A Bold Vision for T&D

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By: **Kurt E. Yeager and Clark W. Gellings**

(Kurt E. Yeager is President Emeritus and Clark W. Gellings is Vice President – Power Delivery and Markets of the Electric Power Research Institute, Palo Alto, California, USA)

INTRODUCTION

Power system engineers are increasingly concerned with the current state of the global electricity enterprise and the infrastructure for which it is responsible. In brief, today's electricity supply system is aging, under stress, often not well maintained, and being physically used in ways for which it was not designed. It is no longer sufficient for the engineer to try to influence the state of the industry by presenting good technical arguments to regulators, policymakers and other stakeholders. Engineers must engage in a broader dialogue about society's choices, about why the electricity sector is so important, and what can be done to transform the power delivery system to better meet the needs of tomorrow's society. In short, engineers must begin to communicate the vision that they have long held about an electricity infrastructure which would meet society's needs for a reliable, secure, clean, and environmentally friendly supply of electric energy.

Unfortunately, this vision is no longer universally shared. Beginning in the 1970s, much of the world's electricity sector has experienced an extensive period during which this vision has fragmented, its stakeholders have become polarized, the industry's commitment to long-term planning and development has eroded, and its credibility has suffered. This period of turmoil has culminated in:

- Market reforms that have often been poorly designed, both in terms of respecting the basic laws of physics, and with rules differing between states.

- Wholesale electricity market competition that has been mandated within the operational context of the existing electricity infrastructure without agreement on the ways and means to execute such markets.
- Unrealistic pressure placed on publicly traded companies to show substantial growth in revenues and earnings, and similarly, on state-owned utilities to return cash to the jurisdiction that formed them through so called “privatization”.

Any of these issues alone, including the general economic conditions, would have been problematic, but certainly manageable. What is so unique about the current situation is that several truly independent and significant issues have all converged at essentially the same time. As a result:

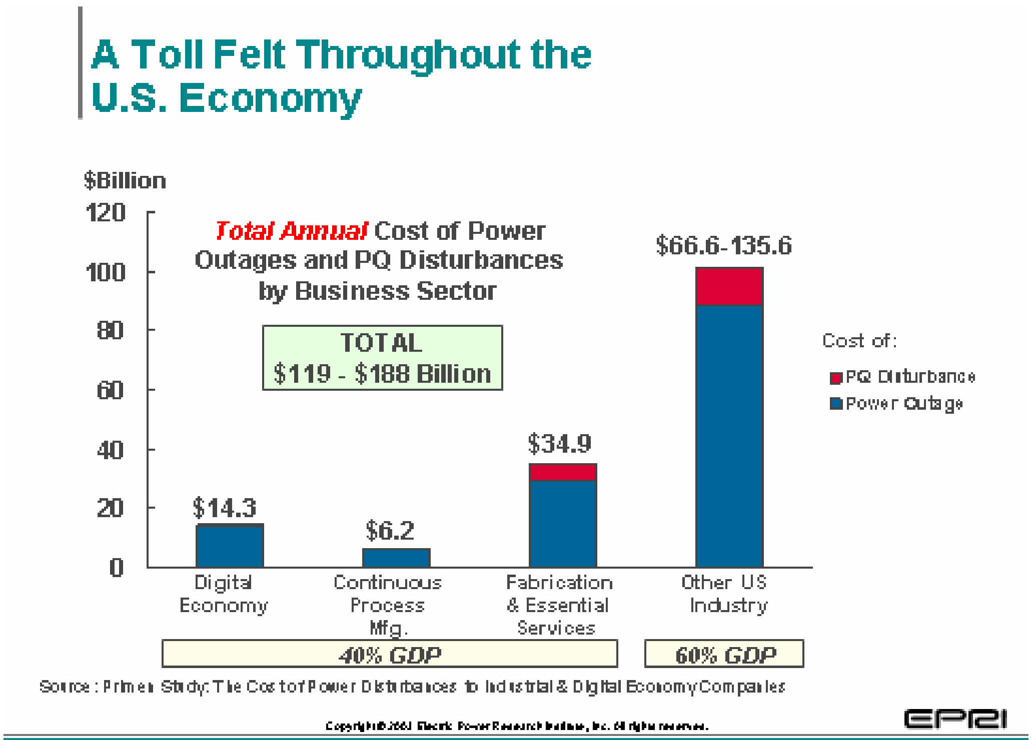
- The evolution of effective wholesale markets is impeded by the inability of the power delivery infrastructure to physically meet the pace and rigor of competitive markets; this is coupled with a lack of agreement on market rules.
- Credit markets have shut out nearly all of the merchant energy companies while other industry members have seen their credit ratings drop --in some cases, significantly so. Because of this, financing costs for the industry have risen dramatically and substantial declines in capital investments have resulted at a time when the economy is increasingly dependent on reliable, high quality electricity.
- Research, development, demonstration, and venture capital expenditures on new technologies have reached historic lows as the electricity enterprise attempts to maintain the lowest possible short-term cost structure at the expense of its future value.

