COUNCIL on FOREIGN RELATIONS

The Future of Solar Power

Center on Global Energy Policy, Columbia University
School of International and Public Affairs
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ARES III

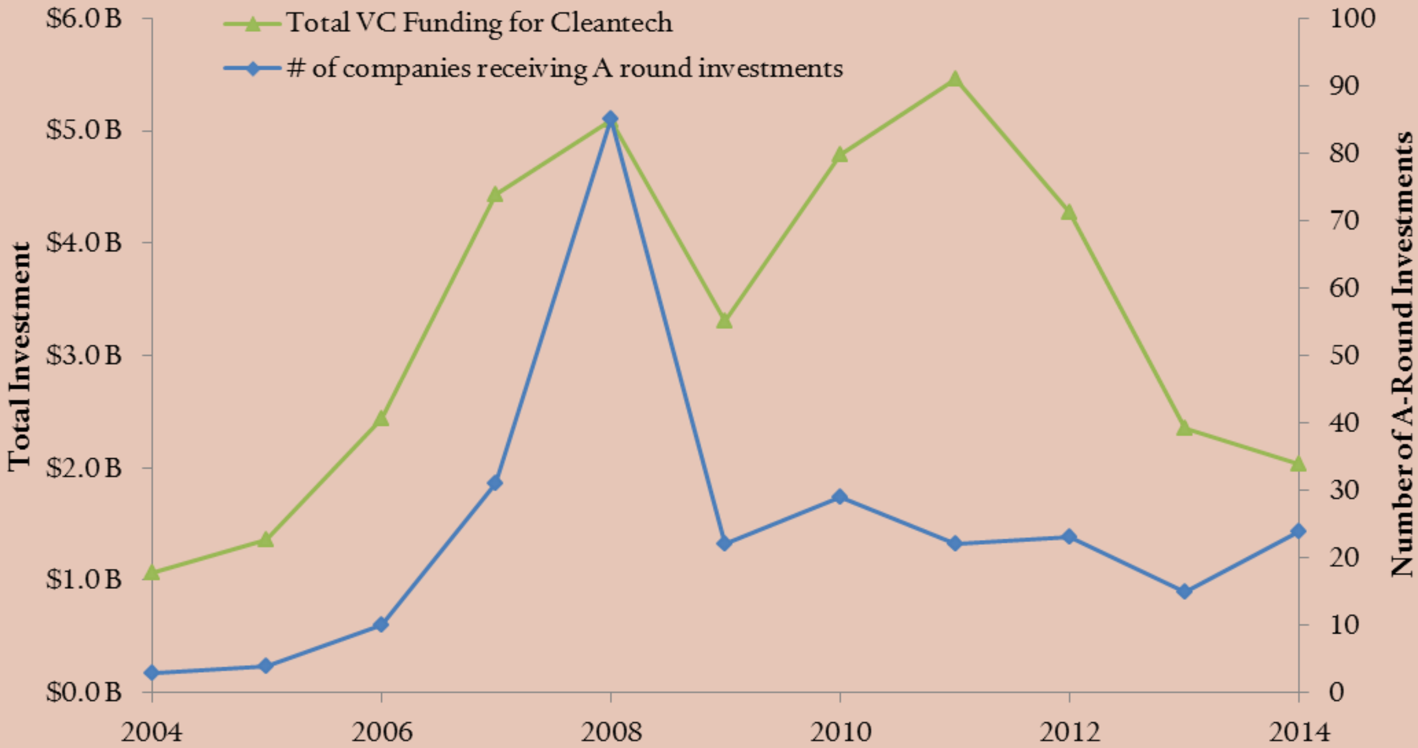
Technology

Preparing for high PV penetration

Policy

The cleantech VC boom, from 2006-2012, is now a bust

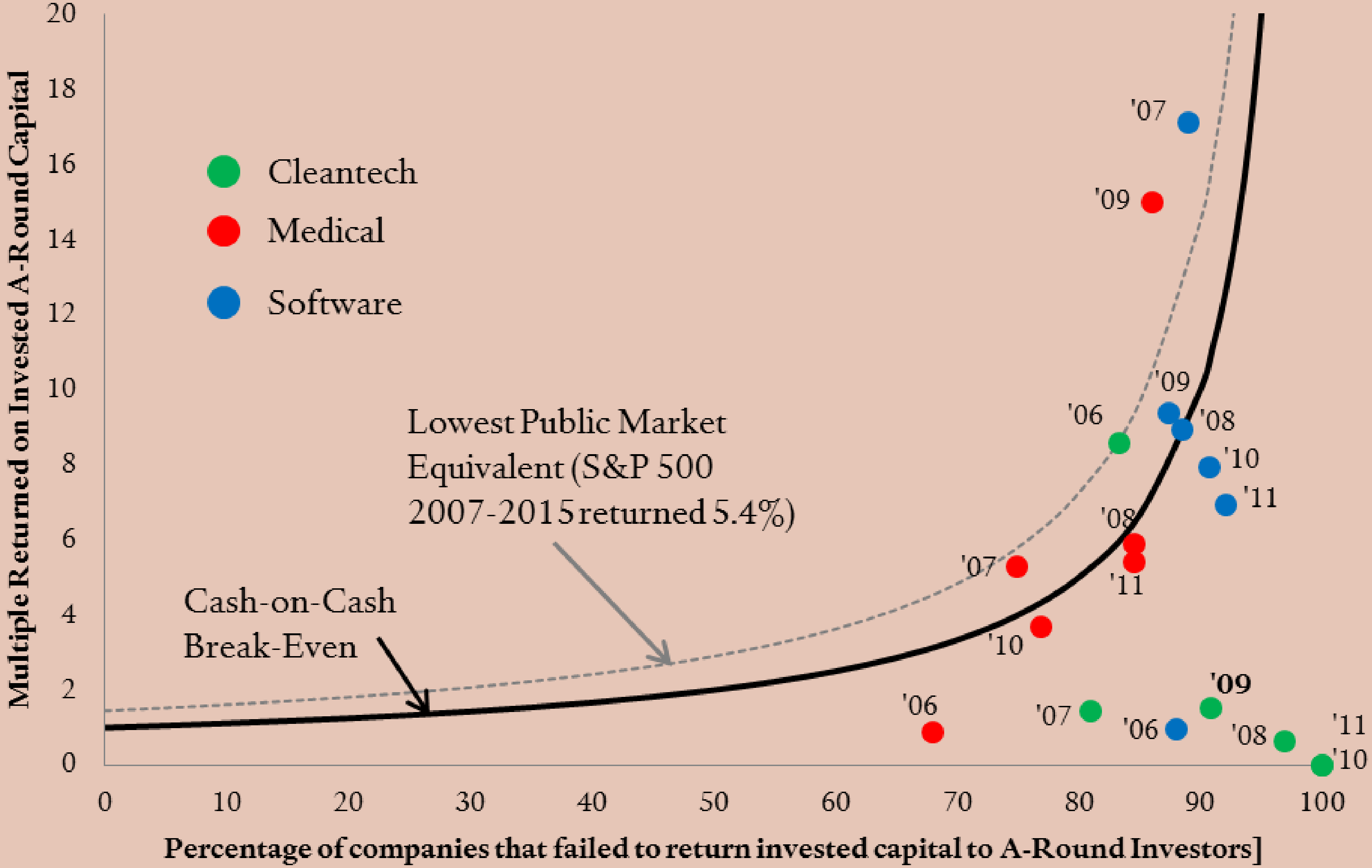
Cleantech entrepreneurship from 2004 to the present. (a) Number of cleantech start-up companies that received A-round funding in a given year. *(Source: CrunchBase)* (b) Total venture capital investment in private cleantech companies by year. (*Source: Bloomberg New Energy Finance*)



