

Addressing Space Power Demands with XTE Plus Technologies and Sitewide Manufacturing Advancements

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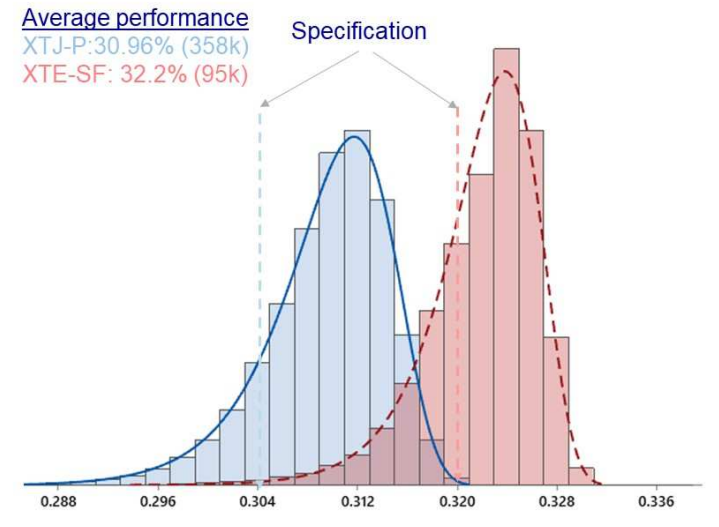
Space Power Workshop, April 23rd - 25th 2024: Energy Generation I

Outline

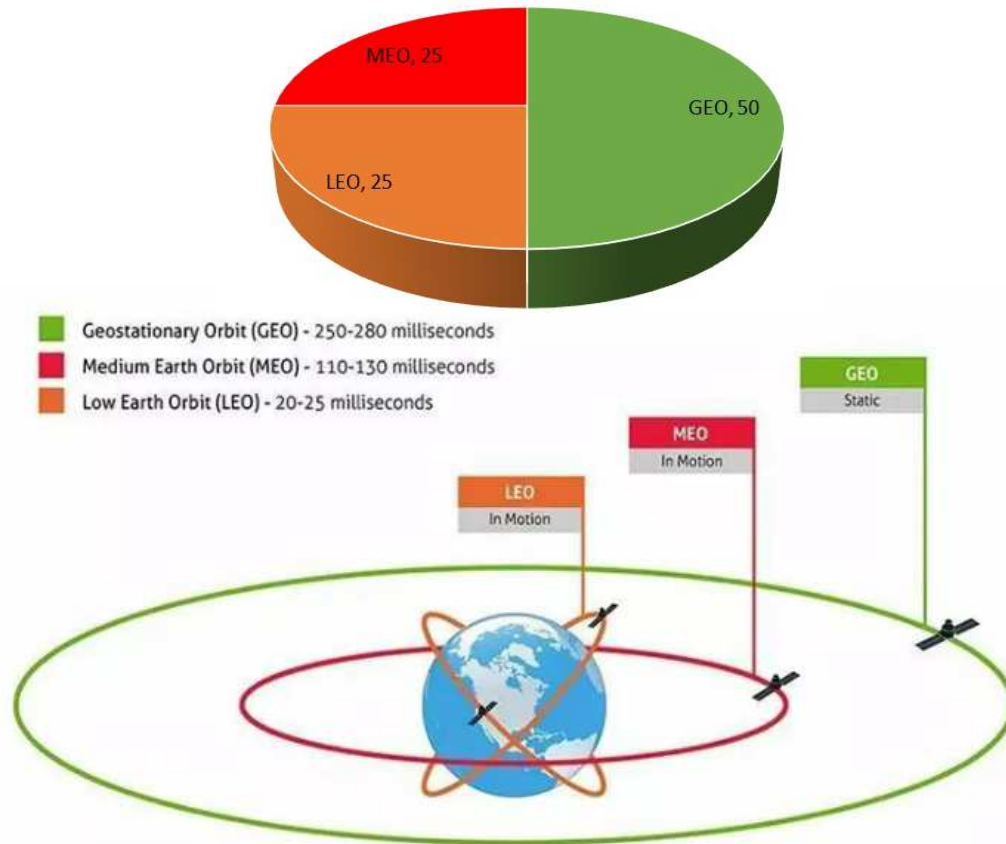
- **Spectrolab Introduction**
- **Market/Product Challenges faced by Spectrolab**
 1. Diversification of missions by orbit
 2. Increase in demand at Bare and CIC
 3. Reduction of Panel repetition
- **Challenge 1 Response: 33% XTE Plus Product**
 - XTE Plus LEO/GEO
- **Challenge 2 Response: Spectrolab Investments in Automation**
- **Challenge 3 Response: Panel Process Improvements**
- **Conclusions**