It is no wonder that many stakeholders in the electricity sector have taken a “treading water” approach. Given the highly political nature of privatizing, deregulation, and industry restructuring, any major strategy decision could be proven wrong by an unpredictable regulatory turn, or by political fiat. Proceeding cautiously until there is more clarity is the most rational course. In the meantime, an obsolescent infrastructure continues to grow older, and little integrated planning is being done to increase or maintain electricity supply.

Based on this pattern of experience, the successful privatization, liberalization, and restructuring of electricity supply and delivery markets depends first on the condition that the public, through its government representatives, be accountable for providing the incentives needed to maintain a robust, reliable and efficient electricity infrastructure—one designed to keep pace with the needs of all consumers and the society they represent while adequately rewarding those who provide the needed capital.

Figure 1 illustrates the result of an extensive U.S. survey in which businesses documented the impact which poor power quality and reliability have on the US economy.

Figure 1



The chart below shows the relationship between the U.S. investor-owned utility industry's annual construction expenditures and its depreciation charges. As shown, in recent years depreciation expenses have exceeded construction expenditures. Since depreciation is the process by which a company gradually records the loss in value of fixed assets, the chart shows that the industry is now generally in a "harvest the assets" mode rather than an "invest in the future of the business" mode. Continuation of this trend has the potential to degrade capacity and performance of the system. In addition, it will prevent resolution of the system's basic vulnerabilities and limitations.

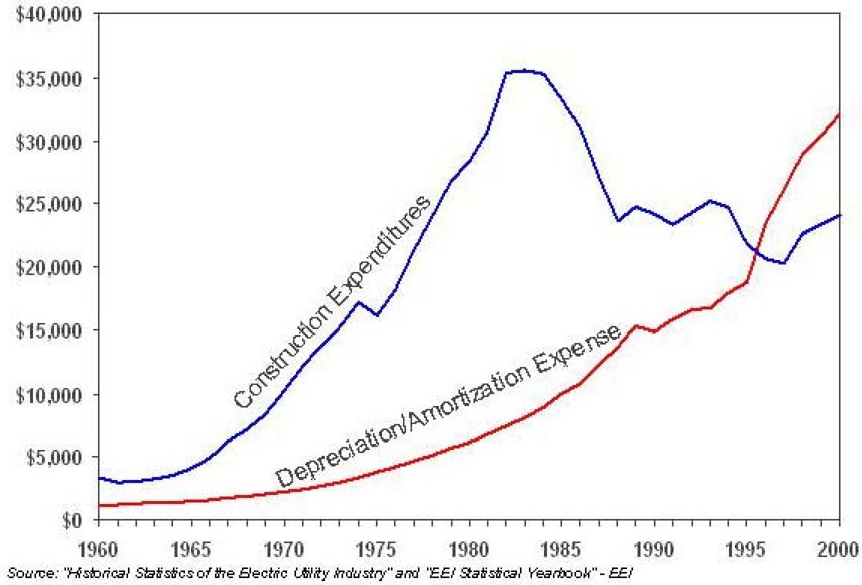


Figure 2. U.S. Utility Construction Expenditures and Depreciation/Amortization Expenses

Magnifying this investment crisis is the fact that the pressures of cost containment have essentially stifled and deferred needed infrastructure investment for at least the past two decades. This electricity delivery infrastructure investment deficit in the US is now on the order of $15 billion per year, if service demands for the 21st century are to be confidently met.

