Terrestrial PV Technology from the Aerospace Industry

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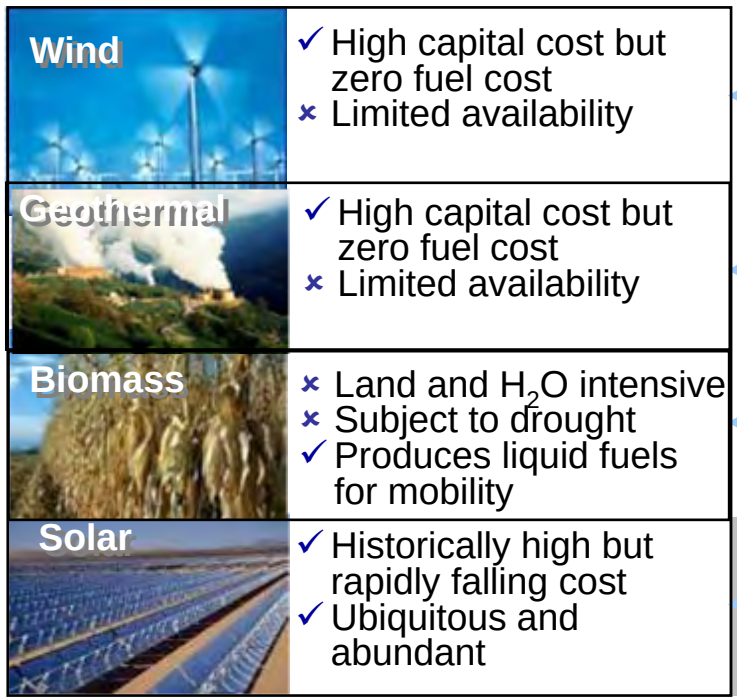
Renewable Energy Solutions are Technology-Driven

Today:
Renewables (other than hydro) are 2% of world electricity generation

Tomorrow:
Technology and market forces will transform renewables from niche to mainstream



Spectrolab has a strong leadership position and history in solar power

Space and Terrestrial Similarities

Space Photovoltaics

- Off-grid at 38,000 km altitude — very high reliability required
- Space customers demand highest efficiency triple junction cells available
- Cells are expensive compared to alternative technologies (i.e., silicon)
- … but are nevertheless the lowest cost option for the system (rather high shipping cost, ~US$20,000 per lb)

Terrestrial Photovoltaics

- Concentrator system customers demand highest efficiency triple junction cells available
- ROI demands very high reliability
- Cells are expensive compared to alternative technologies (i.e., silicon, thin film)
- … but are nevertheless the lowest cost option for the system (leveraging investment in balance of plant)

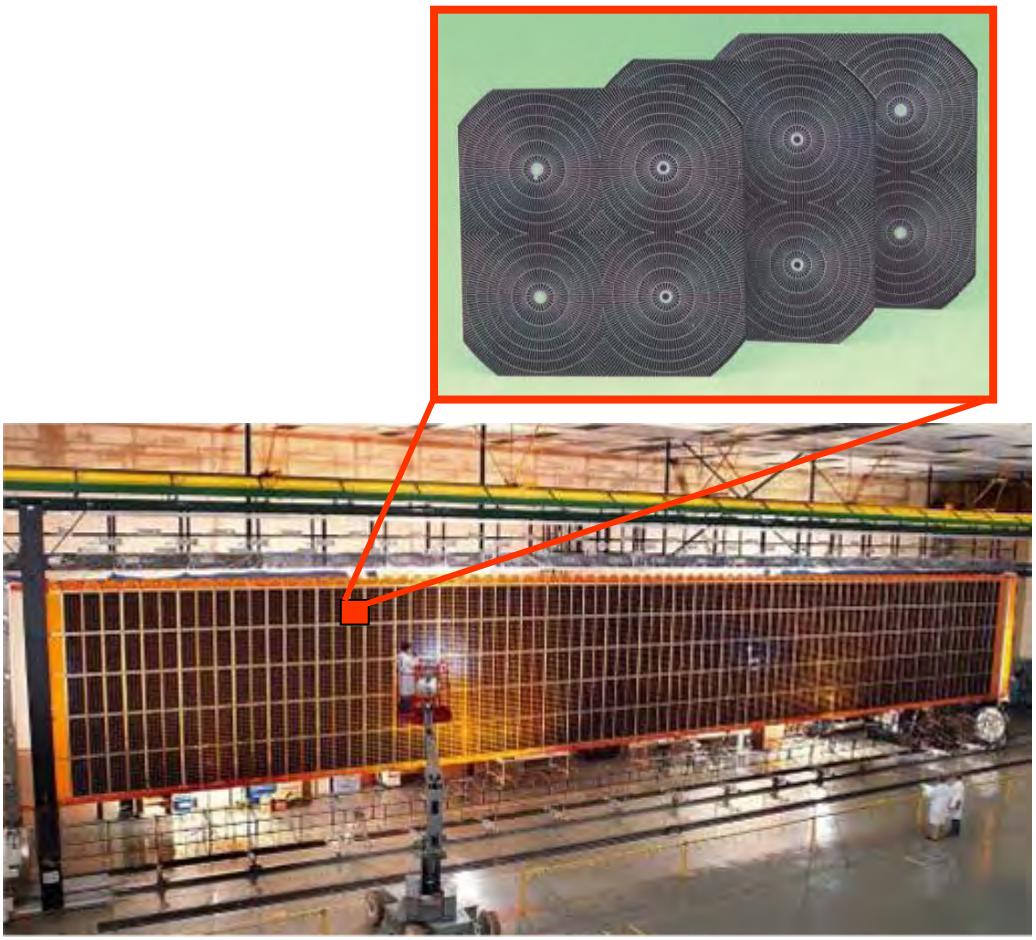
Our goal: be the low cost leader in high efficiency cells, enabling our customers to be low cost leaders in utility-scale solar power

