2 Smart Grid Challenges and Transformations

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Smart grid has numerous definitions and interpretations, which depend on the specific drivers and benefits to each utility, country, and federal goals, and the various industry stakeholders. A preferred view of smart grid is not what it is, but what it does, and how it benefits utilities, consumers, the environment, and the economy.

- The European Technology Platform (comprising European stakeholders and the surrounding research community) defines smart grid as "An electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supply" [1].
- According to the U.S. Department of Energy (DOE), "Grid 2030 envisions a fully automated power delivery network that monitors and controls every customer and node, ensuring two-way flow of information and electricity between the power plant and the appliance, and all points in between" [2].
- The US Electric Power Research Institute (EPRI) defines smart grid as "The modernization of the electricity delivery system so it monitors, protects, and automatically optimizes the operation of its interconnected elements—from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances, and other household devices" [3].

The U.S. DOE's National Energy Technology Laboratory (NETL) established seven principal characteristics that define the functions of smart grid [4]. Table 2.1 summarizes these seven characteristics and contrasts today's grid with the vision for the smart grid.

These seven points have come to define the smart grid for many, although there are variants to the list that emphasize additional points, such as encouraging the deployment of renewable resources in the transmission, subtransmission, and distribution system; the use of sensors and sensory signals for direct automatic control; accelerating automation, particularly in the distribution system; and

TABLE 2.1
DOE Seven Characteristics of a Smart Grid

Today's Grid	Principal Characteristic	Smart Grid
Consumers do not interact with the grid and are not widely informed and educated on their role in reducing energy demand and costs	Enables consumer participation	Full-price information available, choose from many plans, prices, and options to buy and sell
Dominated by central generation, very limited distributed generation and storage	Accommodates all generation and storage options	Many "plug-and-play" DERs complement central generation
Limited wholesale markets, not well integrated	Enables new markets	Mature, well-integrated wholesale markets, growth of new electricity markets
Focus on outages rather than PQ (power quality)	Meets PQ needs	PQ a priority with a variety of quality and price options according to needs
Limited grid intelligence is integrated with asset management processes	Optimizes assets and operates efficiently	Deep integration of grid intelligence with asset management applications
Focus on protection of assets following fault	Self-heals	Prevents grid disruptions, minimizes impact, and restores rapidly
Vulnerable to terrorists and natural disasters	Resists attack	Deters, detects, mitigates, and restores rapidly and efficiently

intelligently (optimally) managing multiobjective issues in power system operation and design. The seven cited DOE elements may be viewed more generically as making the grid as follows:

- *Intelligent:* Capable of sensing system overloads and rerouting power to prevent or minimize a potential outage; of working autonomously when conditions require resolution faster than humans can respond and cooperatively in aligning the goals of utilities, consumers, and regulators
- *Efficient:* Capable of meeting increased consumer demand without adding infrastructure
- *Quality focused:* Capable of delivering the power quality necessary (free of sags, spikes, disturbances, and interruptions) to power our increasingly digital economy and the data centers, computers, and electronics necessary to make it run
- *Accommodating:* Accepting energy from virtually all fuel source including solar and wind as easily and transparently as coal and natural gas; capable of integrating any and all better ideas and technologies (e.g., energy storage technologies) as they are market-proven and ready to come online
- *Resilient:* Increasingly resistant to attacks and natural disasters as it becomes more decentralized and reinforced with smart grid security protocols
- *Motivating:* Enabling real-time communication between the consumer and utility so consumers can tailor their energy consumption based on individual preferences, like price and/or environmental concerns
- *Green:* Slowing the advance of global climate change and offering a genuine path toward significant environmental improvement
- *Opportunistic:* Creating new opportunities and markets by means of its ability to capitalize on plug-and-play innovation wherever and whenever appropriate; moving away from hidden subsidization to support fair and open markets.

Utilities have long been hampered by heavy regulation, modest technology change, and predictable consumer behavior, but utilities are now starting to face the same kind of competitive pressures that have changed other industries. There are significant factors that are currently impacting the traditional business and operating model of utilities, which are helping to realize the smart grid vision, and challenge and transform the electric utility industry. These changes arise due to a convergence of factors, including: more demanding consumers; increased focus on digital technologies; rising cybersecurity threats; and, with the shift toward distributed generation, an increase in regulatory pressure and the number of competitors with the growing popularity of "behind the meter" distributed energy resources (generation and storage), which could impact grid stability. Whether the impacts are potential game-changers and are considered "disruptive" or not, it may get to the point where utilities will need to think about how to disrupt their own business before they are disrupted themselves. This will require not just new technologies and solutions but also innovative thinking around a different grid operating model and changes in the utility business processes.

2.1 FOCUS ON THE GRID-EDGE

Current transmission and distribution grids were designed for the cost-effective, rapid electrification of developing economies. Since the invention of electric power technology and the establishment of centralized generation facilities, the greatest changes in the utility industry have been driven not by innovation but by system failures and regulatory or government reactions to those failures. Smart grid technologies have the potential to be the first true "game-changing" technology since alternating current supplanted direct current in the late 1800s. As an example, the design of today's power system took advantage of the economies of scale through the establishment of large centralized generation stations. Supply and demand are continuously balanced by dispatching the appropriate level of generation to satisfy load. This operating model schedules the dispatch of generation to meet the day ahead forecast load. This supply dispatch model is the predominant method of balancing supply and demand today. One vision to optimize the end-to-end system would entail not just the dispatch of supply but also a complementary dispatch of customer and demand resources, as well as persistent load shaping, such as load-modifying demand response, with pricing programs, such as time-of-use (TOU) rates and critical peak pricing.[1] Currently, generation is matched to supply consumer load plus a reserve margin, and often expensive generating plants are used to satisfy peak demand or supply reserve energy in the case of contingencies.

The utility portfolio of generation and energy resources is undergoing significant change as the impact of various market and legislative forces is felt. Coal provides nearly 50% of the United States' electricity generation at a relatively low average cost. However, its share of electricity generation has been in decline for most of the past decade, while international demand has helped drive its cost steadily upward. While the Energy Information Administration forecasts coal to still produce 45% of the nation's electricity output in 2025, "cap and trade" legislation that constrains carbon emissions will effectively serve as a tax on coal that will necessarily drive producers to revisit and reallocate their fuel portfolio. A reduction in natural gas prices in the US has made it the second largest generation source. Natural gas plants are far cleaner to operate than coal plants and far easier to build than either coal or nuclear plants. Even though no new nuclear plants have been built in the United States in decades, nuclear plants still provide 20% of the nation's electricity at a price point below coal and natural gas. More than 70% of the cost of nuclear energy goes to non fuel operating and maintenance (O&M) expenses, which help to illustrate the plant operation challenges inherent with this power source. Even though nuclear power costs are relatively stable and there is an increasing recognition by environmentalists [5] that its minimal carbon footprint offsets the low probability risk of catastrophic failure, plant construction is exceedingly slow due to regulatory, licensing, and siting issues, as well as increasing competitive pressure from alternative generation options.

Ever-heightening concern about the impact of power plant emissions on the environment and the climate, combined with very favorable government subsidies and mandates in which non-emissive distributed and utility-scale renewables can compete with traditional resources, has led to increased interest in renewable generation sources. Renewable energy accounted for 10% of the nation's electricity generation mix in 2010, with hydro making up the vast majority of this generation followed by wind, biomass, geothermal, and solar. However, every state in the United States has a statewide renewable electricity goal, and twenty-nine states and the District of Columbia have renewable electricity standard mandates, known as RPS (Renewable Portfolio Standards). RPS-type mechanisms have also been adopted in several other countries, including Australia, Western Europe (Britain, Italy, Poland, Sweden, and Belgium) [6], and in Latin America (Chile and Brazil). These mandates vary, but most are stated as a percentage of renewable energy in the generation portfolio by a specified date. These regulations and policies, combined with the potential for federal carbon-constraining legislation and rising fuel commodity prices, and public sentiment that have led companies like Google and Walmart to commit to limiting their greenhouse gas (GHG) footprints, have spurred significant investments in renewable generation. Energy storage technology can have a significant impact on the proportion of wind and solar energy in a generation portfolio. As energy storage becomes increasingly cost effective and scalable, wind and solar energy will be to some extent "dispatchable," and load management will be greatly facilitated. Environmental advocates have long maintained that comparing the relative merits of coal, nuclear, and natural gas (90% of the nation's generation portfolio) alone is fundamentally flawed because it does not include the demand reduction option. Conservation, if viewed as an energy source, can be a suitable and equivalent alternative to a new power plant. The ability to fully leverage this option, however, depends in large part on the following factors: (1) technology that better enables customers to manage and control their usage; (2) rates that send price signals to customers while removing the financial disincentives for utilities to drive demand reduction; and (3) the business model allowing opportunities for utilities to profit from hosting and facilitating the optimization of distributed energy resources.

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[1] Researchers at Lawrence Berkeley Labs estimate that shaping DR resources can be a significant, low-cost resource in California. http://www.cpuc.ca.gov/General.aspx?id=10622.

Large central power plants including environmentally friendly sources, such as wind and solar farms and advanced nuclear plants, will continue to play a major role even as large numbers of smaller distributed energy resources (DERs) are deployed. Various capacities from small to large will be interconnected at all voltage levels and will include DERs, such as photovoltaic, wind, advanced batteries, plug-in hybrid vehicles, and fuel cells. It will be easier and more profitable for commercial users to install their own generation sources, such as highly efficient combined heat and power installations and electric storage facilities. We are proceeding to a world of a decentralized grid, where distributed energy resources can be optimized, and sited at specific customer locations to maximize customer and grid value.

Although distributed generation is on a path to becoming competitive in some markets without subsidies and mandates (e.g., Australia), it still depends heavily on incentives and favorable market rules. Those rules—which are steadily changing in favor of a distributed grid—still create boundaries around what's possible. Even though technology prices are falling, renewable energy (worldwide) is still very heavily subsidized [7]. Subsidies are passed on to consumers in a surcharge, so those consumers who cannot afford to, or are not able or willing to install solar panels, do not receive any credit and are essentially paying more for their electricity. While economies of scale apply to the supply of distributed generation and energy storage technologies (DERs), it does not apply to the collective DER generation of electricity—what will it cost to maintain and operate all the DER units on the grid, and who is going to ensure that the DER units (continually) comply with interconnection requirements or safety standards while economically generating electricity back onto the grid. Even if the DER units are owned, operated, and maintained by a third-party company, the same principles apply. "Behind-the-meter" DER may seem to be an obligatory regulatory requirement and R&D project for now. Until the day-to-day operation of the DER can be orchestrated within the larger grid, the path forward may be more along the lines of larger, community-scale DER units involving the need for third-party and industry partners.

Even with government subsidies, renewable generation and storage are being scaled rapidly by companies such as Tesla Motors and Panasonic. "Energy storage, when combined with solar power, could disrupt utilities in the U.S. and Europe to the extent that customers move to an off-grid approach. We believe Tesla's energy storage product will be economically viable in parts of the U.S. and Europe and at a fraction of the cost of current storage alternatives."—Greentech Media [7]. GE estimates that annual distributed power capacity additions will grow from 142 GW in 2012 to 200 GW in 2020, representing an average annual growth rate of 4.4%. When compared to an average annual growth rate of global electricity consumption of 3.3%, decentralized energy will grow at a rate that is almost 40% faster than demand [8]. Solar PV, distributed storage, electric vehicles, and home energy management platforms are giving many consumers direct technology choice for the first time—enabling third-party companies to erode the market share of incumbent utilities that have mostly operated in a limited competitive environment. In addition, community choice aggregation is exacerbating load defection. For example, Marin Clean Energy now provides service to 250,000 customers within the service territory of PG&E.

As supply constraints continue, there will be more focus on the distribution network and the grid-edge for cost reduction and capacity relief. The smart grid will see an increase in utility and consumer-owned resources on the distribution system. Utility customers will be able to generate electricity to the grid or consume electricity from the grid based on determined rules and schedules. This means that consumers will no longer be pure consumers but both producers (sellers) and buyers of energy ("prosumers"), switching back and forth from time to time. This will require that the grid operates with two-way power flows and create an open market for real time, transactive energy exchange while monitoring and controlling the generation and consumption points on the distribution network in real-time. The distributed generation will be from disparate and mostly variable sources and subject to great uncertainty (at least in the near term until there is greater understanding of, and comfort with, their capabilities that, when aggregated, have the potential to be far more resilient and stable than centralized plants).

From the transmission perspective, increased amounts of power exchanges and trading will add more stress to the grid. The smart grid challenge will be to reduce grid congestion, ensure grid stability and security, and optimize the use of transmission assets and low-cost generation sources.

To keep generation, transmission, and consumption in balance, the grids must become more flexible and more effectively controlled. The transmission system will require more advanced technologies, such as FACTS and HVDC, to help with power flow control and ensure stability. The changes in the generation mix will likely require substantial new transmission growth over the coming decades. Transmission network expansion, especially projects that connect renewable generation to densely populated regions of the country, will help the nation utilize its existing generation fleet more fully while providing stimulus for further investment in additional renewable capacity. However, the transmission network will have additional challenges to cope with, such as the forecasted minimum demand levels for South Australia that show there will be a zero net demand at times on the transmission network by 2023–2024 (in the middle of sunny, minimum demand days) [9].

Monitoring and control requirements for the distribution system will increase, and the integrated smart grid architecture will benefit from data exchange between smarter distribution field devices and enterprise applications. With the focus on the grid-edge, substations in a smart grid will move beyond basic protection and traditional automation schemes to bring complexity around distributed functional and communications architectures, more advanced local analytics, and the management of vast amounts of data. There will be a migration of intelligence from the traditional centralized functions and decisions at the energy management system (EMS) and distribution management system (DMS) level down to the substations and feeders in order to enhance responsiveness of the T&D system. System operation applications will become more advanced in being able to coordinate the distributed intelligence in the substations and feeders in the field to ensure system-wide reliability, efficiency, and security. Smart grid technologies will generate a tremendous amount of real-time and operational data with the increase in sensors and the need for more information on the operation of the system. Real-time pricing and consumer demand management will require advanced analytics and forecasting of the electricity consumption of individual consumers.

While the "cloud" has shown to be a flexible, scalable, agile, and cost-effective alternative to host IT and business applications and platforms, the focus on the "edge" and IoT (Internet of Things) will challenge this centralized, consolidated, and remote computing and data management model. Real-time monitoring, control, data acquisition, and analytics at the grid-edge and in IoT applications will necessitate a different or more advanced approach to today's centralized cloud architecture. This is mostly due to the real-time component requiring computations and communications latency in the order of a few seconds, or in the sub-second range. Add to this the large amounts of data generated and exchanged by edge applications and the IoT, more computing power distributed at the edge of the smart grid will be required and accompanied by an equally effective communications solution. The emphasis will be on locational and real-time processing, interactions, and data exchange. However, smart grid and the IoT will not be the only driver as real-time edge computing is adopted in other industries—consider, as examples, the onerous real-time computing and data exchange in self-driving vehicles and virtual reality. Can edge computing simply be part of the cloud, extended and distributed? Perhaps, but there will be numerous users, interfaces, and systems, possibly with overlapping and interconnected clouds. The solution will need to be more autonomous, and dynamically flexible and agile.

The concepts of "fog computing" and "machine learning," therefore, lend themselves well to the grid-edge and the IoT in order to reduce the amount of data exchanged between devices and communicated to centralized, enterprise-level applications and systems, especially if low data latency is critical. Fog computing, also known as fog networking or fogging, is a decentralized computing infrastructure in which computing resources and applications are distributed in the most logical, efficient place at any point along the data source continuum [10]. The goal of fog computing is to improve computational and communications efficiency by reducing the amount of data that needs to be transported to a central location (or to the cloud) for storage and analysis. The choice of the word "fog" is meant to convey the idea that the advantages of cloud computing should be brought closer to the data source—in meteorology, fog is simply a cloud that is close to the ground. Machine learning is the ability of computing devices to learn and adapt their operation through experience in their specific application, without being specifically programmed [11]. Therefore, machine learning allows computing devices to find hidden insights without being explicitly programmed where to look. Fog computing and machine learning at the edge may also need to take on dynamic characteristics—locational and collective computing and communications resources that could be dispatched, shared (communal), or leased from nearby third-party devices and IoT participants in order to help in times of increased computing and communications demand—much like "crowdsourcing" or a "flash mob," borrowing from social media terms.

2.2 NEW MARKET DYNAMICS

The increase in renewable penetration will soon have significant impact on the operation and stability of the grid. This will require grid operators to look for new alternatives to mobilize large amounts of "flexible controllable reserves." These reserves have historically been conventional generation assets operating in idle as "spinning reserve"; however, these are no longer sufficient, which is encouraging grid operators to look for new alternative resources, composed of flexible demand as well as new portfolios of storage technologies directly connected to the grid or at a consumer premise behind a grid meter. In California, however, regulators are not leaving it up to utilities to decide whether this approach is suitable for them. Instead, to support the growth of energy storage developers, the state's Public Utilities Commission (PUC) has mandated that utilities purchase a predetermined amount of energy storage capacity and that a company other than the utility must own more than half of this capacity, and has approved vehicle-to-grid integration pilots specifically designed to enable day-time EV charging at workplaces to store solar-sourced generation. Concurrently, residential ratepayers are already being given the option of TOU rates that offer low prices at midday to align demand when solar and wind generation curtailment has already become routine [12].

