, CICs & panels
 - Solar simulation equipment
 - High intensity searchlights
 - Rapidly growing CPV business
 - Solar America Initiative (DOE) program
 - Boeing capitalization of factory
- **~175,000 sq. ft. located in Sylmar, CA**
- **Most experienced MJ cell manufacturer**
 - Space: ~680kW (equivalent to ~300 MW CPV)
 - CPV: ~27 MW



ISO9001:2000
REGISTERED

ENVIRONMENTAL MANAGEMENT SYSTEM
CERTIFIED BY DNV
== ISO 14001 ==

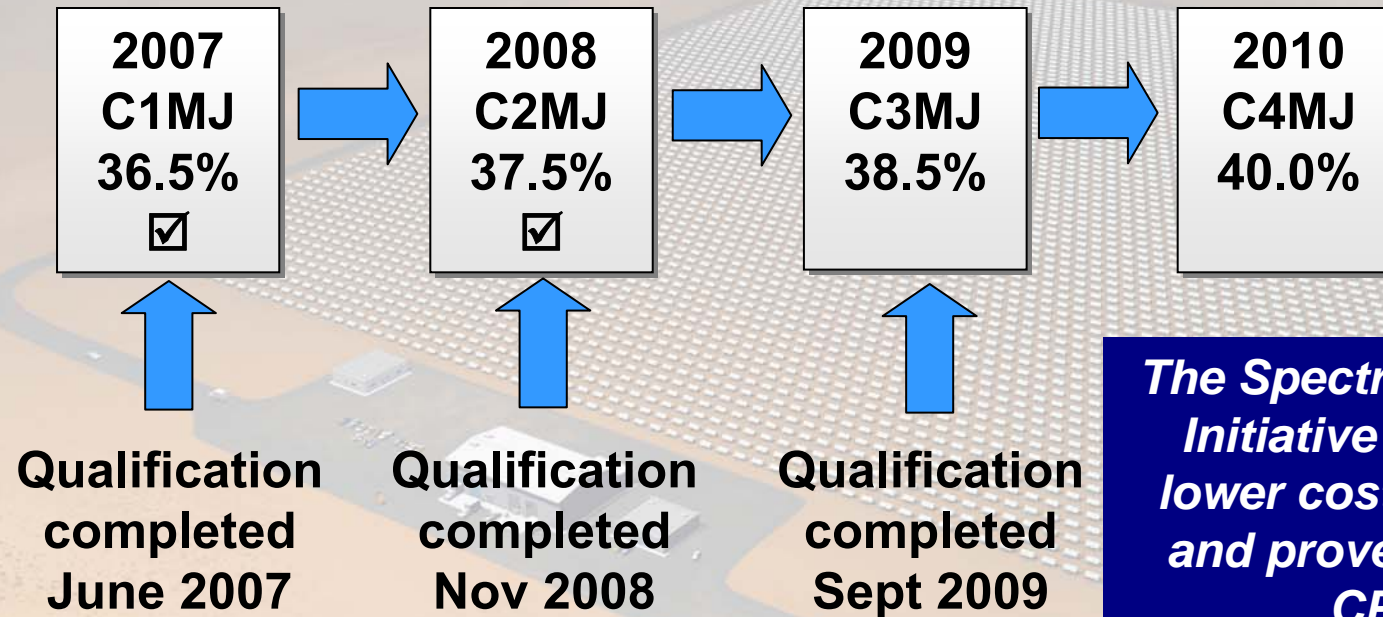
AS9100
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Spectrolab is a proud participant in the US DOE Solar America Initiative

Participating in Technology Pathway Partnerships led by Boeing, Amonix and Soliant

