

COMMENTARY

The Need for Continued Innovation in Solar, Wind, and Energy Storage

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Solar energy, wind energy, and battery energy storage are widely regarded as the three most prominent clean energy technology success stories. In 2017, the International Energy Agency listed them as the only technologies being deployed rapidly enough to help limit climate change.¹ Power from solar and wind farms is now routinely sold at prices below that of electricity from fossil-fueled generators, and cheaper batteries are fueling rising sales of electric vehicles as well as a building boom of grid-scale electricity storage projects.

Governments around the world might conclude that innovation in solar, wind, and storage is no longer a priority. Such a conclusion would be a mistake. The impressive performance and promising projections for these three technologies obscure an underlying stagnation. In each case, a single dominant technological design has emerged, which private industry is presently scaling up. As Figure 1A reveals, crystalline silicon panels have strengthened their near-monopoly in solar photovoltaic energy in recent years. Figure 1B demonstrates that a similar trend is emerging in grid-scale energy storage, as lithium-ion batteries relentlessly increase their market share. And in wind energy, horizontal-axis wind turbines have enjoyed a virtually 100% market share for decades.

While these “dominant designs” have made clean energy more competitive with fossil fuels in the near term, they pose a significant risk in the long term:

“technological lock-in.” Technological lock-in has been documented across a range of industries in the past—especially in legacy sectors with entrenched incumbent firms and regulatory inertia. Once it sets in, new technologies struggle to achieve commercial traction even if they are superior to existing ones.²

The warning signs of lock-in are clear across all three fields. Private industry is devoting virtually no investment to the development of next-generation technologies, while making massive bets on the rapid deployment and incremental improvement of existing technologies. If new solar, wind, and storage technologies are “locked out,” global efforts to reduce greenhouse gas emissions could fall well short of those needed to avoid the worst consequences of climate change. To be sure, it is impossible to be certain that new technologies will be needed, but a prudent risk management strategy would be to prepare for the likely scenario that they are.³

Governments around the world should step in to boost funding for research, development, and demonstration of new solar, wind, and battery technologies that have the potential to outperform the current market leaders. These technologies will not attract substantial private investment without such public support. Well-designed policies would spread public funding across a diverse range of technologies and phase out that support as technologies mature, ensuring maximal return on public investments in innovation.

Locked In Solar Energy

Crystalline silicon has remained the most popular material for solar photovoltaic energy conversion for over half a century, and in recent years its dominance has only increased. Alternative photovoltaic materials, such as thin

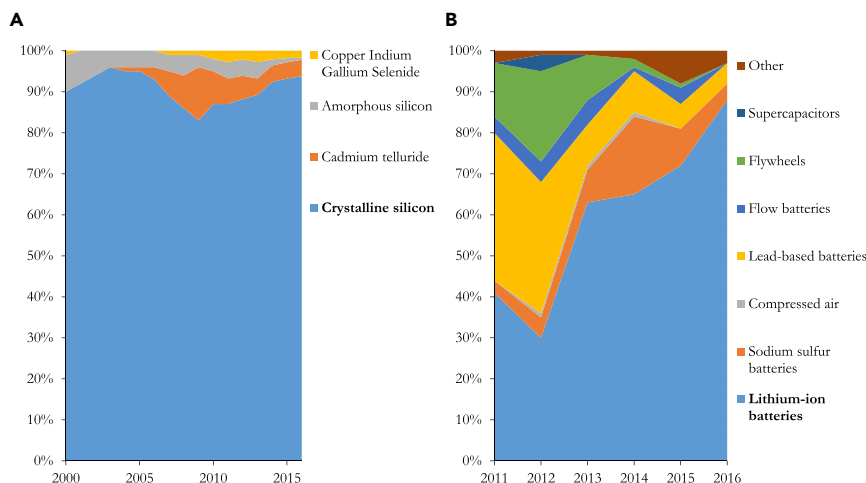


Figure 1. Global Market Shares of Dominant Designs in Solar Photovoltaic and Nonhydro Grid Energy Storage

(A) Percentage of global annual solar photovoltaic panel deployed capacity by technology (Source: Fraunhofer ISE).