The smart grid will link buyers and sellers together—from the consumer to the regional transmission organization (RTO)—and all those in between. With a dynamic distribution grid and new markets for transactive energy, utilities will become empowered to serve as energy clearing houses and address consumer demand with optimal sources of supply. It will facilitate the creation of new electricity markets ranging from the home EMS at the consumers' premises to the technologies that allow consumers and third parties to bid their energy resources into the electricity market. Consumer response to price increases felt through real-time pricing will mitigate demand and energy usage, driving lower-cost solutions and spurring new technology development. New, clean, energy-related products will also be offered as market options. The smart grid will support consistent market operation across regions. It will enable more market participation through increased transmission paths, aggregated demand side management (DSM) initiatives, and the placement of energy resources including storage within a more reliable distribution system located closer to the consumer. As a consequence, the management of the end-to-end energy value chain is currently evolving from the optimization of limited numbers of generation units whose marginal costs were historically largely dependent on their fuel long-term sourcing strategy toward the provision of coordination services for millions of distributed subsystems capable to produce at zero marginal cost when renewables are available and flexibly consume and store energy when economics justify it. Grid operators will seek new contractual arrangements to define their role and responsibility into the overall system balancing and stability management. This is fundamentally changing the energy market structure enabling such transactions, requiring, on the one hand, to open toward prosumers transacting energy peer to peer with each other, as well as to reconsider the way real-time prices are formed to reflect renewable intermittency, demand elasticity as well as storage cycling capability.

At the prosumer aggregation level, virtual power plants (VPPs) will be introduced to aggregate flexible resources from the lowest levels of the grid into the energy market mechanisms operated by the transmission and distribution grid operators. This design has indirectly redefined the roles of both grid operators in this process considering distributed energy resources have both impact on distribution network congestions and constraints (primarily voltage related) and transmission network balancing (primarily frequency related). Considering the regulatory model already in place for wholesale transactions (positioning the grid operator as a regulated monopoly), new market-based interactions have been considered to source flexibility from deregulated market participants. The underlying optimization is performed through the design of an auction mechanism allowing grid operators to source their flexibility at minimal costs while managing controls to prosumers through transactive price signals [13].

There are many questions around distribution grid access for DERs and transactive energy. If a consumer generates electricity to cover most of their needs, but requires power from the grid for only a few times a month, how should the consumer be charged to ensure that the utility is compensated for providing the grid connection service—should it be a fixed connection charge, or a different (higher) kWh rate for the small amount of energy that the consumer received from the utility grid? This is without considering net metering. If the utility does not need the additional power, why should they buy it back from the consumer? What about a charge for the consumer using the utility grid as a backup supply when the consumer does not require additional energy from the utility grid (stranded assets)? What happens if the distribution grid is congested, who has priority to generate or supply energy back onto the grid (or transact energy with another consumer) versus another DER owner, and how will the DER owner be held to any type of energy supply or demand agreement (for availability of the resource), especially when operation and maintenance is the responsibility of the consumer? Also, what happens if a consumer has a transactive agreement to supply or consume energy from another "prosumer," and either party does not hold up to their supply or consumer agreement, and then the distribution grid must supply or consume the additional power, how is everyone compensated? Are these transactive agreements on an energy or demand basis, and how are the transactive agreements or contracts administered and upheld?

With the change in grid-edge dynamics and open market energy exchanges, utilities will need to create an optimized grid with interoperable standards, but this will only be possible through a long-term commitment to partner with both peers and competitors. Engaging with regulators will be essential to redesign the market, using performance-based models that work for all its participants. Early successes are likely to play a role in establishing industry-leading standards; in the long run, they will separate winners from losers. To make this concept a reality, data must be integrated seamlessly into operations, with a customized customer platform at the front end. Electricity companies will need to accept that payback for investments in optimizing the grid may only materialize in the long term [14].

2.3 THE DIGITAL TRANSFORMATION

"The promise of digital transformation is huge. From grid management to customer relations, an effective digital strategy can revolutionize all areas of the power utility business. It's at the heart of the energy transformation challenge."—Norbert Schwieters, PwC's Global Power & Utilities Leader [15].

The smart grid would not be complete without an equal focus on the digital transformation of utilities—data, processes, and business models. Digital technologies can provide unparalleled opportunities for value creation and sweeping transformations across multiple aspects of an industry. While, clearly, digital technology will transform most industries, there are several challenges specific to the utility industry, such as the pace of changing customer expectations, cultural transformation, outdated regulation, and identifying and accessing the right skills—to name just a few [14]. There are several key areas where advanced and digital technologies can significantly transform the utility.

2.3.1 Operations

For decades, utilities have used remote sensing and communications technologies, such as supervisory control and data acquisition, to optimize their generation, transmission, and distribution systems. While the concept of operational efficiencies is relatively obvious, the notion of informational efficiencies is not as apparent. Smart grid devices, from AMI technology to distribution automation components, are essentially various forms of grid sensors that will generate an enormous amount of data. Furthermore, customer-owned devices behind the meter will also be capable of producing data that can facilitate both the integration in a smart grid as well as the conception of new products and services that will build the foundation for the working smart grid and commercial models that serve as base to its operation. Digital technologies will increase the number of sensors and amount of data that utilities must manage by one or two orders of magnitude. The opportunity to understand how energy is consumed closer to the consumer grows bigger—but so does the challenge of extracting meaningful information from volumes of data—turning big data into smart data [16].

The utilities that can develop the analytical infrastructure necessary to transform these data into actionable information, and eventually into decision-making knowledge, will be able to better plan and manage their assets—which will translate into meaningful process improvements, such as better repair/replace decisions or highly targeted preventive maintenance programs. As utilities further mine these data, optimization of distribution network performance based on near real-time (as opposed to historical) information becomes possible.

Grid optimization is possible through real-time load balancing, network controls, and end-to-end connected markets, enabled by connected assets, machines, devices, and advanced monitoring capability. Evolving to the digital grid requires reconsidering the way control principles have been architected to enable bi directional communication and power flow across generation sources (conventional and renewable), managing energy storage on the utility side and consumer side of the meter, as well as dynamic control of flexible loads. This requires reinventing how transactions are managed along the energy value chain—expanding current wholesale energy markets developed at the transmission level into new distribution level markets, and down to the prosumer. Digital grids will ultimately allow new regulatory options by bringing new choices and incentives to electricity consumers and prosumers, exposing them to real-time electricity prices. New digital grid technologies enable the real-time assessment of grid congestion, security, and asset conditions, through the deployment of sensors, controllers, and computers distributed throughout the grid infrastructure, from centralized control rooms to the grid-edge and the consumer. These new architectures will combine centralized IT processing on premise (at the utility) or in the cloud depending on data and process criticality with distributed intelligence deployed throughout the architecture [13].

Digital and mobile tools can also help to improve efficiency and effectiveness of field operations. For example, utilities can improve outage management by pinpointing which customers are experiencing them (integrating advanced metering infrastructure, social media, text messages, and other data), directing resources toward restoration (through traditional distributed and outage management systems, mapping, and GPS), and communicating with customers. Technology solutions can also enable real-time, remote-control, or predictive maintenance to extend the life cycle or operating efficiency of the generation, transmission, or distribution assets and infrastructure.

2.3.2 Convergence of Operational and Information Technologies (OT/IT)

OT/IT integration is not just happening within technology hardware and software but also within the company's functional organizations. These two groups and sets of activities have been converging for some time, but smart grid greatly accelerates that convergence and forces some organizational decisions. For a utility to be successful, it would not be sufficient for IT to simply manage the back-office integration of business systems (the typical purview of most such groups). The technology being deployed in the field via smart grid in many ways bears a greater resemblance to the technology that IT groups have been supporting than it does to what operations technology groups have been supporting. The most successful utilities, if they have not done so already, will find a way to integrate the best of both by:

- Adopting a smart grid patch management process that leverages a tried and true IT process for devices and systems specifically out "in the field."
- Leveraging the capabilities of those responsible for the corporation's data network and bringing that skill base to bear on smart grid communications infrastructure challenges.

- Building a network monitoring process that establishes common visibility to all mission critical systems and networks, whether the systems and networks are in the data center, system operations, a substation, a remote facility, or any other grid-attached location.
- Interconnect with customer devices or with aggregators that manage them in order to bring the visibility of those resources that support the grid to the centers of decision so they are able to operate with the grid and derive value.

2.3.3 Customer Engagement

Industry leaders agree on the need to make deeper customer engagement a priority and the pivotal role of digital technologies in making this a reality. Personalized connected services beyond the electricity value chain ("beyond the electron") are required that adapt to the consumer so that electricity can move from being a commodity to becoming an experience [14]. Mobile, social, and web interfaces give customers a better view of their energy use and enable richer two-way communication between the utility and customers. They also improve the ability of utilities to test and deliver new capabilities, such as customized rate plans based on individual customer usage and needs. Digital technology opens the way for new energy products and services, but utilities will also need to change in order to make the most of these new opportunities. For example, inexpensive sensing and communications technologies will support a range of energy management services from residential smart homes to large commercial and industrial energy efficiency programs. But utilities will need to develop new capabilities to research, develop, market, and support these new services. Utilities will also need to improve their ability to innovate and experiment to help determine which offers make the most sense given their regulatory landscape, competitive markets, and customer base. Mobile is also enabling new business scenarios, while social channels are transforming the ability to connect with customers quickly, directly, and cheaply.

Digital technology also offers utilities both cost-to-serve efficiencies and improved customer intimacy; crowdsourcing, online forums, and wikis all offer ways for companies to learn about customers' views and buying behaviors, at the same time improving brand engagement and loyalty. In addition, instant messaging and mobile applications extend the concept of self-service by allowing people to book appointments or analyze energy consumption patterns in new, easily accessible ways.

The smart home, which integrates features such as security, entertainment, and energy management, is a prime example of the sort of new service enabled by new technologies in sensing and communications. Utilities operating in competitive retail environments can view the smart home as a premium service offering, and a way to improve customer loyalty. UK utilities have bundled premium residential services for years to improve customer loyalty and reduce churn. While it's still early for smart home services, they are likely to bring some of the same benefits to utilities across North America and Europe [16]. To succeed in the smart home space, utilities will need to navigate a complicated ecosystem of platform providers, subscription service providers, and hundreds of device manufacturers. The same applies to the commercial and industrial sectors with original equipment manufacturers offering energy efficiency solutions. Here, too, utilities will need to partner with the right subset of players to tailor offerings to their business and regulatory environments, and test and scale across their customer bases.

Cloud computing is improving business agility, with a time-to-market advantage. Big data is helping companies innovate, with the capability to analyze large quantities of both structured and unstructured data, generating insights in real time. With the emergence of the IoT, the volume of data that electricity companies can access—through the car, connected home, wearables, and smart cities—will increase exponentially [17]. As machine-to-machine or peer-to-peer communications become more prevalent, the interaction and integration of data, applications, people, and organizations will have a far-reaching impact on the utility.

By leveraging the building blocks of digitization, such as service platforms, smart devices, the cloud, social and mobile technologies, and big data and advanced analytics, utilities could increase the asset life cycle of infrastructure, optimize electricity network flows, and innovate with customer-centric products. Yet, the maturity of digital initiatives in the industry varies: from projects using advanced analytics to optimize assets and the widespread implementation of smart meters, to early moves by some utilities to manage and integrate distributed generation resources. Over the coming years, these technologies will combine to deliver a new layer of connected intelligence. It will revolutionize the ability of electricity companies to improve the efficiency of the electricity system and better meet their customers' diverse needs [16]. To realize these digital opportunities, utilities need to transform operations. To begin, they must develop a digital transformation strategy that can be successfully embedded and scaled in the organization. It should be designed around the company's existing value drivers and strengths, including the product portfolio, technical competence, and customer proximity.

The next digital grid business era is not only a matter of technology and change management but also a matter of establishing the right business framework across the energy value chain to enable the necessary transformation. This future framework should consider modernized market design, revisiting market mechanisms across the energy value chain, while leveraging latest market clearing approaches to properly price scarce grid flexibility in real time. The framework should favor the deployment of innovation on both regulated and unregulated domains of the energy value chain taking advantage of the latest digital technologies to lower the cost and barrier to real-time data access. Regulation should favor the development of the new digital grid.

By their very nature, digital transformations also bring about a cultural shift. The business horizons for utilities have traditionally been of long- or medium-duration and for good reason. The industry is based on the use of expensive assets requiring serious investment and taking account of regulatory factors [18]. With the rise of distributed generation, alternative energy sources, and the data-driven customer interface, utilities are intersecting an information-based digital economy. Here success depends on new capabilities, especially the rapid scaling of innovations. As they plan to meet the digital challenge, utilities can, fortunately, draw on a wealth of experience from recent change programs in diverse industries.

The maturity of digital initiatives in the electricity industry is varied—from projects using advanced analytics to optimize assets and the widespread implementation of smart meters, to early moves by some utilities to manage and integrate distributed generation resources. To illustrate, 43% of utilities are currently investing in digital technologies as part of their overall business strategy, indicating a mixed approach [19]. The investment required for the adoption of smart and digital technologies presents utilities with difficult choices [20]. For those who do not plan to utilize digital technologies, there will be doubt regarding their ability to succeed with the smart grid transformation and market changes. For some, there is the option of using digital to make tactical improvements to their existing businesses, by streamlining operations and reducing the cost to serve and cost to acquire, and to get closer to customers. Finally, there are those utilities who will embrace digital technology as the way to transform their business. They will create competitive advantage through digitally enabled cost-effective operations, expand their scope of services to new markets, and use the smart meter as a platform to gain further traction in the smart home of the future. For today's consumers, digital technology is mainstream, as their accelerating adoption of online connectivity and social media demonstrates. With new entrants keen to enter the market, and smart metering offering them a way to do so, utilities are facing the last chance to innovate and stay ahead. To be successful, energy companies must show they can change how they operate, switching from being an "energy supplier" to an "energy services provider."

2.4 CONSUMER PERCEPTIONS AND EXPECTATIONS

Although consumers are becoming more aware of climate change and energy efficiency, the majority are not aware of the necessity to evolve electricity networks as a means of reducing emissions.

The integration of demand side resources in the form of renewable energy and consumer demand management will, in many cases, require making the existing network stronger and smarter, and require the building of new infrastructures. The public may negatively perceive changes in their electricity experience, particularly if it is accompanied by rising bills or tariffs they do not wish or feel incentivized to uptake.

Stakeholders do not see a “burning platform” or a case for change. The societal consequences of inaction (i.e., not modernizing the grid) have not been clearly articulated to our diverse group of stakeholders. A lack of understanding of the fundamental value of a smart grid and of the societal and economic costs associated with an antiquated one has created the misperception that today’s grid is good enough or at least not worth the sacrifices involved in improving it. Even the inconvenience and cost of infrequently occurring large-scale blackouts are quickly forgotten. To secure customer and regulatory support for increased investments in a smart grid, the benefits must be apparent and the risk of doing nothing clear. More work is needed to communicate the concepts and benefits of the smart grid to a wide variety of stakeholders, especially consumers, and to encourage them to embrace the changes that will be needed to achieve the smart grid vision. Smart grid should also be seen in the eyes of the customer, not just the utility industry, and in terms of moving from customer to consumerism. But the utility industry also should understand customer trends and let those guide their roadmaps in what concerns the planning for the smarter grid. Effective consumer education is still lacking. The benefits of a smart grid have not been made clear to consumers. Some potential components of the consumers’ value proposition include

- More effective monitoring and control of energy consumption to reduce overall electricity costs
- Participation in future electricity markets for distributed generation and demand response
- Enjoyment of future value-added services that may be enabled by a smart grid
- Customer situational awareness to enable, e.g., price-to-devices strategies and associated prosumer opportunities

Public perception can create a key barrier to implementing policy and accelerating smart grid deployment. This is especially the case in open- and competitive-leaning markets that consult widely on policy implementation. Public pressure against a perceived societal disadvantage can force policy abandonment. For example, in the Netherlands, the rollout of smart meters was quashed by a small but vocal group concerned about the increased level of personal information that the meters would provide. Conversely, public sentiment, such as a desire to green the electricity and transport sectors, can be directed to support smart grid. Utilities should educate customers before any technology deployment, and budget for costs in significant customer outreach and education. They should be ready to pass through AMI data, along with tools and incentives for customers to manage their onsite energy production, storage, and use—including the ability to safely share their data with third-party entrepreneurs. Customers should understand the real-time price of energy and services they consume, and deliver, to the grid. Ultimately, customers should pay—and be paid—that price (locational marginal pricing [LMP] or another agreed upon market signal). Pilots such as PowerCentsDC [21] have shown consumer enthusiasm for TOU rates when they are carefully designed to provide choice and to help customers understand pricing options.