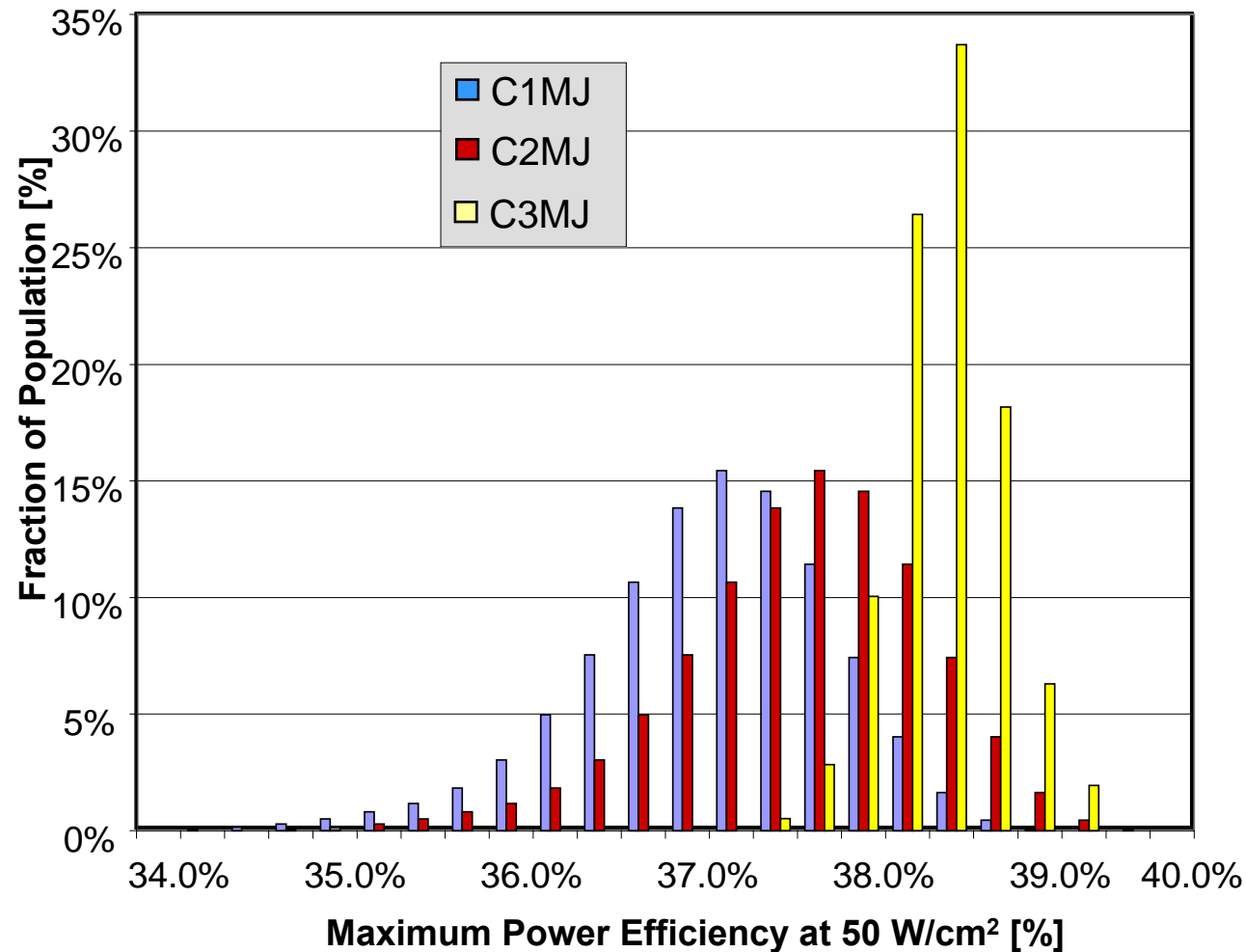
Program Goals and Achievements

- Improve average production efficiency from 36.5% to 40%
- Reduce cost by >50%
- Demonstrate reliability through qualification tests and field trials



The Spectrolab Solar America Initiative program delivers lower cost, higher efficiency and proven reliability to the CPV industry