Spectrolab – Then and Now

- 52 Years and Counting
- Parts on more than 500 satellites were/are on orbit
- Built >7,000 SX and NightSun Searchlights
- Pushed state-of-the-art solar cell efficiency from ~11% to over 30%

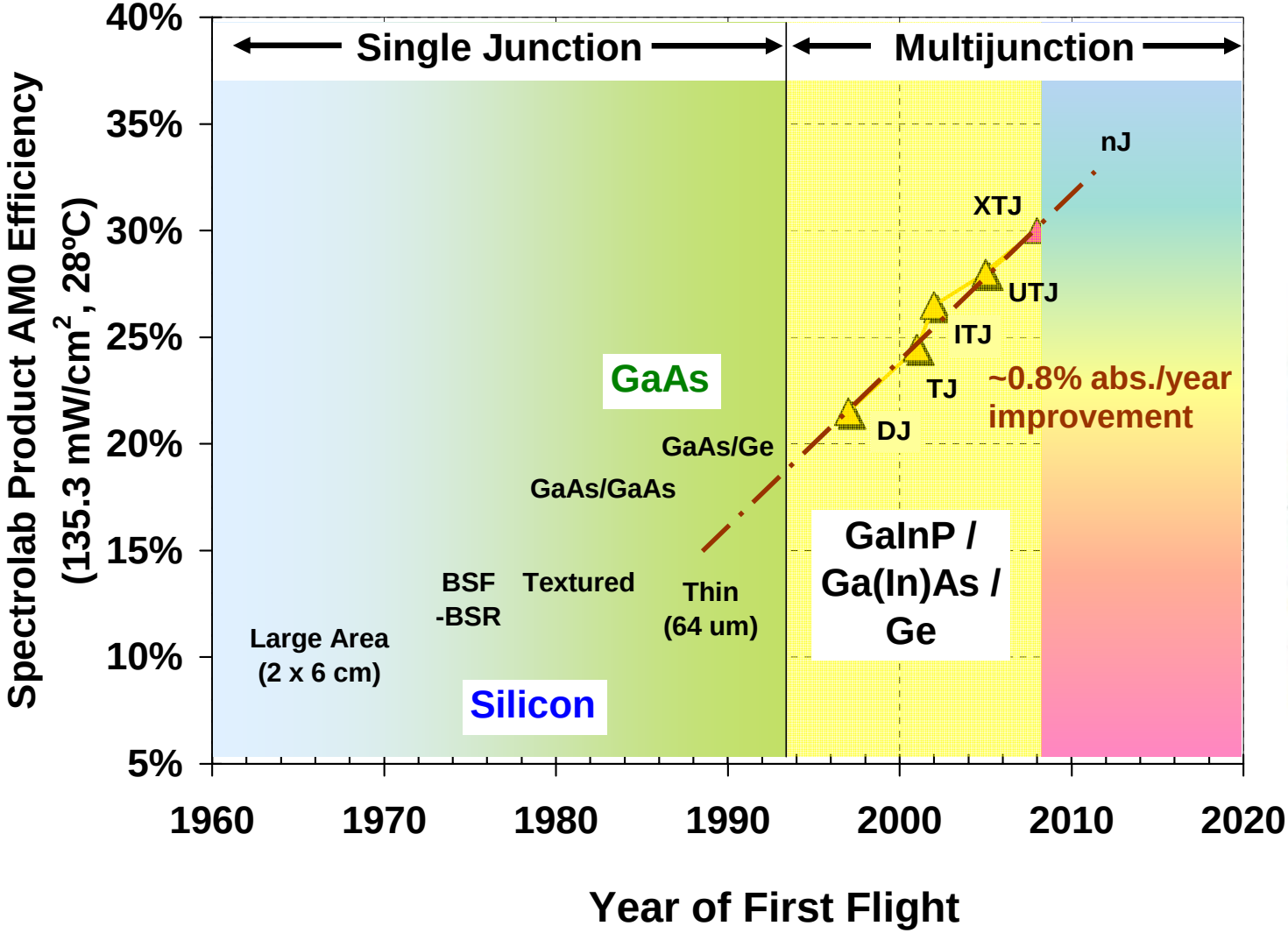
Extensive Silicon History

- 275,000 large area Si cells delivered from 1987 to 1997 (275 kW)
- First panels launched 11/00 (Lockheed Martin)