Spectrolab Overview

- Spectrolab, Inc. : founded 1956, Sylmar, CA
- ~270 employees; 180,000 ft² on 6 acres
- Historical leader in US space solar cell technology and manufacturing
- Product offerings span from bare cell to panel array
- Industry leading 3J cells with performance reaching >32%
- Performance of cells persistently delivered above specification



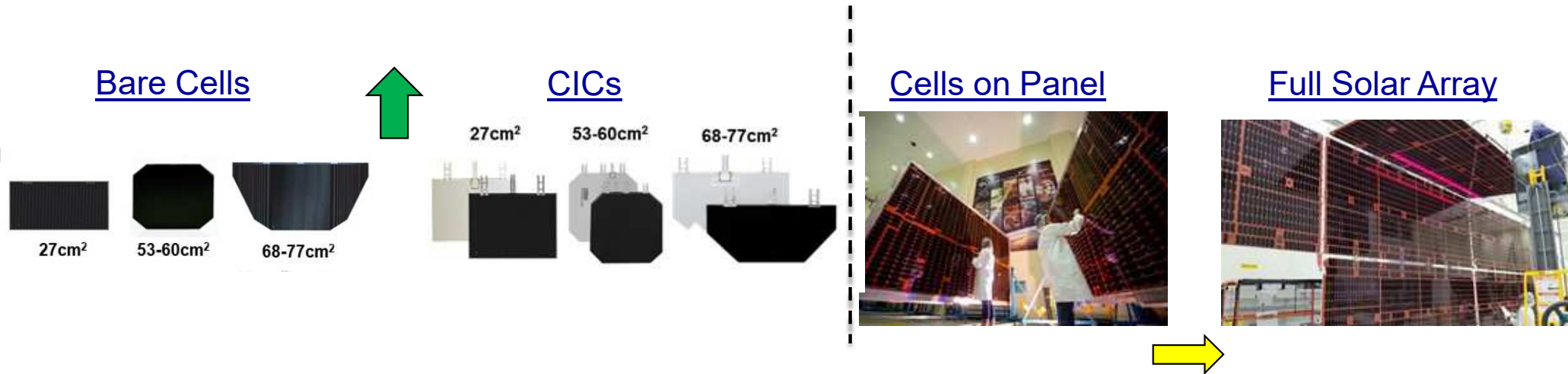
Challenge 1: Orbit Diversity



- For the past 10 years, Spectrolab business has evolved away from only GEO stationary satellites to other missions
- 5 year average business split by orbit is ~ 25/25/50% to LEO/MEO/GEO respectively
- Design for cells must be able account for fluences differences from $1e13$ (LEO) to $1e15$ (GEO) to $1e16$ (MEO), 1 MeV e-/cm^2 equivalent.

