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as the other solutions are viable only under specific conditions. Yet batteries are no panacea.

Although many battery technologies are currently being pursued, none of them appears capable of offering both high efficiency and low cost. (Ultimately, we expect that costs for storing solar-PV-generated power will add from $0.04 to $0.06 to the overall cost per kilowatt-hour in 2015; by 2020, we expect this cost to fall to $0.03 to $0.04.)

Efforts are also under way to enable a more flexible grid system comprising various upgrades that in aggregate are often referred to as a "smart grid." (See the sidebar below.) Although efforts to create a smart grid are advancing rapidly, we do not believe that advanced grid balancing, pricing, and demand-response mechanisms will be fully developed worldwide by 2020.

Despite these challenges, solar PV's explosive growth prospects and ability to claim up to 20 to 25 percent of the total generation mix (if no other intermittent source is present) make it a potential disrupter of the status quo.

Onshore Wind Power: Steady Adoption

Wind is an abundant power source: the global potential for wind electricity generation exceeds total global demand for electricity by a factor of five. Wind is also the most mature of the various alternative-energy sectors, with approximately 140 gigawatts of capacity installed worldwide as of 2009 and an additional 300 gigawatts projected to be installed by 2015. Onshore wind accounts for 99 percent of the total wind capacity deployed to date.

Smart Grid

A Key Enabler for Alternative Energy

A "smart grid" is a collection of equipment, infrastructure, and information technologies designed to optimize the production, transmission, and usage of electricity. Business cases for smart-grid deployment typically combine benefits in the areas of utility cost reduction, generation optimization, and intelligent demand-response management. From the perspective of alternative-energy deployment, it is apparent that two of the most important enabling capabilities of smart grids are improved ability to integrate distributed generation and the ability to implement demand-response programs to improve the management of intermittent generation sources. Both of these are crucial for expanded deployment of wind and solar PV technologies.

To date, deployment of even the basic building blocks of smart-grid technologies—such as advanced metering infrastructure (AMI), or "smart meters"—has been uneven. The U.S. Federal Energy Regulatory Commission's 2008 report showed that AMI adoption in the United States has reached approximately 16 percent for cooperative utilities but less than 5 percent for other utility players.[1] Meanwhile, AMI penetration of European markets is estimated to be approximately 15 percent in total, but Sweden reached 100 percent penetration in July 2009, the first country to do so.

These differences in adoption can be explained in part by examining the major barriers blocking rollout. We believe that the following four barriers are having the greatest impact:

- Questions about the attractiveness of the business case to stakeholders
- Regulatory hurdles
- Implementation challenges
- Concerns about customers' willingness to adopt and sufficiently utilize smart meters

Recouping large up-front smart-grid investments requires pulling multiple value levers simultaneously, and the business cases vary significantly in the extent of their benefits. Our experience shows that although smart-grid technologies can lower a utility's overall cost to serve, returns on individual projects are highly market specific. For example, utilities that have already achieved labor cost savings through prior installations of drive-by or one-way meters lack access to a significant portion of the potential cost savings that smart grids afford.

Regulatory barriers also hinder smart-grid deployment. These barriers range from rate recovery to data privacy

1. U.S. Federal Energy Regulatory Commission, *Assessment of Demand Response and Advanced Metering*, 2008.

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Various forms of subsidies, including production tax credits in the United States and feed-in tariffs in Europe, have been instrumental in the development of the onshore wind industry. Increasingly, however, onshore wind deployment is being driven by its improving standalone economics compared with those of other renewable technologies.

Achieving Cost Competitiveness and Moving Past Subsidy-Driven Growth. Onshore wind generation costs have declined substantially over the years—today, prime wind sites can deliver an LCOE of $0.09 or $0.10 per kilowatt-hour.[45] Given the relative maturity of the technology, cost declines for onshore wind going forward will be incremental in nature and driven primarily by learning curve effects: we expect an approximately 15 percent reduction by 2015, which would drive onshore wind power's LCOE to $0.07 to $0.09 per kilowatt-hour for prime sites and roughly $0.10 per kilowatt-hour for less attractive sites. Onshore wind is well on its way to producing power at rates competitive with traditional energy sources and is rapidly moving beyond subsidy-driven growth.[46]

Overcoming Structural Challenges to Rapid Adoption Once Cost Competitive. Onshore wind is close to moving into a growth phase characterized by greater economic viability. Nevertheless, its adoption will be slowed by several barriers, including transmission limitations and permitting delays. In the United States at the end of 2009,

45. These figures are based on a 32 percent capacity factor (which is defined as the ratio of a site's actual productivity to its potential maximum).

46. This estimate does not account for any additional "balancing" costs that are the result of wind adoption.

and security regulations, data management and usage guidelines, technical standards setting, and rules for the integration of distributed generation and microgrids.[2] Failure to overcome these hurdles threatens to greatly slow smart-grid adoption, and little evidence exists that regulatory bodies are already approaching these challenges with cohesive direction.

Implementation of smart-grid technologies is difficult and can cut deep into utilities' operations and organization. Seemingly simple matters—such as managing data—can be a challenge. BCG's analysis shows that implementing AMI can increase data management requirements by nearly 3,000 times those of traditional meters. Furthermore, complex back-end IT systems must be integrated with new software to ensure smooth operations of functions such as real-time pricing, billing, and customer service.

Concerns about customers' willingness to adopt smart meters and engage sufficiently to realize the meters' potential constitute a fourth barrier to deployment. While smart-grid pilot programs, such as the recent Pacific Northwest GridWise Demonstration Project, have shown positive customer responses at a high level, BCG's recent proprietary customer research points to a much more nuanced picture.[3] It is clear from BCG's research that although most customers are willing to listen to the case for smart meters, it will be a challenge to get customers to buy in and become engaged in the process. For example, 67 percent of the customers we polled believed that smart meters and smart-home tools would help them do a better job of managing their power usage. Simultaneously, 74 percent said that they were concerned about the privacy of their power-usage data, and 70 percent believed that utilities would raise rates as a result of smart-meter deployment.

But large-scale deployment of smart-grid technologies will eventually materialize. And when it does, it will create a powerful tool for lowering energy costs, advancing the deployment of renewable generation sources, and reducing total energy demand. Various industry observers have estimated that demand-side management techniques facilitated through smart-grid technologies could reduce total energy consumption by up to 25 percent, which would not only fully offset the expected growth in energy demand in developed markets but would also satisfy emissions reduction targets for many years. Furthermore, fully developed smart-grid technologies would allow the deployment of greater percentages of intermittent sources, such as wind and solar PV.

2. Rate recovery is the mechanism utilities use to recoup investments in generation and other assets. In the context of a smart grid, which promises to reduce overall energy consumption, rate recovery is a particularly thorny issue: utilities are asked to make investments in infrastructure that will serve to lower their overall revenues.

3. "Capturing the Value of Smart Meters," BCG Working Paper, April 2010.