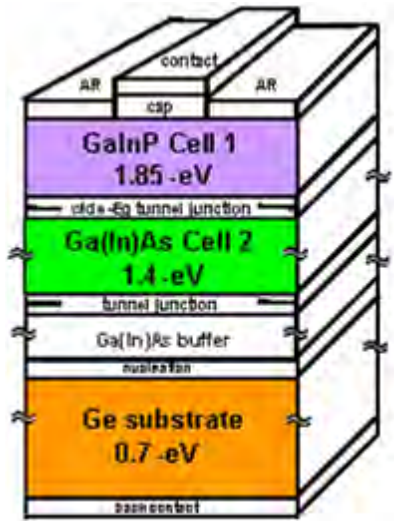


International Space Station

Spectrolab Space PV Leadership



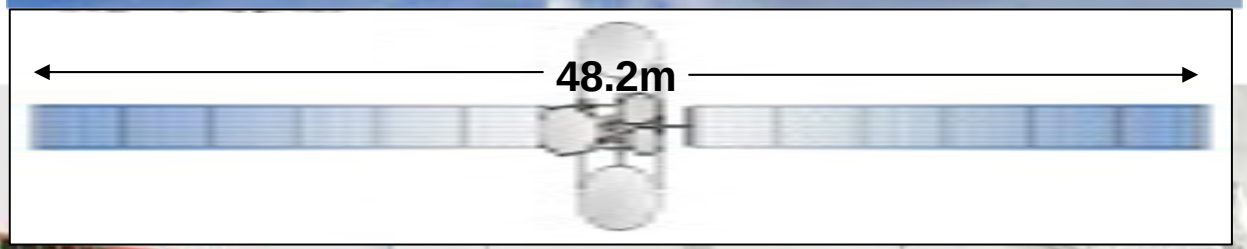
Platform for multijunction solar cells



Space Birds Have Solar Wings

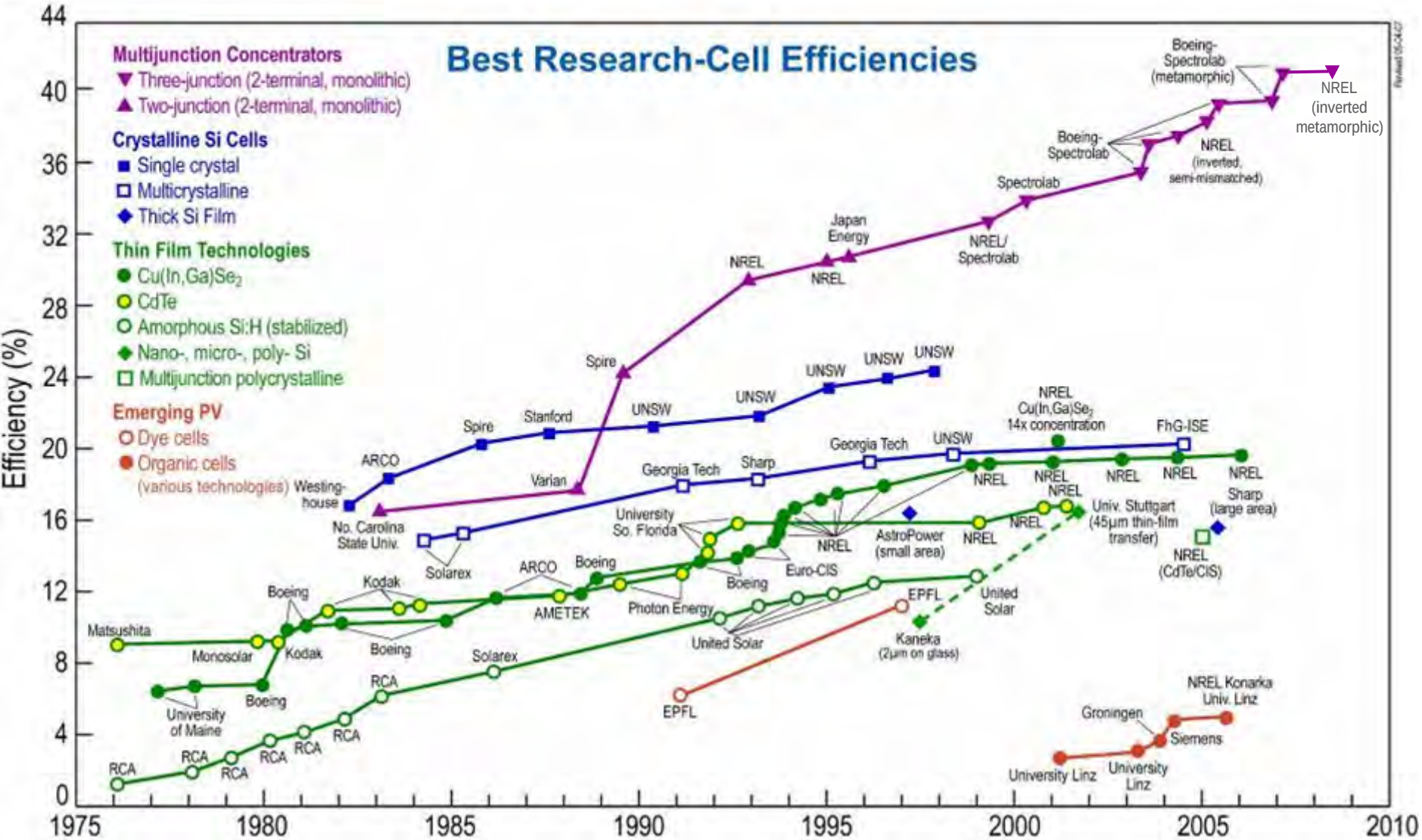
Boeing 787

Boeing 702



- 18 kW at BOL
- 16 kW at EOL (15 years)

Spectrolab Terrestrial Leadership



Why Concentrators?

160 cm^2
2.5 watts (1 sun)