Source: Gaddy and Sivaram, forthcoming

Venture capital flight from cleantech is due to high risk and low return compared with other sectors

Comparison of VC Preferred Risk/Return Profile with Actual Investment Profiles by Sector. Actual A-Round VC investment risk/return profiles by sector and year from 2006–2011, compared with nominal value preservation and lowest public market benchmarks



Source: Gaddy and Sivaram, forthcoming

Perovskite solar: the biggest solar breakthrough in 60 years

GOLD ELECTRODES adorn a red perovskite solar cell, made by the Massachusetts Institute of Technology, that is the size of a postage stamp but much thinner.

ENERGY

out-shining silicon

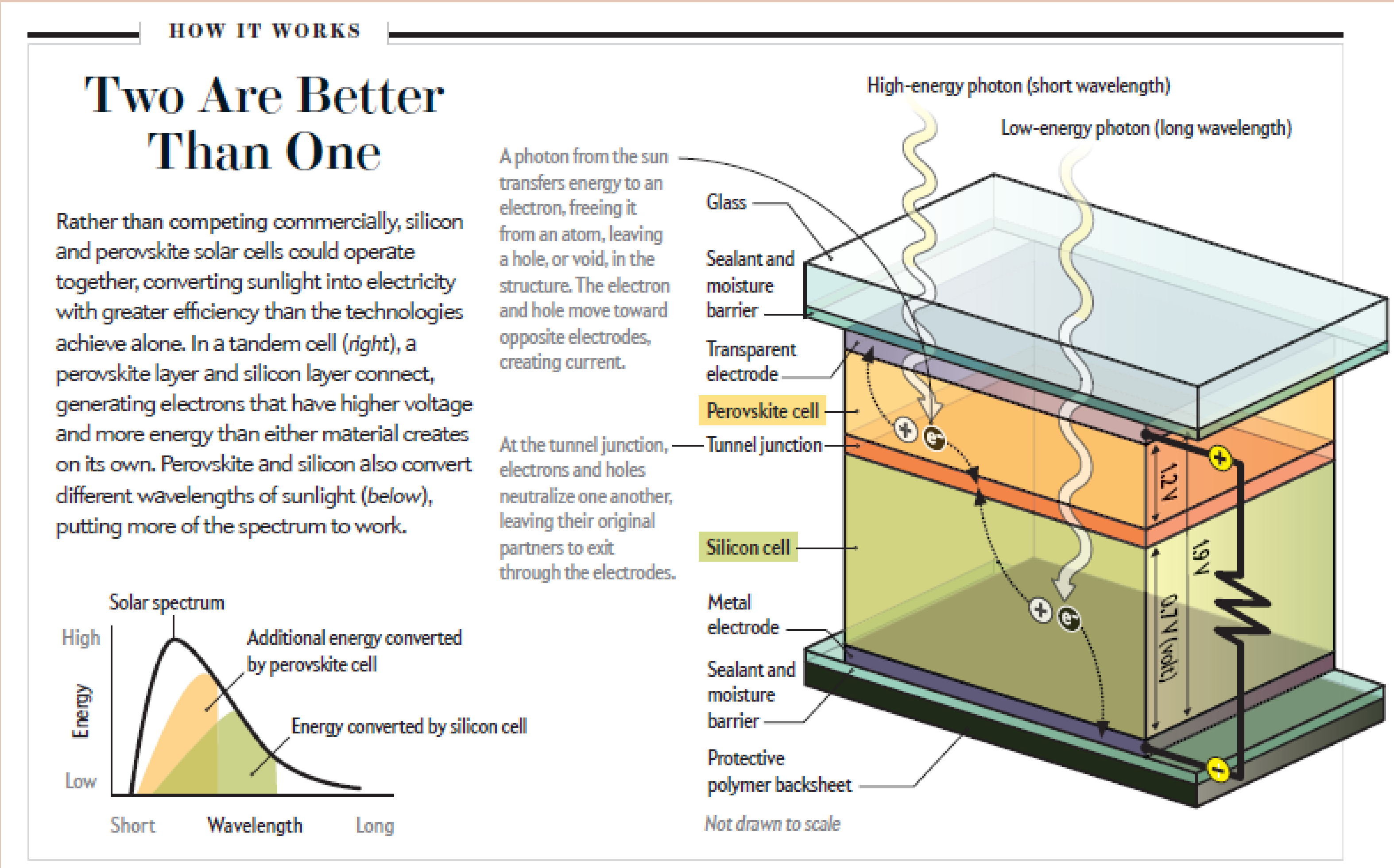
An upstart material—perovskite—could finally make solar cells that are cheaper and more efficient than the prevailing silicon technology