Consumer protections on disconnection and low-income assistance should be provided at the same or improved level, and investment and technology risk should be shared by utilities and their customers. Where customers do pay upfront for these investments, with surcharges or other riders, utilities should be held accountable for delivering the promised benefits. For instance, the California PUC included in its approval of a surcharge the requirement that utilities share projected operational savings—whether realized or not. That is, eight months after the cost of the meter is included in the customer’s bill, the Investor-Owned Utilities (IOUs) must credit customers $1.42/month in operational savings, even if the utility has not realized those savings. Cost recovery mechanisms that reward over-performance will incentivize utilities to seek out the most effective solutions.

Consumer involvement is a required ingredient for grid modernization, and consumer education is the first step in gaining their involvement. Much remains to be done in the area of consumer education. The not in my backyard (NIMBY) philosophy must be resolved to reduce the excessive delays experienced today in deploying needed upgrades to the grid. Solutions are needed to reduce the concerns of citizens who object to the placement of new facilities near their homes and cities. New ideas are needed to make these new investments desirable rather than objectionable to nearby citizens. Communication of the smart grid vision with its goals of improving efficiency and environmental friendliness may help address this issue.

The active participation of consumers in electricity markets will bring tangible benefits to both the grid and the environment. The smart grid will give consumers information, control, and options that allow them to engage in new "electricity markets." Grid operators will treat willing consumers as resources in the day-to-day operation of the grid. Well-informed consumers will have the ability to modify consumption based on balancing their demands and resources with the electric system's capability to meet those demands.

Digital transformation is helping create a more engaged and efficient electricity consumer, while also ensuring they spend less time thinking about the power bill. Utilities will see engagement increase as customers have more options and take more control of their energy sources, whether it's from their own solar panels or whether they participate in a demand response program. Customers will be more engaged and have more control, but they do not need to be as hands-on as they have been in the past. The question of just how much interaction consumers want with the power company is a difficult one. For many consumers, the utility is something best forgotten until rates rise or the lights go out. But utility offerings, when targeted and delivered efficiently, also make for happier customers [22]. Most utility companies are trying to put themselves in front of their consumer base with the options of contacting the utility whenever or wherever the consumers feel are in their best interest [23]. Besides customer service offerings, there are other impactful offerings like demand-side management, load control, and efficiency. J.D. Power reported that more than three-quarters of utilities are increasing investment in customer engagement [24].

Now, with IoT and the increase in data and analytics capabilities, utilities have the advantage of customer insight that can be used to sell in adjacent categories, starting with energy saving and energy production. According to Utility Dive [22], over 70% of utilities consider that billing and customer support are the top ways their utility engages with consumers, followed by outreach, conservation tips, energy usage data and service offerings. Whether it's through the smart meter or other mechanisms, utilities can proactively inform customers and households how they're using energy today, suggesting how to save more and programs they may find valuable. J.D. Power reported [23] that overall utility customer satisfaction is higher primarily due to improvements in corporate citizenship and outage communications. But the results also showed the rate of improvement lagged as similarly demonstrated in utility business models, such as communications and television services.

2.5 OUTDATED POLICIES AND REGULATIONS

To meet operational challenges, the industry is looking toward new technology while still relying on much that is a century old. However, the expectations of the end user have changed dramatically. Increasingly, utilities are attempting to build regulatory support—with mixed results—for smart grid investments. Utilities may find that these operational challenges cannot be met through new technology unless accompanied by increased investment in core technology. Investment, particularly in transmission infrastructure, has been far outpaced by load growth—significantly so in certain parts of the country—due, in large part, to difficulties in getting projects of this magnitude planned, approved, permitted, and funded.

The industry is returning to its reliance on rate cases to secure the level of revenue necessary to maintain a vital component of the national infrastructure but is doing so without the same level of regulatory support it enjoyed prior to deregulation. While rate case frequency has increased, the average awarded return on equity for shareholder-owned electric utilities in the United States has declined steadily. This reflects, in part, the industry's mixed success in rebuilding the regulatory relationships damaged by deregulation initiatives that either failed to generate the expected results or were outright disasters. Rebuilding trust will be essential, whether seeking approval for new technology or simply reaching reasonable outcomes on rate cases. Going forward, the trend is for utilities to submit rate cases far more frequently to regulators than in the recent past. These regulatory discussions are also increasingly turning to matters of technology that could provide enhanced service to customers, including the ability to manage their usage more proactively.

"The thing that keeps me awake at night is the regulatory model is outdated. We're going to get burned by that at some point if we don't start thinking about how we change that regulatory model sooner rather than before it's too late," said Sunil Garg, SVP & Chief Information & Innovation Officer, Exelon Corporation [15].

Some consider the biggest impediment to the smart electric grid transition is neither technical nor economic. Instead, the transition is limited today by obsolete regulatory barriers and disincentives that echo from an earlier era [24]. Public policy is commonly defined as a plan of action designed to guide decisions for achieving a targeted outcome. In the case of grid modernization, new policies are needed if truly integrated smart grids are to become a reality. This statement may sound dire, but, in fact, work is under way in several countries to encourage smart grids and smart grid components. However, the risk still exists that unless policies are modernized to reflect changing grid participant roles and responsibilities, smart grid investments may fall short. This would be an unfortunate outcome when one considers the many benefits of a true smart grid: cost savings for the utility, more choices and better value for customers, improved reliability, and increased environmental stewardship.

The rapid expansion in the penetration of various forms of distributed energy resources and interest in improved local resiliency, through approaches like microgrids, illustrates the fascination many consumers and policymakers have with the interplay between the electric grid and the climate. That said, consumers largely lack a robust understanding of the integral role the smart grid plays in managing the new complexity inherent in a more distributed energy model.

Meanwhile, policymakers face a difficult trade-off between (1) being sufficiently directive to provide clarity to companies on the future shape and rules for the market and (2) providing sufficient incentive for companies to invest in innovative technologies and services. Utilities must establish a positive dialog with regulators to ensure that the industry and market are redesigned so that they work for all participants, and achieve the essential objectives of decarbonization, decentralization, and digitization. The regulation pertaining to the grid-edge is rapidly evolving; the implications of distributed energy resources and their integration into the market are likely to shape and affect the digital regulation outcomes. Equally, the evolution of discussions relating to grid defection has a big role to play in how "connected" and "effective" the future system can be, with a more disconnected system potentially less optimal than a fully connected and optimized system.

While regulation can help in implementing smart grid technologies, regulatory structure and other factors can create revenue uncertainties. If a company is required to invest in smart grid technologies, the revenue model must align with the associated costs and benefits. Yet, many policymakers are resistant to the new mechanisms needed to properly align rate designs with the evolving costs associated with building and maintaining an integrated smart grid. Perhaps, the most glaring, and often quoted, disparity between current revenue drivers and smart grid drivers in many markets is the link between revenue and throughput. If smart grid technologies are successful, energy efficiency measures will be supported that will reduce throughput. In this common scenario, without appropriate regulatory adjustments, the company would be investing to reduce its own revenue. To restructure the regulatory model to address issues such as revenue assurance, both utilities and policymakers need a broad understanding of the primary role that smart grid technologies can play in meeting energy and environmental policy. This understanding will help them define a suitable regulatory regime that can align utilities' rewards with the benefits that their investments bring.

Incentives to stimulate smart grid investments that provide societal benefits are lacking. Regulatory policies often do not give credit to utilities for investments that provide substantial societal benefits (e.g., improvements in reliability and national security, reduction in our dependency on foreign oil, reductions in environmental impacts). Regulators play a vital role in ensuring that customers' interests are reflected in the decision-making of the service provider. As such, regulators are a critically important gatekeeper in a smart grid project life cycle. This is particularly important for AMI, which (1) is a technology that fundamentally transforms the utility-customer relationship, and (2) offers potential benefits that cannot be realized without changes in customer behavior. To the latter point, the most obvious examples are the innovative rate structures, such as critical peak pricing, which can leverage AMI technology to drive beneficial changes in customer usage patterns. To maximize their value, smart meters require smart rates, and smart rate design requires detailed dynamic pricing discussions among utilities, regulators, and customer advocates. Effective collaboration among these groups will result in programs and pricing tailored appropriately to the customer segments being served. Progress is being made to bring clarity to roles and align costs and incentives as evidenced by recent actions taken in a few leading states in the US, such as New York, California, Minnesota, and Massachusetts. While these states show that progress is under way, most energy companies and the communities they serve are still operating under policy structures that have not kept pace with advances in technology. These lagging policies result in market uncertainty regarding how the overall market structure and rules will develop, which technologies merit investment, and the levels of grid capability required.

2.6 SECURING THE VULNERABLE GRID

The smart grid will need to incorporate a system-wide solution that reduces both physical and cyber vulnerabilities and enables a rapid recovery from disruptions. Its resilience will need to deter would-be attackers, even those who are determined and well equipped. Its decentralized operating model and self-healing features will also make it less vulnerable to natural disasters than today's grid. Security protocols will contain elements of deterrence, detection, response, and mitigation to minimize impact on the grid and the economy. A less susceptible and more resilient grid will make it a more difficult target for malicious acts.

Utility investments in security upgrades have been historically difficult to justify. A standard approach is beginning to develop for conducting security assessments, understanding consequences, and valuing security upgrades. NIST (National Institute of Standards and Technology) has developed security assessment models, for example, that are being adopted in many utilities [25]. While there have been recent legislative changes, there is still very limited access to government-held threat information, which makes the case for security investments even more difficult to justify. When examined independently, the costs and benefits of security investments can seem unjustifiable. It is difficult to place a value on preventing a cyber or physical attack through implementation of security measures. However, the consequences of cyber attacks on critical infrastructure have been more widely discussed in the public, and with the growing awareness of the risks, utilities are increasingly being asked to demonstrate their cybersecurity programs' effectiveness.

Various cybersecurity intrusion studies have demonstrated the vulnerability of communication, automation, and control systems to unauthorized access. Many real-world cases of intrusion into critical infrastructures have occurred, including illegal access into electric power systems for transmission, distribution, and generation, as well as systems for water, oil and gas, chemicals, paper, and agricultural businesses. Confirmed damage from cyber intrusions include intentionally opened breaker switches and the shutdown of industrial facilities. Very few of the incidents have been publicly reported, and initiatives aimed at creating an open repository of industrial security incidents encounter resistance. Threats come from hackers, employees, insiders, contractors, competitors, traders, foreign governments, organized crime, and extremist groups. These potential attackers have a wide range of capabilities, resources, organizational support, and motives.

The possible vulnerability of the utility's system, business and customer operations, and consumer premises represent serious security risks; therefore, security must be approached and managed with an extreme level of care. Apart from active, malicious threats, accidental cyber threats are increasing as the complexities of modern data and control systems increase. Security risks are growing in diverse areas, including the following:

- Risk of accidental, unauthorized logical access to system components and devices and the associated risk of accidental operation
- Risk of individual component failure (including software and networks)
- Number of failure modes, both directly due to the increased number of components and indirectly due to increased (and often unknown) interdependencies among components, devices, and equipment
- Risk of accidentally misconfiguring components
- Failure to implement appropriate maintenance activities (e.g., patch management, system housekeeping)

Worldwide, initial security gaps have been highlighted by security companies and were discovered within pilot projects, which are not designed to resist sustained cyber attack. While such systems are now broadly secure against elementary hacking techniques, situations where an insider, who knows the system, can exploit the vulnerabilities are of concern to smart grid technology stakeholders. All parties involved in managing network operations centers or the relevant IT systems should be trained and alert to tamper from the inside. Specially trained security officers need to be working in all potentially vulnerable areas.

Open communication and operating systems may be vulnerable to security issues. Although open systems are more flexible and improve system performance, they may not be as secure as proprietary systems. The increasing use of open systems must be met with industry approved and adopted standards and protocols that ensure system security.

A utility needs to define its own selection of security controls for system automation, control systems, and smart devices, based on normative sources and as appropriate for the utility's regulatory regime and assessment of business risks. The security controls need to be defined within each security domain, and the information flows between the domains need to be based on agreed risk assessments, established corporate security policies, and possible legal requirements imposed by the government. In addition, limitations related to the existing legacy systems must be accommodated in a manner that does not hamper organizational security. Emerging smart grid systems and solutions should be thoroughly tested by qualified laboratories to ensure that new digital communications and controls necessary for the smart power grid do not open new opportunities for malicious attack. The responsibility for this security rests with all market participants—both industry and governments.

The idea of extending an Internet protocol (IP)-based network to the meter level does open the potential for both internal and external hacking. To protect against those threats, the structure of the system architecture should be considered carefully. By having a distributed intelligence in the grid, we mitigate a single point of failure, but also increase the complexity of management. Every utility thinking about providing equipment and services for smart grid technology enterprises should be cognizant of security and standards, with thought given to security certification for hardware and software providers.

The massive amount of potentially sensitive data collected in a smart grid, particularly with the implementation of consumer technologies, offerings, and services (e.g., advanced metering infrastructure [AMI] and DSM), inherently creates data privacy and security risks. Consumer involvement applications and solutions put privacy interests at risk because information is collected on energy usage by a household or business. With granularity, down to fifteen minutes and less, meters already collect a unique meter identifier, timestamp, usage data, and time synchronization every fifteen–sixty minutes. Soon, they will also collect outage, voltage, phase, and frequency data, and detailed status and diagnostic information from networked sensors and smart appliances. Interpreted correctly, such data can convey precisely whether people were present in the home, when they were present, and what they were doing. Utilities implementing consumer technologies, offerings, and services within a smart grid environment that fails to address these issues will encounter consumer and political opposition, restricting their ability to realize the economic promise of smart grid technologies. They may face angry regulators and customers as well as liability issues.

In the consumer context, the right to privacy means the consumer's ability to set a boundary between permissible and impermissible uses of information about themselves. What is impermissible is a matter of culture, as expressed in law, markets, and what individuals freely accept without objection (i.e., consensus values). If customers believe a utility is misusing personally identifiable data or is generally enabling the use of personal information beyond what they deem acceptable (whether legal or not), then they are likely to resist the implementation of vital smart grid functionality related to consumer offerings and services. Consumers may refuse to consent (where required), hide their data, or awaken political opposition. Utilities may face customer liability claims or regulatory fines if inadequate privacy or security practices enable eavesdroppers, adversaries, or bad actors to acquire and use collected data to a customer's detriment. Utilities must take into account privacy and security concerns when designing consumer technologies, offerings, and services, and must persuade consumers, regulators, and politicians that privacy interests are adequately protected.

What constitutes permissible uses of personally identifiable information varies from culture to culture and over time; yet, what goes on inside a residence is generally an area of special privacy concern. The collected data reveal more about what goes on inside a residence than would otherwise be known to outsiders, and the collection and use of such data would reduce the scope of private information. Although privacy is generally considered a personal right, businesses typically have analogous rights.

Once a utility establishes the permissible uses of consumer data, it is in its best interest to assure that unauthorized uses do not occur. For example, if an electricity service provider can sell appliance-related data to a manufacturer or retailer, the utility will want to protect its economic interest by preventing access or use by others who might become competitive data brokers. Every utility will want to avoid regulatory sanctions for violating express or implied privacy policies, as well as damage claims based on compromised customer data or facilities.

Concerns about data privacy in smart grid environments and AMI are now being widely discussed. In the Netherlands, for example, the formerly compulsory AMI rollout was subsequently made voluntary. The US Department of Energy (DOE), responding to this concern, has created DataGuard, which provides a set of principles that, if agreed upon, would enable the utility to use the DataGuard logo as an indicator of their participation in the program [26]. What is ultimately needed is a secure system for utilities to provide key information to the marketplace at very low transactional costs, but with proper protections, in order to unlock the potential for innovative smart grid-enabled services to be realized.

2.7 CONFLUENCE AND ACCELERATION OF STANDARDS

Global standardization is essential for the deployment and successful operation of smart grids. While progress is being made, challenges remain due to fragmentation among stakeholders in the process of standards development, the lack of well-defined standards for smart grid interoperability, and intellectual property issues. At the same time, standards defined too early risk stifling innovative technological advances.

While smart grid technologies continue to progress, without well-defined and technology-neutral interoperability standards, further innovations and opportunities for deployment at scale are limited. Global cooperation for defining standards has not kept pace with technology innovation and development, which could impede large-scale development and rollout. Therefore, interoperability and scalability should be priorities, while taking care to avoid stifling innovation.

Since smart grid technologies encompass a diverse scope of technology sectors, including electricity infrastructure, telecommunication, and IT, misinterpretation and error may arise where there is a lack of interface standardization and related communication protocols. Therefore, even after standardization of the respective technologies, conformity testing and certification of interoperability may prove problematic for providers, since each technology must go through a conformity assessment specifically designed for the particular technology.

Existing international standards development organizations (SDOs) include the following:

- IEC—International Electrotechnical Commission (www.iec.ch)
- IEEE—Institute of Electrical and Electronics Engineers (www.ieee.org)
- ISO—International Organization for Standardization (www.iso.org)
- ITU—International Telecommunication Union (www.itu.int)

In addition to the SDOs, many country or region-based standard associations influence the smart grid standards community. A key barrier is the lengthy process to develop and reach international consensus on a standard. For example, the average development time for IEC publications in 2008 was thirty months. Even after one of the SDOs has defined a standard, it still must go through the harmonization process.