(B) Percentage of global annual grid-scale energy storage deployed capacity by technology, excluding pumped hydroelectric storage (Source: International Energy Agency, Tracking Clean Energy Progress, 2018).

films, including amorphous silicon, cadmium telluride, and copper indium gallium (di)selenide, managed to dent crystalline silicon’s market share in the 1990s and 2000s. However, over the last decade, Chinese producers have massively scaled up production of crystalline silicon solar panels, and most producers of alternative solar materials have gone out of business. As a result, in 2016, crystalline silicon solar panels accounted for 94% of global additions in solar power generation capacity.

Over the last decade, the cost of projects using crystalline silicon solar panels has fallen by over 90%. Consequently, solar power is now the fastest-growing power source in the world as well as the cheapest in many regions. Analysts forecast that these costs will steadily decline in coming years, driven both by cheaper panels—resulting from production economies of scale and learning effects—as well as cost improvements in the installation of full systems.

Nevertheless, this dominant design might not be sufficient to enable solar power to rise from supplying 2% of

global electricity today to 33% by mid-century, a level that is essential for decarbonizing the electric power sector. Why? At high penetrations, solar power becomes much less valuable because it is neither dispatchable nor consistent. Even taking into account potential advances in energy storage and flexible customer demand, a fully installed solar project may need to cost just 25 cents per watt by mid-century for solar to continue to be economical even as more of it is deployed. That cost is less than a third of today’s, a level that is likely to be out of reach for crystalline silicon technology.⁴

New technologies, however, might be able to achieve such low costs. Organic, quantum dot, and perovskite photovoltaic devices could all be made from Earth-abundant materials using low-cost manufacturing processes. Perovskite devices in particular have already demonstrated power conversion efficiencies rivaling those of the dominant design and with a higher theoretical ceiling. These emerging materials could also be more versatile than sili-

con, enabling flexible, semitransparent, and lightweight coatings that would open new markets.⁵

Substantial further work is required to demonstrate the longevity, reliability, and scale manufacturing of these technologies. Unfortunately, private investors are skittish about funding such work. Government action is required to free solar power from its current state of technological lock-in.

Wind Energy

Horizontal-axis wind turbines—in which rotor blades spin around an axis parallel to the ground—virtually monopolize the global deployment of wind power. In the 1970s, when firms first began deploying large-scale wind power installations, they quickly settled on a three-blade, horizontal-axis configuration because it maximized the performance of each turbine. In the decades since, incremental improvements to this design have yielded dramatic results. Taller towers and longer blades have allowed the average onshore turbine’s capacity to increase from 0.05 to 3 MW. Even larger turbines are now being deployed offshore. Greater efficiency and scale drove the cost of onshore wind energy down by 45% over the decade ending in 2017. Wind energy now supplies over 5% of global electricity demand.⁶

But for all its virtues, today’s dominant design for wind turbines may, like that for solar panels, put a ceiling on its contributions to the power sector by mid-century. Although the efficiency of individual modern turbines approaches the theoretical maximum, the overall performance of wind farms is far less than ideal. Turbulent wakes within regular arrays cut production in downwind rows of turbines by as much as 40% compared with the first row.⁷ This performance penalty can be mitigated by spacing the wind turbines far apart, but that means that wind farms must be located on massive tracts of land

with favorable wind resources. As the penetration of the dominant design rises, the costs of land and transmission could balloon, particularly as suitable sites become more limited and farther from population centers. Finally, like solar power, wind power's value declines as its penetration rises, owing to its intermittency.

If they were to achieve commercial traction, alternative technologies might boost wind energy's long-term prospects. For example, vertical-axis wind turbines could vastly improve the land area power density of turbine arrays. They can be spaced much closer together than horizontal-array turbines, in a counter-rotating configuration, without performance degradation from turbulent wakes. Indeed, a wind farm comprising vertical-axis turbines that are just 10 m tall could produce ten times the energy from the same amount of land as a comparable array of much larger horizontal-axis turbines.⁸ Such turbines would also require less maintenance because they have far fewer moving parts.

Moreover, smaller, less intrusive, and quieter vertical-axis wind turbines could open up a range of new applications, including repowering of horizontal-axis turbine arrays and distributed power production in urban settings. The new design could sustain and even accelerate the deployment of wind energy without incurring exorbitant land and transmission costs.⁹ Nevertheless, virtually no private investment is flowing toward vertical-axis turbines or other alternative wind energy technologies. As in solar power, public investment will be required if the potential of wind energy is to be realized.