By Varun Sivaram, Samuel D. Stranks and Henry J. Snaith

Photographs by Plamen Petkov

July 2015, ScientificAmerican.com 55

Perovskite solar: Trojan Horse approach to market entry



Source: Sivaram, Stranks, and Snaith, *Scientific American*, 2015

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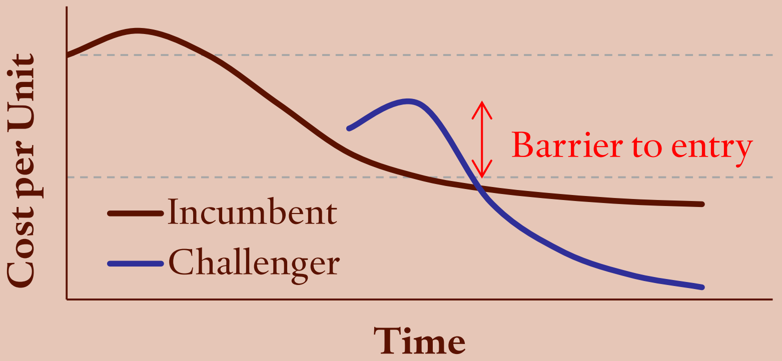
Solar is in danger of reaching technological "lock-in," where a first-generation solution crowds out next-generation tech

First mover creates a barrier to market entry…

- The first technology to achieve scale in the market benefits from **learning-by-doing**, reducing its costs and increasing its market share
- Theoretically superior technologies face a Catch-22: they need scale in order to fulfill low-cost, high-performance potential, but they cannot scale up against an entrenched incumbent

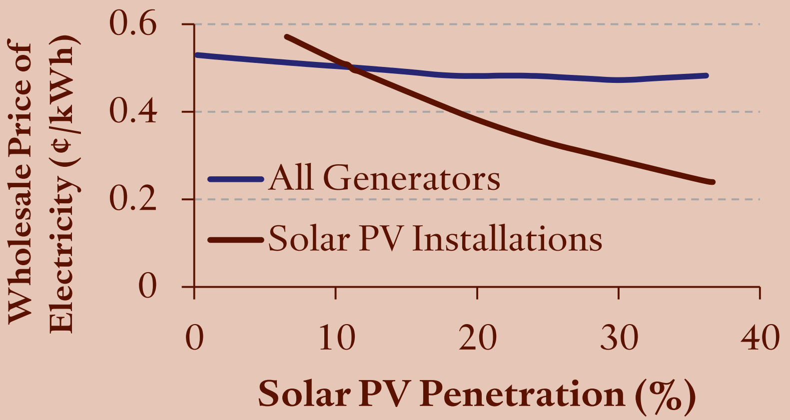
Learning Curves for a Technology Market



…endangering long-term emissions reduction

- The cost and performance targets to materially displace fossil fuels are much lower than those which can be achieved with current technologies
- **MIT "Future of Solar"** study demonstrates that solar faces a **moving target** for cost-competitiveness that will become harder as more solar is deployed
- "Think 'potato chip,' not 'silicon chip'" ~Nate Lewis, Caltech Professor

