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The US as a Climate Leader: Policy to Develop Photovoltaics

Introduction

Is green the new black – will widespread adoption of photovoltaic (PV) power generation really displace the world's dependence on cheap fossil fuels? The expansion of production capacity and demand for solar in recent years suggests that the technology is indeed rapidly approaching the maturity to supply the terawatts of power consumed globally – and everyone wants a piece of the industry. The EU are current world leaders in consumption of photovoltaics, and China is the lead global producer – so where does the United States fit in? Using the latest scientific publications on R&D potential of new solar technologies and grid-scale solar implementation challenges, we determine how the United States should act swiftly to capitalize on the economic possibility offered by photovoltaics, and critically, to maintain its parity with China and other growing photovoltaic innovators.

The Role of Uncertainty and New Technologies in Competitiveness

In the past decade, photovoltaic systems have improved drastically in efficiency as higher-volume production of panels has driven down costs, but challenges for a PV-backed fully renewable energy sector remain. In addition to pushing a light-to-energy conversion efficiency that hovers around 10-15% for standard Silicon modules, new research on PV technology largely focuses on increasing module lifespan and economic predictability. The ability to produce systems with consistent operating lifespans and rates of return is a prerequisite to further solar adoption by power producers, yet even expert analysts in the commercial solar sector are yet to achieve reliable results.

A study of 26 German and Spanish PV power plants found that the uncertainty of their "state of the art long-term yield predictions" varied from actual yields by an overall 8%. They found that nonreversible, age-based solar panel performance degradation was highly dependent on panel manufacturer and was misestimated by 5% in the long term; fluctuations and an overall upward trend in solar irradiance intensity contributed another 3% uncertainty over time, possibly due to climate change. The authors conclude that more research into economic models is necessary, because 8% can easily distinguish a profitable project from a poor investment (Müller et al. 2016).

The race for PV technology that provides increased yields and stands the test of time continues in the lab, and there are several new contenders: perovskite, quantum-dot, and organic PV cell technologies. Although they have received considerable media coverage and research interest, the relative adolescence of quantum-dot and organic PV technologies make them unlikely contenders for terawatt-scale implementation in the next decade. However, improvements on traditional crystalline solar technologies like perovskite have much greater potential because of preexisting manufacturing infrastructure. The demonstrated efficiency of panels made with perovskite has climbed to over 20% in just the four years since its first use; by comparison, other technologies like Silicon Oxide have only slowly improved over the past three decades. However, despite its promises for meteoric efficiency increases and easy manufacturing, environmental concerns over the significant quantity of highly bioavailable lead in perovskite panels cloud their future (Stranks and Snaith 2015). If commercial implementation of perovskite PV's in their current state takes place, policymakers will need to account for potential environmental externalities, perhaps with safe recycling incentive programs.

Rethinking Grid Technology

In conventional power generation schemes, generators driven by fossil fuels or nuclear reactors are alternating-current power sources that can respond to spikes in demand by increasing rotational speed, thereby increasing electrical current output. However, solar lacks this responsive capability – if an industrial user of a purely solar grid turns on a large piece of equipment with a high current draw, the PV modules in the power plant cannot generate more power, causing electricity prices to spike in peak demand times in highly-PV-dependent grids, like Germany's (Wozabal, Graf, and Hirschmann 2016). And because solar represents a variable renewable energy (VRE) like wind, its capacity to produce electricity depends on time of day and cloud cover. These caveats necessitate improved inverter and new grid technology, especially large-scale power storage solutions. Luckily, the inverters that link solar panels to line-voltage AC power have recently become much more efficient – 97% to 98% with current state-of-the-art – and with new types of power transistors that will soon come to market, solar-to-grid conversion efficiencies will approach 100% (Kouro et al. 2015).

However, the availability of suitable storage technologies poses the biggest barrier to terawatt-scale adoption of VRE's. Batteries seem the obvious solution: High-tech lithium-ion technology like Tesla's has already been used in grid-connected solar farm installations. But batteries are expensive, especially for solar power projects, which already have potentially dubious financial outlooks. Haegel et al. 2017 write that unsubsidized PV power plant installations can provide electricity profitably only in especially favorable markets today, and that storage will add significantly to capital costs. However, they posit that with new innovations and continued falling cost trends, by 2030 PV's should be able to achieve total expenses of just $.03/kWh for panels and conversion and $.05/kWh for storage. $.08/kWh overall will be competitive in many domestic markets, but even at a futuristic $.05/kWh, battery-based storage technology will still prohibit complete solar penetration in all markets. Some scholars have researched distributed energy storage in which on-grid consumers can choose to store and dispense power using their electric vehicle (EV) batteries, or receive of tax credits for purchasing and operating in-home batteries. For example, Italy operates a 50% rebate on battery costs over 10 years, which has contributed to increased storage capacity in their grid (Bayod-Rújula et al. 2017).