Energy Storage

Lithium-ion batteries were first commercialized in the 1990s to power consumer electronics. Today, these lightweight, energy-dense devices po-

wer most electric vehicles as well, and they are rapidly moving into grid-scale energy storage. Setting aside pumped hydroelectric energy storage, an older-vintage technology whose further expansion is geographically limited, lithium-ion batteries made up 88% of new additions to grid-scale energy storage globally in 2016. That figure was just 30% as recently as 2012, and it is expected to rise even further as new data come in.

Lithium-ion batteries' dominant market share is the result of an impressive cost decline of three-quarters between 2010 and 2016 along with the rapid development of market niches for grid applications that suit its technical characteristics. Reasonable doubts exist as to whether these supply and demand trends will continue. Materials requirements and limited economies of scale may slow cost declines, while the best-developed grid-scale market niches are beginning to be saturated. Lithium-ion batteries are not well suited to serve the much larger grid-scale markets that are essential for deep decarbonization, especially storage beyond a few hours.¹⁰

While governments and private firms continue to invest in RD&D for energy storage technologies other than lithium-ion batteries, there are some worrisome signs that lock-in may be setting in. In particular, several leading specialty companies have gone out of business over the past year, while some diversified manufacturers have withdrawn from this field. Massive capacity for producing lithium-ion batteries is under construction, especially in China. If demand for electric vehicles falls short of absorbing this new supply in the coming years, as seems likely, the glut may lead to below-cost pricing for grid-scale applications. This all-too-likely scenario would put alternative technology producers under even more intense pressure. The resemblance to the process that led to crystal-

line silicon solar panel technology lock-in is uncanny.

Still, there are encouraging signs of progress toward long-duration storage solutions, such as recently reported advances in aqueous sulfur flow batteries and manganese-hydrogen batteries, both made with cheap, Earth-abundant materials.^{11,12} Yet, taking technical breakthroughs in energy storage from the bench to the global scale is an expensive and slow process that will require large amounts of patient capital. Lock-in to lithium-ion batteries in the near future would eliminate the many potential sources of such capital and could well leave the most promising solutions stranded.

Policy Recommendations

Policymakers around the world should support the maturation of the next generation of technologies in solar, wind, and energy storage, even as the existing generation continues to spread. Robust public funding for basic research, applied technology development, prototyping, and field demonstration should nurture a diverse range of options in varying stages of maturity.

Following through on the 2015 Mission Innovation pact, in which 20 major governments committed to doubling energy RD&D funding over 5 years, would be an important first step toward ensuring that clean energy technologies continue to improve.¹³ Judicious public investment can embolden private investors, who ultimately will need to supply the bulk of the capital for new technologies to break through.

Policymakers should also combat technology lock-in by ensuring their clean energy deployment policies support emerging technologies. Governments at both the state and national levels can create protected markets for new technologies to help achieve scale through public procurement, and they

can provide subsidies to emerging technology vendors to help them compete against dominant incumbents. Such subsidies should decline as technologies mature, so that policy pushes against, rather than abets, lock-in. Effectively administering such targeted subsidies is challenging—for example, policymakers must make determinations about the maturity levels of different technologies, and cutting subsidies to mature technologies can provoke political pushback from established industries. But policies that foster market adoption of emerging products—known as “pull” policies—are crucial complements to the “push” policies that support RD&D into new technologies, because firms often face a dearth of private funding to commercialize promising technologies, known as the “valley of death.”¹⁴ Technically competent and farsighted policymakers will be needed to design a portfolio of push and pull policies that is resilient to political interference.

Government support for open technology standards is another way to avert lock-in. For example, standards for grid-scale energy storage systems to interact with the power grid should enable a diverse range of technologies to “plug and play.”¹⁵

The success of solar, wind, and battery storage technologies to date is encouraging but not cause for premature celebration. In each of these areas, one or more further revolutions may yet be critical to enable a full and affordable worldwide transition to clean energy. Prudent policymakers should act now to safeguard continued innovation before it is too late.

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AUTHOR CONTRIBUTIONS

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DECLARATION OF INTERESTS

J.O.B. declares the following patents related to the technologies described in this article: Dabiri, J.O., Whittlesey, R.W. (2013) Two-dimensional array of turbines. US patent 8545168; and Smedley, G.T., Dabiri, J.O. (2015) Devices and methods for harvesting power from arrays of wind turbines. US Patent 9214811.

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