Solar PV's "Moving Target" for Grid Parity



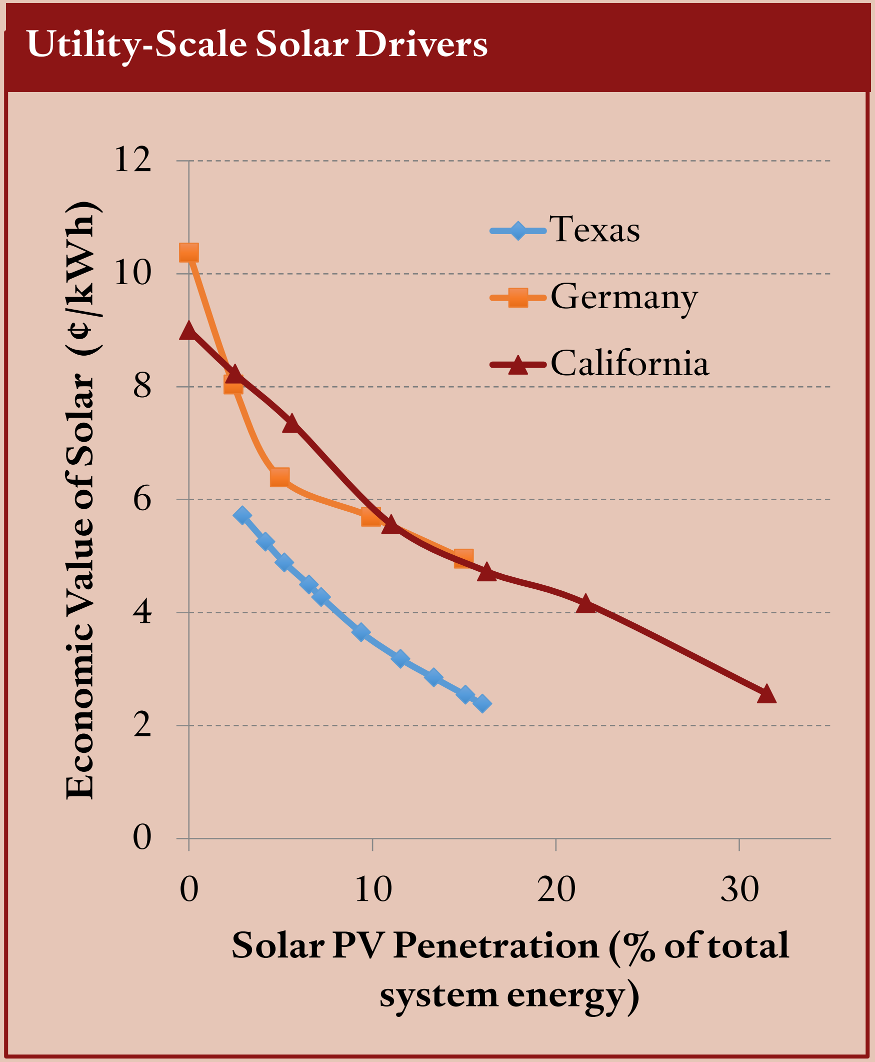
Sources: Texas: MIT, 2015

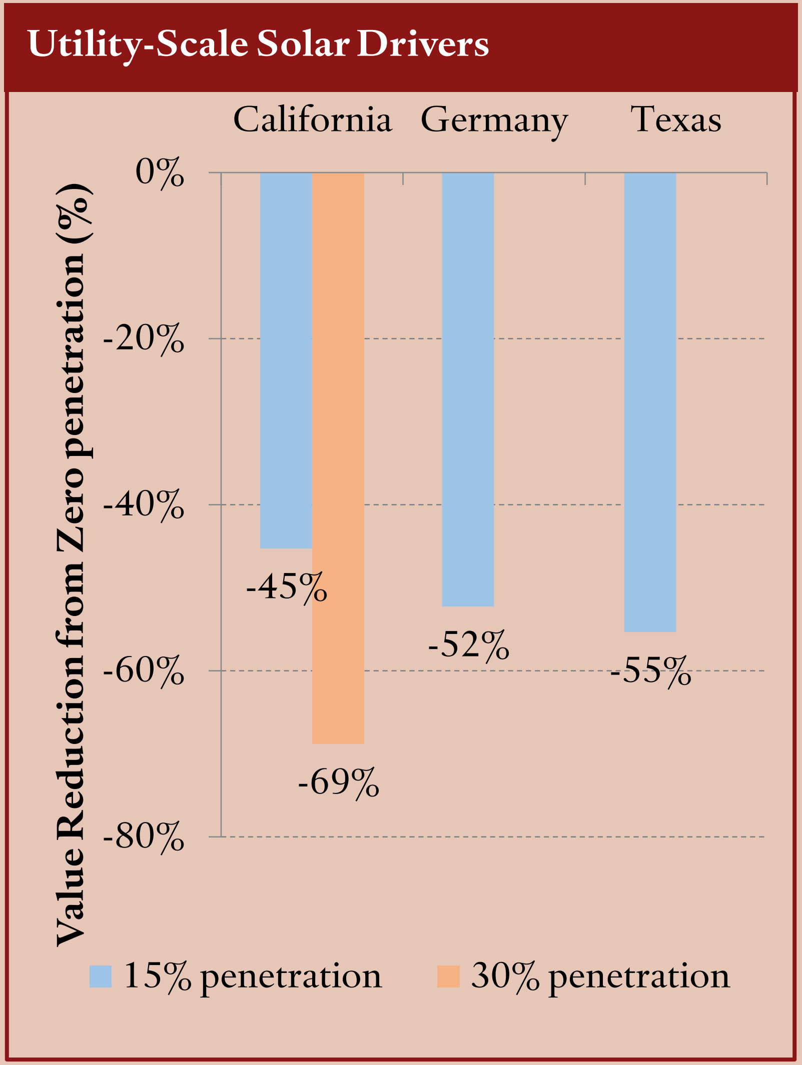
Nuclear, solar, and batteries are examples of “lock-in” from the past, present, and future, respectively

Examples of today’s dominant designs and tomorrow’s emerging technologies

	Dominant Design	Path to Dominance	Emerging Technologies
Nuclear 	• Light water reactor (LWR) • All U.S. reactors and most reactors around the world are LWRs	• Adm. Rickover chose LWR for U.S. submarines Civilian power sector followed this design	• Gen. IV reactors (gas/salt/liquid metal cooled) offer safety, cost advantages • Small, modular reactors more versatile
Solar 	• Crystalline silicon solar panel • Silicon controls >90% of the global market	• 1950s Bell Labs invention • Chinese scaled up due to familiarity with microchip processing	• Printable materials (e.g., perovskites) promise lower cost, higher efficiency • Applications include window coatings
Batteries 	• Lithium-ion battery • Tesla, BYD to scale up production by >10X for EV, grid applications	• Companies like Panasonic have scaled up Li-ion from electronics applications to electric vehicles	• New chemistries (Li-S, Mg-ion) increase energy density • Applications include long-range EVs, better grid storage