THE 21ST CENTURY TRANSFORMATION

The needs and aspirations of the diverse stakeholders of the electricity sector embrace a comprehensive vision of the power industry of the future, one we refer to as the "21st Century Transformation". In summary, these aspirations represent a future where:

- The rules, roles and responsibilities of the major electricity industry stakeholders have been clarified, enabling a revitalized public/private partnership that maintains confidence and stability in electricity sector financing. The risk premium declines, investors return, and the rate of investment in the essential electricity infrastructure is substantially increased.
- The electricity sector again provides a robust world platform for technical innovation and continued economic prosperity. Technological progress continues to advance on a broad front, but one of the linchpins for economic growth is digital control of the power delivery network, coupled with consumer-based technologies that replace the traditional meter with a "consumer portal" for two-way flow of information and energy. Eventually, it is expected that this platform will enable every end-use electrical appliance to be linked with the open marketplace for goods and services, including, but not limited to, electric power.

- Thus, consumer-enabling technology provides entirely new capabilities for participation in the electricity marketplace. Innovation finally breaks open the commodity box currently constraining both the electricity industry and consumers, and ushers in an era of energy/information services beyond our imagination today.
- Economic productivity increases substantially as a result of the transformation of the electric power sector, generating additional wealth to deal with the large societal, security and environmental challenges of the 21st Century.
- The role of regulation has evolved from oversight of operations and "protection" of consumers or ratepayers to oversight of markets, as well as enabling and guiding specific public-good services (i.e., reliability standards, provider-of-last-resort, market transformation, etc.).
- The industry's commitment to environmental protection emphasizes market mechanisms to incent the move toward more efficient, cleaner, low-carbon-emitting technologies, and reduced air emissions linked to health and welfare risks, based upon sound science.
- Security and energy policies emphasize fuel diversity, placing electricity at the center of a strategic thrust to 1) create a clean, robust portfolio of energy options (including fossil, nuclear, and renewable energy sources, along with end-use efficiency), 2) electrify transportation to reduce dependence on foreign oil, and 3) develop a sustainable hydrogen/electric energy system.

Transformation is a matter of necessity, if not survival. The key questions are how long will it take, will it be driven predominantly by the current participants or others, and what can be done to enable a smooth and predictable transition rather than a series of disruptive and expensive, crisis-laden experiences. Equally important is ensuring that the costs of the transition—and any discomfort experienced by the consuming (and voting) public while reaching the desired state—do not outweigh the benefits; in short, the transition should do no harm.

The 21st Century Transformation represents the integrated, sustainable solution to the rising expectations of the broad stakeholder community in the 21st Century.

In brief, the advantages of transforming the electricity/information infrastructure include:

- Increasing productivity.
- Increasing the value and output of goods and services, thus creating the wealth needed to fund the growing societal costs of an aging population.
- Improving energy efficiency and electricity intensity.
- Accelerating the reduction in carbon emissions.
- Improving the security of the power system.

The result will be significantly greater efficiency and productivity throughout the economy, together with an ever-higher and more sustainable quality of life for all.

Focus on the Destination – Building the Value of Electricity

Nevertheless, as with the history of other technologically based enterprises, markets may move along a path that is not necessarily controlled either by regulators or the existing entities serving those markets. In this case, the ultimate force pulling the electricity sector into the 21st Century Transformation is not so much the technology of supply as the technology of demand— specifically, intelligent technologies enabling ever-broader consumer involvement. As long as consumer involvement is limited to the on-off switch and to time-of-day pricing, the commodity paradigm will continue to dominate the business, and require regulation to protect a relatively weak consumer from cost-constrained suppliers. It is important to remember that supply and demand in the electricity industry still rely on the same basic technology used since the dawn of electrification a century ago. This is a remarkable record of performance, but one that can no longer be sustained through the evolutionary changes to the status quo.

Consumer-based technology that can change the traditional relationship of consumers and suppliers is the stepping stone to the elusive retail electricity service business that seemed so promising a decade ago, but now has few proponents. Nevertheless, if the experiences in other consumer-based industries are any guide, the time for retail will come. History has shown the power of consumer knowledge and actions in redefining and reconfiguring industry after industry.

New consumer-based technology enables empowerment of the electricity consumer, opening the door to new, innovative service combinations emphasizing speed, convenience and comfort, along with different levels and types of electric power. A vigorous, price-sensitive, demand-response from many, if not most, consumers becomes an integral part of the electricity marketplace. A smart, “self-healing" power delivery system becomes the conduit for greater use of productivity-enhancing digital technology by all sectors of the economy, leading to accelerated productivity growth rates. The power system enables new energy/information products and services across the board, and reduces or eliminates the parasitic costs of power disturbances characteristic of today.

