4 Smart Grid Barriers and Critical Success Factors

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Our electricity infrastructure is on the cusp of game-changing investments: embedding sensors, communications, and controls—a brain and nervous system—throughout the entire system, from power plant all the way through to consumer devices. Those investments have the potential to unleash entrepreneurial innovation and open up the biggest of all global industries—and the single largest source of global warming pollution on the planet—to a vast new diversity of clean energy resources, including thousands we have not yet dreamed of. This smart grid—at its core—will be an enabler: facilitating deployment at scale of clean, low-carbon energy and transportation, and reducing our fossil fuel burden. By making demand flexible and responsive to available supply and incorporating electricity storage and grid awareness technologies, it will enable high penetration of variable renewable generation and plug-in electric vehicles without compromising grid stability. It will transform the historically passive electricity consumer to an aware and active participant in electricity markets, able to produce and sell electricity and ancillary services. It will deliver accurate, real-time price signals, influencing the load curve to realize a far more efficient system overall. In short, the smart grid will facilitate a new paradigm: structured around renewable and distributed resources, integrated with the transport sector through mass deployment of clean electric vehicles, and inclusive of many more suppliers of energy and services—adding up to a system that is vastly more efficient, flexible, reliable, cost-effective, and clean [1].

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 to invest in and implement the right level of smart technology. 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 and a wide range of non-utility companies providing diverse technologies, solutions, applications, and services to deliver the full value from smart grid deployment (e.g., 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 e-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, and the host governments.

Although smart grids provide an essential supporting infrastructure for energy efficiency and environmental measures (e.g., intermittent renewable generation), by themselves they create benefits outside of network operational efficiencies. Wider societal value scales up (e.g., through real-time consumer propositions and carbon reduction) only when all of these electricity companies interact to provide the range of commercial services that a smart grid supports. To be effective and efficient, any market stimulation must be designed to overcome barriers to the development of the supporting smart grid infrastructure and commercially viable associated products, offerings, and services. Different countries have different drivers for, and expectations of, a smart grid, and contain one or many different market and regulatory structures that will need to support their development.

Smart grid implementation brings many opportunities as well as extraordinary "change management" challenges. In fact, "challenge management" may be the more operative term. Smart grid implementation is complex and the impact both on the utility organization and electricity consumers is potentially formidable. This fact contrasts with the countless articles that have focused on the many purely technological challenges to which utilities must rise. One could suggest that even more critical may be the challenge of managing change along several dimensions and integrating multiple components into a seamless, real-time system.

Barriers and success for smart grid involves several factors, not only just from the utility standpoint, but also from the consumer, regulatory, and utility industry perspective. Another important aspect is the need for the education and skills to support the evolution of smart grid. A successful smart grid implementation is a multifunctional effort:

- Regulatory matters need to be addressed, including designing dynamic rates and obtaining key approvals to proceed with a reasonable cost recovery mechanism.
- Adequate funds need to be raised in the capital market.
- Vendor partners need to be selected.
- An extensive construction effort needs to be managed.
- Systems need to be implemented and integrated.
- Processes need to be redesigned.
- A robust customer communications campaign needs to be conducted.
- New customer-facing services need to be developed.

While these tasks appear to be functionally specific, maximum efficiency and efficacy can only be achieved if they are managed across organizational boundaries. This includes the most critical task of all: the realization of customer benefits.

The stakes are high when dealing with a service as vital to consumers, business, and industry as is electricity and are that much more so when one considers how stimulus funding and other factors have raised public awareness of the smart grid. Simply put, there is a need to "upgrade the airplane while it is in the air"—and do so seamlessly. With that in mind, consider the inherent challenges in the "to do" list provided earlier:

- Business requirements will need to be flexible enough to accommodate changes while being specific enough to enable construction.
- Vendor selection process will be complicated by a lack of extensive track records.
- While system implementation will be challenging enough, interoperability between these cutting edge systems and the utility's legacy systems (including the billing engine) must be achieved.
- Rate structures must be developed that properly and adequately balance customer risk and reward.
- The technology to be deployed, in the case of advanced metering infrastructure (AMI), touches every customer.
- Some of the benefits to be realized are under the control of the utility while others are dependent on changes in customer behavior.

As one utility Vice President of Business Transformation puts it, "If you look at this as just reading meters remotely, you've missed the boat." An important corollary to this is, "If the Smart Grid is being viewed as belonging to any one department within your utility, your effort is on the road to failure."

There are many reasons the smart grid is not emerging more quickly. Fundamentally, no single business owns or operates the grid. Individual players have little incentive to risk major change. With so many players in the grid system, finding a common interest in or vision for change is difficult but imperative. The benefits are so broad and far reaching that perhaps only government can account for the cumulative societal value. Longer-term financial incentives are needed to enable the larger infrastructure investments needed for grid modernization. Many barriers exist today and more will arise before the vision is realized. These challenges are daunting, but they can be overcome. With a clear vision, we can generate the alignment needed to overcome the barriers as well as those yet to be identified. Some options include the following:

1. Regulatory and legislative barriers—change statutes, policy, and regulations to eliminate those that inhibit progress and create those that encourage progress and create a "win-win" scenario for all stakeholders. For example,
    a. Capture and include the full set of societal benefits when addressing the costs of grid modernization.
    b. Provide regulatory framework to present rate cases for recovery of smart grid investments.
    c. Establish grid modernization goals, metrics, and coordination mechanisms to better manage the transition to the smart grid.
    d. Provide enhanced returns on smart grid investments.
    e. Modify the model that links utility profit to sales volumes.
2. Culture and communication barriers—increase the understanding and awareness of stakeholders on the value of the smart grid and encourage them to embrace the needed changes within their organizational cultures.