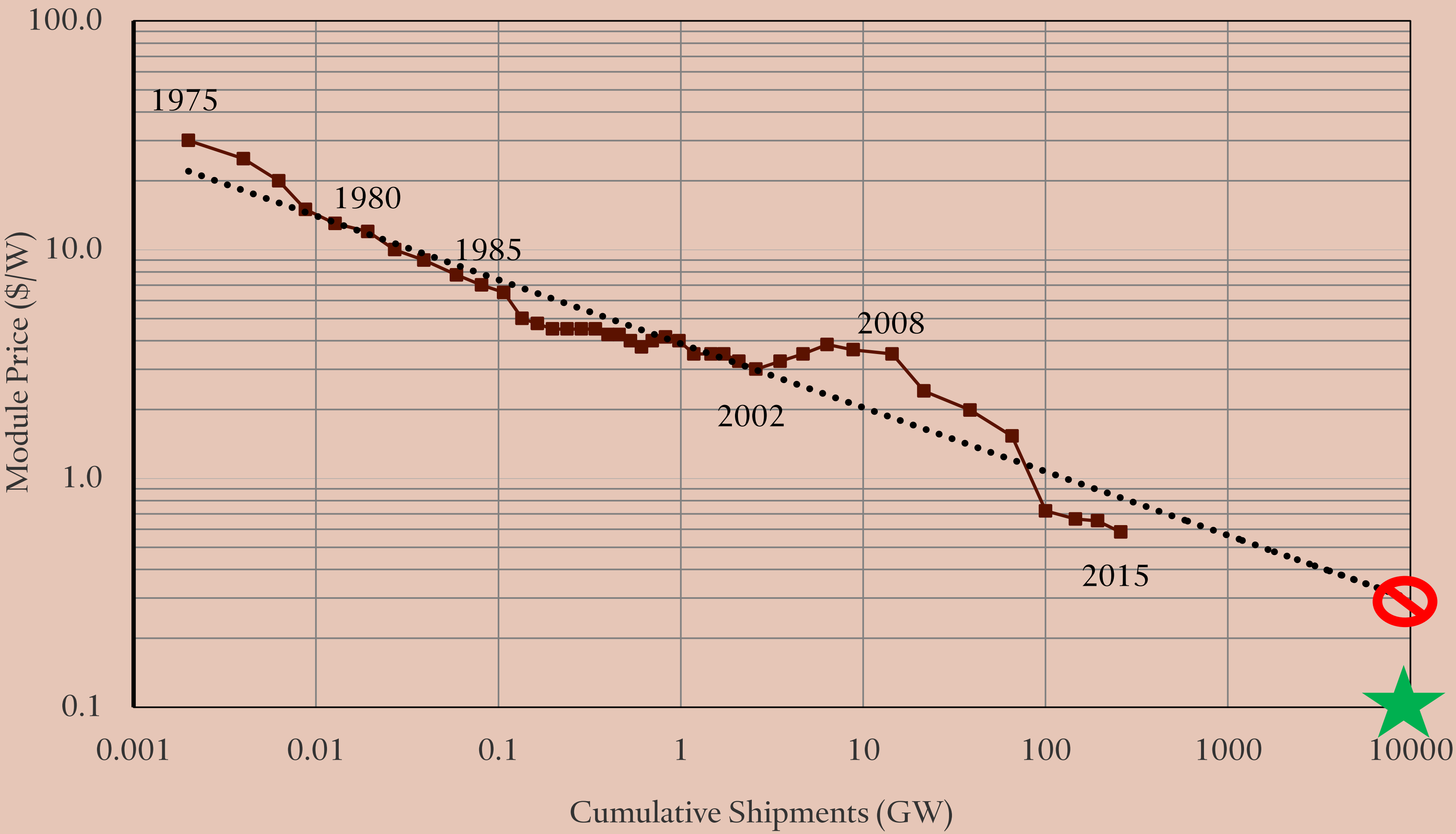
To outrun "value deflation," the solar industry should set a **$0.25/W target by 2050**





Sources: Texas: MIT, 2015; Germany: Hirth, 2014; California: Mills and Wiser, 2012

Learning curve likely will not reduce the cost of silicon solar panels to "pennies per Watt" by 2050—new tech needed!