The most important feature of this transformation is the focus on serving consumer needs through multiple channels. It is possible to divide the products and services provided by the power sector into three broad categories:

- **Products and services that have economic value in private markets**. Private markets are willing to pay for many of the services envisioned by the increased functionality of the transformed power supply system. If government help is required, it will be to overcome market imperfections that limit the incentive to innovate.

- **Public goods for which markets can be created**. Here the most efficient policy is to create markets through incentives. The government role is to create the market (e.g., pollution control), and let the private sector be responsible for introducing the technology. The key here is that the government is a reliable market creator so that investors can be assured of cost recovery.
- **Public goods for which markets cannot be created.** The benefits of a transformed electricity delivery infrastructure, for example, are large but their common-carrier nature discourages market creation. Therefore, the most effective government role here is to recognize through institutions, incentives and investments, the shared utility value of this infrastructure.

Development of the 21st Century Power System

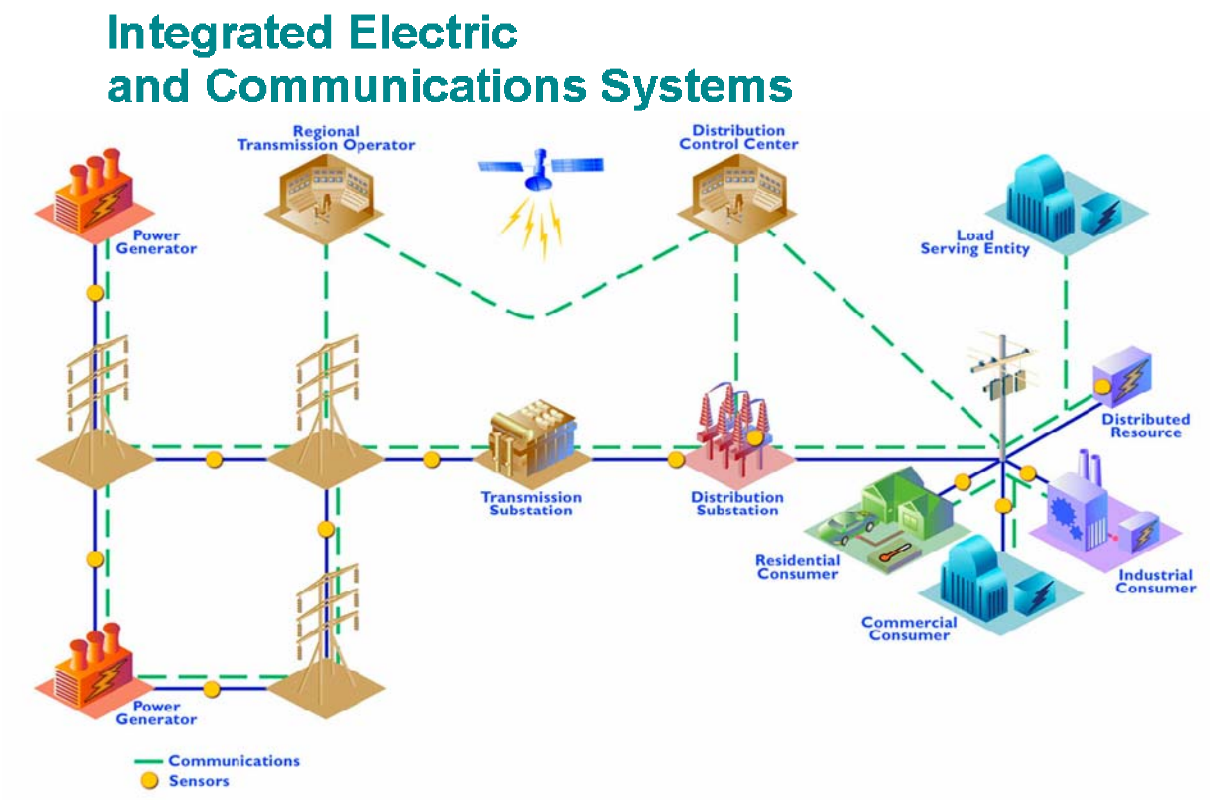
Advanced technology now under development or on the drawing boards holds open the promise of fully meeting the electricity needs of a robust digital economy. The architecture for this new technology framework is becoming clear through early research on concepts and the necessary enabling platforms. In broad strokes, the architectural framework envisions an integrated, self-healing, electronically controlled electricity supply system of extreme resiliency and responsiveness—one that is fully capable of responding in real time to the billions of decisions made by consumers and their increasingly sophisticated microprocessor agents. In short, the potential exists to create an electricity system that provides the same efficiency, precision and interconnectivity as the billions—ultimately trillions—of microprocessors that it will power.