15% efficiency

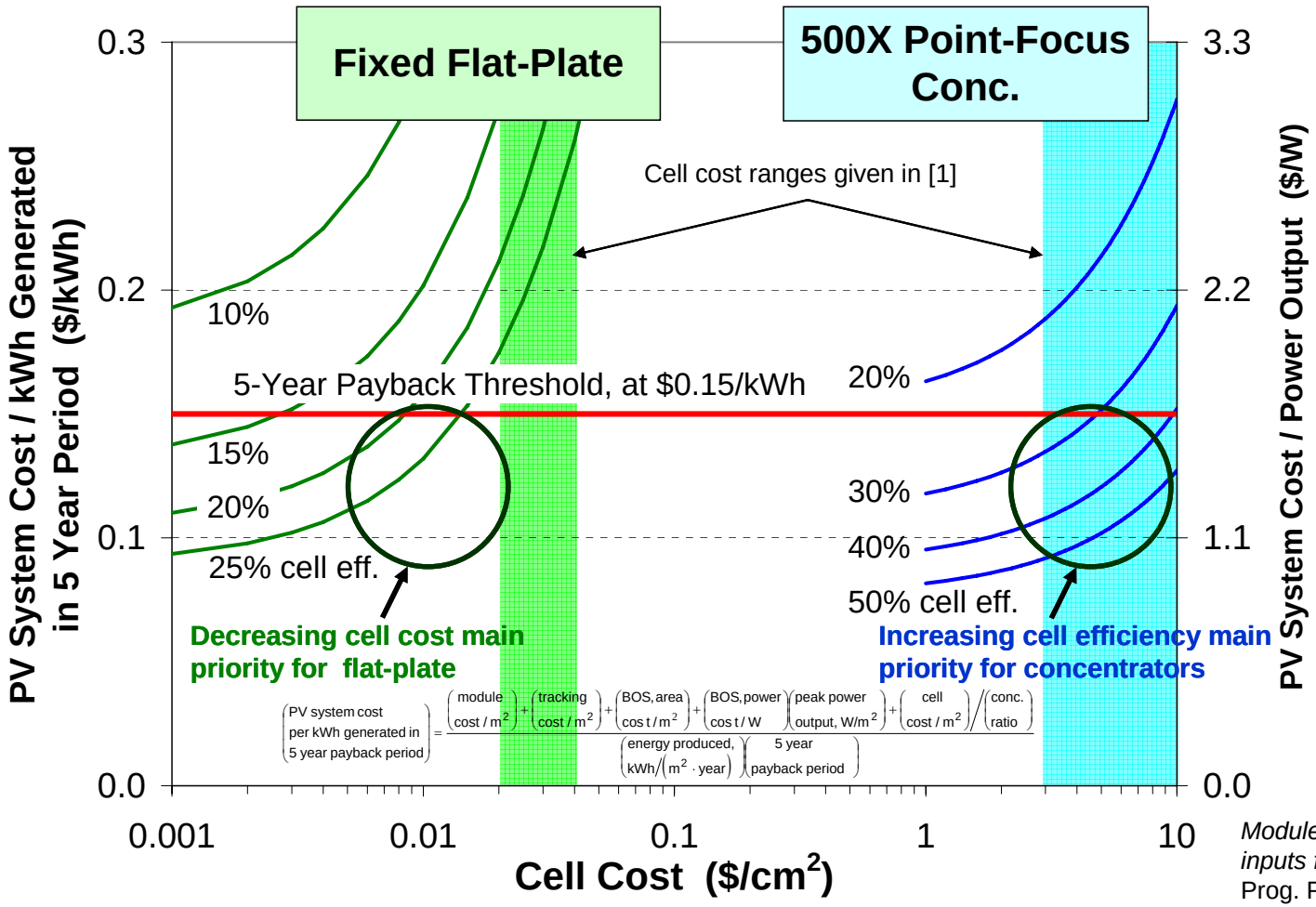
35% efficiency

(45% target)

1 cm^2
15 watts (500 suns)

- World production of silicon solar modules was limited in 2006 due to a shortage of polycrystalline silicon
- Spectrolab 35% efficiency solar cell requires ~1000 times less semiconductor material for the same power output
- Higher efficiency of multijunction cells reduces overall energy generation costs (balance of systems costs are fixed)

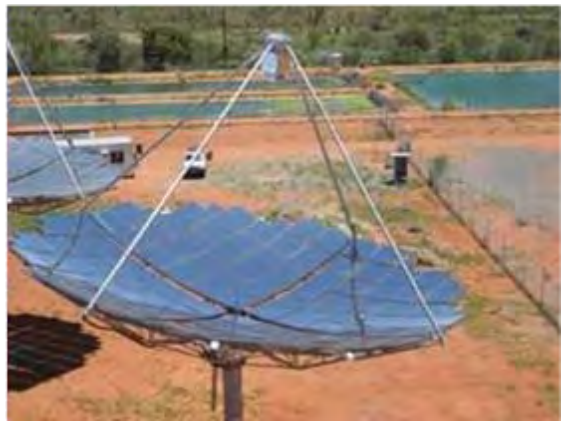
Terrestrial PV System Cost vs. Cell Cost



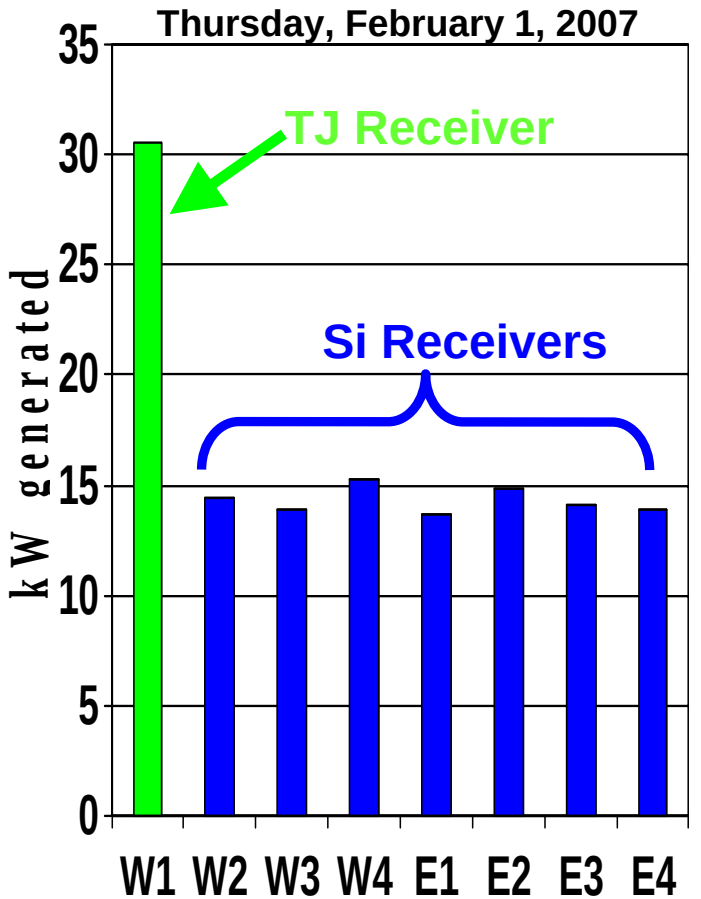
Module and BOS cost inputs from: [1] Swanson, Prog. Photovolt. Res. Appl. *8, 93-111 (2000).*

From: R. R. King et al.,* 3rd Int'l. Conf. on Solar Concentrators (ICSC-3), *Scottsdale, AZ, May 2005

Real Impact of Multi Junction Solar Cells vs. Silicon



Photos courtesy of Solar Systems, Pty.