Sources: GTM Research; Sivaram and Kann, forthcoming

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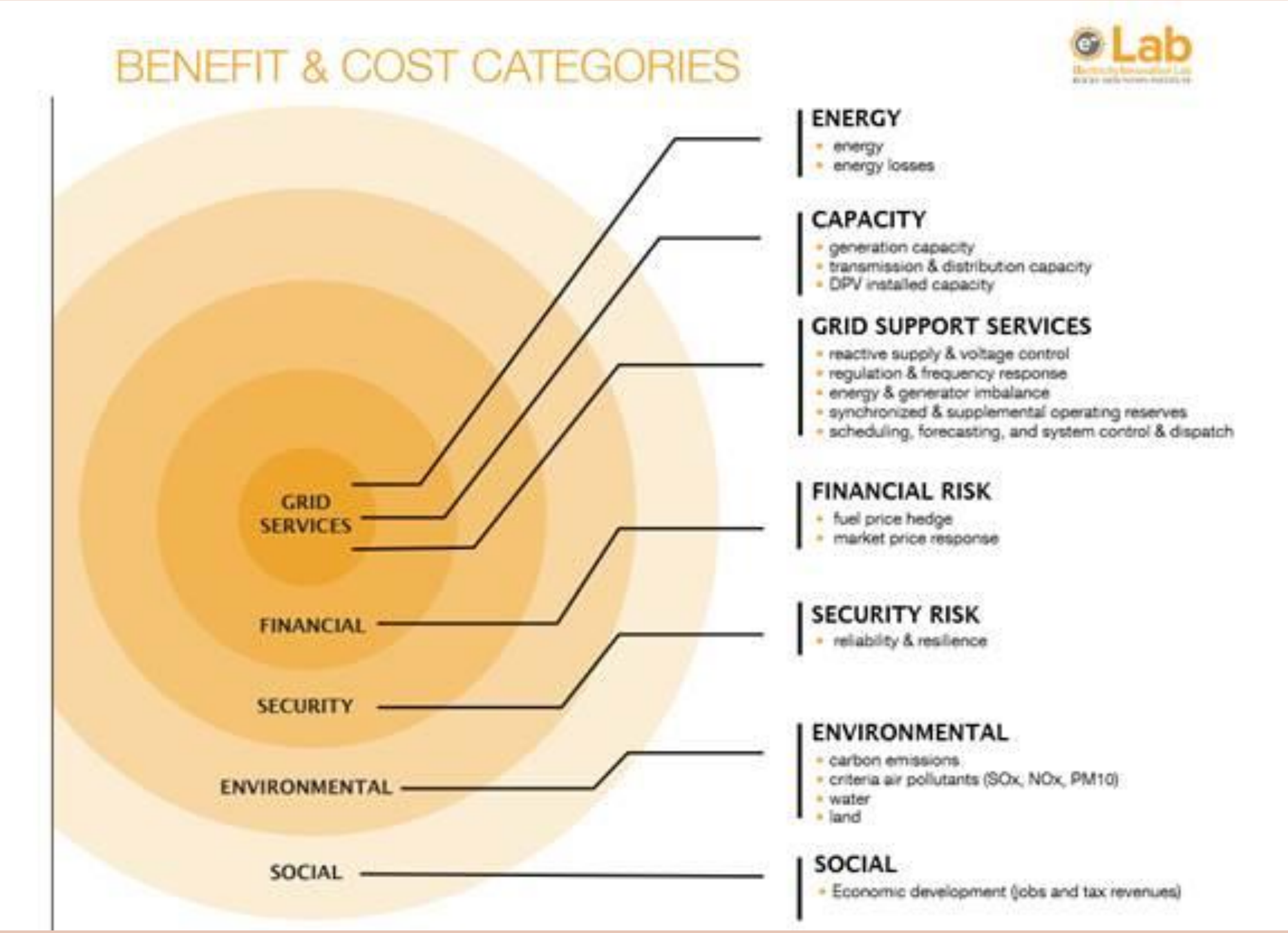
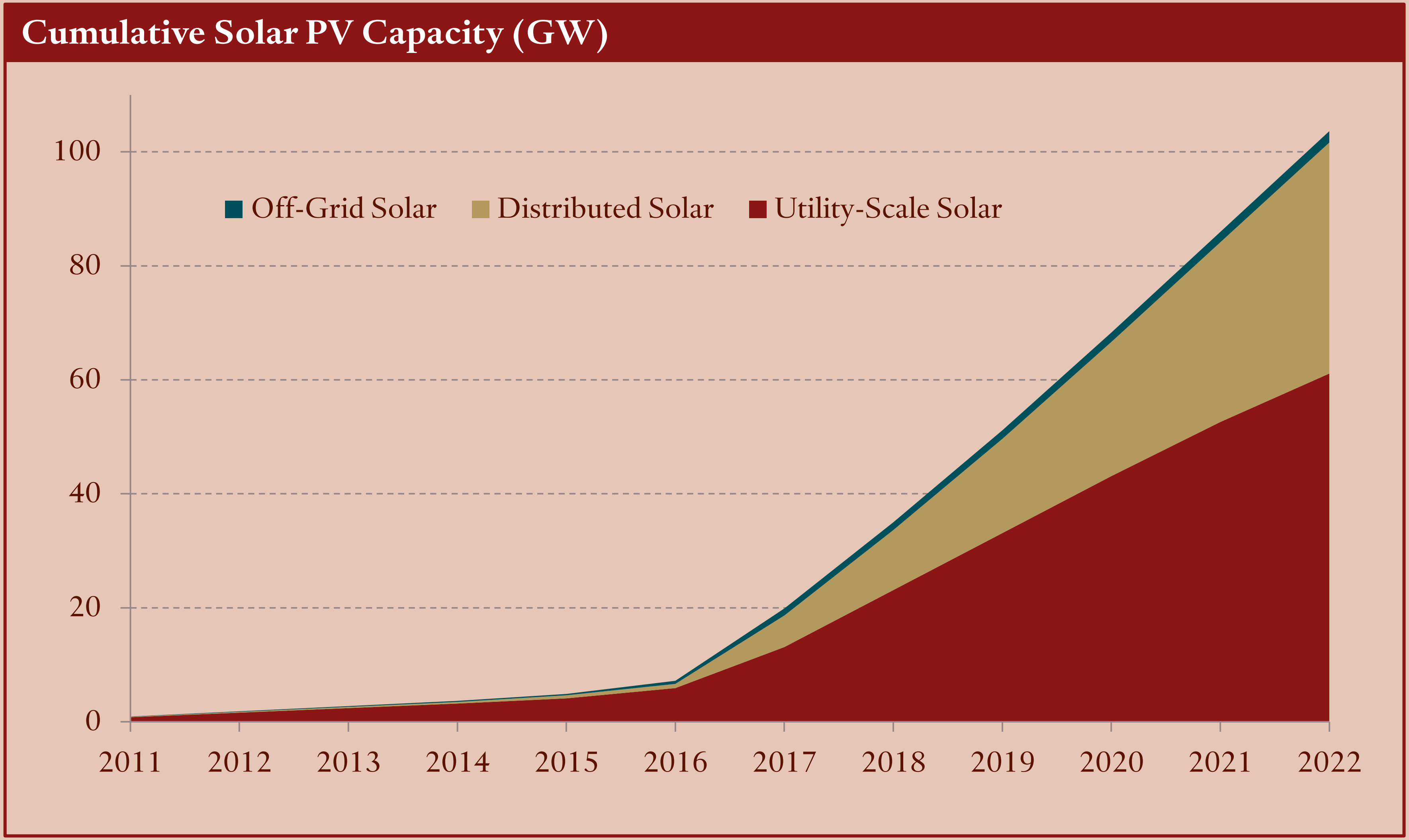
Distributed solar could bring many benefits, but a sophisticated market is required to realize those benefits