Spectrolab Cell Generations



Efficiency distributions at 555 suns (50.0 W/cm^2) from Spectrolab's C1MJ production cell, and for the next generation C2MJ and C3MJ cell, all with 1.00 cm^2 area

Incremental improvements have yielded ~1.5–2% efficiency gain

Multi-Junction Solar Cell Efficiency Improvement Strategies

Now in Product Implementation Phase: Mid-Term

C2MJ cell (Gen 2, 37.5%) and
C3MJ (Gen 3, 38.5%)

Evolutionary approach:

- 3J lattice-matched (LM) cell
- Wafer process optimization

Mid-Term

C4MJ (Gen 4, 40%) cells

Evolutionary:

- 3J lattice-matched (LM) cell

Revolutionary:

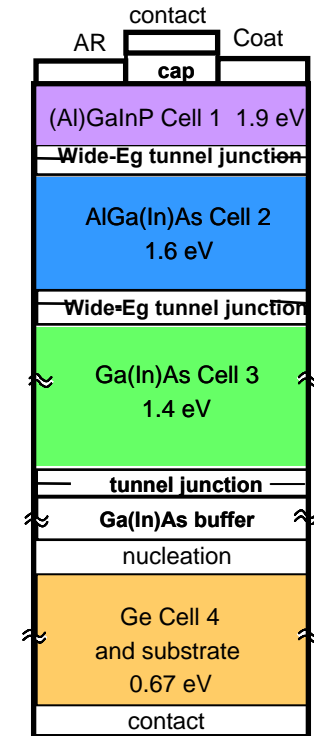
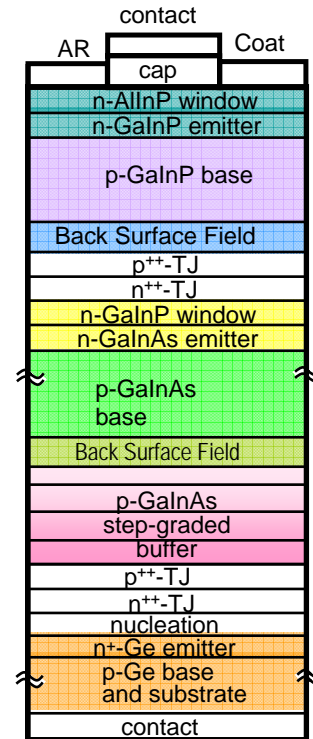
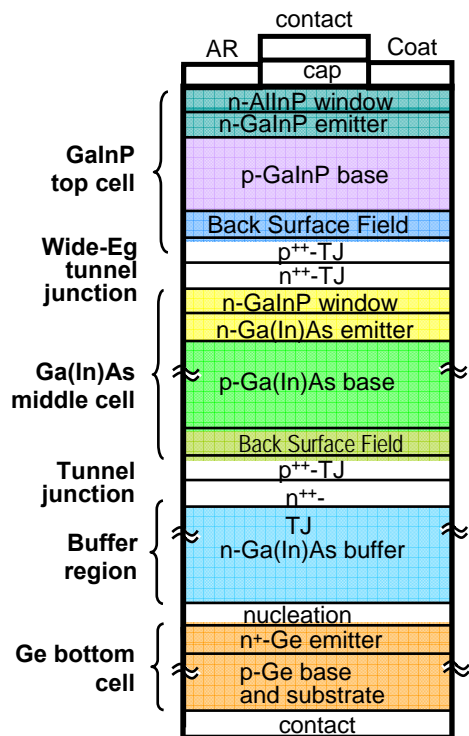
- 3J upright metamorphic (MM) cell
- 4J lattice-matched cell

Long-Term

Phase II cell (43%)