3. Industrial barriers—define the case for change, the "burning platform," and provide the necessary incentives to engage industry on grid modernization. Industry will respond when it understands there is a profitable market for grid modernization technologies and services.
4. Technical barriers—increase the speed of research, development, and deployment.
5. Increase funding to support research, development, and deployment for those technologies that are needed for grid modernization.
6. Work more closely with academia to develop the human resources with skills needed for the modernized grid.
7. Apply more priority and resources to the development of needed standards.
8. Clarify the pathway to the smart grid by developing a transition plan that shows the intermediate milestones for achieving its vision.

4.1 UTILITY ORGANIZATIONAL AND BUSINESS PROCESS TRANSFORMATION

A broad consensus for the smart grid vision throughout the power industry is gaining momentum but has not yet been institutionalized. A greater understanding of the advantages and benefits of the smart grid is needed. Moreover, once consensus is reached, a transition plan defining the pathway for transforming today's grid into the smart grid is needed.

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. However, the consequences of "doing nothing" should be considered:

- 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
- Rising product prices
- Greater environmental impact

More cooperation and the free exchange of information among the approximately 3000 diverse utilities is needed to successfully achieve the smart grid vision. Some industry observers believe that, as a result of deregulation, the industry's corporate culture has moved from cooperation and coordination to competition and confrontation. Relationships among utilities need to shift to a more collaborative model to foster sharing metrics that capture best practices and lessons learned in order to reduce time and investment in the smart grid transition.

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 over reliance on 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.

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 as an active resource. Smart grid principles have generally not yet been incorporated into technical policies and standards that 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 the area of 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. Early adopters are forging the way for followers that will benefit from an easier logical transition to modernize their grids.

None of the aforementioned 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 as a whole. Since smart grid 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 of 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 4.1).

Take a moment to reflect back 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

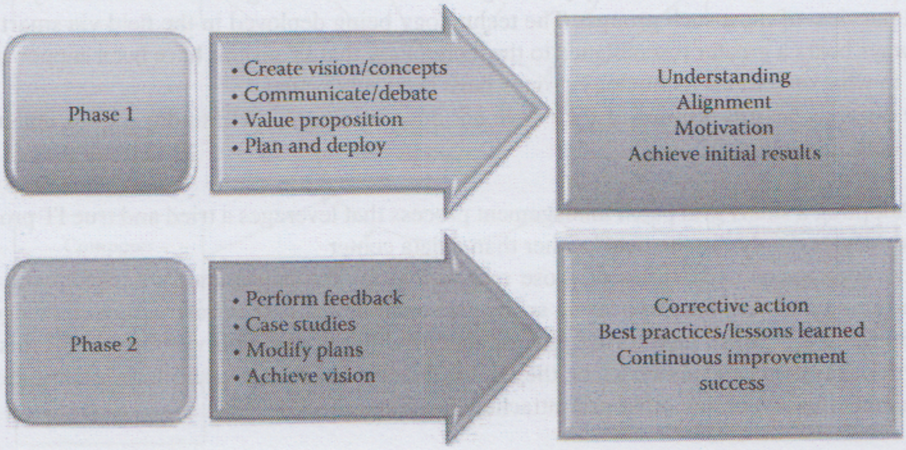

FIGURE 4.1 Components of managing change. (From Sharing smart grid experiences through performance feedback, National Energy Technology Laboratory, Morgantown, WV, http://www.netl.doe.gov/smartgrid/docs/PFP%20for%20the%20Smart%20Grid_Final_v1.0_031511.pdf)

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.

4.2 CONVERGENCE OF OPERATIONS TECHNOLOGY AND INFORMATION TECHNOLOGY

The smart grid changes many things for the customer and countless others for those who serve the customer. A relatively easy way to think about this issue is in its primary component parts: operational efficiencies and informational efficiencies.

A smart grid business case is driven in no small part by operational efficiencies, such as (1) cost reductions through automating or eliminating manual tasks and (2) improving outage duration metrics through the deployment of greater computing power in the field. As critical as it will be to apply sound program and project management skills to ensure that these multiple, interdependent efforts are aligned and effective, it will be just as important to leverage the informational capabilities of the technology being deployed.

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. The utilities that can develop the analytical infrastructure necessary to transform these data into information will be able to better 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.

As with other disruptive technologies—such as those that revolutionized correspondence, the recording industry, and publishing, to name just three—the potential benefits are high for those that properly "manage the challenge."

The convergence of operations technology and information technology (IT) 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 enough 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. For example,

- Adopting a smart grid patch management process that leverages a tried and true IT process for devices, only "in the field" rather than a data center
- 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, be they in the data center, system operations, a substation, a remote facility, or any other grid-attached location

Investments in security upgrades are difficult to justify. A standard approach is lacking for conducting security assessments, understanding consequences, and valuing security upgrades. Additionally, limited access to government-held threat information 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.

4.3 INTEGRATED SYSTEM APPROACH

The smart grid approach to the design and operation of generation, transmission, and distribution systems requires an integrative strategy. That is, several technologies must be brought to bear on the design and operation philosophy as shown in Figure 4.2.

Demonstration and pilot projects are essential for the smart grid transition, so that the whole chain of technologies can be tested together. This allows weaker areas to be identified and refined, and deployment and commercial models to be tested. Although many pilot and demonstration projects exist globally, there are limitations on their effectiveness. Few are at a scale large enough to provide a thorough understanding of how they will operate in full-scale deployment or to make them economically and functionally viable. Limited, although not coordinated, learning and knowledge sharing is emerging from these projects.