Solar Cell Efficiency Improvement Strategies

Now in Product Implementation Phase:

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:

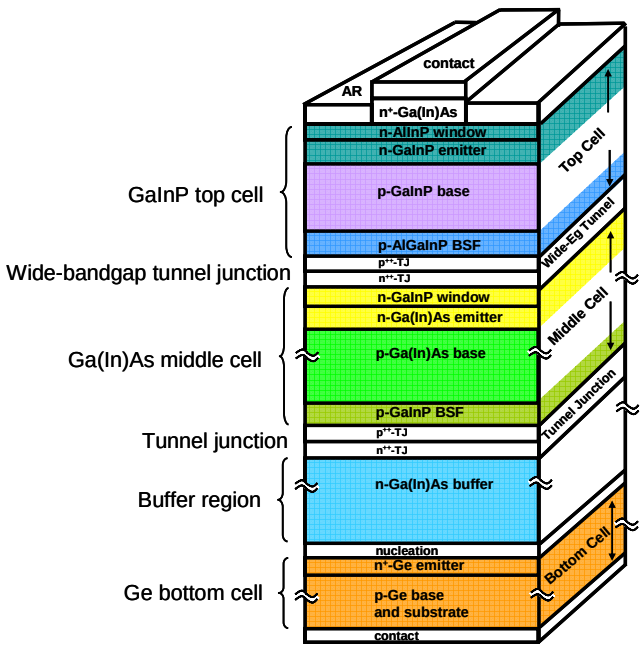
- 3J upright metamorphic (MM) cell
- 4J lattice-matched cell

Long-Term

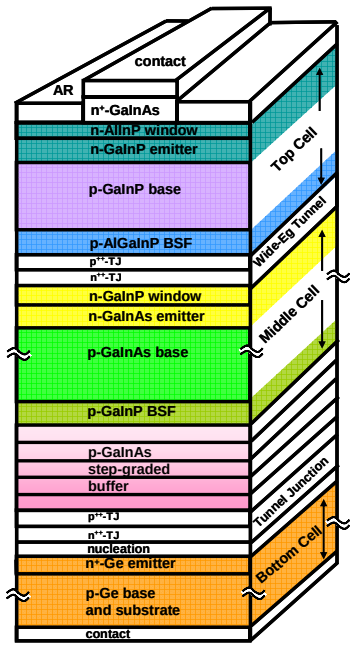
Phase II cell (43%) technology

Revolutionary:

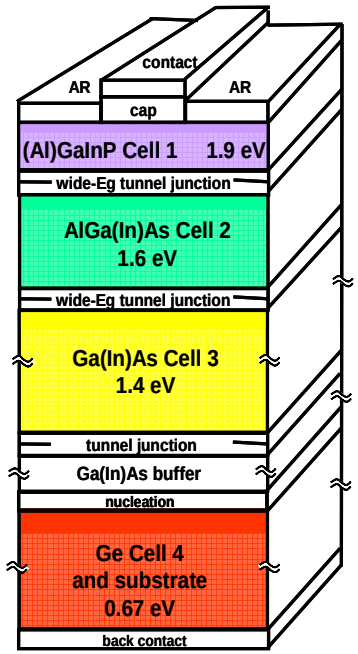
- Inverted metamorphic (IMM) cells
- 5-6J lattice-matched cells
- 4-6J metamorphic cells



Lattice-Matched (LM)