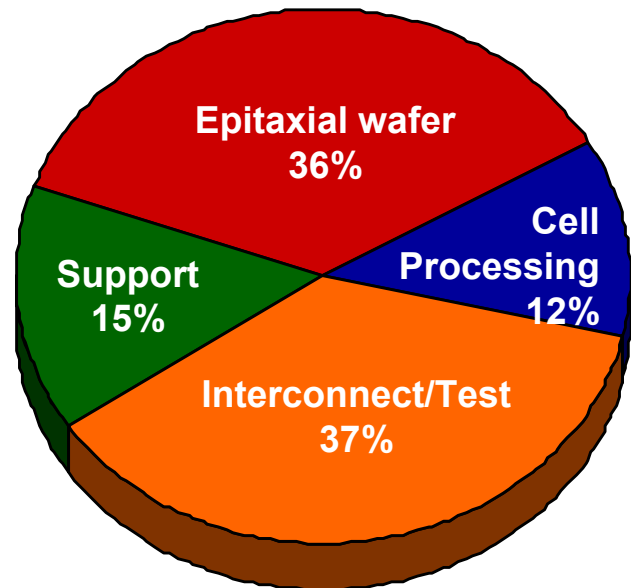
Revolutionary:

- Inverted metamorphic (IMM) cells
- 5-6J lattice-matched cells
- 4-6J metamorphic cells

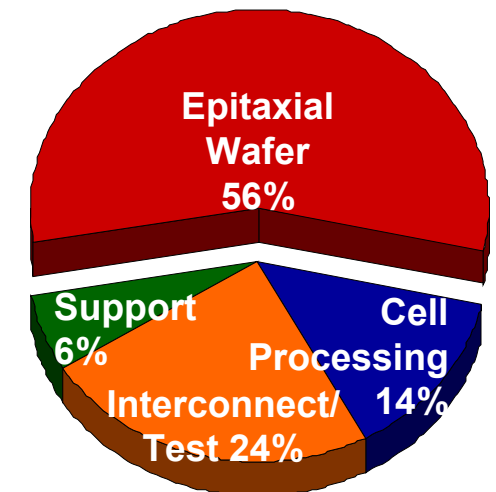
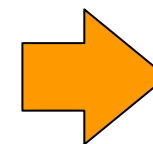


Spectrolab has established multiple approaches to achieve long term efficiency goal