Integration of smart grid solutions requires a versatile and flexible communication infrastructure. Communications requirements of the smart grid are much more demanding than of the legacy grid. The real-time requirements for exchange of data and information require low

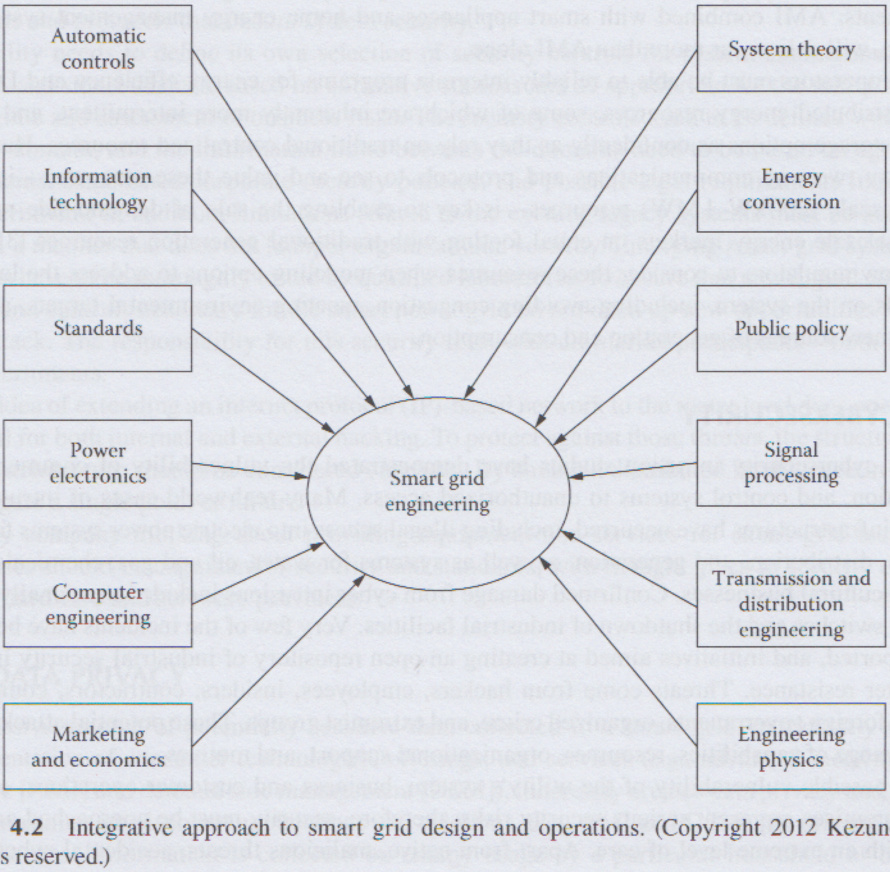

FIGURE 4.2 Integrative approach to smart grid design and operations. (Copyright 2012 Kezunovic, M. All rights reserved.)

latency and redundancy in communication paths. The back office data processing and storage requires communication support for distributed databases and processing facilities. The communication infrastructure also has to enable the system integrity protection schemes critical to reliable system operation and control. The increased interest and emphasis on communications design arises from

- Need for security in all systems and subsystems
- Conformity of protocols to accelerate the use of components from diverse vendors
- Making a set of sensory signals available for operation and control of all systems and subsystems

A smart grid can reduce the need for new central station power plants and transmission lines, but only if the planning processes are linked. As the California Public Utilities Commission (PUC) found, "the Smart Grid can decrease the need for other infrastructure investments and these benefits should be taken into account when planning infrastructure." Conventional supply-side solutions should become just one among many options considered for meeting demand growth, with costs and benefits of competing strategies comprehensively assessed. Utilities and regulators will need, for example, to consider whether wider reliance on demand response (DR) will offset peak demand at a lower financial and environmental cost than a new peaking plant and transmission to serve it. More broadly, they will need to determine which path best meets their constituent's goals: which, for instance, will ensure the lowest-cost achievement of state and federal energy and environmental policies and which foundational investments will best support future innovation, multiple functionalities, and economies of scale. Integrated solutions will inevitably deliver far more than piecemeal investments: AMI combined with smart appliances and home energy management systems, for instance, will deliver far more than AMI alone.

Grid operators must be able to reliably integrate programs for energy efficiency and DR along with distributed energy resources, some of which are inherently more intermittent, and various energy storage options as confidently as they rely on traditional centralized resources. Having the necessary two-way communications and protocols to see and value these resources—including smaller scale (200 kW–1 MW) resources—is key to enabling the sale of demand-side resources into wholesale energy markets on equal footing with traditional generation resources [3]. It will also allow regulators to consider these resources when modeling options to address the long-term demands on the system, including avoiding congestion, meeting environmental targets, and integrating new sources of generation and consumption.

4.4 CYBERSECURITY

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 particular concern to smart grid technology stakeholders. All parties involved in managing network operations centers or the relevant IT systems have to be trained and alert to tamper from the inside. Specially trained security officers need to be implemented 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 are not 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 have to be thoroughly tested by qualified laboratories to ensure that new digital communications and controls necessary for the smart power grid do not open up 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 up 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.

Every company 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.

4.5 DATA PRIVACY

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 demand side management [DSM]), inherently creates data privacy and security risks. Consumer involvement applications and solutions (e.g., AMI and DSM) put privacy interests at risk because information is collected on energy usage by a particular household or business.

Consumer-based smart grid technologies put privacy interests at risk because a core purpose is to collect information related to a particular household or business. With granularity to a minute, meters already collect a unique meter identifier, timestamp, usage data, and time synchronization every 15–60 min. 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 or not legal), 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 privacy and security concerns into account 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 is allowed to 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 damages claims based on compromised customer data or facilities.

Concerns about data privacy in smart gird environments and AMI, in particular, are now being widely discussed. In the Netherlands, for example, the formerly compulsory AMI roll out was subsequently made voluntary.

4.5.1 GRID SECURITY IN THE UNITED STATES

In August 2009, the U.S. President Barack Obama cited smart grid security as one reason for creating a new White House cybersecurity position. The announcement came after a string of press reports emerged about intrusions into power system security. These accounts included an anonymously sourced *Wall Street Journal* article claiming that foreign spies had infiltrated a grid system, and claims by cybersecurity firm IOActive that it had proven it could hack into smart meters, potentially cutting the power to millions of homes at once and causing the grid to fail.

4.6 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. Meanwhile, the increased number of players and 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 [3,4].

