The U.S. Electricity Enterprise

Past, Present, and Future Prospects

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Galvin Electricity Initiative

The Galvin Electricity Initiative seeks to identify opportunities for technological innovation in the electric power system (broadly defined) that will best serve the changing needs of consumers and businesses over at least the next 20 years. Of paramount importance will be insuring that the electricity system provides absolutely reliable and robust electric energy service in the context of changing consumer needs.

For more information about this publication or the Galvin Electricity Initiative, please contact Galvin Electricity Initiative at 650-855-2400 or visit us at www.galvinelectricity.org.

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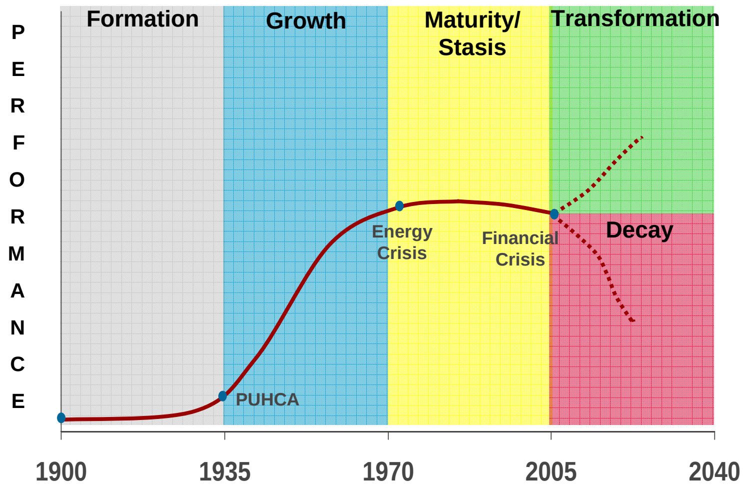
Introduction

The following brief historical synopsis describes the development of the electricity enterprise in the United States. For Galvin Electricity Initiative participants, this document can serve as a common background for addressing the Initiative's tasks, regardless of prior knowledge or experience with the U.S. electricity enterprise. A reading list of more detailed accounts of the electricity enterprise, on which this summary is based, is also attached.

The organization of this synopsis corresponds with the stages in the Electricity Sector Life-Cycle shown in Figure 1. The Galvin Electricity Initiative is particularly timely because it coincides with the inflection point noted in **Figure 1**. As a result, this Initiative has the potential to be the pivotal guiding beacon for transforming the reliability and value of the electricity enterprise, and for identifying the innovations on which that transformation will ultimately depend.

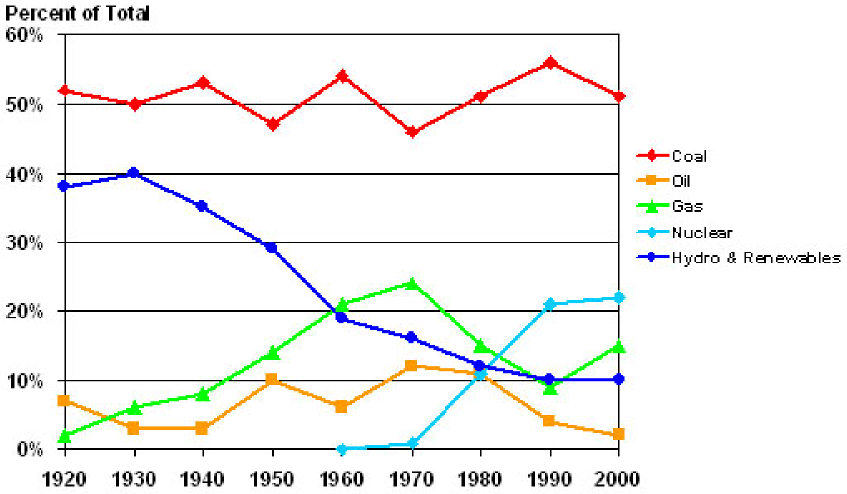
Figure 1. Electricity Sector Life-Cycle—A Fork in the Road



Electricity now powers American life to an unprecedented degree. In 1900, electricity's share of the nation's energy use was negligible. That share has now risen to nearly 40%. Electricity is produced from fuels through a costly conversion process so that its price per thermal unit has always been higher than that of the fuels themselves. So, something other than cost must account for the sustained growth in electricity's market share. Simply put, electricity can be used in ways that no other energy form can. Technological progress over the past century has led to radically improved ways of organizing productive activities as well as new products and new techniques of production, all of which have been heavily dependent on electricity. As a result, electricity has become the life blood of the nation's prosperity and quality of life. In fact, the U.S. National Academy of Engineers declared that "the vast networks of electrification are the greatest engineering achievement of the 20th Century."

Figure 2 summarizes the historical trends in the energy sources for U.S. electricity generation. Notable is the persistence of coal as the dominant fuel.