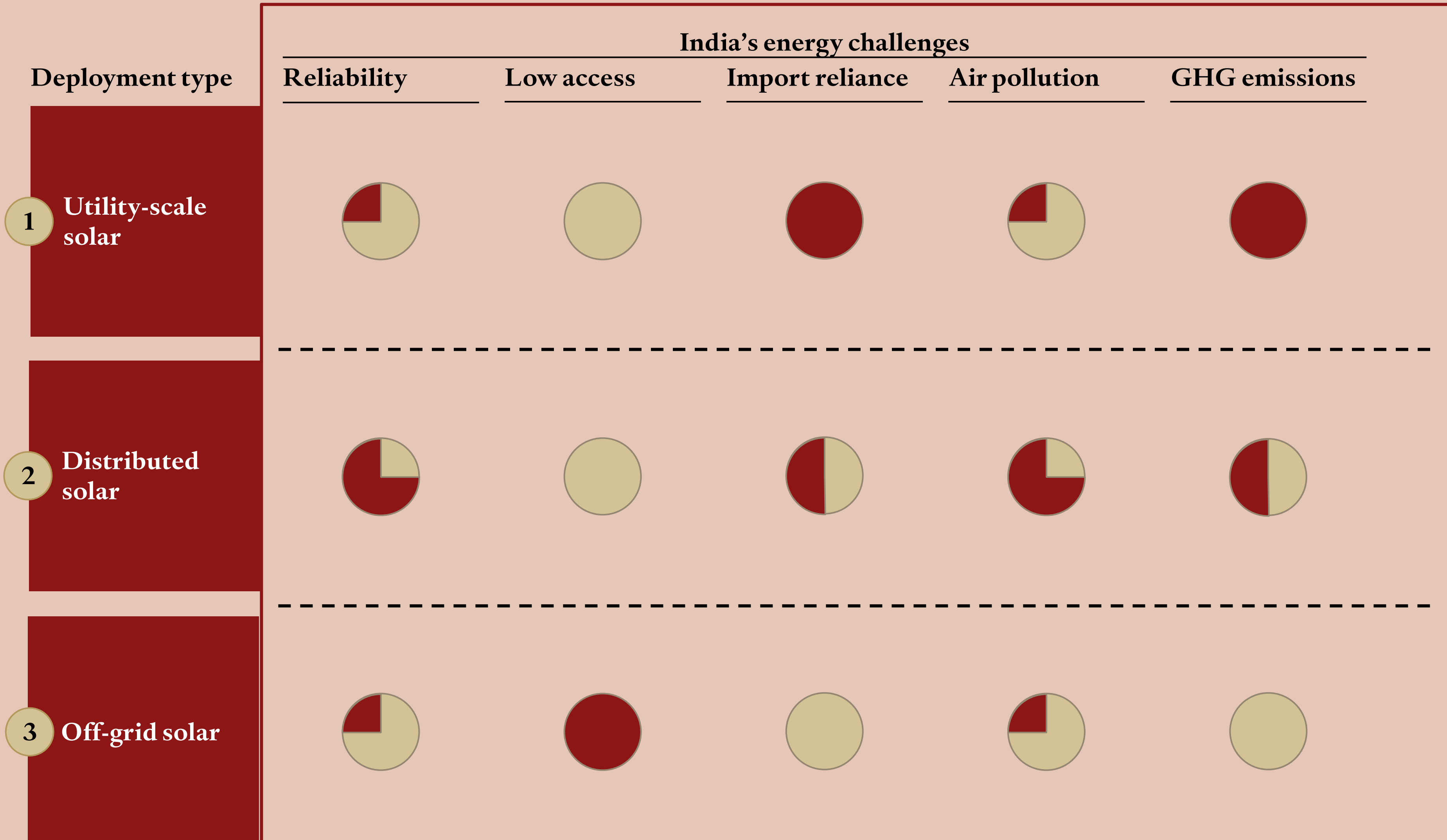


Source: Rocky Mountain Institute, 2013

Under Prime Minister Modi, India has made an ambitious commitment to deploy 100 GW of solar by 2022



In India, multiple deployment types of solar are needed to realize PM Modi's vision of an "ultimate energy solution"



Source: Sivaram, Shrimali, and Reicher, Stanford Steyer-Taylor Center, forthcoming blogs.cfr.org/levi

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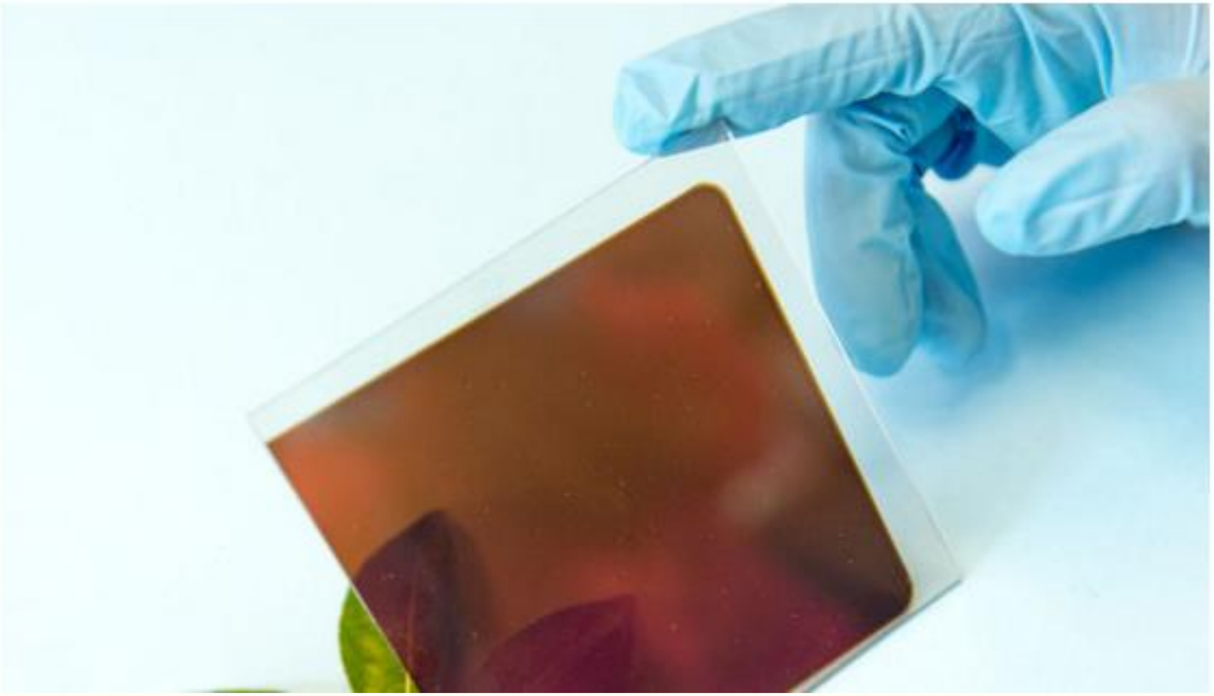
The World Needs Post-Silicon Solar Technologies