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 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.

Some smart grid benefits are under the control of the utility while others are dependent on changes in customer behavior. This is a critical point. For most utilities:

- Operational benefits will be driven by activities such as the elimination of manual meter reading, the implementation of remote connect/disconnect capability, improvement in billing activities, reduction of off-cycle meter reading, optimization of assets, and reduction in maintenance costs, all of which require regulatory support for changes in business processes
- DR benefits will be driven in part by direct load control efforts, which in most jurisdictions will require customer adoption through voluntary enrollment
- DR benefits will be driven primarily by a form of dynamic pricing, which requires regulatory approval, establishment of a customer "opt in" or "opt out" approach, customer awareness, and changes in customer behavior
- Reliability benefits will depend on various factors, such as the expected efficiency of automated sectionalizing and reclosing (ASR) scheme operations, but as with all system performance measures, actual benefits will vary due to non-controllable factors, such as weather

The approach to meeting these challenges successfully will necessarily be transformational, evolutionary, and multidimensional. Overall, it is an effort with significant implications for how work gets done, how information is used, and how customers are served. Fundamentally, it is about moving beyond the traditional, "transactional" customer relationship and becoming a "trusted energy advisor."

At many utilities, the smart grid has been advanced first by the engineering group. Obviously, the role of engineering cannot be overstated. An ASR scheme, for example, is not something that can be bought shrink-wrapped. However, to help underscore the importance of cross-organizational teamwork in meeting these challenges effectively, consider the role that many other functions will need to play in achieving smart grid success.

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 are 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. Done properly, greater utilization of these new technologies and innovative rate structures will be driven.

Few regulatory bodies, if any, are receptive at this time to a transition to mandatory dynamic pricing for all customers. Therefore, dynamic pricing will most likely be offered on a voluntary, "opt in" basis, and the most likely rate structure will be a critical peak rebate rather than critical peak pricing (i.e., a rate structure predicated on a "carrot" rather than a "carrot and the accompanying stick"). Both of these factors greatly increase the importance of marketing the potential benefits to the customer base. This necessarily implies the need for a growing understanding of what messages (and message delivery vehicles) are most effective in reaching different customer segments—something at which regulated utilities are typically not expert. Until now, they have never needed to be.

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 (a) increasing enrollment and retention in dynamic pricing programs, (b) improving behavioral responses to pricing options and usage information, and (c) 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 IVVC
   c. Reduced capital expenditures through M&D (Monitoring and Diagnostics), DSM, and IVVC
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

Customer choice, energy efficiency, and customer value are seen as 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. 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.

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 business case is intended as an overall guide for utilities in developing a long-term strategy. The business case relies on system estimates, sometimes educated guesses on benefits and costs, and compares the net present value of phased implementations of smart grid candidate technologies. Some parallels can be drawn between utility service areas and served customers, but not all utilities are at the same level or phase of technology implementation and therefore expected benefits and costs will vary. Industry standards, such as reliability indices, can be used as an overall comparison of the operations of a utility, but the comparison of smart grid implementations and expected benefits can vary widely across utilities with a similar number of customers. Not all business cases are the same—"your mileage may vary." While current smart grid initiatives are driven by regulatory pressure and tend to focus more on the meters as a direct impact on consumers, we are likely to see more technology-rich initiatives after well-proven smart grid evaluations ("staged deployments").

A key smart grid market barrier is business case fragmentation, particularly in competitive-leaning fragmented markets. A network business operating separately from generation and supply companies, with different companies operating in each part of the value chain, is an indicator of a fragmented market. In contrast, a concentrated market has one or two vertically integrated companies.

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-leaning 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).

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.

For a vertically integrated market, most of these benefits accrue to the lead incumbent company, and therefore the immediate benefits (excluding societal), investment, and risk are borne by the same party. This makes business cases more straightforward—assuming that societal benefits can be adequately captured.

The EPRI Electricity Sector Framework for the Future estimates $1.8 trillion in annual additive revenue by 2020 with a substantially more efficient and reliable grid [5]. 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 [6].

"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.

The efficient technologies can dramatically reduce total fuel consumption—and thereby potentially reduce fuel prices for all consumers. Virtually, the nation's entire economy depends on reliable energy. The availability of high-quality power could help determine the future of the U.S. economy. Additionally, a smart grid creates new markets as private industry develops energy-efficient and intelligent appliances, smart meters, new sensing and communications capabilities, and passenger vehicles [7].

Around the globe, countries are pursuing or considering pursuit of greenhouse gas legislation suggesting that public awareness of issues stemming from greenhouse gases has never before 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" [8].

Implementing smart grid technologies could reduce carbon emissions by

- Leveraging DR/load management to minimize the use of costly peaking generation, which typically uses energy resources that are comparatively fuel inefficient
- Facilitating increased energy efficiency through consumer education, programs leveraging usage information, and time-variable pricing

- 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
- Integrating plug-in hybrid electric vehicles (PHEVs), distributed wind and photovoltaic solar energy resources, and other forms of distributed generation

4.7 PERFORMANCE GOALS AND PROGRESS METRICS

Smart grids can and should accurately measure their own performance, including overall efficiency, use of renewable energy, DR, and energy storage, as well as impacts on air pollution, water consumption, and land. Frameworks are now available to aid regulators and utilities in evaluating smart grid deployment plans and benefits and power purchasers in assessing the quality of their electric supply [9,10]. Power companies and utilities should be held accountable for delivering promised benefits—with allowed rates of return on investment linked to performance.

To avoid the problem of stranded assets and to maximize the economic and social return on investments, important questions of timing will need to be resolved. Some strategies, like voltage regulating devices (Volt/VAr), can already reliably reduce the strain on the electric system and save substantial amounts of energy: efficiency standards for power lines or market incentives could accelerate the deployment of such technologies. More consumer-focused options, such as residential time of use pricing, have been shown in pilots across the country to shave peak demand and reduce overall consumption, but will require outreach to consumers and time to adapt. This suggests a phased approach—investing in off-the-shelf options that deliver benefits in the near term while building the capacity for longer-term strategies, making use of lessons learned to guide deployments going forward.