The smart grid is a large and complex marriage of the traditional electrical infrastructure and modern IT systems. This is truly a global effort involving thousands of utilities and vendors to implement and deploy the smart grid. To complete, a successful and cost-effective deployment of the smart grid "international standards" will have to be followed by all who participate in its deployment. Why do we say this and why are standards so important to success? The following points characterize the importance of standards:

- Shareability—economies of scale, minimize duplication
- Ubiquity—readily utilize infrastructure, anywhere
- Integrity—high level of manageability and reliability
- Ease of use—logical and consistent rules to use infrastructure
- Cost-effectiveness—value consistent with cost
- Interoperability—define how basic elements interrelate
- Openness—supports multiple uses and vendors, not proprietary
- Secure—systems must be protected
- Scalable—low- or high-density areas, phased implementation
- Quality—many entities testing and verifying

The smart grid is broad in its scope, so the potential standards landscape is also very large and complex. Therefore, "standards" adoption has become a challenge. However, the opportunity today is that utilities, vendors, and policymakers are actively engaged and there are mature standards that are applicable and much work on emerging standards and cybersecurity can be leveraged. Technology is not the primary barrier to adoption. The fundamental issue is organization and prioritization to focus on those first aspects that provide the greatest customer benefit toward the goal of achieving an interoperable and secure smart grid. It is critical that we find a process that will accelerate the adoption of new smart grid standards. First, consider the challenges the industry must overcome to accelerate the smart grid standards adoptions:

1. There are many standards bodies and industry committees working in parallel with many duplicate and conflicting efforts. The industry must come together in a concerted effort to accelerate the adoption of the stands on which they are focused.

2. The number of stakeholders, range of considerations, and applicable standards are very large and complex, which require a formal governance structure at a national level involving both government and industry, with associated formal processes to prioritize and oversee the highest value tasks.
3. The smart grid implementation has already started and will be implemented as an "evolution" of successive projects over a decade or more. Standards adoption must consider the current state of deployment, development in progress, and vendor product development life cycles.
4. Interoperability is generally being discussed too broadly and should be considered in two basic ways, with a focus placed on prioritization and acceleration of the adoption of "inter-system" standards.

How can these challenges be quickly overcome?

1. NIST (National Institute of Standards and Technology) should continue its work in developing and coordinating smart grid interoperability standards (https://www.nist.gov/engineering-laboratory/smart-grid/about-smart-grid).
2. Develop a smart grid "road map" that outlines a path and direction of deploying existing and future standards giving the industry clear direction forward.
3. Identify focus areas are as follows:
   a. Common information model
   b. Cybersecurity
   c. Interoperability base on open protocol
   d. Application interface standards
   e. Messaging
4. Governance principal definitions include the following:
   a. Openness
   b. Integrity
   c. Separation of duties and responsibility
   d. Compliance
5. Establish clearly defined test and verification methodologies and certification bodies shall be established to certify compliance with standards.
6. Encourage rapid vendor adoption of established standards.

The grid will become "smarter" and more capable over time and the supporting standards must also evolve to support higher degrees of interoperability enabling more advanced capabilities over time. The implication of the smart grid evolution for standards adoption is that at any point in time the industry will be characterized by a mix of no/old technology, last generation smart technology, current generation smart technology, and "greenfield" technology opportunities. Smart grid implementation is an evolutionary process involving long project development life cycles from regulatory approvals through engineering and deployment. Given that technology life cycles are much shorter than the regulatory-to-deployment cycle, it is very likely that the grid will continuously evolve in the degree to which intelligence is both incorporated and leveraged.

The issue of evolution is particularly important because investments are a continuum based on policy imperatives, system reliability, and creating customer value. Policymakers and utilities must balance these considerations regarding certain smart grid investments before a complete set of standards has been adopted and customer benefit dictates moving forward. In many instances across the nation, utilities and regulators have given much thought to balancing accelerating customer benefits, project cost-effectiveness, and managing emerging technology risks. While there is no single "silver standards bullet" for legacy and projects currently in development, projects that are in the customers' and public policy interest should proceed. However, not having clear standards going forward compounds the technology obsolescence risk.

There is no technical reason to attempt to standardize all aspects of the smart grid today if engineered and designed correctly. Nor is it likely possible, considering the lack of clear definition of all the elements and uses of the smart grid and complexity and given the number of systems involved. Smart grid systems architected appropriately should be able to accept updated and new standards as they progress, assuming the following standards evolution principles are recognized:

- Interoperability must be adopted as a design goal, regardless of the current state of standards.
- Interoperability through standards must be viewed as a continuum.
- Successive product generations must incorporate standards to realize interoperability value.
- Smart grid technology roadmaps must consider each product's role in the overall system and select standards compliant commercial products accordingly.
- Standards compliance testing to ensure common interpretation of standards is required.

These principles are being followed by many utilities implementing smart grid systems today by requiring capabilities such as remote device upgradability and support for robust system-wide security, and identifying key boundaries of interoperability to preserve the ability of smart grid investments to evolve to satisfy increasingly advanced capabilities.

Accelerating smart grid standards adoption can be achieved by focusing industry efforts on the right tasks in the right order. A system's engineering approach provides a formal, requirements-based method to decompose a complex "System of Systems," such as the smart grid, from a high intersystems view through a very structured process to a lower intrasystems view. Applying systems engineering to smart grid capabilities and supporting standards reveals that it is more important to create a unifying design for the entire system operationally than to focus on implementing individual elements at the risk of future systems operations. This means that it is not necessary to first resolve interoperability of "intrasystem" interfaces within the utility's smart grid implementations before projects can proceed. This is true, if the important "inter-system" boundaries are well understood and the following interoperability design concepts are preserved.

2.8 BUILDING THE BUSINESS CASE, MOVING PAST THE PILOTS

All stakeholders must be aligned around a common vision to fully modernize today's grid. Throughout the twentieth century, the electric power delivery infrastructure has served many countries well to provide adequate, affordable energy to homes, businesses, and factories. Once a state-of-the-art system, the electricity grid brought a level of prosperity unmatched by any other technology in the world. But a twenty-first-century economy cannot be built on a twentieth-century electric grid. There is an urgent need for major improvements in the world's power delivery system and in the technology areas. Several converging factors is driving the energy industry to modernize the electric grid. These factors can be combined into the following five major groups.

Policy and Legislative Drivers

- Electric market rules that create comparability and monetize benefits
- Electricity pricing and access to enable smart grid options
- State regulations to allow smart grid deferral of capital and operating costs
- Compatible Federal and state policies to enable full integration of smart grid benefits

Economic Competitiveness

- Creation of new businesses and new business models and adding of "green" jobs
- Technology regionalization
- Alleviation of the challenge of a drain of technical resources in an aging workforce

Energy Reliability and Security

- Improve reliability through decreased outage duration and frequency
- Reduce labor costs, such as manual meter reading and field maintenance, etc.
- Reduce non labor costs, such as the use of field service vehicles, insurance, damage, etc.
- Reduce T&D system delivery losses through improved system planning and asset management
- Protect revenues with improved billing accuracy, prevention, and detection of theft and fraud
- Provide new sources of revenue with consumer programs, such as energy management
- Defer capital expenditures because of increased grid efficiencies and reduced generation requirements
- Fulfill national security objectives
- Improve wholesale market efficiency

Customer Empowerment

- Respond to consumer demand for sustainable energy resources
- Respond to customers increasing demand for uninterruptible power
- Empower customers so that they have more control over their own energy usage with minimal compromise in their lifestyle
- Facilitate performance-based rate behavior
- Accommodate customers that bring their own generating and storing devices, and be able to create value for them beyond self-generation and consumption

Environmental Sustainability

- Respond to governmental mandates
- Support the addition of renewable and distributed generation (DG) to the grid
- Deliver increases in energy efficiencies and decreases in carbon emissions

Many of these drivers are country- and region- specific and differ according to unique governmental, economic, societal, and technical characteristics. For developed countries, issues such as grid loss reduction, system performance and asset utilization improvement, integration of renewable energy sources, active demand response, and energy efficiency are the main reasons for adopting the smart grid. Many developed countries experience system reliability degradation resulting from aging grid infrastructure. Inadequate access to "strong" T&D grid infrastructure limits the potential benefits of the integration of renewable energy generation.

The smart grid provides enterprise-wide solutions that deliver far-reaching benefits for both utilities and their end customers. Utilities that adopt smart grid technologies can reap significant benefits in reduced capital and operating costs, improved power quality, increased customer satisfaction, and a positive environmental impact. With these capabilities come questions: What is the potential of the smart grid? Is there one set of technologies that can enable both strategic and operational processes? How do the technologies fit together? How do you leverage benefits across applications? Smart grids should be based on integrated solutions that address business and operating concerns and deliver meaningful, measurable, and sustainable benefits to the utility, the consumer, the economy, and the environment (Figure 2.1).

Various components come into play when considering the impact of smart grid technologies. Utilities and customers can benefit in several ways. Rate increases are inevitable, but smart grids can offer the prospect of increased utility earnings, together with reduced rate increases (plus improved quality of service). Viewing smart grid programs in the context of, for example, a "green" program for customer choice or a cost reduction program to moderate customer rate increases can help define

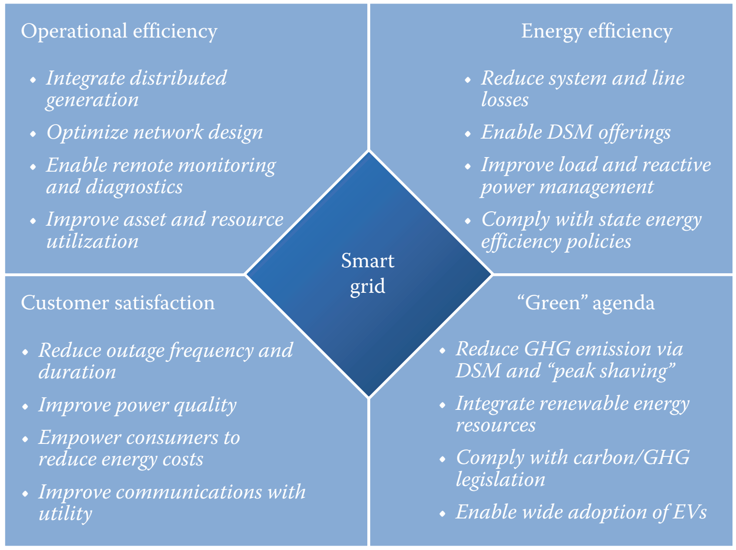

FIGURE 2.1 Smart grid benefits.

utility drivers and shape the smart grid roadmap. A smart grid program should have a robust business case where numerous groups in the utility have discussed and agreed upon the expected benefits and costs of smart grid candidate technologies and a realistic implementation plan. In some cases, the benefits are modestly incremental, but a smart grid plan should minimize the lag in realized benefits that typically occur after a step change in technology. A smart grid deployment is also intended to allow smoother and lower cost migrations to new technologies and avoid the need to incur "forklift" costs. A good smart grid plan should move away from the "pilot" mentality and depend on wisely implemented field trials or "phased deployments" that provide the much-needed feedback of cost, benefit, and customer acceptance that can be used to update and verify the business case.

2.8.1 Utility Benefits

Improving grid reliability and operational efficiency is possible using more intelligence in the delivery network to monitor power flow in real time and improve voltage control to optimize delivery efficiency and eliminate waste and oversupply. This will reduce overall energy consumption and related emissions while conserving finite resources and lowering the overall cost of electricity. Software applications—including smart appliances, home automation systems, etc.—that manage load and demand distribution help to empower consumers to manage their energy usage and save money without compromising their lifestyle—encouraging consumers to become smart consumers in smart homes, by giving them access to TOU rates and real-time pricing signals that will help them to save on electricity bills and cut their power usage during peak hours. This also helps to improve overall system delivery efficiency and reduce the number of power plants and transmission lines that will need to be built.

In 2008, the United States had electricity distribution losses adding up to 271 billion kilowatt-hours [27], more than 6% of total net generation. Xcel Energy estimates that the smart grid can reduce those losses by 30%, utilizing optimal power factor performance and system balancing [28]. The U.S. DOE estimates that conservation voltage reduction and advanced voltage control can reduce GHG emissions from electricity by 2% nationally in 2030 [29].

The rapid deployment of smart grid technologies across the country reflects the multiple operational and reliability benefits utilities expect to realize, including savings on operation and maintenance costs and the avoidance of costly outages. Operational and energy efficiency benefits are highly valuable, but will not always—by themselves—justify the ratepayer expense. Boston

Consulting Group (BCG) estimates that just 60% of the cost of smart grid deployment can be justified through the utility business case alone. Making smart meters, for example, a “winning proposition,” per BCG, will require that 20%–30% of a utility’s customers use the new technology to reduce their overall consumption or peak demand by 15%–20%. “Falling short of that threshold,” says Pattabi Seshadri, a consultant at BCG’s Energy Practice, “will likely prevent the utility from delivering the necessary return on investment” [30].

Increasing reliance on distributed and demand-side resources, reducing line losses, and increasing capacity of existing transmission lines using dynamic thermal rating and wide area control technology—all could reduce the need for new transmission and generation units, saving money and avoiding impacts on land and wildlife [31]. The California Public Utility Commission recognized that value in its June 2010 decision on smart grid deployment plans: “The Smart Grid can decrease the need for other infrastructure investments and these benefits should be considered when planning infrastructure” [32].

Such analyses elsewhere in the country have resulted in the deferral of several transmission lines. Synapse, for instance, has provided expert testimony on electric power transmission issues on behalf of consumer advocates and environmental groups in Pennsylvania, Virginia, and Maine. The key issue in all three cases was “how recent increases in demand response and energy efficiency affect utility and RTO forecasts of the need for new transmission over the next decade.” In Virginia, they demonstrated that—factoring in efficiency and demand response resources under development in PJM’s easternmost states—an AEP/APS (American Electric Power/Arizona Public Service) proposed 765 kV line would not be needed within the ten-year planning period. PJM sensitivity studies confirmed Synapse’s estimates, and the transmission line application was withdrawn [33].

2.8.2 Consumer Benefits

Under the current regulatory structure, investor-owned utilities propose investments, regulators approve those investments—the rate of return the utility will earn on them—and consumers (ratepayers) foot the bill. As witnessed in the United States in Indiana, Maryland, and elsewhere, regulators around the country are requiring utilities to demonstrate that they will deliver long-term benefits to consumers commensurate with the public’s investments. Designing to maximize those benefits will, in turn, benefit utilities. As J.D. Power and Associates found in a consumer survey: “Utility providers that develop smart systems with customer satisfaction in mind may be able to get things right the first time, ultimately saving in long-term development and implementation costs” [34].

Fortunately, a well-designed smart grid can deliver significant additional benefits, which can repay that investment many times over. Consumers will benefit from reduced bills and much greater control: the ability to use electricity when it is cheapest and to produce and sell power and other services into the grid when demand and prices are high. Entrepreneurs and their employees will benefit from new opportunities to provide energy services—from storage at substations to behind-the-meter “energy apps.” Communities will enjoy greater energy security, as they rely increasingly on distributed energy resources in their own backyards. The most valuable benefit could be the opportunity to radically reduce the hidden costs of electricity to the environment and public health.

The smart grid will enable significant reductions in both overall energy consumption [35] and peak use of electricity by giving customers real-time information and pricing, facilitating much broader use of demand response, providing the necessary information to support “continuous commissioning” in the built environment, increasing the capacity of existing transmission lines, and reducing T&D line losses.

Numerous studies have found that giving customers real-time energy usage information cuts consumption by 5%–15%. Adding pricing incentives and automated home energy management tools, such as programmable thermostats and smart appliances linked to home area networks, can double those savings [36,37].

A June 2010 report from the American Council for an Energy-Efficient Economy (ACEEE) found that U.S. consumers could cut their household electricity use as much as 12% and save $35 billion or more over the next twenty years if U.S. utilities go beyond AMI deployment to include a wide range of energy-use feedback tools that engage consumers in using less energy. ACEEE based its findings on a review of fifty-seven different residential sector feedback programs between 1974 and 2010, concluding that "to realize potential feedback-induced savings, advanced meters must be used in conjunction with in-home (or on-line) displays and well-designed programs that successfully inform, engage, empower, and motivate people" [38].

The Pacific Northwest National Laboratory (PNNL) and the Brattle Group have found that conservation tends to be strongest when feedback is based on actual usage data, provided on a frequent basis over a year or more, involves goal setting and choice with specific behavioral recommendations, and involves normative or historical comparisons [39].

Existing demand response programs, focused on large industrial users, can currently deliver 37 GW nationwide. Without new programs, that capacity will grow little over the coming decade, to just 38 GW by 2019, saving just 4% compared to a scenario with no demand response programs at all. A smart grid will almost quadruple those savings, according to modeling done for Federal Energy Regulatory Commission (FERC): large-scale deployment of AMI, enabling technologies, and dynamic pricing will enable peak reductions of 138 GW by 2020 [40].