The Hydrogen Economy

With the meteoric rise of EV's and suitable lithium-ion technology, batteries are a comfortable option. However, compressed hydrogen provides an even better route to a fully renewable power grid. Batteries contain many hazardous chemicals that pose environmental challenges as battery packs reach their cycle limits and must be disposed of. Economically, batteries will continue to be heavy and expensive, and lithium-ion provides poor overall energy density by weight. Conversely, Hydrogen is an extremely energy-dense compound by weight and its potential becomes most promising when paired with PV's. To cleanly produce pure Hydrogen through electrolysis, electricity flows between two specialized plates submerged in electrolyte-enriched water, yielding separated H_2 and O_2 gas at each of the terminals. The Hydrogen is then collected and pressurized, and can later be used directly in fuel-cell vehicles or in large-scale fuel cells that convert it back to electricity for the grid. This eliminates the need for batteries and would precipitate the creation of a zero-emission Hydrogen economy. Fuel cell vehicles like the Toyota Mirai are already commercially available, but most Hydrogen is currently produced from fossil fuels at high cost and carbon footprint.

The most crucial advantage Hydrogen has over batteries is its capacity for long-term energy storage, which can compensate for seasonal variation in sunlight hours and intensity in addition to regular day/night PV production intermittence. This kind of system, which uses excess PV-produced electricity to electrolyze water and store the resulting Hydrogen, is economically viable for an off-grid consumer, and at a larger level, would support a fully renewable grid (Pötzinger, Preißinger, and Brüggemann 2015). The installation of excess Hydrogen fuel-cell capacity that engages in response to demand spikes could also solve the spot-price spiking dilemma.

Recently, researchers at Stanford demonstrated 30.0% overall solar-to-electrolysis hydrogen production efficiency over a 48-hour experiment. Since the best PV cell produced to date has 46.0% efficiency, this unprecedented result represents some of the most efficient water electrolysis ever achieved. This success was largely a result of better matching of the electrode voltage to the PV cell voltage (Jia et al. 2016). However, further investment and research are required to make a PV-led Hydrogen economy as efficient as possible. Lithium-ion charge-discharge efficiency is high at 80-95%, while the full Hydrogen electrolysis + fuel cell conversion approach has thus far only achieved documented overall efficiencies of 70% (Pötzinger, Preißinger, and Brüggemann 2015). With more research in parallel with commercial adoption, the promise of Hydrogen as a truly green fuel that requires no more wasteful, heavy batteries could even catalyze rapid expansion of solar power to sectors like aviation where battery storage is not viable.

Policy Recommendations and Conclusion

The last three years of research have demonstrated very favorable lab results and excitement that groundbreaking innovations in efficiency will continue at historical rates – but this does not necessarily indicate that all these technologies are ready for commercial application, so more research is needed to improve PV module, grid, and storage technologies for systems efficiency and longevity.

Now, after the widespread adoption of the Paris Climate Accords, is the best time for the United States to drastically boost funding for solar technology R&D, in the onslaught of increases in demand for reliable, more efficient, and scalable technology (Jäger-Waldau 2017). This will help maintain the US's position as a global leader in climate science research. Government funding is the best avenue for achieving innovation domestically because solar prices are currently too low for private-sector investment in R&D to be economically feasible without external funding. The National Renewable Energy Laboratory (NREL) has already demonstrated its commitment to finding new substrates for PV – they were the organization that first discovered the usage of perovskites in 2012 – so we recommend a two-pronged investment approach of (a) allocating more funding and resources to the NREL and (b) commissioning more National Science Foundation (NSF) grants focusing on aspects of solar energy policy.

Secondly, the United States is falling behind in adoption of the solar technologies its researchers pioneered. It should follow the lead of the European Union in using incentive programs to encourage adoption of renewable technologies by power providers. With country-wide construction of more PV power projects and grid integration of more solar, the technology will also mature further to overcome many of its current shortcomings. Germany has the biggest solar success story of the EU since it began a feed-in tariff (FIT) program in 2001. Feed-in tariff schemes reduce uncertainty and incentivize investment for renewable power producers by guaranteeing a fixed purchasing price for their renewably-generated electricity that begins at a premium to cover initial costs, then decreases over time as the cost of renewable electricity decreases and eventually equals the market rate for electricity. Although taxpayer funds would be necessary to fund a FIT scheme, they would quickly provide economic benefits stemming from a new period of "green growth" throughout the economy as industries modernize and innovate in a switch to renewable energy. Germany's FIT regulations have made it the country with the highest number of solar installations and the world's largest market for photovoltaics (Baran 2015).

Ultimately, given the incredible but not fully-tapped potential of terawatt-ready PV technology and a global attitude oriented towards green energy, the United States should once again establish itself as a state sponsor of innovation where it will create economic prosperity and a cleaner future.

1739 words

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