4.8 TECHNOLOGY INVESTMENT AND INNOVATION

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, 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 needs to be accelerated.

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 all 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%) (Figure 4.3). Competitive high-tech industries are 5–10 times higher. Yet, the move to make electricity competitive has not spurred more industry R&D. R&D costs are often 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

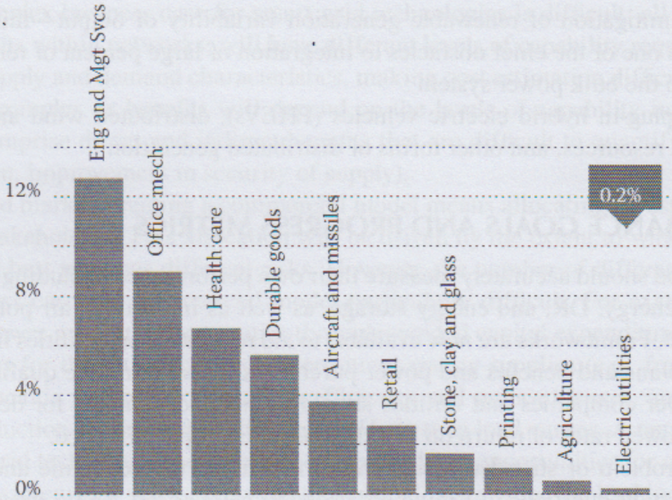

FIGURE 4.3 Industry R&D as a percentage of revenue. (From National Science Foundation.)

to 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 in their own right may well be left behind, leaving a maturity gap in the smart grid technology chain.

The integration of multiple key technologies has not yet occurred. 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.

The price of many new technologies is currently not competitive with traditional alternatives and should be reduced to stimulate the level of deployment needed to achieve the smart grid. As the price ultimately is reduced, technical performance is proven and societal benefits recognized, the demand for these technologies will increase leading to further reductions in prices. 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.

4.9 CONSUMER ENGAGEMENT AND EMPOWERMENT

More work is needed to communicate the concepts and benefits of the smart grid to a wide variety of stakeholders and the general public and to encourage them to embrace the changes that will be needed to achieve the smart grid vision. Smart grid should be seen in the eyes of the customer, not just the utility—one from customer to consumerism.

Smart grid technologies demand behavioral changes in power consumption as DR involves consumer participation. 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 renewable energy sources and DR will, in many cases, require making the existing network stronger and smarter and building new infrastructures. The public may negatively perceive changes in their electricity experience, particularly if it is accompanied by rising bills.

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. More effort is needed to communicate and educate our citizens in the following areas:

- Today's grid is vulnerable to attack.
- An extended loss of the national grid would be catastrophic to our nation's security, economy, and quality of life.
- Today's grid will not address the security and economic challenges of the twenty-first century.
- A smart grid will be the platform, system, and network that will enable clean technologies, DSM and other options for addressing climate change to be deployed.
- A smart grid will help the United States become less dependent on foreign energy.
- A smart grid will be a more efficient and less costly grid.
- The performance of today's grid may lead to loss of jobs in the future as work is transferred to countries with more reliable and economic grids.

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 DR, spinning reserve, energy, etc
- Enjoyment of future value added services that may be enabled by a smart grid

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.

Utilities should educate customers before any technology deployment, building in costs for 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 have shown consumer enthusiasm for time of use 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 on 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, 8 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.

4.10 VENDOR PARTNERSHIPS

It is important to utilize technical talent, regardless of where it is located within an organization. It is also important to identify vendor partners that bring the necessary technical talent. A project of this breadth cannot be readily outsourced to even the most capable of vendors, but keeping them at arms' length will not be beneficial either.

Building a smart grid is not a single vendor task and utilities need to be prepared for a deliberate and complex vendor evaluation process to ensure that the right solutions, for both the short term and the long term, are selected. The vendor selection process itself needs to be very carefully and very rigorously done. If the sourcing process that a utility undergoes for smart grid is not painful, then it is probably not a sufficient process. A holistic view of smart grid technology is vital—not just the pieces of the puzzle, but how they fit together and what picture they form. If that complexity is not fully recognized and managed, the likelihood of making the right sourcing decisions declines significantly.

4.11 STANDARDS DEVELOPMENT, COORDINATION, AND ACCELERATION

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 ISOs, a large number of 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 30 months. Even after one of the SDOs has defined a standard, it still has to 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. In order 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

Across the United States, many utilities have already or are in the process of implementing smart technologies into their transmission, distribution, and customer systems based on several factors such as implementing legislative and regulatory policy, realizing operational efficiencies, and creating customer value. Smart grid value realization by utility customers and society at large is, in part, linked to the pace of technology implementation that enables a secure, smart and fully connected electric grid. Utilities agree that the development and adoption of open standards to ensure interoperability and security are essential for a smart grid. In many cases, utilities have defined open standards in the requirements for smart technology.

The smart grid is broad in its scope, so the potential standards landscape is also very large and complex. This is why "standards" adoption has become a challenge. However, the opportunity today is that utilities, vendors, and policy makers 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.

Although we are starting with a broad suite of standards that can help the country implement the smart grid in a timely and efficient manner, there are still a large number of standards that have to be developed on standards already in progress, which have to be completed in a timely manner. It is critical that we find a process that will accelerate the adoption of new smart grid standards. First, consider the challenges the industry has to overcome to accelerate the smart grid standards adoptions:

1. There are a large number of standards bodies and industry committees working and industry committees working in parallel with many duplicate and conflicting efforts. The industry must come together to focus concerted effort to accelerate the adoption of the stands which they are focus on.
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 are these challenges to be overcome and quickly?