XTE Plus with multiple variants addresses orbit diversity challenge

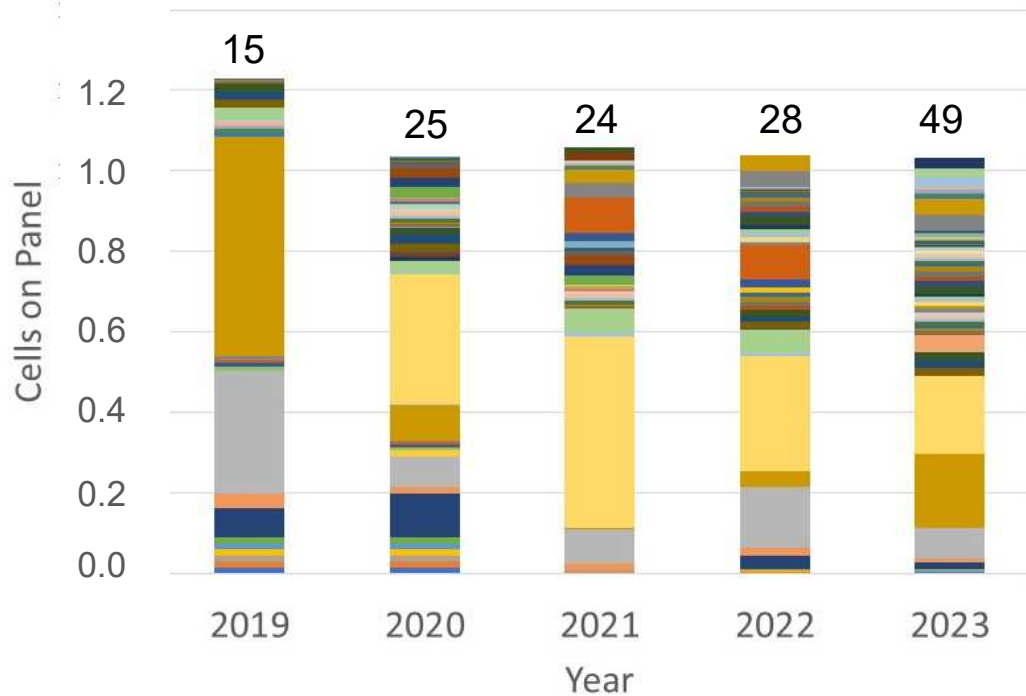
Challenge 2: Increasing Bare Cell / CIC Demand



- Spectrolab sells products at 4 levels of indenture: Bare Cell, CIC, Panel, Array
- Past 2 years have seen a significant increase in demand at Bare Cell and CIC levels of indenture
- CIC and Bare Cell demand levels exceed 2022 levels of capacity