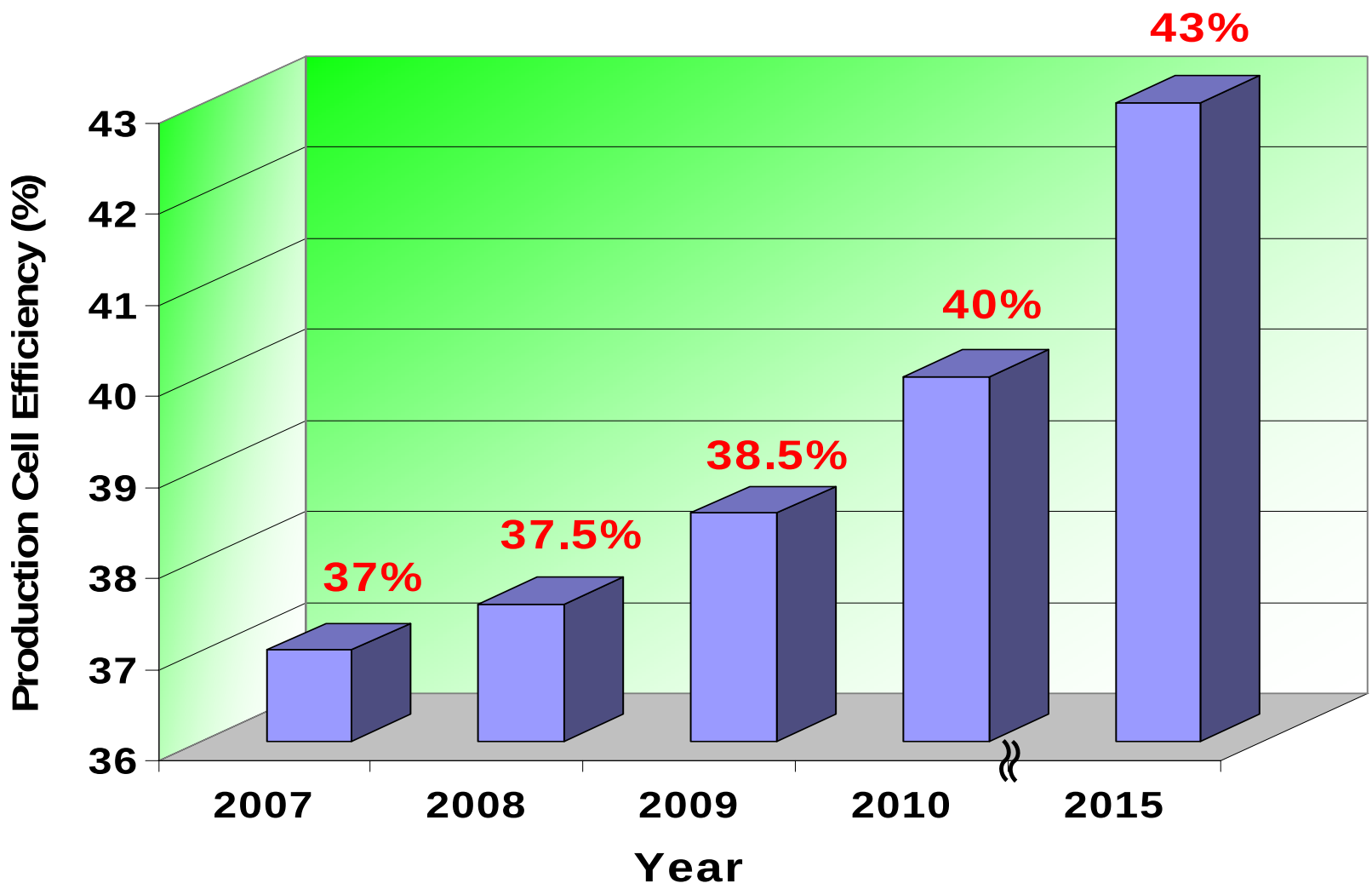
Metamorphic (MM)



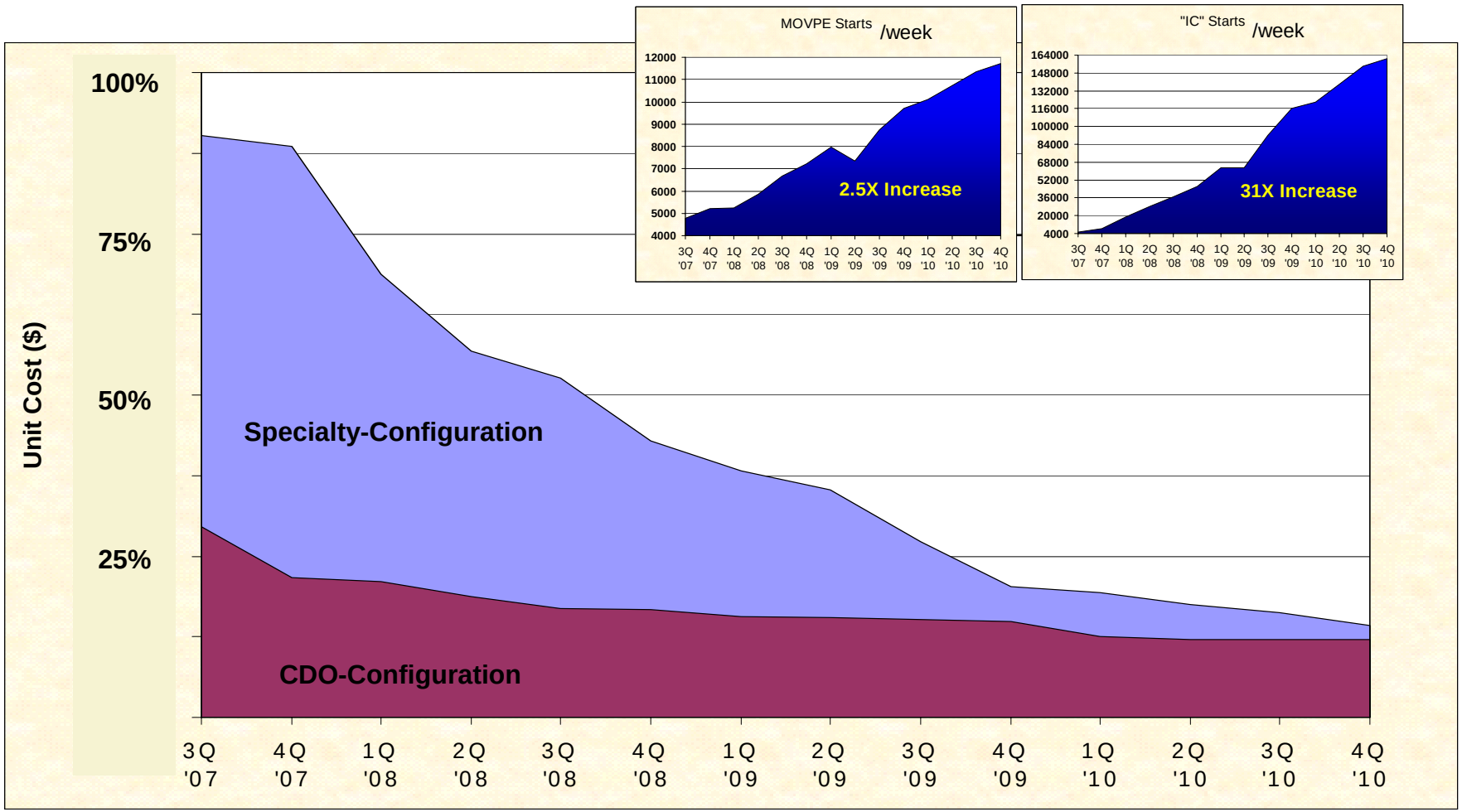
4-Junction

Spectrolab has established multiple approaches to achieve long term efficiency goal