1. A single national standards body should be established to take over formal control of smart grid standards adoption/NIST should immediately establish a more formal governance structure and related processes to prioritize smart grid standards selection and ensure an open unbiased process including key stakeholders. NIST shall coordinate the efforts of all existing standards bodies and industry committees to focus their attentions on a common goal and remove duplication of efforts.
2. Develop a smart grid "road map" that outlines a path and direction of deploying existing and future standards giving the industry clean 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, etc.
4. Governance principle definition includes the following:
   a. Openness
   b. Integrity
   c. Separation of duties and responsibility
   d. Compliance
5. Clearly defined test and verification methodologies and certification bodies shall be established to certify compliance to 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. Policy makers 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 a number of 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—concrete action is needed in 2009 to standardize a few key aspects.

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 given the lack of clear definition of all the elements and uses of the smart grid and complexity 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, 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 systems 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, as long as the important "intersystem" boundaries are well understood and the following interoperability design concepts are preserved.

4.12 POLICY AND REGULATION

According to some vocal experts, 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 [12]. Public policy is commonly defined as a plan of action designed to guide decisions for achieving a targeted outcome. In the case of smart grids, new policies are needed if smart grids are actually to become a reality. This statement may sound dire, given the recent signing into law of the 2007 Energy Independence and Security Act (EISA) in the United States. And, in fact, work is underway in several countries to encourage smart grids and smart grid components such as smart metering. However, the risk still exists that unless stronger policies are enacted, grid modernization investments may fail to leverage the newer and better technologies now emerging, and smart grid efforts will never move beyond demonstration projects. This would be an unfortunate result when one considers the many benefits of a true smart grid: cost savings for the utility, reduced bills for customers, improved reliability, and better environmental stewardship. The U.S. Energy Policy Act of 2005 was a good first step in addressing barriers to grid modernization, but more is needed. Legislators and regulators have not yet taken a strong leadership role in support of grid modernization. A clear and consistent vision for the smart grid has not been adopted by legislators or regulators. Much has been said about individual technologies such as renewables and about specific energy issues such as environmental impact, but little has been said about the overall vision for a modernized grid—a vision that integrates the appropriate technologies, solves the various grid related issues, and provides the desired benefits to stakeholders and society.

Unclear policy increases market uncertainty with regard to how the overall market structure and rules will develop, which technologies merit investment, and the levels of capability required of the network. Market uncertainty varies depending on the market structure. Competitive-leaning markets place the emphasis on market participants, motivated by profitability and/or growth, to most efficiently allocate capital and select which technologies to apply. Centralized markets are subject to a more directed approach by the government or regulatory body acting within powers set by the government.

Governments and regulators in competitive-leaning markets will avoid the charge of picking winners and will attempt to let the market decide on the best structure and technology, often through lengthy consultations. However, where there is a lack of clarity about future market structure, roles, and rules, competitive markets tend to lock up. Companies then base investment decisions on the status quo and use tried-and-tested technologies to avoid the risk of picking the losing market technology. However, once the new market structure is defined and technologies are proven, rapid adoption of technology and associated innovation can be expected.

Network companies within centralized markets are more likely to be subject to government or regulatory directives, whereby direct mandates are given to the market participant(s) to invest in certain areas. Although this approach will gain quick results in the short term, a centralized market will, by its nature, provide political/regulatory risk, and not necessarily offer the rewards that could encourage the innovative new markets and services needed to realize the full potential value of a smart grid. This implies the need for a 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.

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 benefits expected and provide assurance of return—at least for the payback period of investment.

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. The network company in this unreconstructed market would be investing to reduce its own revenue.

Network companies are rewarded for their success in delivering (approved) capital expenditure programs, providing the capacity to avoid network congestion—many by having revenue directly tied to the value of their asset base. Smart grid investment will reduce the need for network reinforcement capital expenditure. Networks could operate more efficiently, with less headroom than currently required, if peaks in demand are smoothed out through DR offerings enabled by smart grid technologies. On the face of it, investment in smart grid technologies in many regulatory environments would be undermining a utility's growth and revenue model by placing downward pressure on the requirement to build additional capacity.

To restructure the regulatory model to address issues such as revenue assurance, 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.

A number of initiatives exist to address these areas, in some cases setting out legislative and market frameworks to provide the right market environment for smart grid development, in others cases implementing full-scale projects that develop business cases and test financing arrangements. This section highlights a few examples of current initiatives for discussion and is not intended to be a comprehensive review.

Market uncertainty—can be largely overcome by defining a clear roadmap or strategy for smart grid development, together with supporting legislation that designates targets and incentives for those responsible for delivering the required infrastructure. The European Climate and Energy Package establishes a compelling rationale for the development of smart grids to support the introduction of renewable energy and energy efficiency measures that will help meet its targets. However, until this package is backed up by a stable and transparent carbon market that places a value on those targets, other interests will likely drive smart grid development (e.g., security of supply and reliability issues).

In the United States, the American Recovery and Reinvestment Act (ARRA) allocated a total of U.S.$4.5 billion to help subsidize smart grid modernization efforts and an additional U.S.$7.25 billion in loans for transmission infrastructure projects, coinciding with the U.S. Energy Independence and Security Act of 2007 [25] and the American Clean Energy and Security Act of 2009 [26]. Over the past year, such clear government support has generated a great deal of movement in smart grids and DR initiatives in the United States.

The recently proposed ACES 2009 includes a mandate for load-serving entities (distribution and retail companies) or state entities to publish peak demand reduction goals. Reduced capacity by DR is already being traded in a U.S. wholesale power market (e.g., the Pennsylvania-New Jersey Maryland [PJM] Regional Transmission Organization [RTO]).

In most cases, a clear mandate, together with associated incentives from the government, is required to quickly drive an industry forward. For example, in Italy ENEL originally developed its own business case for its smart meter program, originally recovering its investment through a significant cost reduction and increase in efficiency. Later, recognizing the benefits for the entire electricity system, the regulator decided to compensate this initiative through the tariff. This led to the rapid rollout of a program to replace 30 million electromechanical power meters with smart meters and the preparation of the supporting system hardware and software architecture.