A smart grid greatly expands the potential participants in demand response programs by making it possible to send the necessary signals, including dynamic prices, to residences and small- and medium-sized businesses. A Battelle-PNNL pilot, for instance, using predefined customer preferences and fast, autonomous controls on clothes dryers and water heaters to respond to ancillary service signals on very short timescales, achieved peak residential demand reductions of 16%, and average demand reductions of 9%–10% for extended periods of time [41]. In Oklahoma Gas and Electric's pilot, customers with smart thermostats achieved peak demand reductions of 57% [42].

Dynamic pricing is particularly valuable for cutting peak power demand. Analyzing a range of experiments, Brattle's Ahmad Faruqui found that TOU rates cut peak demand by 3%–6% and critical peak pricing (CPP) cut peak demand by 13%–20%. When accompanied with enabling technologies, CPP cut peak demand by 27%–44% [36].

Several studies have shown that customers respond to, and appreciate, TOU rates. PowerCentsDC [21]—an American Recovery and Reinvestment Act of 2009 (ARRA)-funded pilot in the nation's capital—ran from July 2008 through October 2009. This voluntary program chose 900 customers at random, providing each with a smart meter and smart thermostat and assigning them to one of the three pricing plans. One of those plans, a Critical Peak Rebate, rewarded customers for reducing their use below baseline during critical peaks. It cut peak use by 13%, with low-income customers achieving savings in line with others' results. Nearly three-quarters of the customers who participated were satisfied with the program and 93% preferred the dynamic rates over the utility's standard rates [21]. A September 2010 meta-study for the Edison Foundation Institute for Electric Efficiency found similar results in its assessment of recent dynamic pricing programs at Connecticut Light and Power, Baltimore Gas and Electric, and Pacific Gas and Electric. They not only found that low-income customers did shift load in response to dynamic pricing but also found that because they began with a flatter load, they saved money even when they did not shift load [43].

The economic benefits of these peak reductions are broadly shared, even by consumers who do not shift their consumption. Shifting just 5% of peak demand reduces prices substantially for everyone, both because the most expensive peak power plants do not get turned on and because new peakers need not be built [44].

2.8.3 Environmental and Economic Benefits

Environmental, health, and other social benefits of the smart grid can contribute real value to these calculations if the grid is designed to capture them. Capturing those social benefits is especially important because it is customers, ultimately, who are financing this new grid. Smart grids will enable broader deployment and optimal inclusion of cleaner, greener energy technologies into the grid from localized and distributed resources, including rooftop solar, combined heat and power plants and DG, thereby reducing dependence on coal and foreign oil and promoting a sustainable energy future. Electric and plug-in hybrid electric vehicle (EV) integration will bring another distributed resource to market, but one at scale—with supporting rates and billing mechanisms that can help flatten the load profile and reduce the need for additional peaking power plants and transmission lines potentially reducing the carbon footprint and fostering energy security and independence.

Electricity generation and use in the United States is one of the biggest sources of pollution on the planet, accounting for more than one-fifth of the world's CO_2 emissions [45]. The U.S. power plants also draw a huge fraction of the nation's freshwater supply. Nearly 40% of all domestic water withdrawals in the United States are used for cooling thermoelectric power plants. Depending on the cooling system, that water may be returned to the source at a higher temperature and with diminished quality, or evaporate and be lost for good [46]. In the Interior West, for example, where power plants rely primarily on recirculating cooling systems, approximately 56% of the water is lost to evaporation [47]. Conventional power plants in Arizona, Colorado, New Mexico, Nevada, and Utah consumed an estimated 292 million gallons of water per day (MGD) in 2005—approximately equal to the water consumed by Denver, Phoenix, and Albuquerque combined. By 2030, water use for power production in the Rocky Mountain/Desert Southwest region is projected to grow by 200 MGD—that water would otherwise be available to meet the needs of almost 2.5 million people [47]. In Texas, power plants consume as much water as three million people, each using 140 gals per person, per day [48]. With climate change already impacting water resources—reducing, for instance, snowpack in the West, a major source of freshwater—and with U.S. energy demand projected to grow 1.7% per year through 2030, these stresses will only grow [47].

Peak shaving delivers huge environmental and health benefits that 138 GW of peak reductions forecast by FERC is equivalent to the output of 1300 peaking power plants [40]. Many of these plants—often inefficient natural gas turbines—are in or near major population centers, where their smog-forming emissions harm public health. As with the coal fleet, the National Academy of Sciences (NAS) study found that just 10% of natural gas-fired power plants contribute a majority (65%) of the air pollution damages from all the 498 plants they studied. Replacing those plants with smart-grid enabled efficiency and demand response would significantly reduce public health impacts as well as GHG emissions, cutting 100–200 million tons of CO_2 per year—5%–10% of total GHG pollution from the U.S. power sector in 2007.

A concerted effort to make full use of demand response opportunities in regions now served by the dirtiest coal-fired power plants could also multiply benefits for human health by altering the economic calculus for those plants [49]. The entry of low-cost demand-side resources into the PJM market, for example, has put downward pressure on the capacity revenues earned by marginal power plants for being on standby to meet demand spikes. This downward price pressure contributed to the decision to retire two old, marginal coal plants in Philadelphia, and is putting financial pressure on other high-polluting, marginal coal, oil, and natural gas-fired units in the region; it may well cut more pollution than the direct effects of avoided demand [50].

The biggest environmental gains of demand response will come from the combined effects of these shifts on the overall generation portfolio: providing demand-side balancing for renewables in place of fossil-fueled backup generation, avoiding the need for new peaker plants, and hastening retirement of old dirty coal. Whether load shifting will also directly reduce emissions will depend on the current resource mix: Since the emissions from one source of electricity are effectively traded for those of another, the environmental result will depend on the emissions profile of that second source. For example, carbon emissions will go down when the use shifts from inefficient, simple cycle natural gas-fired plants that serve peak loads to efficient, combined cycle plants that serve intermediate loads. One analysis of twelve NERC subregions showed that most regions would shift to natural gas and reduce carbon emissions, but a few would shift to coal and increase carbon emissions [29]. As clean energy makes up a larger portion of base load generation, shifting away from peak power will have an increasingly positive impact. Applying an algorithm with CO_2 reductions as its primary objective and adding energy storage will make possible still greater reductions in CO_2 [29].

A 2003 Synapse model of demand response in New England indicates that a system-wide analysis will also be necessary to capture critical health benefits. It found that if demand response was used for more efficient unit commitment, reduced operation of oil- and gas-fired steam units, and increased operation of combined-cycle units in New England, it would significantly reduce NO_x, SO_2, and CO_2 in summer months. Those benefits would not be realized, however, if it simply shifted load to on-site diesel- or natural gas-fueled internal combustion (IC) engines [51].

As the smart grid improves the ability to measure real-time environmental impacts of dispatch decisions, it will facilitate prioritization of cleaner alternatives. Because power plant dispatch presents thousands of options for rearranging the generation mix, Charles River Associates (CRA) and others have been developing sophisticated modeling tools to precisely measure the actual carbon impact of electricity use in real-time, or "marginal carbon intensity" (MCI). CRA's analyses indicate that the real-time and locational variability of carbon emissions is as great as the variability of electricity prices: both depend on which marginal generators are brought online or displaced as the system is redispatched to accommodate changes in load and transmission congestion [52]. PJM Interconnection—which administers the competitive wholesale market serving 51 million people in Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia—has begun applying a similar analysis to estimate CO_2 reductions from demand response, energy efficiency measures, and increases in carbon-free generation [53].

PJM is among the leaders in incorporating demand response into wholesale markets: more than 9000 MW of demand-side capacity resources participated in its 2010 capacity market, equivalent to 120 grid-scale, gas-fired combustion turbines or eighteen medium-sized coal-fired power plants. Roughly a quarter of this, 2444 MW, participated as an economic resource, responding solely to market price signals to provide service to the grid. The remainder was emergency capacity, which jumps into service at the direction of the grid operator. In terms of actual energy delivered, PJM received 94,000 MWh from all demand-side resources in 2010, 60% on price signal alone. Though some of this DR may have come from on-site generators, most came from avoided energy consumption, translating to about 77,000 tons of avoided carbon. In short, PJM's demand response market rules enabled about 6% of the region's total peak load to be served by demand-side resources, up from less than 2% four years ago but still, less than half the 15% potential DR Brattle found in this region.

Smart grid-enabled monitoring of chillers, control systems, and other equipment in large (>100,000 ft^2) commercial buildings can detect suboptimal performance and prescribe operational improvements or maintenance, thus achieving overall electricity savings of 9% [54]. Applied in 20% of such buildings nationwide, the annual energy savings would be 8.8 billion kWh, avoiding 5 million metric tons of CO_2 emissions [55]. A smart grid will also provide detailed consumption data: Utilizing that data for improved diagnostics in residential and commercial buildings will allow for accurate targeting of efficiency investments in HVAC, lighting, and other systems, translating to a 3% reduction in U.S. CO_2 emissions from the electricity sector in 2030 [29].

Monetizing these environmental impacts gives a clearer sense of the real price we currently pay for conventional electricity generation and use. A report from the NAS (National Academy of Sciences) on "Unpriced Consequences of Energy Use and Production" estimates that in 2005 alone, environmental externalities from U.S. electricity production cost $120 billion. That figure underestimates the true costs, the report notes, because it does not include the costs of climate change or damage to ecosystems. Half of that $120 billion comes from aggregate damages from sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) from production of coal-fired electricity at 406 plants, for an average of $1.56 million per plant. Natural gas plants tend to be less polluting due to their cleaner fuel and smaller size, but are not without cost—averaging $1.49 million in annual damages per plant [49].

These are not theoretical costs but real costs—for water, health care, and premature deaths—borne directly by citizens. In Utah, for instance, burning coal to provide electricity for its residents and for neighboring states produces health and water impacts of up to $2.1 billion dollars per year [56]. These costs include hospital visits from respiratory injuries and asthma and the use of twenty-four billion gallons of water annually, adding as much as $45 per MWh to the cost of fossil fuel generation. Those harmful externalities, in other words, effectively double the true cost of that electricity.

Like the NAS numbers, the Utah figure does not include costs from GHG emissions. Nationally, the costs of climate change impacts related to real estate loss due to sea level rise, damages from more extreme hurricanes, increased energy costs to keep comfortable in a warmer world, and water supply impacts are forecasted to exceed $270 billion by 2025 [57]. U.C. Berkeley researchers David Roland-Holst and Fredrich Kahrl found that if no action is taken to avert the worst effects of global warming, California alone will face damages of "tens of billions per year in direct costs, even higher indirect costs, and expose trillions of dollars of assets to collateral risk." Costs in the water, energy, tourism and recreation, agriculture, forestry, and fisheries sectors will be as high as $23 billion annually, with another $24-billion annually in public health costs [58].

Air pollution impacts are not evenly distributed: The NAS study notes that just 10% of coal-fired power plants account for 43% of all damages. For those dirtiest plants, the damages cost a stunning 12 c/kWh [49], five times greater than the price the plants pay for coal today [59]. The distribution is even more extreme for natural gas—the top 10% of the most polluting facilities produce 65% of air pollution-related damages [49]. Developing smart grid-enabled alternatives to those plants will be particularly valuable.

The smart grid has the potential to radically reduce costly damage to the environment and public health—while increasing energy independence and security and creating new industries and jobs by:

1. Increased reliance on clean, renewable energy—integrating plug-in hybrid electric vehicles (PHEVs), plug-in electric vehicles (PEVs), distributed wind and photovoltaic solar energy resources, storage and other forms of distributed generation
2. Facilitating mitigation of renewable generation variability of output—mitigation of this variability is one of the chief obstacles to integration of large percent of renewable energy capacity into the bulk power system
3. Vastly improved efficiency of electricity production, transportation, and use, including the ability to shift demand to lower impact times and supply resources
4. Leveraging DR/load management to minimize the use of costly peaking generation, which typically uses energy resources that are comparatively fuel inefficient
5. Avoiding the curtailment of renewable generation capacity with technology and policy innovations needed to signal energy users, their buildings, appliances, and cars to use electricity when it is abundant, cheap, and clean
6. Facilitating increased energy efficiency through consumer education, programs leveraging usage information, and time-variable pricing
7. Decarbonization of the transport sector
8. Reduced water impacts—wind, solar photovoltaics (PVs), and demand-side resources use very little or no water to generate electricity [47]

A well-designed smart grid will help electricity customers meet their need for affordable, adaptable, and efficient power. It will equip communities to protect public health, conserve water, and promote energy self-sufficiency and local economic development. And it will maximize the diversity of clean, low-carbon energy production, reducing the overall environmental footprint of the largest and most polluting industry in the world.

2.8.4 Benefits Realization

Business cases for investing in smart grid processes and technologies are often incomplete and therefore not compelling. It is often easier to demonstrate the value of the end point than it is to make a sound business case for the intermediate steps to get there. Societal benefits, often necessary to make investments in smart grid principles compelling, are normally not included in utility business cases. Additionally, lack of protection from inherent investment risks, such as stranded investments, further impacts the ability of these investments to pass financial hurdles. An example of that is the lack of visibility on what consumers will do (e.g., purchase solar PV and batteries) that will impact the asset that is being considered for upgrade. Meanwhile, the increased number of players and the extent of new regulation has complicated decision-making. Credit for societal benefits in terms of incentives and methods for reducing investment risks might stimulate the deployment of smart grid processes and technologies.

Smart grid cost-benefit analyses should take into consideration the full range of benefits of deployment, including the reduced use of high-polluting peak power plants; reduced land and wildlife impacts (through avoided construction of power plants and transmission lines); and the lowest cost achievement of state and federal energy and environmental policies through efficiency and generation options made possible by smart grid investments [60,61]. Some smart grid benefits are under the control of the utility while others are dependent on changes in customer behavior.

While the typical non-price regulated entity seeks to earn a return on its investment through profit-maximizing pricing, product and marketing strategies, a price-regulated entity such as a power delivery utility does not have that level of autonomy. Benefits maximization rather than profit maximization is the key goal. A portion of these benefits is in the control of the utility—such as the reliability improvements gained through effective distribution automation implementation or the operational benefits gained through automated meter reading. The bulk of the potential benefits, however, are driven by changes in customer behavior, specifically their consumption levels and patterns. To help drive that behavior, customer education is critical—as is the transition of a utility's customer care function from a transactional "call taker" to a trusted energy advisor. But we also expect that utilities will still be wires and poles companies, receiving fees for hosting distributed energy resources, and motivated to help customers find third-party solutions providers. In this respect, the utility advises their customers and facilitates vendors. More importantly, education goes both ways since the customer must be heard and the utility will have to understand how best to deliver the lifestyle the customer expects. The nimbler aggregators and providers of energy services behind the meter, much more used to understanding the consumer, may move quicker and make available products the customer engages in, which then will need to be integrated into the overall considerations and plans for the smart grid.

An example of an approach to benefits realization that recognizes the need for collaboration and education would be as follows:

1. Prioritize customer-facing smart grid benefits and work toward "early delivery"—while effectively managing stakeholder expectations.
2. Establish stakeholder-working groups that provide opportunity for detailed discussions about dynamic pricing programs and their benefits.
3. Conduct public regulatory hearings that assess and verify the cost and benefits of programs.
4. Provide greater availability of information to customers through improved website capabilities (and ensure customer care access to the same information to facilitate "energy advisor" conversations).
5. Launch proactive customer programs that provide a clear, simple message about the utility's offerings and programs to manage customer expectations. Ideally, these programs would be informed by market research that focuses on (1) increasing enrollment and retention in dynamic pricing programs, (2) improving behavioral responses to pricing options and usage information, and (3) ensuring that benefits flow to all customers.

One of the greatest obstacles in smart grid initiatives is approval from public utility commissions when a rate case is required by utilities to fund smart grid programs. The rates that regulated utilities are allowed to charge are based on the cost of service and an allowed return on equity (ROE). Once base rates are established, the rates remain fixed until the utility files for a rate change. Throw in an environment where power generation has been deregulated and the business case for a wires company still under regulation is more challenging. An additional challenge is presenting a rate case where the total system load decreases with DR and energy efficiency programs.