The institutional and economic framework envisioned for the 21st Century Transformation ultimately depends upon building new types and levels of functionality into the power system. These needed capabilities will be "enabled" in the broadest sense by several breakthrough innovations, including but not limited to the following:

- **Digitally controlling the power delivery network** by replacing today's relatively slow electro-mechanical switching with real-time, power-electronic controls. This will become the foundation of a new "smart, self-healing power delivery system" that will enable innovative productivity advances throughout the economy to flourish. Digital control is the essential step needed to most cost-effectively address the combined reliability, capacity, security, and market-service vulnerabilities of today's power delivery system. As a practical matter, this technical expansion is the only way that these vulnerabilities can be comprehensively resolved.
- **Integrating communications** to create a dynamic, interactive power system as a new "mega-infrastructure" for real-time information and power exchange. This is the capability needed to enable retail energy markets; power interactive, microprocessor-

based service networks; and fundamentally raise the value proposition for electricity. Through advanced information technology, the system would be "self healing" in the sense that it is constantly self-monitoring and self-correcting to keep high-quality, reliable power flowing. It can sense disturbances and instantaneously counteract them, or reconfigure the flow of power to cordon off any damage before it can propagate. (See Figure 3)

Figure 3



- **Automating the distribution** system to meet changing consumer needs. The value of electricity distribution system transformation—fully automated and integrated with communication—derives from four basic functionality advantages:

1. Reduced number and duration of consumer interruptions, system fault anticipation, and faster restoration.
2. Increased ability to deliver varying "octane" levels of reliable, digital-grade power.
3. Increased functional value for all consumers in terms of metering, billing, energy management, demand-response, and security monitoring, among others.

4. Access to selective consumer services including energy-smart appliances, power-market participation, security monitoring, and distributed generation.

Even initially, the value of these advantages to consumers, suppliers, and society alike more than justify the needed public/private investment commitment. More importantly, this transformation will enable additional innovations in electricity service that are bounded only by our imagination.

- **Transforming the meter** into a consumer gateway that allows price signals, decisions, communications, and network intelligence to flow back and forth through the two-way energy/information portal. This will be the linchpin technology that leads to a fully functioning marketplace with consumers responding (through microprocessor agents) to price signals. For consumers and providers alike, this offers a tool for moving beyond the commodity paradigm of 20th Century electricity service, and quite possibly ushering in a set of new energy/information services as diverse as those in today's telecommunications.
- **Integrating distributed energy resources.** The new system would also be able to seamlessly integrate an array of locally installed, distributed power generation (such as fuel cells and renewables) as power system assets. Distributed power sources under 20 MW per unit could be deployed on both the supply and consumer side of the energy/information portal as essential assets dispatching reliability, capacity and efficiency. Today's distribution system, architecture, and mechanical control limitations, prohibit, in effect, this enhanced system functionality.
- **Accelerating end-use efficiency** through digital technology advances. The growing trend toward digital control of processes can enable sustained improvements in efficiency and worker productivity for nearly all industrial and commercial operations. Similarly, the growth in end-use electrotechnologies, networked with system controls, will afford continuous improvements in user productivity and efficiency.

Capabilities of the Smart Power Delivery System

The knowledge-based economy of the future will require a smart-power delivery system that links information technology with energy delivery. The concept of the smart power delivery system includes automated capabilities to recognize problems, find solutions and optimize the performance of the system. The basic building blocks include advanced sensors, data-processing and pattern-recognition software, and solid-state power flow controllers, such as flexible AC transmission systems (FACTS), to reduce congestion, react in real time to disturbances, and redirect the flow of power as needed. There are three primary objectives:

- **Optimize the overall performance and resilience of the system.** An array of sensors will monitor the electrical characteristics of the system (voltage, current, frequency, harmonics, etc.) as well as the condition of critical components, such as transformers, feeders, circuit breakers, etc. The system will constantly "fine-tune" itself to achieve an optimal state, while constantly monitoring for potential problems that could lead to disturbances. Examples of such potential problems would be a transformer with unusual gassing activity or a cable termination with higher than normal partial discharge. When a potential problem is detected and identified, its severity and the resulting consequences will be assessed. Various corrective actions can then be identified, and computer simulations run to study the effectiveness of each action. When the most effective response is determined, a situational analysis will be presented to the operator, who can then implement the corrective action very efficiently by taking advantage of the grid's many automated control features, such as dispatch control of distributed resources, parameter tuning of solid-state power flow controllers, etc.

