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Comments on Research Needs for Thin-film PV Technologies

Additional submitted attachment is included below.

Comments to CEC Staff on Research Needs for Thin-film Photovoltaic Technologies

Chris Eberspacher
Managing Director, Tandem PV, Inc.
ceberspacher@tandempv.com

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Background : I have worked in the photovoltaics industry, mostly in California, mostly in technology development, for the past 35 years, spanning from the early 1980s when ARCO Solar in southern California was the world's largest PV cell and module manufacturer to today when California is home to several world-leading PV companies that mostly do their manufacturing elsewhere, e.g. in Asia. Throughout this period California has been a global leader in PV technology development that has yielded - directly or indirectly, through products manufactured here or elsewhere - significant economic and quality of life benefits to the residents of California. Proper targeting of CREATE Solar program monies can play a critical role in continuing / furthering this history of high return on California's solar R&D investment.

Prioritizing Outcomes : DOE's Solar Energy Technologies Office (SETO) through its SunShot initiative lays out impactful outcomes – e.g. 3 ¢/kWh LCOE utility electricity in average US climate – without over-defining preferred pathways to achieving those outcomes and then does quantitative analyses of various options, e.g. Tinker's "There are Many Technology Pathways" slide at the scoping workshop. These analyses indicate that SunShot 2030 PV goals require PV module performance – e.g. > 25% module efficiency, < 25 ¢/W module price, > 30 year module life - very possibly beyond what single-junction PV technology could ever deliver. Single-junction silicon and conventional thin films are unlikely to deliver the needed module efficiency; III-Vs are unlikely to achieve the needed module cost; organic/polymers are unlikely to have the needed module durability. If one prioritizes the ultimate outcome and is unwilling to settle at the outset for less than that outcome, then SunShot analyses indicate that single-junction PV is very likely not up to the task.

Focusing on Promising Pathways : Multi-junction PV is a much more promising pathway to achieving aggressive targeted outcomes, including for example the cost and scale needed for California's 100% by 2045 goals. III-V multi-junctions dominate spacecraft power applications but are unlikely to achieve cost goals, especially in built-environment applications, e.g. rooftops. The most promising multi-junction PV technologies incorporate thin-film wide-bandgap perovskite materials in concert with narrow-bandgap materials, e.g. crystalline silicon, thin-film CIGS, etc. Multi-junction PV comprising perovskite top cells and silicon bottom cells leverages – rather than competes with – incumbent Si PV manufacturing to deliver high-efficiency – e.g. > 30% - and low cost – e.g. < $/W of single-junction Si PV. California is a hot bed of perovskite PV innovation and research, and California-based research groups and companies are well connected with global perovskite PV technology centers, e.g. NREL, ASU, UW, EPFL, etc. Perovskite / Si tandem cells have achieved record efficiencies above those of Si and have considerable additional upside potential.

The two main challenges for perovskite-based tandems are: 1) processes and tools needed to scale high-quality perovskites to module areas – e.g. from few mm^2 research cells to several m^2 module products, and 2) demonstrating cell stability and module durability required by the commercial marketplace. The first challenge is an under-explored aspect of perovskite PV technology; California has the opportunity to lead in this area. The second challenge is clearly evident in the research literature on quick degradation of early-generation perovskite cells, but the more recent literature – e.g. by ASU & Stanford – evidences significant improvement through attention to perovskite composition and microstructure, to perovskite cell architecture and materials selection, and to module design. A particularly promising module design is mechanically-stacked four-terminal structures that combine a superstrate perovskite submodule and a standard silicon PV circuit in a commercial glass/glass module format; this design strongly leverages the unique advantages of perovskites and the economies of scale of Si PV. R&D programs aimed at perovskite cell efficiency and stability, at perovskite processing at module sizes and production speeds, and at multi-junction module designs optimized for specific PV system applications – e.g. commercial / industrial rooftops versus ground-mount utility arrays - are promising pathways for the CREATE Solar program to provide myriad benefits to California.

Coalescing R&D Infrastructure : California has a long history of global competitiveness, entrepreneurial innovation, and enterprise formation and growth. These strengths are evident in high-margin new industries, e.g. social media, AI, EVs, etc. These strengths were evident in the PV industry of the 2000s but are difficult to replicate in the current private capital investment environment. Looking forward, the PV industry – in particular the technology innovation sector of the PV industry – needs a new more-collaborative paradigm to assemble the resources and infrastructure needed for success. The CREATE Solar program should consider collaborative / shared-infrastructure projects that could provide multiple competing PV ventures the resources to develop and evolve competing technologies and/or product visions using shared capital-intensive infrastructure, e.g. processing tools, characterization labs, prototype product assembly/test labs, etc.