Utilities are looking for that magic "easy" button for smart grid deployments, but smart grid plans may be "subject to regulatory approval." Therefore, it is important to not only have a solid business case internally but also a business proposition around the view of regulatory approval. The focus on the business case should also show regulators

1. How smart grid technology maintains low customer bills. Benefits may include
   a. Reduced O&M through lower meter-related and outage costs
   b. Reduced cost of energy through DSM and Integrated Volt/VAr Control (IVVC)
   c. Reduced capital expenditures through M&D (Monitoring and Diagnostics), DSM, and IVVC
   d. Ability to provide customer network support programs that give a return for the participating customer in exchange for the delivered service, instead of only pursuing an assets augmentation policy
2. What smart grid does to secure the "green image" of the state or service territory. Benefits may include
   a. Lower carbon emissions through reduced energy consumption and field force drive time via DSM, IVVC, AMI, and FDIR (fault detection, isolation, and restoration)
   b. Renewable energy source integration, facilitated by DSM and DER (distributed energy resources) to help with renewable energy intermittency
   c. Distributed generation and plug-in hybrids facilitated by AMI and DA (distribution automation)
3. How the smart grid improves poor reliability. Benefits may include
   a. Significant SAIFI (system average interruption frequency index) and SAIDI (system average interruption duration index) improvement through AMI, FDIR, integrated OMS (outage management system), and FFA (field force automation)
   b. Improved power quality for an increasingly digital economy
   c. Ongoing M&D will further improve reliability
   d. Improved customer service through billing accuracy and reduced outages
4. How proper management of the grid during emergencies can reduce large-scale outages and blackouts by
   a. Making outage management more cost effective through predictive analytics
   b. Reducing system blackouts using system-wide monitoring, control, and protection
   c. Increasing system resilience through topology switching and preventive control
   d. Improving dependability and security of relaying schemes using adaptive, corrective, and predictive protective relaying approaches

Customer choice, energy efficiency, and customer value are key to a successful smart grid implementation platform and the likely acceptance by regulators. The opportunities lie in leveraging the foundation of AMI to support a more comprehensive smart grid program, but also going beyond AMI and working with behind the meter resources. In response, utilities will be looking to regulators to provide incentives for smart grid programs, such as accelerated depreciation and higher returns for rate cases. The bottom line for regulators and consumers: "Look for Smart Grid initiatives that are likely to reduce long-term bills as well as emissions and outages."

The importance of the business case will vary from country to country. In some centralized markets, the development of a smart grid may be a matter of policy, driven primarily by security of supply, environmental, or research and development (R&D) aspirations. In competitive markets, an economic business case may be more important, with clearly defined internal rate-of-return hurdles to jump.

Creating a complex business case for smart grid technologies is difficult: All networks within a market, and circuits within networks, will have different levels of capability required, all driven by interdependent supply and demand characteristics, making cost estimation difficult. Benefit estimation is similarly complex as benefits will depend on the levels of capability in different network areas and will comprise direct and indirect benefits that are difficult to quantify (e.g., carbon and pollution reduction, improvement in security of supply).

A key smart grid market barrier is business case fragmentation, particularly in more competitive fragmented markets. A utility with different companies operating individually in each part of the value chain will have a fragmented business plan that may not realize the synergies of benefits. In a fragmented market, creating a commercial model means allocating investment, reward, and risk among the stakeholders. This allocation will be driven by the extent to which each party captures benefits and best manages different risks. However, the number of different entities involved makes the business case and commercial model particularly difficult. For example, a smart grid project benefits power generation companies through avoided capital expenditure required for generation, or support for the introduction of intermittent energy supplies (e.g., from wind). For networks, benefits include improved operational efficiency and reduced losses, and for retail, it can support the introduction of innovative offerings and help trim load curves. A networks-only investment into smart grid technologies will, therefore, support huge opportunities for other parties. However, given recent quick adoption of customer technologies, such as solar PV and soon batteries, smart grid projects may become part of a strategy to reduce the risk of load defection, therefore maximizing the utilization of the grid by customers who make such investments. There is also controversy about the long-term benefits of smart grid-enabled policies; e.g., long-term generation, transmission and distribution system savings associated with the broad adoption of TOU rates are hard to defend in the near term, even if the benefits can be real and significant in the future. In addition, a regulatory cost-benefit analysis that considers long-term, total societal benefits will need to use total resource cost (TRC) comparisons. Some would argue that the true societal cost of carbon is considered much higher than the abatement cost.

It is also possible that a less savory outcome will involve utility smart grid investments without delivering the full suite of potential benefits, thereby leaving customers with the costs of a gold-plated grid that exceed benefits. In this less pleasant future, load defection will be exacerbated by an expensive grid that underperforms. The EPRI (Electric Power Research Institute) report, *Electricity Sector Framework for the Future, Vol. 1*, estimates $1.8 trillion in annual additive revenue by 2020 with a substantially more efficient and reliable grid [62]. To elaborate, according to the Galvin Electricity Initiative, “Smart Grid technologies would reduce power disturbance costs to the U.S. economy by $49-billion/year. Smart grids would also reduce the need for massive infrastructure investments by between $46-billion and $117-billion over the next 20-years. Widespread deployment of technology that allows consumers to easily control their power consumption could add $5-billion to $7-billion per year back into the U.S. economy by 2015, and $15-billion to $20-billion per year by 2020. Assuming a 10% penetration, distributed generation technologies and smart, interactive storage capacity for residential and small commercial applications could add another $10-billion/year by 2020” [63].

Around the globe, countries are pursuing or considering pursuit of GHG legislation suggesting that public awareness of issues stemming from GHGs has never been at such a high level. According to the National Renewable Energy Laboratory (NREL), “utilities are pressured on many fronts to adopt business practices that respond to global environmental concerns. According to the FY 2008 Budget Request, NREL stipulates that, if we do nothing, U.S. carbon emissions are expected to rise from 1700-million tons of carbon per year today to 2300-million tons of carbon by the year 2030. In that same study, it was demonstrated that utilities, through implementation of energy efficiency programs and use of renewable energy sources, could not only displace that growth, but actually have the opportunity to reduce the carbon output to below 1000-million tons of carbon by 2030” [64].

2.9 TECHNOLOGY INVESTMENT

Smart grid represents a complete change in the way utilities, regulators, customers, and other industry participants think about electricity generation, delivery, and its related services. This new thought process will likely lead to constantly evolving technologies and solutions, and will benefit from greater integration of utility engineering, IT, operations, and new business models. The set of solutions that will provide these benefits is vast. Perhaps more importantly, it is also about the new information made available by these technologies and the new customer-utility relationships that will emerge. Enabling technologies, such as smart devices, communications and information infrastructures, and software, are instrumental in the development and delivery of smart grid solutions (Figure 2.2). Global, regional, and national economics and growth will serve as the cornerstones for investments in smart grid infrastructure and in greater use of integrated communications and information technologies. Drivers will include national and state government policy directives and incentives to enable energy futures and development of smart infrastructure.

A high-level review of the smart grid technology functionalities and capabilities landscape suggests representative maturity levels and development trends as shown in Table 2.2. This assessment is based on the scale and level of deployed technologies in existing smart grid projects across the globe.

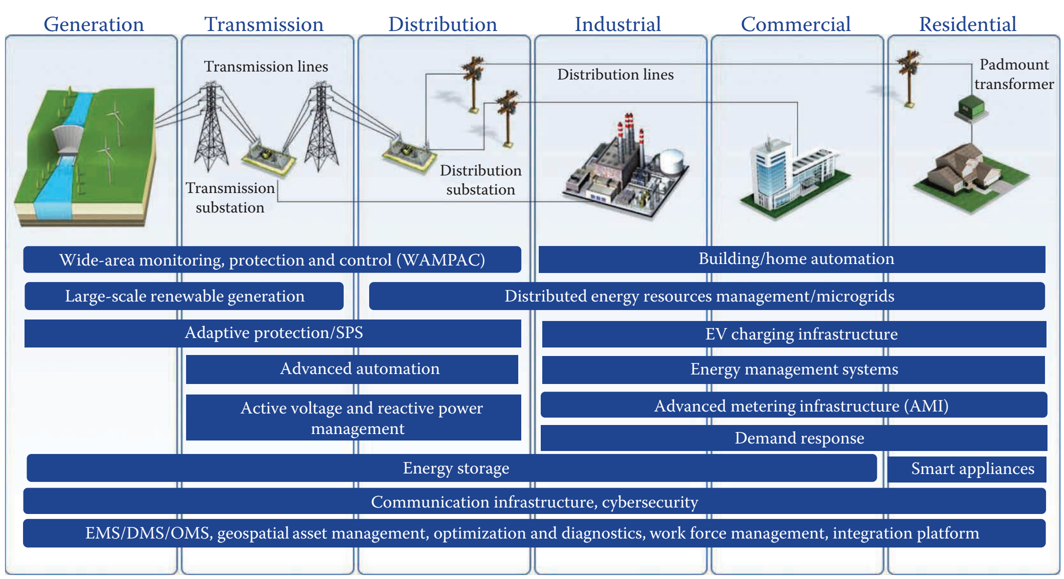

FIGURE 2.2 Smart grid technologies span the entire electric grid. (Copyright 2016 General Electric. All rights reserved. With permission.)

TABLE 2.2
Smart Grid Technology Landscape

	Functionalities and Capabilities	Maturity Level	Development Trend
1	Communication and security	Developing	Fast
2	EVs, large-scale renewable generation, DERs	Developing	Fast
3	Metering	Mature	Fast
4	Embedded sensing automation protection and control	Developing	Fast
5	Advanced system operation	Developing	Moderate
6	Advanced system management	Mature	Fast
7	Advanced system planning	Developing	Moderate
8	Intentional islanding (microgrids) and aggregated load	Developing	Moderate
9	Home/building	Developing	Fast

Technical challenges the smart utility will face include the following:

- Managing an increasing number of operating contingencies that differ from "system as design" expectations (e.g., in response to wind and solar variability, possible occurrence of zero demand in transmission in the middle of the day, etc.)
- Facilitating the introduction of intermittent renewable and distributed energy resources with limited controllability and dispatchability
- Mitigating power quality issues (voltage and frequency variations) that cannot be readily addressed by conventional solutions
- Integrating highly distributed, advanced control, and operations logic into system operations
- Developing sufficiently fast response capabilities for quickly developing disturbances
- Operating systems reliably despite increasing volatility of generation and demand patterns, given increasing wholesale market demand elasticity
- Increasing the adaptability of advanced protection schemes to rapidly changing operational behavior (due to the intermittent nature of renewable and DG resources)
- Accommodate customer diversity of preferences in their generation, storage and loads options, and respect and be guided by customer choice

Many of the technologies necessary for smarter grids are available today as discrete capability building blocks. However, the levels of maturity and commercial viability differ. R&D efforts continue to advance the development of these technologies, particularly those essential to the advanced capabilities of smart grid solutions: communications, embedded sensing, automation, big data, and remote control. The speed of technology research, development, and deployment in the power industry has been slower than in other industries. Technology development and deployment need to be accelerated. Utility regulators do not want to allow recovery for failed R&D efforts, so most R&D efforts are through the industry vendors.

Each of these technologies has differing requirements for R&D to reduce technology and deployment risk, lower costs, and secure confidence that they can be implemented at scale. The challenge is to develop all component technologies necessary for an integrated smart grid solution to a level of maturity sufficient to deploy them all at scale at the same time. For this to occur, R&D for some components may need to be accelerated. An emerging area for R&D is the integration of component technologies to ensure interoperable, coordinated, secure, and reliable electric system operations. This focus area includes the integration of high-penetration renewable energy (e.g., wind, solar), distributed generation, and electric vehicles into the electric grid.

The level of R&D spending in the utility sector is amazingly low. Utilities are among the lowest of all industries in R&D as a percent of revenue (<1%) [65]. Competitive high-tech industries are five to ten times higher. Yet, the move to make electricity competitive has not spurred more industry

R&D. R&D costs are typically not explicitly stated as a line item in rate cases. As a result, these costs are often the first to be cut when less than favorable rate case decisions are made.

Technology development efforts lack coordinated R&D for both individual technology components and integrated smart grid projects. Smart grids are potentially a global solution, albeit, in different forms for different markets. However, R&D is not entirely coordinated, and there is a natural tendency for institutes and companies to choose to develop those technologies most closely aligned with their own capabilities and interests. This may leave some technologies with less focus than others. Given the high cost of R&D, technologies with less potential economic payback may well be left behind, leaving a maturity gap in the smart grid technology chain.

The integration of multiple key technologies needs greater focus. The benefit realized from the integration of suites of technologies normally exceeds the sum of the benefits of the individual ones. For example, the deployment of integrated communication systems, including supercomputers, is needed to support the processing and analysis of the large data volumes that will be supplied by advanced technologies of the smart grid. Deployments of individual technologies often fail because they have not been adequately integrated with other needed technologies. Economies of scale and design innovation are needed to drive costs down. For example, our ability to store electrical energy remains limited. One of the most fundamental and unique limitations of electricity is that it cannot easily be stored for use at a later time. Although incremental progress is being made in energy storage research, the discovery of a transformative storage technology would greatly accelerate grid modernization. But also, mass adoption of storage by customers may bring storage capability to the grid sooner, as long as a smarter grid allows the usage of such resources and provides the foundation for a business model that incentivizes customers to do so. At the prosumer level, new-generation smart inverters have been deployed to enable full controllability of photovoltaics resources to be able to curtail outputs in case of grid congestions. Simultaneously, smart inverters allow customers to focus on self-consumption, reducing their energy export by using loads when solar is maximized, or using batteries to absorb the excess power and increasing self-consumption at night. Battery storage and demand response have also been integrated into the grid to provide grid support services, such as voltage support on the distribution system, as well as frequency reserve on the transmission system.

2.10 BUILDING KNOWLEDGE, SKILLS, AND A READY WORKFORCE

2.10.1 Industry Expertise and Skills

A declining infusion of new thought is occurring. The technical experience base of utilities is graying. The talent pool is shrinking due to retirements and a shortage of new university graduates in the power engineering field. Additionally, fundamental knowledge and understanding of power system engineering principles are being lost as more and more of the technical analysis is done by computers rather than by human resources. This, in turn, has led to a reduction in the number of power systems programs being offered by engineering schools across the US [66].

It is common knowledge that baby boomers in the United States are beginning to retire and leave the workforce. The electric power and energy industry is already beginning to experience shortages caused by these retirements. Over the next five years, roughly one-half of the utility industry engineers may retire or leave for other reasons. These experienced engineers provided the expertise needed to design, build, and maintain a safe and reliable electric power system. Over the years, they have planned for and expanded the system to serve a growing population, developed needed operating and maintenance practices, and brought about innovations to make improvements.

The departure of this engineering expertise is being met by hiring new engineers and by using supplementary methods, such as knowledge retention systems. The future engineering workforce will supplement traditional power system knowledge with new skills, such as in communication, cybersecurity, data analytics, and IT. Traditional and new skills will still be necessary to successfully deploy advanced technologies while maintaining the aging infrastructure.

Meeting the functional needs of a smart grid will require consideration not only of the end state when a smart grid vision is realized but also the evolutionary period to that state during which the legacy infrastructure will be used side-by-side with new technologies. To integrate engineering elements in design and operation, the engineer must have a sufficient depth of understanding to put aside preconceived legacy notions. These legacy notions admittedly comprise most power system engineering, but to realize new paradigms, a more holistic approach is required. For example, the use of time-varying wind power, or solar power available in an uncertain schedule, the engineer needs to consider: (1) at the design stage, control error tolerances, timing of controls, electronic designs of inverters needed to incorporate the alternative energy sources, and other basic system configurations; and (2) in power system operation, the operating strategies of generation control, system control, and managing multiple objectives.

The integrative requirements of smart grid philosophies require that the depth of comprehension of engineers extend to the several areas illustrated in Figure 2.3. It appears that the legacy power engineering educational programs, while valuable for the installation of legacy systems, and maintenance of those systems, are not sufficient to accommodate the main elements of the smart grid. To ensure that our society has the well-qualified power and energy engineers it needs, the following objectives must be sought [66]:

1. Develop and communicate an image of a power engineer based on a realistic vision of how engineers will be solving challenges facing companies, regions, the nation, and the world, thereby improving the quality of life. Youth want to choose jobs that make a difference in the world and make their life more meaningful.
2. Motivate interest in power and energy engineering careers and prepare students for a post-high-school education in power and energy engineering. Students should be exposed to

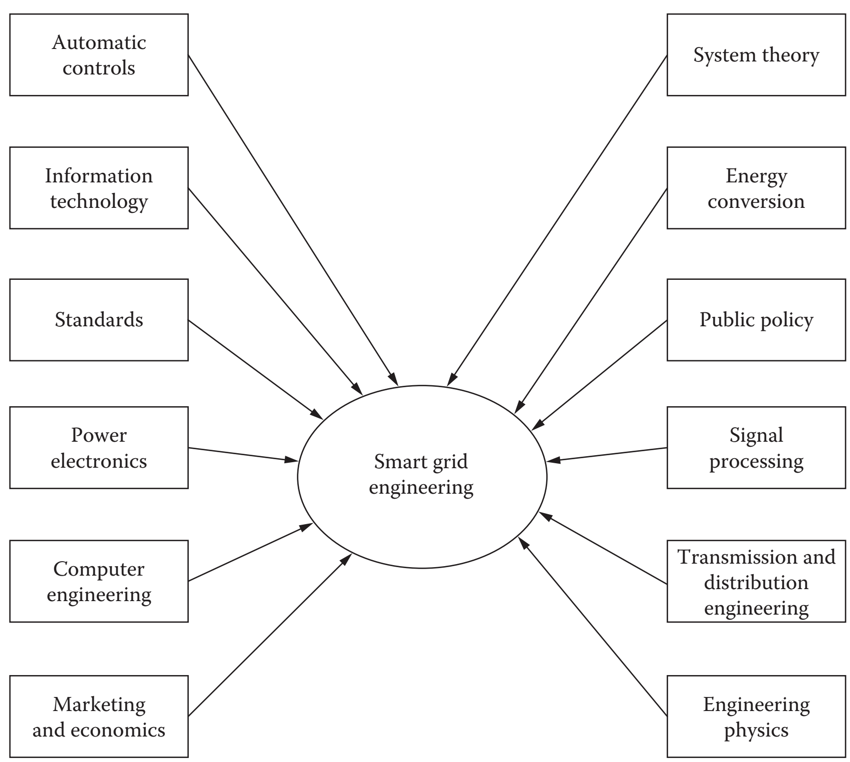

FIGURE 2.3 Integrative approach to smart grid design and operations. (Copyright 2012 Kezunovic, M. All rights reserved. With permission.)

engineering even before high school. Teachers, counselors, and parents must be the target of information as well as the students.

