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Solar Energy Technologies Program

National Solar Technology Roadmap:

Concentrator PV

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National Solar Technology Roadmap: Concentrator PV

Scope

This roadmap addresses high-concentration (>10x) photovoltaic (PV) systems, incorporating high-efficiency III-V or silicon cells, trackers, and reflective or refractive optics.

Technology development stage: Prototype testing.

Target applications: Because of the need for tracking, concentrator PV systems have traditionally been multiple kW, with some systems >30 kW. Key target applications are commercial (including ground-mount and rooftop) and utility; however, systems suitable for residential use are now entering the market, as well.

Background

Concentrating PV (CPV) has been predicted to have lower costs than other approaches once large-volume production is reached. The recent accomplishment of >40% cell efficiencies, together with the strong industry growth, has inspired substantial venture capital investment in CPV in recent years. Prototypes are being tested in preparation for large-scale deployment. The *concentrator hardware* development leverages work done for silicon CPV and concentrating thermal technologies. The *solar cell* development leverages technology from the existing space-cell manufacturing base. Key differences from flat-plate PV include the potential for lower levelized cost of electricity (LCOE). But challenges include additional complexity, a much smaller market presence, and a very limited history of reliability/field-test data. The steps needed to overcome these challenges to realize the LCOE potential are discussed in the roadmap overview.

Roadmap Overview

Estimates by Arizona Public Service have projected high-concentration CPV to overtake tracked flat-plate PV as the most cost-effective PV for commercial/utility-scale applications, with costs coming down to 6¢/kWh as economies of scale take effect and advanced high-efficiency cells are incorporated into the technology. However, to date, the total installed CPV capacity is <1 MW in the United States and a few MW worldwide—virtually all using silicon cells. Thus, the fundamental challenge of CPV is to lower cost, increase efficiency, and demonstrate reliability to overcome the barriers to entry into the market at a large scale. These challenges must all be addressed at the system level.

System-Level Design: The receiver, optics, and tracking must be engineered to work together. Systems need to be designed for manufacturability, as well as cost, with attention given to tolerance chains, automation, scalability, and assembly.

Reliability: Reliability factors specific to CPV include the high-flux, high-current, high-temperature operating environment encountered by the cells; weathering and other degradation of the optical elements; the bonding of concentrating optics to the solar cell; and the operation of the mechanical parts of the trackers. For the cells, further understanding is needed of failure modes and the relevant acceleration factors for accelerated testing; encapsulation; and interconnection. Relatively little data are available to date on long-term cell reliability under concentration, especially for III-V cells, and this will require special attention. The knowledge base from the light-emitting-diode industry may provide useful guidance on III-V cell reliability and packaging. For the reliability of other parts of the system, existing silicon-cell-based systems will be a good platform for reliability testing/field experience.

Cost: The cell cost is a substantial fraction of the total system cost—a reasonable estimate for a 500x system would be 30%–50%%--and so, it is one important target for cost reduction. A variety of approaches to this are available, especially for the III-Vs. These include reduction of epitaxy costs via mechanisms including developing improved growth methods and growth precursors; reduction of substrate costs via recycling and reuse; increased use of automation in processing and testing, combined with transition to a larger substrate diameter; improved yield; and increased solar concentration. Approaches to lowering the cost of trackers include system design for reducing required tracking accuracy, as well as refined mechanical engineering of the tracker. The optics costs involve developing techniques for inexpensive, robust fabrication of what may in some designs be sophisticated optical surfaces.

Efficiency: Improved efficiency is a direct way to lower the cost of the system and the area required to host the system; the area can have a significant effect on LCOE for rooftop systems. As with cost and reliability, efficiency must be addressed at the system level to reduce parasitic losses so that systems can realize their potential efficiencies. At the cell level, there is room for considerable efficiency improvement in the III-Vs, even over the ~40% state-of-the-art, by developing advanced cell designs for improved spectral utilization and optimizing for higher-concentration operation. Cell performance must be considered in the context of real-world operating conditions, including spectral variations, flux nonuniformity, and high temperature. For lower-concentration systems using silicon cells, the efficiency of those cells used may be improved, as well. System-level optimization also motivates customization of cell designs for specific system optical characteristics and spectral conditions.

Metrics

Parameter	Present Status (2007)	Future Goal (2015)
$/W installed cost	$7–10/W	<$2/W
¢/kWh	>30¢/kWh	<7¢/kWh
System reliability – IEC qual. spec.	5 years	20 years
Commercial system efficiency	17%	29%–36%
Champion device efficiency	40.7% (III-V) 26.8% (Si)	48% (III-V) 28% (Si)
Commercial device efficiency	35%–37% (III-V) 20%–26% (Si)	42% (III-V) 22%–26% (Si)
Optical efficiency	75%–85%	80%–90%
III-V cell cost, $/cm^2	$10–15/cm^2	$3–5/cm^2

Identified Needs

Need	Significance	University	Nat'l Lab			Industry		
			NREL	Sandia	Other	TPP	Incubator	Other
Establish reliability of prototypes	Needed for market entry. Address at all levels, from detailed understanding of individual failure mechanisms through field testing of systems.	x	x	x	x	x	x	x
Optimize design of overall system	Many opportunities for cost reduction; system-level approach needed.					x	x	
Reduce system cost	Address cell, optics, and tracker; cell cost reduction alone could reduce system cost by 10%–15%.	x	x	x	x	x	x	x
Increase system efficiency	Reduce system losses from optics; increase cell efficiency; increase of cell efficiency from 35% to 39% could reduce the ¢/kWh by 10%.	x	x	x	x	x	x	x
Develop industry product and rating standards	Market entry	x	x	x	x	x		x
The following address the above general needs in more depth								
Develop next-generation, high-efficiency cell structures	Includes multijunctions and other high-efficiency approaches	x	x				x	x
Establish science underpinnings of semiconductor growth and properties	Enable higher-efficiency cell designs over long term; reduce cost	x	x					
Develop next-generation concentrator approaches	Could include ultra-high, 1000–5000x systems	x	x	x	x		x	
Develop more-efficient and more-forgiving optical systems	Improve efficiency; simplify manufacturing; ease operation and maintenance	x	x	x	x	x	x	x
Understand system performance as a function of solar resource	Specify performance of system to customers for market entry		x	x	x	x	x	x
Develop concentrator-specific inverters	Improve handling of maximum power-point tracking (MPPT) and start-up/shut-down for big power fluctuations from array			x	x	x		x