Targeted efforts to increase throughput in Bare Cell and CIC lines by 25%

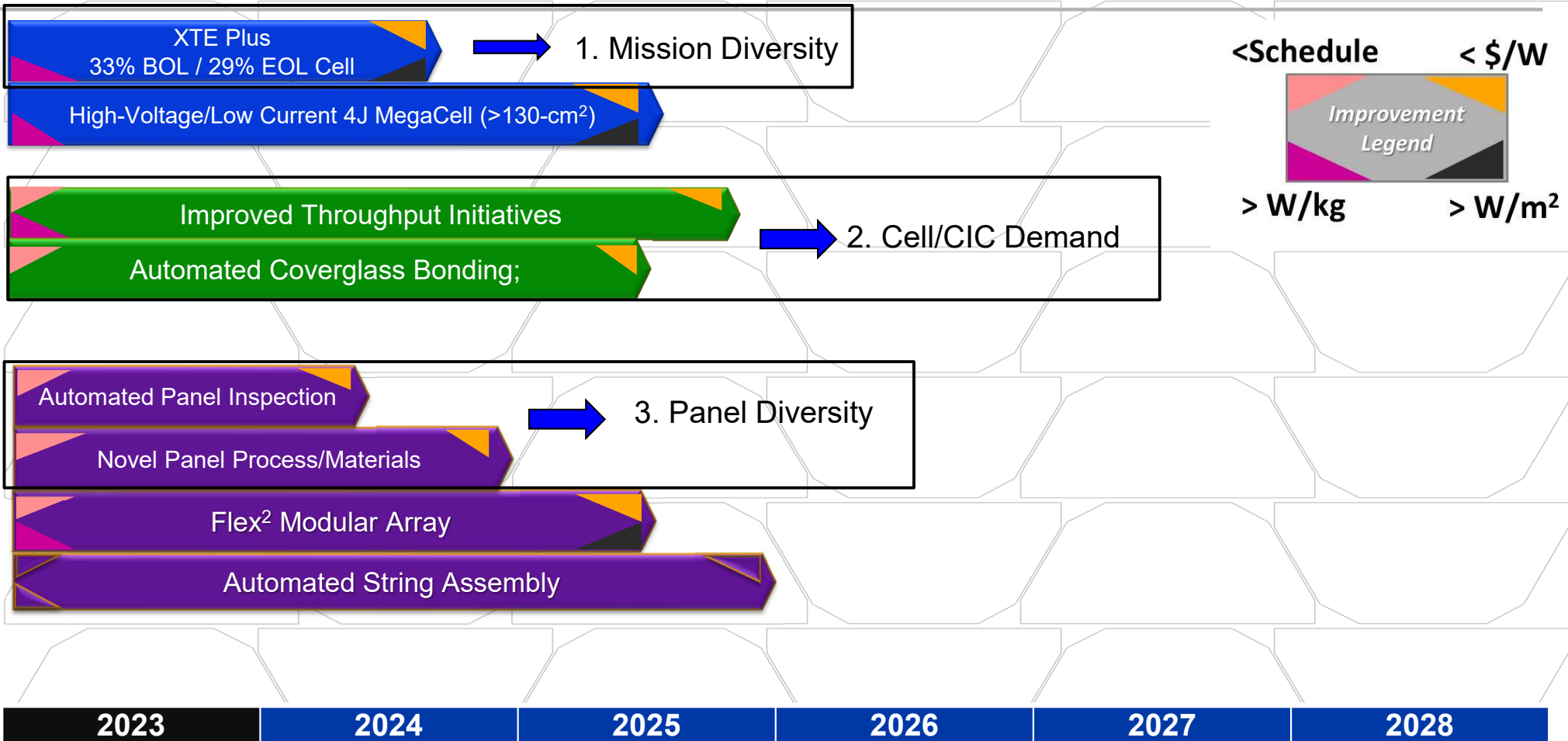
Challenge 3: Increasing Panel Diversity



- Each color is unique Panel Part Number (PN). Size of the bar is numbers cells for that Panel PN
- Numbers above the bar are the number Panel PN with <1000 cells
- 2019 dominated by 2 Panel PNs (>70%)
- Total number of small Panel PNs increasing rapidly
- Recent large repeat business observed in small solar panel modules
- Challenging to manage NRE and manufacturing costs for diverse set of **small, non-repetitive** panels

Need for a consolidation to novel panel process and materials

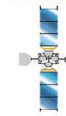
Product & Technology Roadmap



1. XTE Plus Variants

Both variants are currently undergoing
delta AIAA S111 qualification: ETC 4Q2024

GEO: 15 year expectation
27.6% EOL XTE Plus GEO; -3% \$/W from XTE-SF



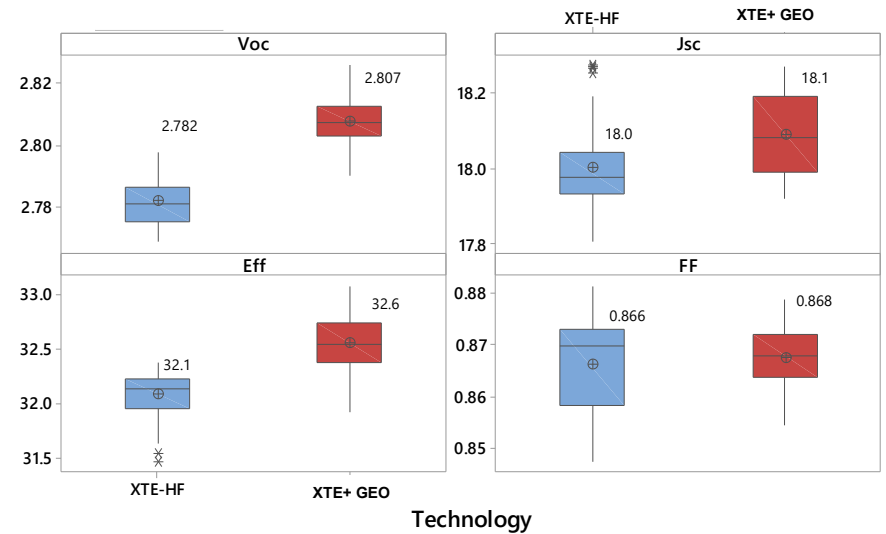
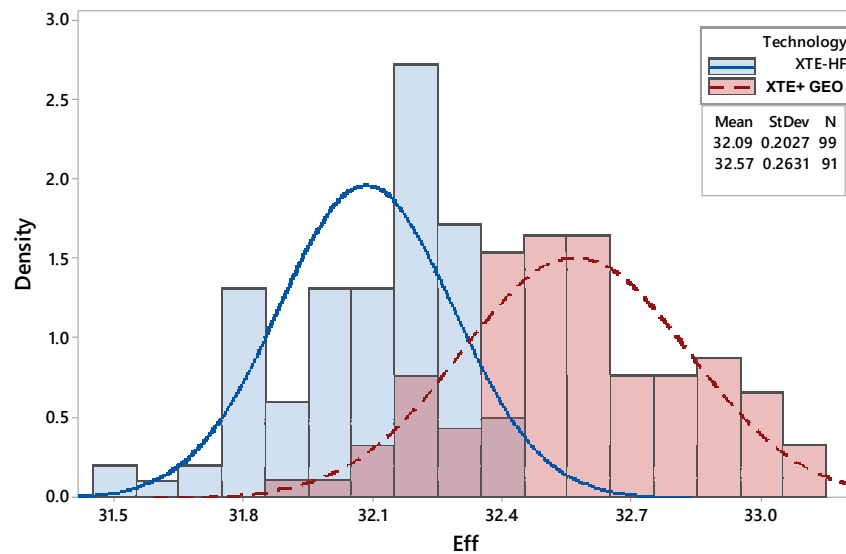
MEO: 7 year expectation
Optimized EOL efficiency in high p+
24% EOL XTE Plus GEO; -3% from XTE-SF