- **Instantly respond to disturbances to minimize impact.** When an unanticipated disturbance does take place on the system, it can be quickly detected and identified. An intelligent islanding or sectionalizing scheme, for example, can be activated instantaneously to separate the system into self-sustaining parts to maintain electricity supply for consumers according to specified priorities, and to prevent blackouts from propagating.
- **Restore the system after a disturbance.** Following system reaction to a major disturbance, actions will be taken to move the system towards a stable operating regime. To do so, the state and topology of the system need to be monitored and assessed in real time, allowing alternative corrective actions to be identified and the effectiveness of each determined by look-ahead computer simulations. The most effective actions would then be implemented automatically. When a stable operating state is achieved, the system will again start to self-optimize.

Meeting these objectives is an iterative process with optimizing the system being the primary objective during normal operation. When a disturbance occurs, the operating objectives move from reacting to restoring and, finally, back to optimizing. The smart power delivery system is thus said to be "self-healing."

Figure 4

Attributes and Benefits: Power Delivery Infrastructure of the Future

Power Delivery (Improvements/ Benefits)	Attributes	Consumer Portal (Improvements/ Benefits)
O&M Cost Capital Cost of Asset T&D Losses	***Cost of Energy (Net delivered life-cycle cost of energy service)***	End Use Energy Efficiency Capital cost, end user infrastructure O&M, End User Infrastructure Control/Manage Use
Increased Power Flow New Infrastructure Demand Responsive Load	***Capacity***	Improved power factor. Lower End User Infrastructure cost through economies of scale and system streamlining, expand opportunity for growth
Enhanced Security Self Healing Grid for Quick Recovery	***Security***	Enhanced Security and ability to continue conducting business and every day functions
Improve Power Quality and enhance equipment operating window	***Quality***	Improve Power Quality and enhance equipment operating window
Reduce frequency and duration of outages	***Reliability & Availability***	Enhanced Security Self Healing Grid for Quick Recovery Availability Included
Reduced EMF Reduction in SF6 (sulfur hexafluoride) emissions Reduction in cleanup costs Reduction in power plant emissions	***Environment***	Improved Esthetic Value Reduced EMF Industrial Ecology
Safer work environment for utility employees	***Safety***	Safer work environment for end-use electrical facilities
Value added electric related services	***Quality of Life***	Comfort Convenience Accessibility
Increase productivity due to efficient operation of the power delivery infrastructure Real GDP	***Productivity***	Improved consumer productivity Real GDP

Figure 4 lists the possible capabilities of the Smart Power Delivery System and the benefits which would accrue to the power system and consumers.

Developing this power delivery system for the 21st century will be costly, but not prohibitively expensive in light of historic investments patterns. The incremental cost of both transmission and distribution transformation is about $13 billion/year, or 65% over and above current business-as-usual investment of about $20 billion annually. It's important to note the importance of the timing of critical activities in transforming the power delivery system. A phased approach to system implementation will allow the utility to capture many cost synergies. Equipment purchased, for example, should emphasize switchgear, regulators, transformers, controls, and monitoring equipment that can be easily integrated with automated transmission and distribution systems. Long-term plans for equipment upgrades should also address system integration considerations.

CONCLUSION

Simply replicating the existing system through expansion or replacement will not only be technically inadequate to meet the changing demands for power, but will produce a significantly higher price tag. Through the transformative technologies outlined here, the nation can put in place a 21st Century power system capable of eliminating critical vulnerabilities while meeting intensified consumer demands, and in the process, save the rate payers considerable expense. Significant savings are evident by technically optimizing all aspects of the electricity infrastructure (supply, transmission, distribution and end-use) as an interdependent, integrated system. For example, a smart, digitally transformed power supply system can simultaneously provide greater functionality for consumers, enable better utilization of existing generation capacity, and accelerate efficiency and productivity throughout the economy.

This progress requires a unified industry leadership vision and commitment that electricity, through innovative technology, has a service value greater that its traditional basic commodity value. This vision of innovative opportunities to transform the reliability and value of electricity for the 21st century must ultimately be sold to the public and its policy leaders who can credibly advocate the message. In addition, initiatives to educate electricity stakeholders must be expanded as an essential mechanism for strengthening industry credibility, and building trust and support for electricity sector modernization.