Cell Efficiency Targets

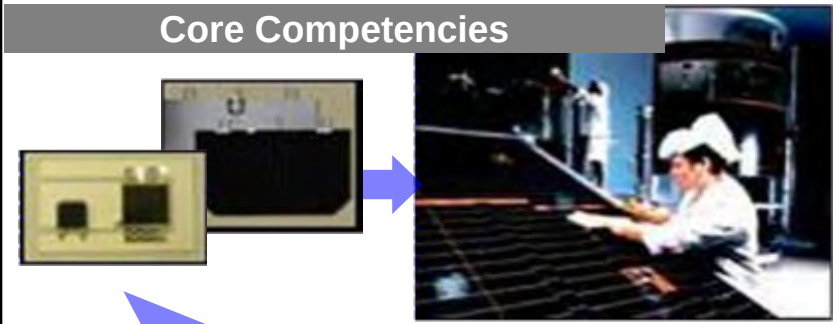


Cell Cost Reduction Targets

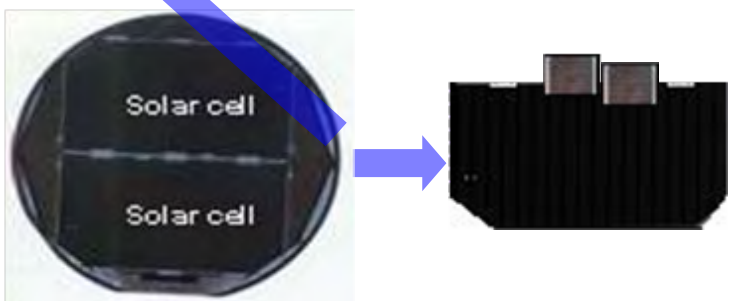


Operations Strategy – Leverage Product and Capability Synergies

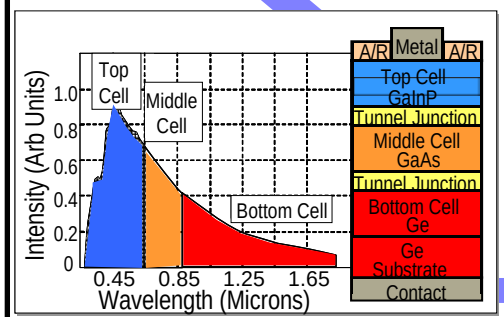
Core Competencies



Assembly Integration (“CICs”/Panels)



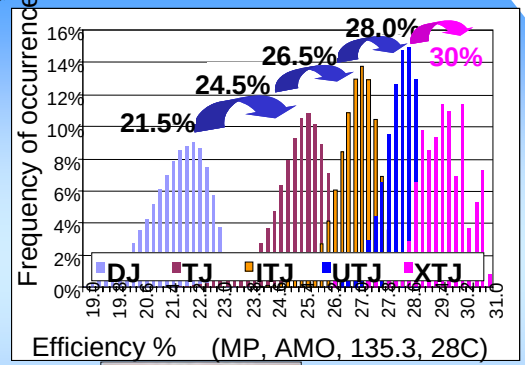
Wafer Processing (Devices/“Chips”)

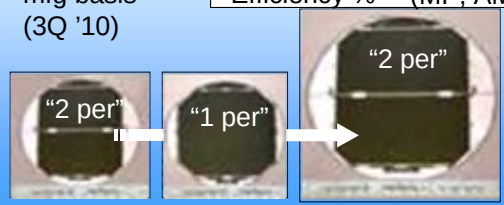


Material Engineering (Wafers)

Space Power

- XTJ (30%) solar cell
- Piece part reduction
  - ➢60cm^2 “Leone” cell (complete)
  - ➢6” Wafer mfg basis (3Q ’10)





Terrestrial Power

- Automation of Chip>IC processing
  - ➢ Chip handling, edge coat, welding, testing
- Labor/material cost reductions
  - ➢ 6” Ge wafer/fab, purchased materials
- Capitalization

Synergy

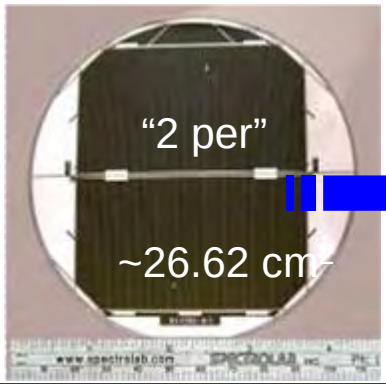
Lean Enterprise Foundation

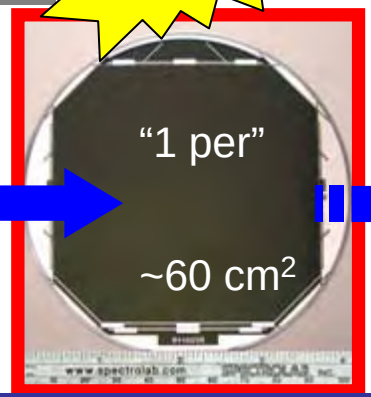
6” Wafer Manufacturing Synergies

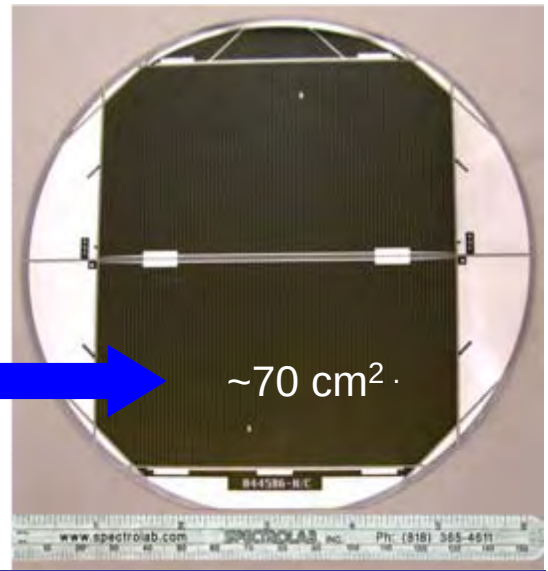
Space

Cost reduction through piece-part reduction (labor savings)