LEO/Constellation: 0 to 5 year expectation
Optimized for high BOL efficiency
32.5% BOL: XTE Plus LEO; -5% \$/W from XTE-SF

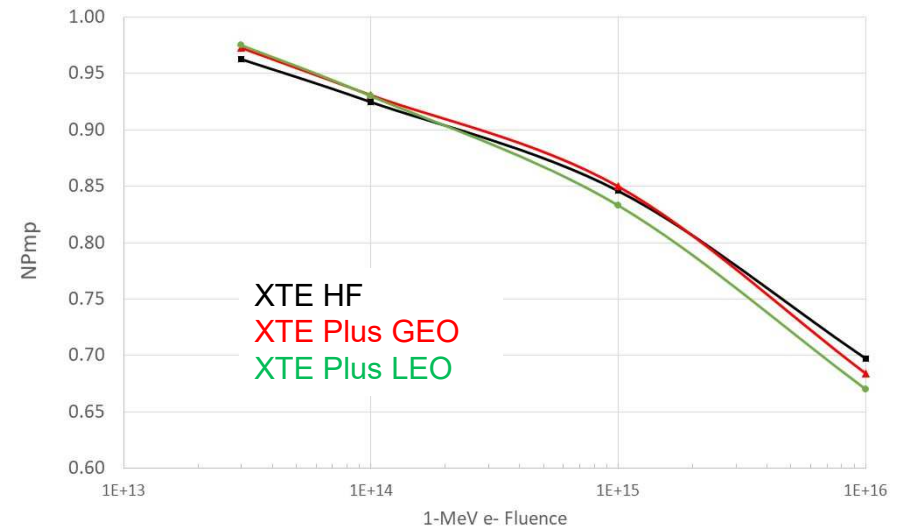
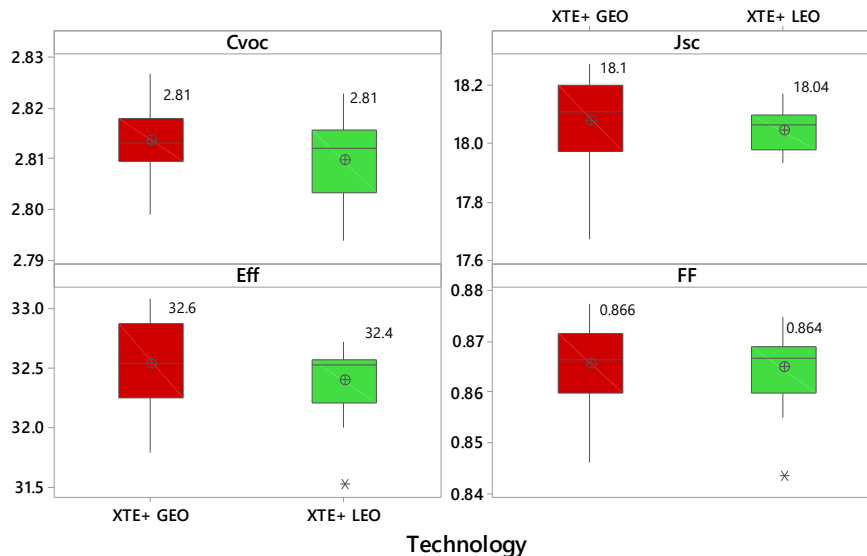