Where a full-scale direct mandate does not match the market philosophy of a country, other measures are required. In the United Kingdom, a regulatory review by the Office of Gas and Electricity Markets (Ofgem) will set a long-term regulatory environment for the development of a low-carbon energy market. However, this is supplemented in the shorter term by a £500 million fund to promote the development of networks, including smart grid projects aimed at initiating smart grid infrastructure spending and innovation [27].

Global, regional, and national economic recovery and growth will serve as the cornerstones of increasing investments in development of smart electric power infrastructure and increased reliance on integrated communications and IT. Drivers will include national and state government issuance of clear policy directives and incentives concerning energy futures and development of smart infrastructure.

Current rate designs limit progress in grid modernization. Real-time rates that reflect actual wholesale market conditions are not yet widely implemented, preventing the level of demand side involvement needed in the smart grid. Net metering policies that provide consumers full retail credit for energy generated by them are also not widely deployed, reducing the incentive for consumers to install DER. Also, policies and regulations to encourage investment in power quality (PQ) programs, including those that provide pricing related to grades of power are not in place.

Some regulatory policies penalize utilities for supporting and investing in smart grid technologies. For example, from a strictly financial perspective, utilities are motivated to address system peak issues by investing in new generating facilities—which increases their revenue requirement—rather than supporting consumer-side DR opportunities—which reduces their revenues. New methods are needed to provide the incentive for marketers and utilities to invest in technologies that benefit society and are consistent with grid modernization even when those investments negatively impact their revenue stream. New regulatory models that decouple profit from revenue may be a solution to this conflict.

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) represents a wholesale replacement of not-yet-obsolete assets, (2) is a technology that will fundamentally transform the utility-customer relationship, and (3) 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. Financial incentives at both the federal and state levels would enable such projects to pass financial hurdles that they otherwise could not—enabling the projects to proceed.

Deployment of smart grid technologies is costly, and without such incentives, utilities and energy providers are reluctant to invest in these needed technologies when they would bear all of the costs but where many of the benefits would accrue to other parties or to society as a whole. And, the absence of regulatory certainty inhibits technology deployments, as utilities and energy providers are left to weigh the risks of advanced technology investments with little assurance that the investment will be recoverable.

In addition to regulatory changes, changes in the tax law should be considered to make smart grid investments tax preferred. Tax incentives have been in place for many years for other preferred areas such as energy efficiency and renewable energy. Investment tax credits and incentives tied to more efficient operation of the grid and/or reduction in electricity costs might be helpful.

Regulations that support integrated electricity markets are needed. Federal and state regulations should support and not interfere with the development of large integrated wholesale electricity markets, which meet the needs of consumers and system operators. In the transition to fully enabled markets, there may be individual dissatisfaction along the way, but consumers, and society as a whole, will win. Regulations should support the ability of the smart grid to enable markets where they are appropriate.

Inconsistent policies among the states and with federal regulators prevent effective collaboration across a national footprint. Differing regulations among states that are electrically interconnected present challenges to the operation of a larger interconnected network and to the development of one that is even more integrated and dynamic. The optimal model for the electric industry has not been found and the lack of a consistent solution is a barrier to grid modernization. Coordination among local, state, and federal agencies on this issue is needed.

Alignment of regulatory policies to support grid modernization is generally weak. In general, regulatory policies were not designed with grid modernization in mind. Consequently, various specific policies need to be reviewed and updated. Some examples include the following:

- State legislatures and regulatory commissions currently focus on protecting consumers from the risks of consumer choice. Regulatory policy does not currently support the transition of consumers from passive protected users to proactive informed users as has occurred in other industries such as telecommunications and transportation.
- A significant reduction in R&D expenditures by utilities is an unintended drawback of deregulation and should be addressed to support grid modernization.
- Some existing utility assets are technologically obsolete and are incompatible with new smart grid technologies. Regulatory policies are needed for addressing the replacement or modification of these assets so that smart grid technologies can be integrated with them. Recovery of remaining book value of retired obsolete equipment is needed.
- Current policies often penalize consumers rather than utility shareholders for ineffective management decisions.

- The consequences of such actions as renewable portfolio standards (RPS), carbon tax, cap and trade, and carbon capture and sequestration will impact how the grid evolves and performs. Climate change legislation and regulations should be developed in the broader context of grid modernization so that both objectives can be effectively and efficiently met.

Regulatory structures should recognize and capture the full range of benefits of smart grid technology and provide assurance of appropriate cost recovery (particularly important given that the regulatory approval process varies by state, and may result in vastly different outcomes for a utility operating across state lines). The regulatory view should focus on the consumer and discussions with regulators should

- Encourage regulators to shift discussions toward "where's the value" away from "must comply"
- Include reliability directives and green initiatives
- Subtly emphasize the value of long-term, integrated smart grid components and not just short-term, individual projects to realize the synergies of satisfying multiple objectives; the role of the PUC in providing support for technology evolution and obsolescence is also critical and the recent precedent established by the U.S. Congress in October 2008, which allows utilities to depreciate smart grid investments over a 10 year period instead of 20 years, provides indication of such support required
- Reinforce the message of scarce options for new generation and the importance of energy efficiency, demand management, and load shifting programs in order to add urgency to the need for smart grid initiatives

4.12.1 EXAMPLES OF POLICY MEASURES

4.12.1.1 Climate and Energy Package 20-20-20 (EU)

The EU Climate and Energy Package 20-20-20, passed by European Parliament in 2008, resulted in specific carbon reduction targets on countries, their industry, and utilities. Voted for by more than 550 members and voted against by fewer than 100 members, this package focuses on three major policy areas: greenhouse gas emissions reduction, renewable energy, and energy efficiency. An important instrument to achieve the goal set by Europe is the Strategic Energy Technology Plan (SET Plan) including seven priority energy technologies to be deployed, one of which being the smart grids.