3. Make the higher education experience relevant, stimulating, and effective in training high-quality and professional power and energy engineers. Establish and maintain a direct link between power engineering and the solution of major challenges facing the United States and the world.
4. Increase university research funding to find innovative solutions for pressing challenges and enhance student education.

Expertise and skill development are facilitated by government policies, such as the U.S. Green Jobs Act and Workforce Investment Act, which formalize investment in next-generation skills development. There are also international efforts like CCiNet (Climate Change Information Network) of the UNFCCC (United Nations Framework Convention on Climate Change), which include education, training, and public participation programs. Currently, major initiatives specifically dedicated to developing smart grid skills are few in existence, with a noted exception being the workforce development in the United States for the electric power sector to implement a national clean-energy smart grid. This U.S. $100 million initiative—as part of the ARRA U.S. $4.5 billion investment to grid modernization—targets new curricula and training activities for the current and next-generation workforce, including cross-disciplinary training programs spanning the breadth of science, engineering, social science, and economics.

The facts indicate there are workforce and education system problems summarized as follows [66]:

- Over the next 5 years, approximately 45% of engineers in electric utilities will be eligible for retirement or could leave the engineering field for other reasons. If they are replaced, then there would be a need for over 7000 power engineers by electric utilities alone: Two or three times more power engineers may be needed to satisfy the needs of the entire economy.
- About 40% of the key power engineering faculty at U.S. universities will be eligible for retirement in 5 years with about 27% anticipated to retire. In other words, of the 170 engineering faculty working full time in power engineering education and research, some fifty senior faculty members will be retiring. This does not account for senior faculty who are already working less than full time in the area. Finally, even more faculty will be needed to increase the number of power engineering students to meet the demand for new engineers in the workplace.
- The pipeline of students entering engineering is not strong enough to support the coming need, with surveys showing (1) that most high school students do not know much about engineering and do not feel confident enough in their math and science skills; and (2) that few parents encourage their children, particularly girls, to consider an engineering career. Furthermore, often career counselors and teachers know little about engineering as a career. Workforce diversity is also a concern. Women constitute only 18% of the engineering enrollments and 12% of the electrical engineering students. Enrollment of underrepresented student populations should be higher.
- Enrollment by university students in power and energy engineering courses is increasing (perhaps fueled by interest in renewable energy systems and green technologies); however, the overall number of students interested in electrical engineering is declining. A shrinking pool of electrical engineering students limits the future supply of new power engineers.
- The hiring rate of new power engineering faculty is beginning to grow after years of insufficient hiring to replace retiring faculty; however, as time has passed, many historically strong university power engineering programs have ended or significantly declined;
- There are less than five very strong university power engineering programs in the United States. A very strong program has (1) four or more full-time power engineering faculty; (2) research funding per faculty member that supports a large but workable number of graduate students;

(3) a broad set of undergraduate and graduate course offerings in electric power systems, power electronics, and electric machines; and (4) sizable class enrollments of undergraduate and graduate students in those courses. The general lack of research funding opportunities has made it difficult for faculty in existing programs and new emerging programs to meet university research expectations and for engineering deans to justify adding new faculty.

For electric and gas utility employees, the results of a survey by the Center for Energy Workforce Development (CEWD) in 2008 showed that approximately 50% of all employees would be eligible for retirement within ten years [67]. The survey was comprised of fifty-five electric and gas utilities nationwide, as well as all electric cooperative organizations. As of 2010, indications were that nearly 45% of the eligible retirement age employees would have to be replaced by as early as 2013 [68]. An updated survey by the CEWD in 2016 [69] (Figure 2.4) shows that overall, the electric and natural gas utility workforce is now getting younger, with lineworkers, engineers, and nuclear operations being the youngest of the surveyed jobs. Hiring has increased, particularly in the 23- to 38-year age group, and a little over half of the hires reported were in key jobs, with almost 20% of all hires in the lineworker category. At the same time, the number of older workers has declined as workers in key jobs are retiring, with retirement forecasts in future years trending downward for the first time since CEWD began surveying.

Current estimates of global job losses due to digitization range as high as two billion by 2030, but there is considerable variation in these projections. The World Economic Forum (WEF) predicts significant opportunity in the electricity sector for digitization to create jobs. They expect digital initiatives will create up to 3.45 million new jobs between 2016 and 2025—translating to 10.7% job growth in the electricity industry. Job creation potential is highest in the consumer renewables sector, with energy storage integration creating up to 1.07 million new jobs. New jobs in smart asset planning (925,000) and asset performance management (596,000) will more than address job loss from automation or more efficient technologies. The WEF notes that a significant problem that utilities are facing is an aging workforce, with a weak pipeline of new talent and a potential productivity gap as new employees are recruited and trained. Digital initiatives go some way in ensuring that experience is captured as the workforce retires, with significant productivity gains expected [70].

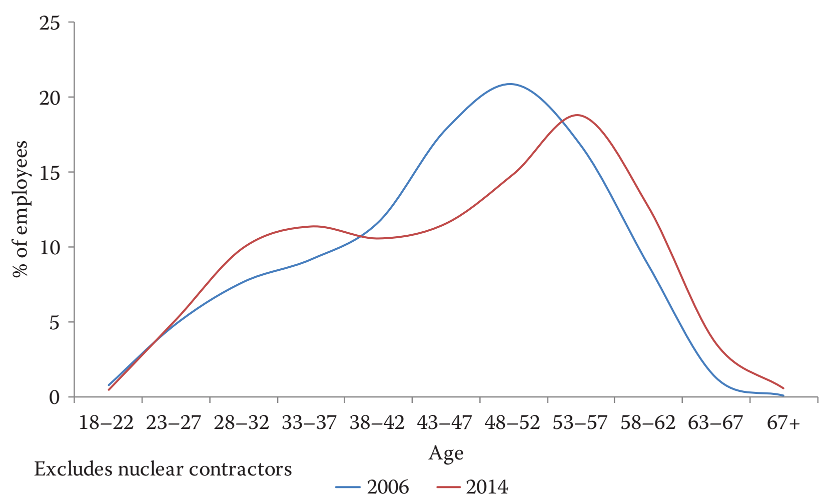

FIGURE 2.4 US Electric and Natural Gas Utilities Age Distribution Total Company 2006 vs. 2014. (From Center for Energy Workforce Development, Gaps in the Energy Workforce Pipeline 2015 CEWD Survey results, 2015. With permission.)

2.10.2 Knowledge and Future Education

Since implementing the smart grid initiative will take engineering professional resources of broad expertise and different profile than previously available, one may naturally ask the question as to where the new generation of electrical and electronic engineers shall come from with the specialized integrated skills needed by smart grid engineers.

Traditional power engineering skills include

- Power system dynamics and stability
- Electric power quality and concomitant signal analysis
- Transmission and distribution system operations
- Economic analysis, energy market, and planning
- Reliability and risk assessment

The traditional power engineering educational programs, while valuable for the installation of legacy systems, and maintenance of those systems, are not sufficient to accommodate the main elements of the smart grid. This is the case since simple replicative engineering is not sufficient to formulate new designs and new paradigms. The innovation extends to power system operation as well. The solution to this quandary appears to be in the integration of new technologies into the power engineering curriculum programs, and extending the depth of those programs through a master's level experience. It is desirable that the master's level experience is industry oriented in the sense that the challenges of the smart grid be presented to the student at the master's level.

Traditional power engineering education, the source of engineers for the future grid, needs to include several topics that are not traditionally included in a power engineering program. Among these are

- The design of wind energy systems
- The design of photovoltaic solar energy systems
- The design of solar thermal (concentrated solar energy) systems
- The calculation of reserve margin requirements for power systems with high penetration of renewable resources
- The modeling of uncertainty/variability in renewable energy systems
- Inclusion of cost-to-benefit calculations in generation expansion studies
- Conceptualization, design, and operation of energy storage systems, including bulk energy storage systems
- Discussion of the socio-political issues of renewable energy development
- Data System Architecture and Big Data Analytics
- Cybersecurity

The desired elements of the cross-cutting energy engineering skills for the next generation of "smart grid" power engineers appear to include all or most of the following elements. The exposure to these subjects is not recommended to be a casual, low-level exposure; rather, the exposure is recommended to be at a depth that analysis is possible in a classroom environment. Moreover, it is recommended that research is performed by the student so that synthesis can be accomplished. Some of the elements identified are discussed in the following.

Direct digital control: The importance of direct digital control is important in realizing most of the smart grid objectives. Direct digital control needs to be examined not only in terms of classical automatic control principles (including, if not emphasizing discrete control) but also how digital control relies on communication channels, how these controls need to be coordinated in terms of safety and operator permissive strategies, the impact of latency [71] new instrumentation, and how that instrumentation will impact the power system design and operation.

Identification of new roles of system operators: Components of the system that need to be fully automated versus components that are "operator permissive" controlled need to be identified. This must be presented to the students in a way that integrates computer engineering and power engineering. As an example, visualization of power systems is an especially important subject area [72].

Power system dynamics and stability: Power system stability is a classical subject. However, the new issues of this field relate to how maximal power marketing can occur and yet still ensure operationally acceptable system operation and stability. The subject appears best taught as an in-depth semester course that includes modeling and practical examples. The examples should be examined by the students in a project format.

Electric power quality and concomitant signal analysis: With the advent of electronic switching as a means of energy control, electric power quality has taken on a new importance in power engineering education. Again, we find that simply a casual discussion of this topic is insufficient to achieve the analytical stage: Rather, it is recommended that a semester's course, complete with project work and mathematical rigor, is needed as instruction. Power quality is discussed as an educational opportunity in Ref. [73].

Transmission and distribution hardware and the migration to middleware: New materials are revolutionizing transmission designs. Transmission expansion needs to be discussed in an in-depth fashion that includes elements of high-voltage engineering and engineering physics, new solid-state transformer designs, and solid-state circuit breakers [74]. Classical power engineering seems to leave a gap between software and hardware, and it is recommended that hardware-oriented courses at the master's level include issues of middleware applications. The use of intelligent electronic devices (IEDs) is deemed important. This development is especially important in the area of substation automation and synchronized phasor measurement systems [75].

New concepts in power system protection: With increased loading of power systems and dynamic behavior due to accommodating deregulated electricity markets and interfacing renewable resources, designing protective relaying solutions that are both dependable and secure has become a challenge. Introduction of microprocessor-based relays, high-speed communications, and synchronized phasor measurement systems made opportunities for adaptive and system-wide relaying. Learning how the relaying field evolves from traditional approaches designed for handling $N - 1$ contingencies to new schemes for handling $N - m$ contingencies becomes an integral part of a modern power systems curriculum. The use of modern modeling and simulation tools is required [76].

Environmental and policy issues: Exposure to environmental and policy issues need to be included in the master's level in power engineering education. This exposure needs to go beyond "soft science" and it needs to appeal to the students' capability in mathematics and problem-solving [77].

Reliability and risk assessment: There is little doubt that the importance of reliability of the power grid is widely recognized. However, when transformative changes are planned and implemented, the traditional tried and tested rules to ensure reliability cannot be relied on. Such changes need to be modeled and analyzed for reliability assessment based on sound mathematical foundations. Fortunately, now a large body of knowledge exists for modeling and analysis of power system reliability and risk assessment. The students at the master's and doctoral level should be provided this knowledge so that they can effectively use it in the integration and transformative process.

Economic analysis, energy markets, and planning: Planning can no longer be done incrementally, motivated largely to satisfy the next violation of planning reliability criteria. Investment strategies must be identified beyond the standard 5- to 20-year period at an interregional if not national level, to identify cost-effective ways to reach environmental goals, increase operational resilience to large-scale disturbances, and facilitate energy market efficiency. Engineers capable of organizing and directing such planning processes require skills in electric grid operation and design, mathematics, optimization, economics, statistics, and computing, typically inherent only in programs for PhD graduates [78]. Engineers from the BS and MS levels will be needed to participate in these processes, and these engineers will require similar skills at the analysis level or above.

The smart grid approach combines advances in IT and data analytics with the innovations in power system management to create a significantly more efficient power system for electrical energy. Modern society is migrating to an Internet-based business and societal model. As an example, it is common to pay bills, order equipment, make reservations, and perform many of the day-to-day tasks of living via the Internet. In power engineering, one needs only to examine such tools as the Open Access Same-Time Information System (OASIS) to realize that the same Internet model applies to power transmission scheduling [79]. The identical model appears in many power engineering venues including setting protective relays, transcommuting of engineering personnel, managing assets and inventory, scheduling maintenance, and enforcing certain security procedures. Cloud data storage and virtual networks may be a key to solving operational issues associated with concerns on the distribution grids, such as localized peak loads caused by concentrated areas of charging electric vehicles. While the open Internet has security issues, similar models in an intranet or virtual private network may be used to enhance security. As this general model progresses, in many cases, one may wonder why certain procedures, whether in power engineering or elsewhere, have not been automated.

Automation is at the heart of the smart grid. That is, various decisions in operation may no longer be relegated to operators' action. Instead, operating decisions considering a wide range of multiobjectives might be "calculated" digitally and implemented automatically and directly. While safety, redundancy, and reliability considerations are clearly issues as this high level of direct digital control is implemented, it is believed to be possible to realize the objectives of the smart grid. To this end, the analogy between the needs of Internet opportunities and the needs of smart grid translates into a new philosophy in power engineering education: Develop the cognitive and cyber skills while focusing on domains of specific expertise. This often translates to instruction tools that are highly interactive and have strong modeling and simulation background. Interestingly, the very same Internet philosophy may be applicable to the identification of where engineering expertise will be obtained—and how the complex issues of power engineering, public policy, and IT can be presented to students in undergraduate and graduate programs.

To tackle the smart grid research issues, a variety of engineering and non-engineering disciplines need to be brought together. Almost every engineering discipline has its role in this development: electrical and computer engineering (grid generation, transmission, and distribution enhancements), petroleum engineering (alternative fuels for electricity generation), nuclear engineering (sustainable electricity production), chemical engineering (alternative and renewable electricity production), aerospace engineering (wind energy infrastructure), mechanical engineering (design of generators and energy-efficient buildings), civil engineering (environmental impacts), etc. In addition, some non-engineering disciplines are needed to resolve associated economic, societal, and environmental and policy issues: economics, sociology, architecture, chemistry, agriculture, economics, public policy, etc. The fact that some of the disciplines are allocated to different colleges should not be underestimated since bringing those resources together will require a concerted university-wide effort.

2.10.3 Forms and Goals of Future Learning

University education: The overall education model will include a combination of in-residence and distance education programs offered by universities, community colleges, and government and industry providers. In addition, the model will include certificate programs and professional development programs. Universities can hire nontenured staff, such as adjunct professors, relatively quickly to supplement the available instruction time of university faculty. This will allow universities to expand educational opportunities to address the rising shortage of well-trained power engineers. However, actions must also be quickly taken by industry and government to build and sustain university power engineering programs through increased research support for faculty. Strong university power programs are needed to meet the needs for innovation, for future engineers, and for future educators. The following are recommendations for the university education:

- Work toward doubling the supply of power and energy engineering students.
- Continue enhancing education curricula and teaching techniques to ensure an adequate supply of well-qualified job candidates who can be successful in the energy jobs of the future.

- Increase research in areas that can contribute to meeting national objectives.
- Get involved in state and regional consortia to address workforce issues.
- Conduct seminars and encourage industry to provide information sessions to develop university student interest in power and energy engineering careers.
- Build communications and collaborations with industry, particularly between industry executives, department chairs, and college deans.
- Communicate with industry about education needs that may require innovative approaches to education.
- Ensure that adequate educational opportunities exist for retraining engineers with education and experience in fields other than power engineering.
- Use college or university student recruiting programs to also spread the word about opportunities in power and energy engineering.

Career and technical education

- Identify and communicate needs and ideas on education materials, lesson plans, and computer-based learning related to energy and engineering.
- Encourage students to consider engineering as a career.
- Increase the number of specialized teachers in math, physics, and chemistry to improve scientific education and increase professional awareness.
- Work with industry to provide projects, case studies, field trips, and learning-by-doing experiences into lesson plans to increase student interest in engineering.

Continuing education

- Inform students about engineering career opportunities.
- Provide course opportunities that prepare students for an engineering education at a university.
- Work with universities to establish credit transfer programs so that students can continue education at a university after graduating from a community college.