Factory Automation Upgrades



2007-2008



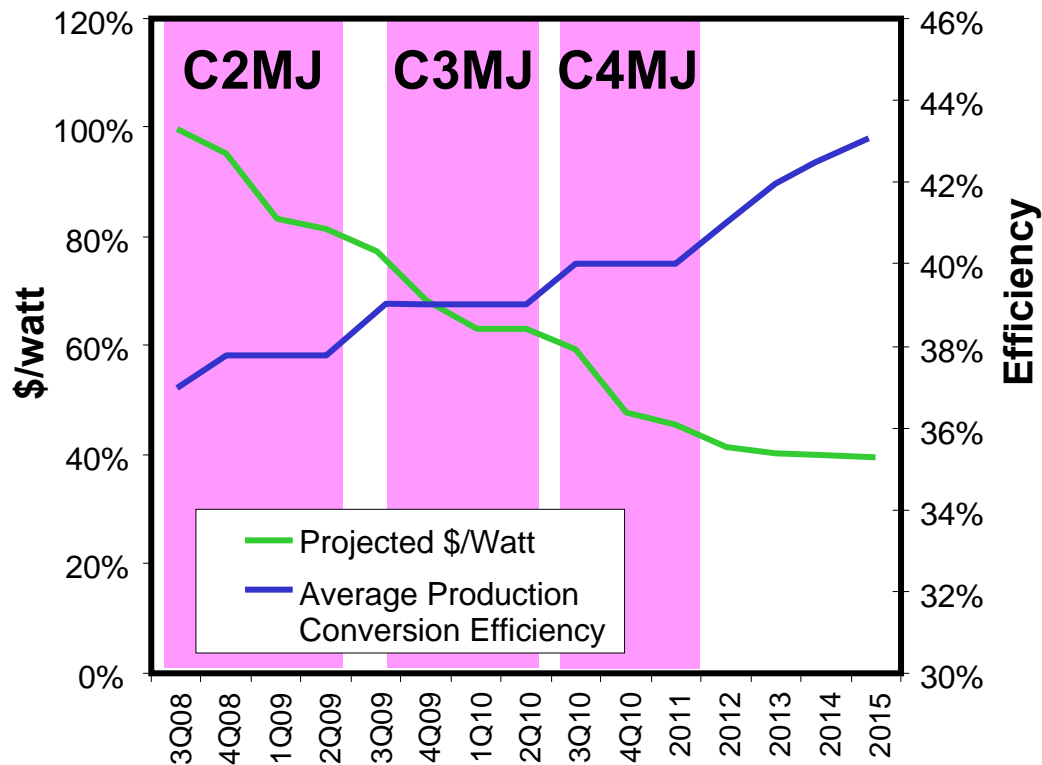
2010

Spectrolab Cost and Efficiency Roadmap



CDO-100-IC

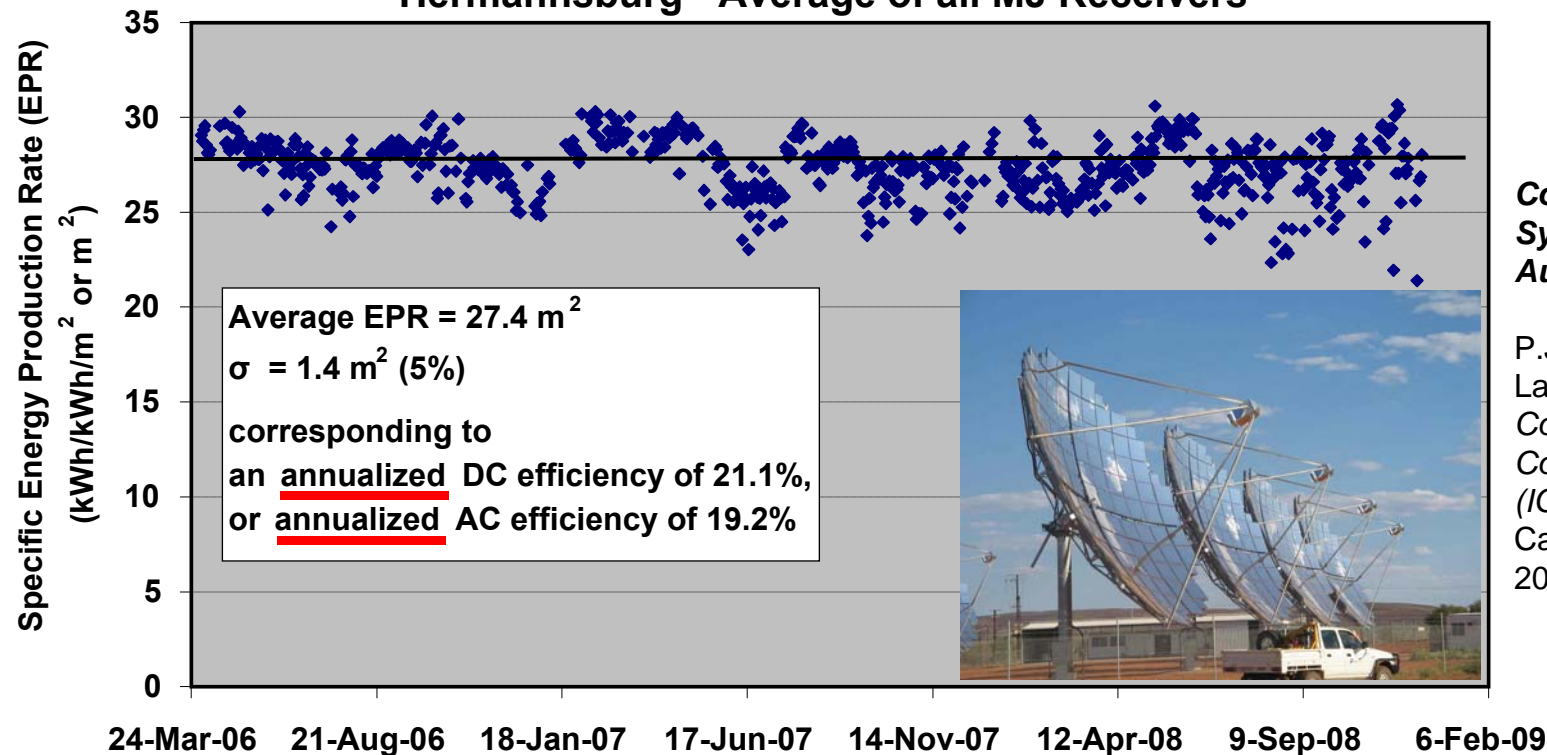
Cell Cost and Efficiency Roadmap



- DOE/Spectrolab jointly funded development in the SAI
- The SAI efficiency targets are ones we have high confidence of being able to meet
- Cost reductions are driven by implementation of automation, upgrade to 150mm wafer line, and growth of production capacity

Field Performance of III-V Multijunction Concentrator Cells

Hermannsburg - Average of all MJ Receivers



Courtesy of Solar
Systems Pty. Ltd.,
Australia

P.J. Verlinden and J.B.
Lasich, *International
Conference for Solar
Concentrators 5
(ICSC-5)*, Palm Desert,
California, November,
2008

$$\text{EPR} = \frac{\text{Energy generated by dish system per day}}{\text{Solar energy incident on one m}^2 \text{ of collector per day}}$$

Reliable performance of Spectrolab solar cells for ~3 years in actual field conditions

Space Reliability Heritage Adds Confidence to Terrestrial Products

Environment	Unit	Space ¹	Terrestrial	
Mission duration	yr	15	25	
Sun hrs per year	hr	8,760	2,700 to 3,400	
Operating Temp	°C	-180 to 70	-20 to 100	
Equivalent life @ 70°C	yr	15	2 to 36 ²	
Thermal cycle				
# of cycles		20,000--80,000	60,000	
Avg Temp Range	°C	-100°C to + 100	0--70	
Substrate CTE	ppm	-2 to 6	5 to 8	
UV radiation	W/m ²		Primary	Cell ³
UVA	W/m ²	85	22	21790
UVB	W/m ²	17.4	0.21	210
UVC	W/m ²	6.9	0	0