1. XTE Plus GEO Performance



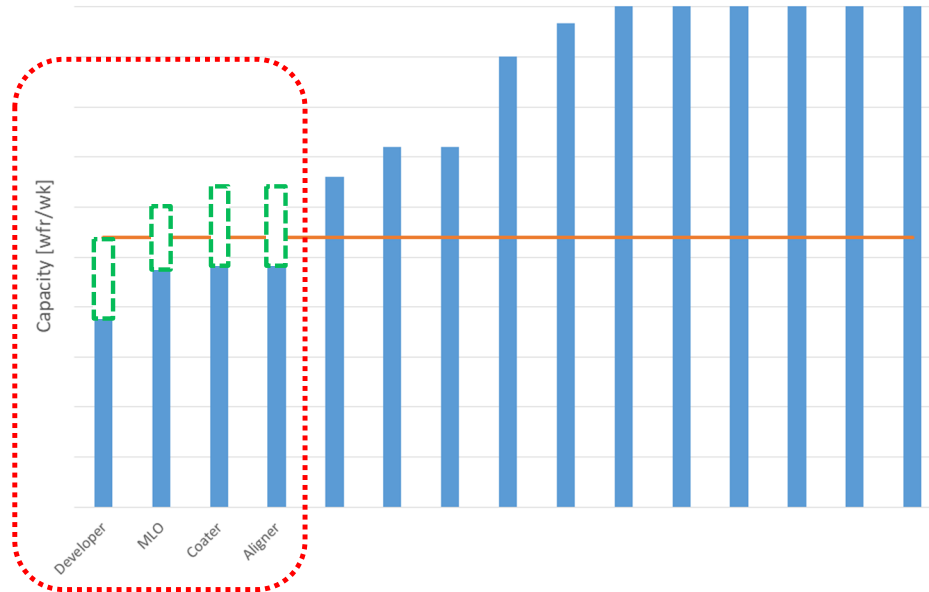
- Histogram compares 27.22 XTE Plus IDR batches to XTE-HF qual cells
- Clear 1.5% relative increase in efficiency observed in histogram from ~32.1 to 32.6%
- Increase in efficiency due primarily to a 0.9% increase in V_{OC} and 0.5% increase in J_{SC}

1. XTE Plus LEO Performance



- Boxplots comparing BOL efficiency of XTE Plus GEO (red) and XTE Plus LEO variants (green)
- Very minor differences BOL performance due to small differences in J_{SC} only
- Larger difference in EOL retention between the two products at fluences >1e15

2. Bare Cell Throughput Initiatives



Installed Photolithography Tool

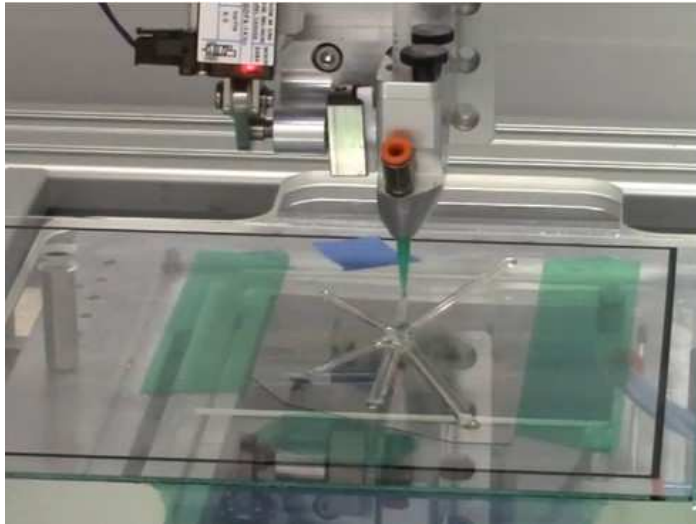


- Before 2023, major throughput limitations of bare cell are: (1) photolithography & (2) metal liftoff
- Focus on process optimization has increased metal liftoff process (MLO) by 25%
- Completed purchase and installation of additional set of photolithography tools to increase throughput of photo steps by 33%