4.12.1.2 EISA, ACES (United States)

The United States enacted the Energy Independence and Security Act of 2007 (EISA 2007) to decrease their dependence on imported energy. It required standards around renewable fuels, vehicle efficiency, and electric appliance efficiency, and outlined a general federal policy on electric grid modernization.

In the American Clean Energy and Security Act of 2009 (ACES 2009), more specific details are set out to promote clean and efficient energy, to facilitate the deployment of a smart grid with DR applications, and to require electric utility providers to integrate electric vehicles into current grid infrastructure.

4.12.1.3 Regulatory Review (United Kingdom)

The U.K. regulator, Ofgem, is undertaking a full-scale regulatory review (RPI-X@20) to ensure that companies are rewarded for performance that aligns with the government roadmap toward delivery of a low-carbon energy sector.

4.13 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 is being lost as more and more of the technical analysis is done by computers rather than by human resources.

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 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 the evolutionary period to that state during which the legacy infrastructure will be used side-by-side with new technologies. In order 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 the majority of power system engineering, but in order 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 multiobjectives.

The integrative requirements of smart grid philosophies require that the depth of comprehension of engineers extend to the several areas illustrated in Figure 4.2. 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 insure that our society has the well-qualified power and energy engineers it needs, the following objectives must be sought [13]:

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 engineering education in power and energy engineering. Students should be exposed to 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 to 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 includes education, training, and public participation programs. Currently, major initiatives specifically dedicated to develop 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.

4.13.1 Indicators of Declining Workforce Supply in the United States

For electric and gas utility employees, the results of a survey by the Center for Energy Workforce Development (CEWD) in 2008 show that approximately 50% of all employees will be eligible for retirement within 10 years [14]. Figure 4.4 shows the electric and gas utility employee age distribution from this survey. The survey was comprised of 55 electric and gas utilities nationwide, as well as all electric cooperative organizations. As of 2010, indications are that nearly 45% of the eligible retirement age employees may need to be replaced by as early as 2013 [15].

The facts indicate there are workforce and education system problems summarized as follows [13]:

- Over the next 5 years, approximately 45% of engineers in electric utilities will be eligible for retirement or could leave 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 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 actually retire. In other words, of the 170 engineering faculty working full time in power engineering education and research, some 50 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.

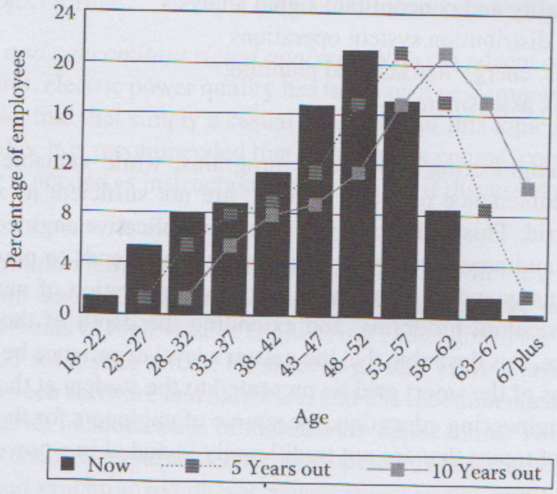

FIGURE 4.4 (See color insert.) Electric and gas utility employee age distribution.

- The pipeline of students entering into 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 undergraduates 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.

4.14 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 be 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, need to be educated on a number of 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

The desired elements of the cross cutting energy engineering skills for the next generation of "smart grid" power engineers appears 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 be 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 (e.g., Ref. [16]), 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 (e.g., Ref. [17]).

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 insure 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. [18].

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 (e.g., Ref. [19]). 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 [20].

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 systemwide 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 [21].

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. The main issues are discussed in Ref. [22].

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 5–20 year period at an interregional if not national level, to identify cost-effective ways to reach environmental goals, increase operational resiliency 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 PhD graduates [23]. Engineers from 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 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 [24]. 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 solve 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 having 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, a number of 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.

4.14.1 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 non-tenured 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 insure an adequate supply of well qualified job candidates that 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.
- Insure 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 aides in education planning and a career awareness video for engineers in cooperation with professional societies.
- Publish promotional material 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, where individuals, chapters, or regions as a whole, to get involved in responding.
- Develop training plans targeted toward life-long 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 is in fields other than power and energy engineering.
- Provide opportunities to bridge promising student talent and industry.

4.14.2 EXAMPLE OF AN INITIATIVE TO BUILD KNOWLEDGE: U.K. POWER ACADEMY

A decreasing trend of acceptance for study at U.K. power engineering courses ranging around 28% in the period 2002–2007 was observed. To cope with the progressively decreasing number of power engineers, a group of seven leading U.K. universities and 17 companies (including utilities, manufacturers, service providers, and transmission and distribution system owners and operators) joined forces founding the Power Academy. The aim of the Power Academy is to address the shortfall in engineering expertise in the electricity power industry by attracting new talent into the industry primarily at the undergraduate level leading to graduate employment.

Students supported by the Power Academy receive a bursary, a book allowance, a financial contribution toward university fees, the participation in a summer seminar, 8 weeks of training experience under the supervision of a company mentor and the free membership to the U.K. Institution of Engineering and Technology. This initiative has seen more than 240 applications in 2008 and the 3 leading companies have supported over 40 scholars each in the past 4 years.

It has been argued that, since its foundation, the Power Academy has been a success with increasing numbers of scholars and a significant majority of positive responses from an annual survey of their experiences. However, the level of influence it has on the degree choices by school and college graduates is yet to be determined and remains a challenging area, not only for the Power Academy partners, but also for the U.K. Government in respect to its overall skills agenda. Another benefit of the Power Academy partnership is that these collective efforts provide the best chance of addressing the challenge of shortfall of power engineering experience, and of influencing the government in its future course of action.

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