Ambient		Indoor air – 5 yr Vacuum - 15 yr	Outdoor air	
Moisture		indoor, controlled	outdoor, uncontrolled	
Current Density	A/cm ²	0.017	6 to 14	

1. GEO mission used for duration & operating temp. LEO orbit used for thermal cycling
2. Calculated from TMY2 data for Phoenix, AZ, Dagget, CA and Pueblo, CO. Assumes cell temp = $T_a + 50^\circ\text{C}$ & cell $E_a = 0.8$ to 1.2
3. 1,000 sun concentration

- Existing qualification testing and space heritage mitigate many CPV reliability risks
- First generation CPV cells have passed qualification
- A qualification/reliability standard is needed to cover products offered by cell suppliers
- Reliability case studies
 - High temperature durability has been demonstrated by qualification test
 - Space qualification test results demonstrate reliability of multijunction cells in terrestrial applications
 - Bare cells degrade under moisture → Good design at cell packaging and system levels will be required to ensure reliability

Existing qualification testing and space heritage address many reliability concerns

Summary

- Spectrolab has a focused, funded plan to drive down the cost and increase efficiency of MJ cells
 - Greatly improving the economics of CPV systems
 - Multiple promising paths for efficiency improvement exist
- Proven reliability in space applications has been extended to CPV through field demonstrations
 - Now >3 years continuous operation

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Thank You!