by Varun Sivaram
May 26, 2015



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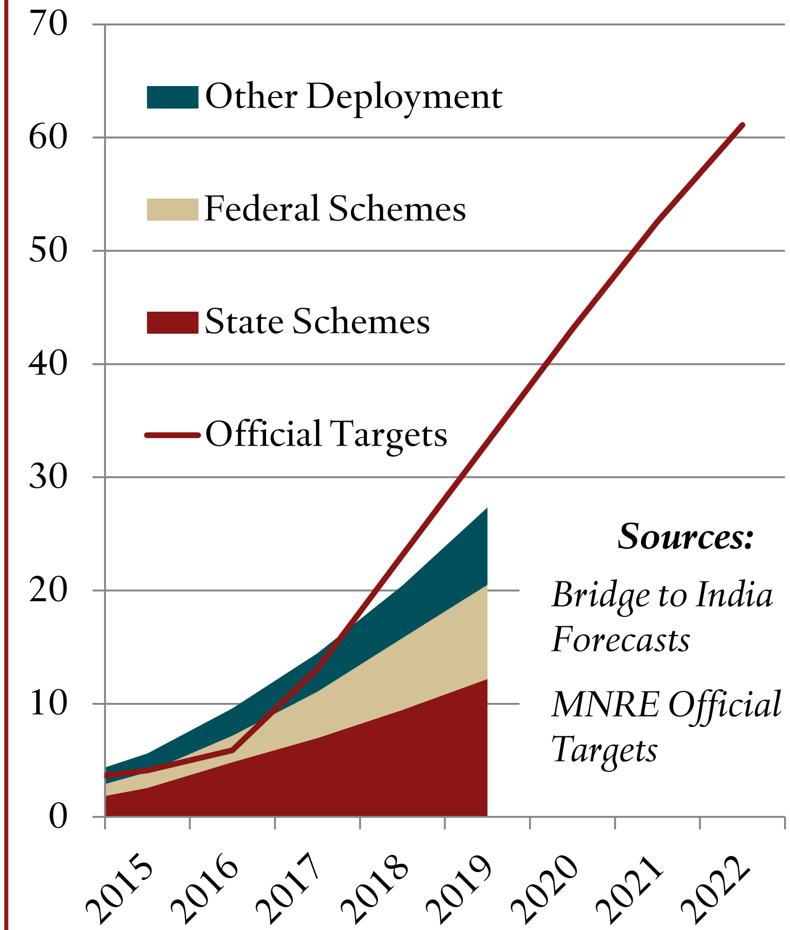
Supplementary slides on India

Utility-Scale Solar Deployment Is on Track for Official Targets, Driven by Federal and State Policies

Utility-Scale Solar Drivers

- **Federal Schemes**
  - Solar Parks: 25 "Ultra-Mega" solar projects of at least 500 MW each will collectively produce 20 GW
  - National Thermal Power Corporation Viability Gap Funding scheme will procure 15 GW by 2019
- **State Schemes**
  - Each state has a solar target, and most progress is likely to come from utility-scale solar: e.g., Maharashtra (7.5GW), Andhra Pradesh, Telangana (5GW),
  - Almost all state schemes involve private developers bidding in a reverse auction for a guaranteed tariff to sell power to the state
- **Other Deployment**
  - Utilities and power companies bound by renewable purchase and generation obligations (RPOs and RGOs) are expected to procure 7 GW by 2019

Utility-Scale Solar Forecasts (GW)



Sources:

Bridge to India Forecasts

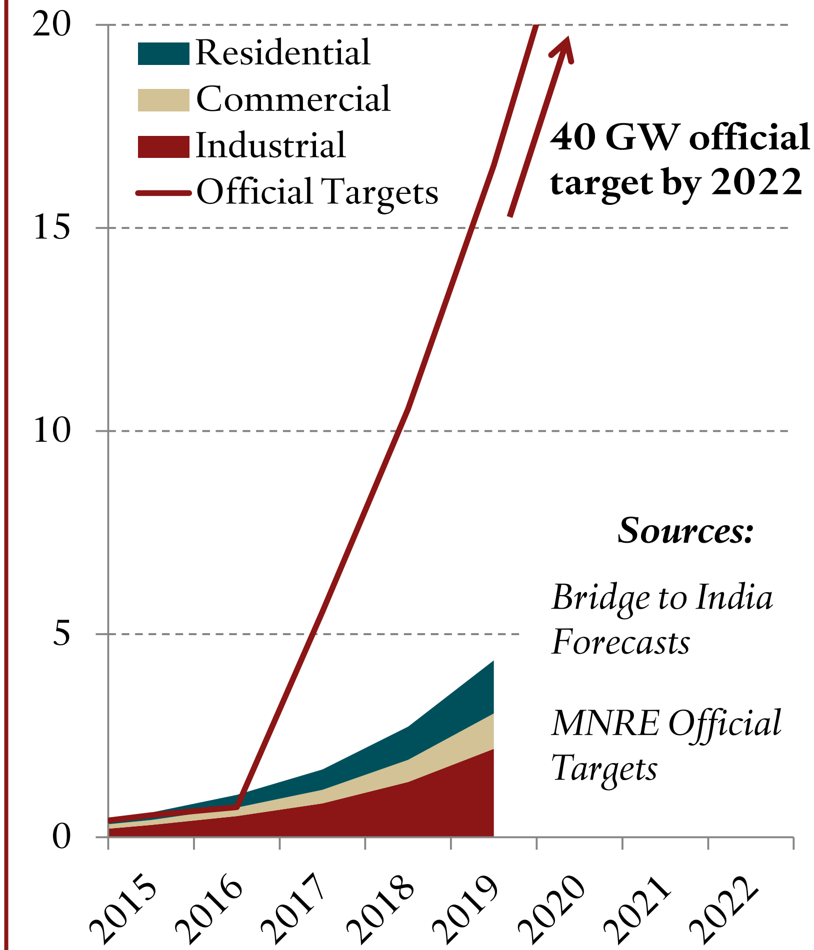
MNRE Official Targets

Distributed Solar Deployment is Projected to Dramatically Lag Official Targets

Types of Distributed Solar

- **Residential**
  - Rooftop solar for residential customers is not currently economic anywhere in India
  - Subsidized residential electricity tariffs prevent significant savings from solar under net metering
- **Commercial**
  - Distributed (<1MW) solar systems for commercial buildings are economic in 12 states
  - Favorable federal tax treatment supports solar competitiveness
- **Industrial**
  - Industrial sector is slightly less economic for distributed solar than commercial sector because of lower tariffs
  - Still, with favorable tax treatment, distributed solar systems for industrial facilities are economic in 12 states

Distributed Solar Forecasts (GW)



Sources:

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