15% Total Cost Reduction





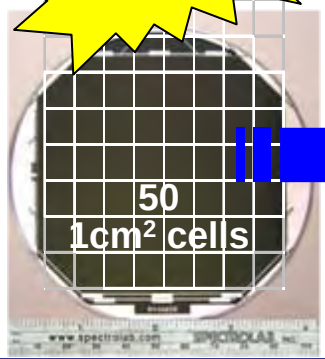


Cells Required for 10P 702	21,500	9,600	8,200

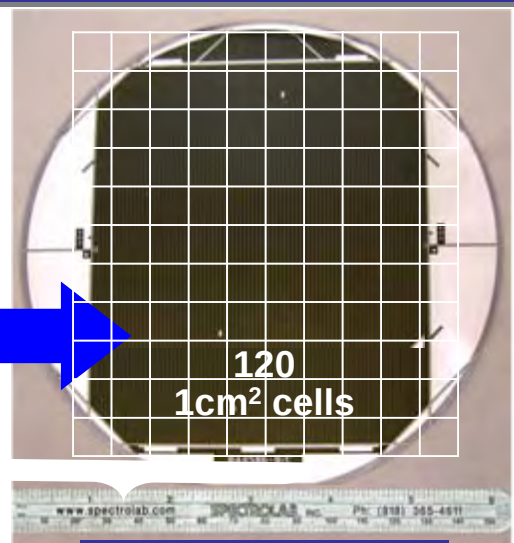
Terrestrial

Cost reduction through piece-part reduction (labor savings) and greater wafer utilization (better packing factor)

15% Total Cost Reduction



1 MW = 1400 wafers



1 MW = 600 wafers

Factory Automation Upgrades

Next Generation MOVPE Reactor

- Optimized for 6" wafer
- Improved source material utilization
- Improved in-situ diagnostics & process control
- ~50% throughput increase from increased wafer capacity and reduced cycle time

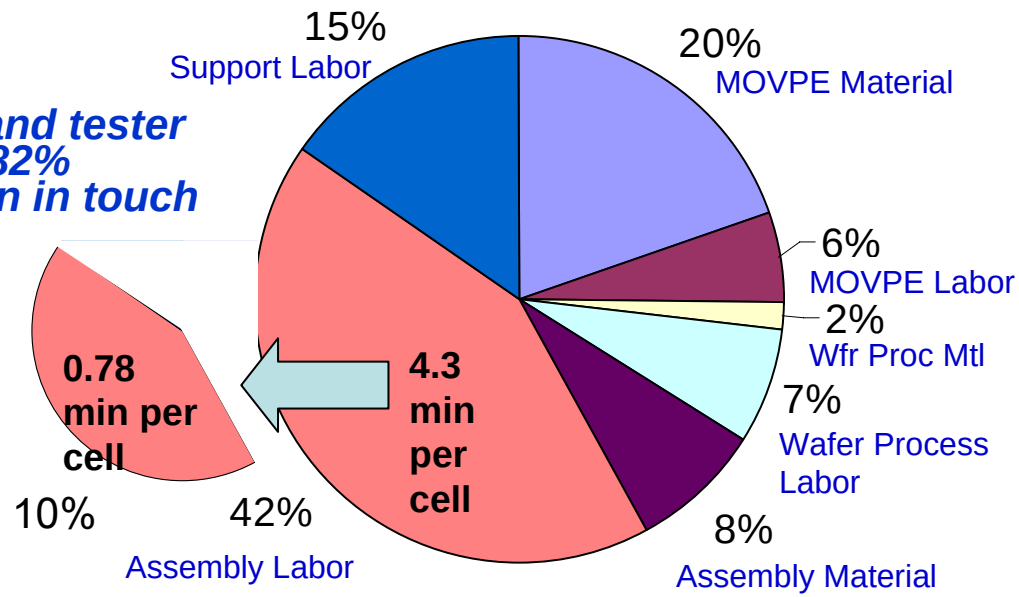
Automated Welder

- Achieved 30 sec cycle time versus a goal of 24 sec for ICDO-100

Automated Cell Tester

- Achieved 14 sec cycle time versus a goal of 12 sec

Welder and tester yielded 82% reduction in touch labor



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°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 demonstrate three results
  - High temperature durability has been demonstrated by qualification test
  - Space qualification test results demonstrate reliability of multijunction cells in terrestrial applications. Testing is planned
  - 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

Spectrolab's Cells under Sun

Amonix
Since October 2000

APS – CTEK
Since May 2004

Solar Systems
since February 2006

SolFocus
Since February 2007

Energy Innovations
Since May 2007

Boeing Phantom Works
Since August 2007

OPEL, Inc.
Since February 2008

SolFocus Gen 1.1
Since June 2008

Concentrix
(w/SPL EPI Partner Azur)

- **Spectrolab terrestrial product applications are multiplying and maturing**
- **Growing field experience, space reliability heritage, and rigorous in-house qualification for terrestrial use are establishing the cost-effectiveness of the technology**