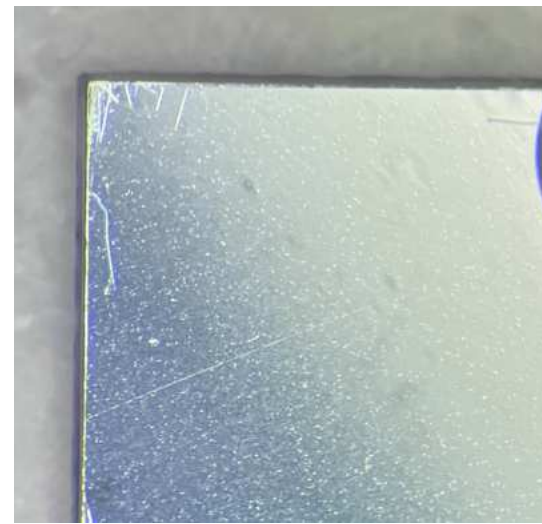
Focus on photolithography and MLO steps increased bare cell throughput by 33%

2. CIC Throughput / Cost Initiatives

Automated CG bonding Tool



Resultant CG Alignment



- Completed thorough engineering confidence tests for automated coverglass bonding tools
- Expect 25% increase in throughput, 2x reduction in attrition, 2x reduction in labor in coverglass bonding step
- Secured Capital for equipment purchase

3. Automated Inspection of Panels

String Inspection System



Small Module Inspection

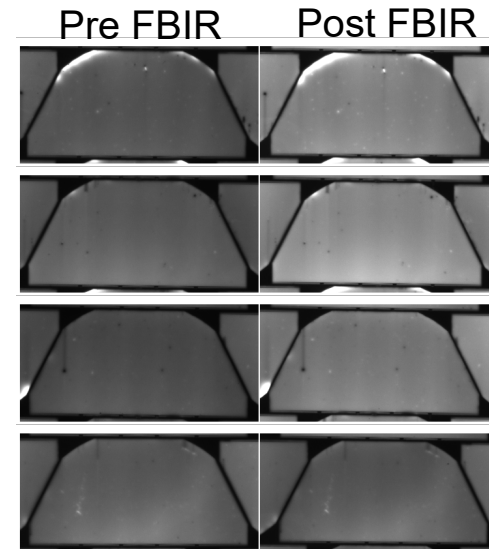
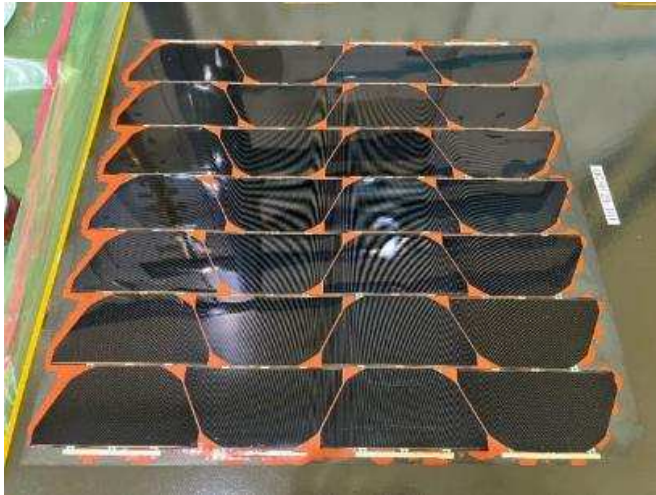


- Automated inspection for crack defects in all circuits prior to panel bonding
- Computer algorithm recognize crack defects with >99% accuracy from forward-bias infrared images
- Similar design and software utilized in automated crack inspection tool of small modules (up to 5'x5')



3. New Panel Materials / Processes

Engineering Confidence Coupon



- Change process and materials to significantly reduce cost and cycle time associated with frontside and backside bonding steps
- 500 cycles (-150 to 180°C) engineering confidence test completed with no issues with observed
- New process to be included as part of the XTE Plus qualification coupons

Moving to consolidate most customers to improved panel process

Summary and Acknowledgements

- Two variants of XTE Plus cells to address multi-orbit market demands:
 - GEO / MEO orbits: XTE Plus GEO
 - LEO / Constellations applications: XTE Plus LEO
- Both XTE Plus variants currently in AIAA S111 qualification
- Variety of capital equipment acquisitions to increase throughput in the front-end-of-the-factory to meet bare cell and CIC demand
- Improvements in panel process and inspection automation to mitigate increase in panel variety



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