Certification and professional licensing

- Provide education opportunities for trainees to obtain the certification or license for engineering career.
- Build tools and relationships to recruit and train people leaving the military and from underrepresented populations.

Training of non-engineering workforce segment

- Partner with professional societies in areas of career awareness, workforce development and education, and workforce planning.
- Provide support in education planning and a career awareness video for engineers in cooperation with professional societies.
- Publish promotional materials and presentations that target potential power and energy engineers and transitioning military personnel; adjust messaging to appeal to underrepresented groups.
- Develop industry-wide and regional solutions that maximize the efficiency of electric utility workforce development activities.
- Perform annual electric utility surveys to identify high-priority energy industry engineering workforce needs.

Role of professional societies

- Take advantage of delays in retirements due to the economic downturn to more fully develop collaborations to implement wide-scale training and marketing programs.
- Keep the organization and its members knowledgeable of engineering workforce issues, and mobilize the membership, so individuals, chapters, or regions as a whole get involved in responding.
- Develop training plans targeted toward lifelong learning. The development needs to consider the adjustment of skills arising out of technological change and new fields.
- Explore ways to support retraining of engineers whose education and experience are in fields other than power and energy engineering.
- Provide opportunities to bridge promising student talent and industry.

2.11 NEW BUSINESS MODELS FOR GROWTH

Adherence to a set of core principles will maximize the return on the enormous investments countries around the world will make over the next two decades in electric infrastructure. The fundamental question that each market will face is how to provide incentives for electricity companies, consumers, and service providers to invest in, and implement the right level of smart technology. This question is immediately followed by another important set of questions: What is the commercial business model that makes sense to accommodate the new services and new prosumers, which still allow investments to be recovered by utilities? What are the regulatory models that will support those commercial ventures, while still focusing on grid efficiency and resilience? Electricity companies, in this case, should be viewed in the broadest sense. They include both traditional utility network companies that will be responsible for the provision of the underlying electricity network infrastructure, generators, retailers, and a wide range of nonutility companies providing diverse technologies, solutions, applications, and services to deliver the full value from smart grid deployment, such as communications companies behind home-area networks, companies providing microgeneration and devices to support advanced end-user services, electric vehicle and battery manufacturers, and companies that will provide the associated electric vehicle charging and billing infrastructure. In market terms, a smart grid supports a whole new range of product offerings, services, and opportunities that create value for users, electricity companies, third-party vendors, and host governments.

Electricity consumption in the United States and Europe represents approximately 40% of global demand, but demand has been declining in both regions in recent years. In contrast, energy consumption in the rest of the world grew by 5.1% from 2007 to 2012, driven by a higher rate of economic growth in emerging economies [14]. With cleaner energy available from renewable energy and the increased interest in shale gas in North America, utilities are now forced to evaluate and evolve their generation supply mix and innovate and change their business outlook and processes in order to protect their customer base. Customers are also changing their perspective on energy supplies and are looking to reduce consumption and produce energy themselves. Utilities are also driven by mandates and regulations to reduce CO_2 emissions in their generation mix, and are faced with excess generation capacity, certainly in northwest Europe. While the nature of this trend is uncertain in the longer term, in part, due to the growth of renewables and distributed generation, clearly, utilities must act now to decouple their revenue growth from future electricity demand in developed markets.

"The writing is on the wall and we have to change. The whole economics of the sector is changing—from old-style cost-plus economics to a world of high renewables feed-in and where customers want to have a say in decision-making and the economics of energy."—Praveer Sinha, CEO, Tata Power Delhi Distribution [15].

For American utilities, the current economy has led to leveling or even a decline in retail demand and corresponding revenues. In Europe, where the high penetrations of distributed generation have been a major effect on wholesale markets, this has led to enormous losses in utility revenues. While these changes threaten the financial stability of power companies, they do not yet indicate the end of traditional utilities. For some, the coming of the "utility death spiral" is inevitable. In such a scenario, utilities that don't actively invest in distributed generation and find new ways to engage their customers, will wither away and die, and large-scale power stations—the backbone of traditional utilities—could be "on a path to extinction" [7]. Disruption is inevitable, more notably driven by the customer, but it is important that utilities recognize that there are many other stakeholders and companies vying for the customer and grid-edge business. Utilities will need to be proactive and address the economic challenges early in the process, and look to new business models going forward. Ultimately, all stakeholders must embrace change in technology and new business models in order to maintain a viable utility industry. Distributed energy resources are the most imminent threat and could become the biggest driver of industry growth. While we frequently hear about the threat of the "utility death spiral," distributed energy resources could be seen by utilities as a growth opportunity [22].

The traditional utility business model is being challenged, placing utilities under pressure to innovate. Many integrated utilities have struggled to deliver shareholder returns amid regulatory changes, price volatility, and demand fluctuations. According to the World Economic Forum (WEF) [14], the return on invested capital (ROIC) for the 25 largest integrated utilities worldwide declined from an average of 6.6% in 2009 to 4.1% in 2014. Most of the decline for these companies was due to a decrease in operating profits, where twelve of the utilities had profits that fell by an annual rate of 5.2% over a 5-year period. Despite this decline in profits for integrated utilities, profits for the utility industry increased at an annual rate of 2.7% from 2009 to 2014, mostly from independent power producers in Asia, particularly China, whose profits grew at an annual rate of 25%. The shift to renewable generation, coupled with slowing demand growth in developed markets, has meant that a larger share of industry profits is now captured by nonintegrated energy companies—particularly those engaged in renewable equipment manufacturing, generation, and distribution. The WEF notes that analyst forecasts indicate that nonintegrated energy companies have captured a larger share of the industry profit pool over the past five years, and this trend is expected to continue. A vast number of nontraditional entrants in renewables are challenging incumbents, and investment in advanced renewable technologies is a significant source of innovation within the electricity industry. The WEF also notes that solar received the largest amount of startup investment in renewables from 2012 to 2015, totaling $5.4 billion, with Sunrun and SolarCity among the major recipients. In addition, investment in wind power totaled $2.2 billion over the same period, with Pattern Energy, a major startup in wind power generation and transmission, accounting for most of the investment. Investment by both disrupters and incumbents into emerging technologies and the unbundling of services across the value chain will result in a major shift of value over the coming decade. Utilities will need to react to changes in their business models and growth expectations.

Utility Dive notes [22] that as utilities shift away from traditional profit centers, regulators must enable them to adopt new business models. More than half of the utilities see distributed generation as an opportunity, and are now building new business models around it, the report found, and 55% say partnering with a third-party provider is the strongest investment in the new space, followed by potential regulated investment in distributed energy resources.

A study by the World Economic Forum (WEF) [14] shows that digital initiatives have tremendous potential to deliver exceptional value in the electricity market as a function of financial performance and shareholder value; customer value in terms of affordability, reliability, and satisfaction; and environmental and social value in terms of economic growth, sustainability, and job creation. In this study, the WEF estimates that from 2016 to 2025, a potential total of U.S. $1.3 trillion of industry and societal value will be generated globally from the following eleven initiatives identified in terms of value and opportunity time line:

1. Asset performance management—high value, short-term
2. Real-time supply and demand platforms—high value, medium-term
3. Energy solution integration—medium value, medium-term
4. Real-time network controls—medium value, long-term
5. Digital customer models—medium value, short-term
6. Energy storage integration—medium value, medium-term
7. Energy management—low value, short-term
8. Energy aggregation platforms—low-value, medium-term
9. Connected and interoperable devices—low value, short-term
10. Digital field workers—low value, short-term
11. Smart asset planning—low value, short-term

Of the eleven initiatives included in their analysis, the first five are worth at least U.S. $100 billion over the next ten years and should be prioritized for investment. WEF's estimates of the societal benefits are based on three factors: (1) value creation for customers (worth $986 billion); (2) reduction in carbon emissions ($754 billion); and (3) net job creation ($271 billion).

The WEF study concluded that asset performance management can provide the highest additional value to the utility industry at $387 billion, of which $276 billion is expected from the sale of smart sensors and software services. Energy technology companies have already identified asset management as a key growth potential, such as GE (General Electric) with their Industrial Internet and Predix platform initiatives. Real-time supply and demand platforms provide the largest societal benefits in addition to significant industry benefits, where customers can expect to gain up to $559 billion of value from postponing consumption during peak demand periods. Connected and interoperable devices are expected to generate more than 5% of the cumulative industry profits over the next 10 years. The WEF also notes that customers can expect to realize up to $290 billion of savings from lower peak demand consumption between 2016 and 2025, and the impact could be significantly higher if adoption rates increase further. In addition, initiatives that increase the penetration of renewable energy sources, such as the integration of energy storage, also have the potential to add significant value; however the current higher costs of renewable and energy storage supply compared to traditional fuel-based resources are likely to keep adoption rates suppressed over the next four to five years, after which grid parity is expected.

As part of the focus on the consumer, most utilities are digitizing the customer experience by investing in online (and especially mobile) customer services, such as on-line bill payment, outage notification and status, and energy usage reporting. In some cases, this presents an additional revenue opportunity for utilities while improving customer satisfaction and lowering costs. While many of the efforts to date have yielded optimal results, some lag with respect to usability and the interface between the online and traditional sales channels—a multichannel platform that seamlessly connects customer interactions across all channels—online, mobile, call center, and local sales [18]. For utilities, their digitization efforts also result in improved and more cost-effective customer processes, and a seamless multichannel platform allows them to increase customer interaction touch-points and obtain more data about customer usage and behaviors. Utilities are using advanced analytics to enhance service quality, lower costs, and preserve and deepen customer relationships. Utilities can also use customer data analytics to make process improvements and increase up-selling and cross-selling opportunities. While previous attempts by utilities to move into adjacent markets have generally been unsuccessful, with digital and smart technology, utilities will have much more meaningful customer level data on which to build new propositions, which could include bundling a range of home services [20].

"Our strategic imperative must be to invent and invest in our own disruptive business model before somebody else does that against us."—Erwin van Laethem, Chief Innovation Officer at RWE (Rheinisch-Westfälisches Elektrizitätswerk AG) [15].

Business as usual in the smart grid will look very different: partnering with peers and competitors to offer valuable customer services, improving and optimizing the grid, adopting digital technologies, and thinking beyond the traditional business model and processes will become core business activities for utility and technology companies. Services in this new business model will include markets where utilities have not traditionally ventured, such as big data and analytics. Utilities will need to move beyond traditional industry boundaries and position themselves as consumer brands by providing innovative cross-industry services. However, in doing so, utilities will need to work cooperatively with vendor partners, both inside and outside the utility industry.

2.12 EMBRACING CHANGE

Many electric utility executives do not see a burning platform that would motivate them to change. Most say that their customers are happy, their reliability is good, and their customers want lower rates not higher ones. They are hesitant to make major investments in their systems. In fact, the financial markets are driving them to minimize investments and there is no force on the horizon to make them do otherwise, apart from customer trends (e.g., solar PV adoption) that have yet to reach the scale to impact those utilities in the short term. Regulators are equally hesitant to allow rates to increase and are pushing for decreases in some areas of the world (e.g., Australia). However, the consequences of "doing nothing" should be considered:

- Disruptive change that could achieve a tipping point
- Increasing number of major blackouts
- More local interruptions and power quality events
- Continued vulnerability to attack
- Less efficient wholesale markets
- Higher electricity prices
- Limited customer choice
- Increased load defection whereby customers provide some of their needs with self-generation, load shifting, and storage strategies, thereby reducing the ability of utilities to recover their investments through volumetric energy tariffs. In some instances, this can be a self-fulfilling prophesy. If utilities continue to see rate basing as the primary means of cost recovery for all grid modernization, then they can enable the same future "grid parity" that they are trying to prevent.
- Rising product prices
- Greater environmental impact

More cooperation and the free exchange of information are needed among the approximately 3000 diverse utilities, to successfully achieve the smart grid vision. Some industry observers believe that because of deregulation, the industry's corporate culture has moved from cooperation and coordination to competition and confrontation. These relationships must span beyond the utility industry and encompass the new players who are coming to behind meter space.

Industry executives are reluctant to change processes and technologies. Some utility cultures are resistant to change and operate in "silos" organizationally. As a result, processes and technologies that are based on long-standing practices and policies are difficult to change. Additionally, senior managers today may be more focused on marketing and legal issues, rather than the technical aspects of power systems. The result may be an overreliance on regulation and/or markets to address grid modernization issues rather than proactive investment in new processes and technologies. Integration of change management techniques into utility organizations might stimulate change in their culture. Utilities are unlikely to heavily invest in areas with uncertain regulatory treatment; regulators are unwilling to permit rates to rise without good cause in the face of customer/advocate pushback. Alignment of utility shareholders and customer needs seem paramount.

"The biggest threat to innovation is internal politics and an organizational culture, which doesn't accept failure and/or doesn't accept ideas from outside, and/or cannot change."—Gartner, July 2016 Financial Services Innovation Survey.

Industry technical staffs are reluctant to change planning and design traditions and standards. Utility planning and design traditions and standards generally focus on the traditional model of the electric grid—centralized generation, legacy technologies, and little reliance on the consumer's decisions on energy (e.g., consumers buying Solar PV and Batteries) as well as looking at them as an active resource that can provide grid support services. Smart grid principles have generally not yet been incorporated into technical policies and standards, which can limit the deployment of new processes and technologies that exist today. A significant change management effort is needed to encourage technical staffs to modify their current approach. Resources at many utilities (both human and financial) are limited and stressed. The amount of resources available to look beyond day-to-day operations is limited. While it may seem that slow progress is being made in grid modernization from the project deployment perspective, there has been significant progress in aligning utilities around the core smart grid concepts that will ultimately build strategic plans, as evidenced by the development of standards for the new technologies. Early adopters are forging the way for followers who will benefit from an easier logical transition to modernize their grids.

None of the previously mentioned can be done without multiple perspectives at the table, working with a common definition of success and common guiding principles, and commitment to collaborate to achieve the best outcome for the organization. Since smart grid, from a utility perspective, is a company-wide challenge, not a technology deployment, there will necessarily be some new organizational components to consider. These could include, if they are not in place already, some notions that are relatively new to the utility industry, such as a senior business transformation executive, an enterprise architecture function, a design authority to which technology issues and opportunities are directed, a company-wide smart grid steering committee to ensure alignment across all the activities described earlier, and a commitment to a change management discipline and process. Among other things, this change management process should include a standard approach for measuring performance and providing feedback across the stakeholder community. Openly sharing successes and unsuccessful efforts is at odds with the current utility culture. However, doing so would ultimately break down many of the barriers that would cause untimely starts and stops and potentially reduce the overall investment by eliminating rework (Figure 2.5).

Take a moment to reflect on the tasks and challenges noted at the outset:

- Business requirements that are both flexible and specific
- Vendor selection under uncertainty
- System interoperability, both new and legacy
- Innovative rates that are effective and acceptable
- High-profile technology deployment that needs to be as transparent as possible
- Behavioral-driven benefits

These are not tasks and challenges that are purely technical in nature and these are not tasks and challenges that can be wrestled to the ground by any one group, or by a series of groups working independently. This effort requires subject matter expertise, certainly, but more importantly, it requires a cohesive application of that expertise across organizational boundaries to achieve the full range of operational, informational, and behavioral benefits made possible by the smart grid.

Matching internal culture to a new and changing digital customer environment is a challenge. It is a drastic change for utilities in terms of customer orientation. PwC's research [15] concluded that customers see a role for the utility in advising them how to make an energy transition, that they

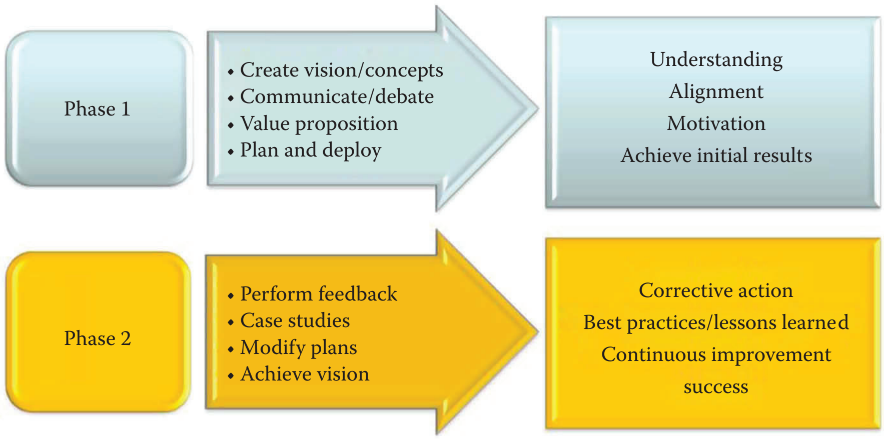

FIGURE 2.5 Components of managing change. (From Sharing smart grid experiences through performance feedback, National Energy Technology Laboratory, Morgantown, WV.)

trusted utilities to help them, or at least be a backstop to help them make that transition. Utilities need to be more customer-centric with a sales and outward-focused mindset, with skills and capabilities around business intelligence and business analytics.

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