Figure 2. Sources of Energy for U.S. Electricity Generation



Electricity, despite its mystery and complexity, is simply the movement of electrons. Each of these tiny sub-atomic particles flows only a short distance as it displaces another around a circuit but this transfer occurs at the speed of light (186,000 miles per second). This invisible wonder occurs virtually everywhere in nature. For example, it transmits signals from our brains to contract our muscles. What's relatively new is our ability to put electricity to work lighting and powering our world.

For example, steady advances during the course of the 20th century improved electric lighting efficiencies by an order of magnitude. Looking forward, full-spectrum lightemitting diodes (LEDs) may increase the efficiency of U.S. lighting by 50% more within 50 years. At the same time, electric motors have revolutionized manufacturing through unprecedented gains in the reliability and localized control of power vis-à-vis steam engines, et al. By 1932, electric motors provided over 70% of all installed mechanical power in U.S. industries. The proliferation of household appliances has also been primarily due to the use of small electric motors. Today, the ubiquitous electric motor in all its forms and sizes consumes two-thirds of all U.S. electricity production.

Electricity is indeed a superior energy form; however it is not a tangible substance, but rather a physical effect occurring throughout the wires that conduct it. Electricity must be produced and consumed in absolutely instantaneous balance and it can't be easily stored. Its delivery, therefore, today requires the ultimate just-in-time enterprise that balances supply and demand at literally the speed of light. Yet the status quo suffers numerous shortcomings. Efficiency, for instance, has not increased since the late 1950s, and U.S. generators throw away more energy than Japan consumes. Unreliable power—the result of blackouts or even just momentary surges and sags—annually costs America more than $100 billion. This is equivalent to about a 50¢ surcharge on every dollar of electricity purchased by consumers.

Moreover, the U.S. bulk electricity infrastructure is aging and becoming obsolescent. The average generating plant was built in 1964 using 1950s technology, whereas the factories constructing computers have been replaced and updated five times over the same period. Today's high-voltage transmission lines were designed before planners ever imagined that enormous quantities of electricity would be sold across state lines in competitive transactions. Consequently, the wires are often overloaded and subject to blackouts. Yet demand is increasing at twice the rate of capacity expansion. Finally, the local distribution systems that connect the power supply to each consumer are effectively a last bastion of analog, electromechanically controlled industry. This is a particularly notable paradox given the fact that the nation's electricity supply system powers the digital revolution on which much of the current and future value depends. Keeping the lights on 99.97% of the time is simply not good enough. That still means the average consumer doesn't have power for 2.5 hours a year. In today's impatient, increasingly computerized world that is more than just a nuisance.

In spite of these deficiencies, the traditional producers and deliverers of electricity—the nation's electric utilities—hold assets exceeding $600 billion; with 70% invested in power plants, 20% in distribution facilities, and 10% in transmission. They form one of the largest industries in the U.S.—roughly twice the size of telecommunications and nearly 30% larger than the U.S. automobile industry in terms of annual sales revenues. The Achilles Heel here is the fact that supplying electricity is also extremely capital intensive, requiring far more investment per unit of revenue than the average manufacturing industry. This investment challenge is further intensified by the fact that the U.S. electricity enterprise is made up of over 5,000 commercial entities, both public and private. The largest individual corporate market cap in the enterprise today is that of Exelon at $32 billion. This compares with Exxon-Mobil, for example, with a market cap of $365 billion. In fact, only about 17 electric utilities have market equity value greater than $10 billion. As a result, the decision to invest the billion or more dollars needed to construct a major new power plant or power delivery (T&D) line is effectively an uncertainty-laden, long-term, "bet the company" decision to be avoided by most electric enterprise corporations today.

Meanwhile, the market for portable electric devices continues to grow dramatically from the traditional flashlights and auto ignitions to a diverse array of computers, communications and entertainment products, cordless tools, medical devices, military products, etc. This innovative diversity has been accomplished by exploiting the synergy between the products themselves, the electricity storage devices they employ—including batteries, ultracapacitors, and fuel cells—and the power-management systems that charge these storage devices. Today, the global portable electricity storage market is about $50 billion per year, of which $5 billion is allocated to rechargeable (secondary) batteries. Demand growth is estimated at 6% annually, as compared to grid-supplied electricity demand growth of about 1.5% per year.

A new generation of energy-hungry devices, such as digital cameras, camera phones, and high-performance portable computing devices, is expected to continue to drive this rapid growth in portable electrification. Notably, the kWh-equivalent price of portable electricity can be as much as $100, compared to about 10 cents for grid-supplied power. This is one indication of the potential for highly flexible, individualized electricity services to enhance electricity's value beyond the commodity energy value proposition and business model of the traditional electricity enterprise.

The history of this magical energy form, electricity, provides keen perspective on the real-world interplay among technical progress, business struggles, and political debates. Electricity's ongoing evolution also suggests how the potential for renewed electricity-based innovation could curtail pollution and spur a wide array of electro-technical advances, while continuing to improve U.S. quality of life, and that of billions more worldwide.

Looking to the future, the final section of this summary discusses the performance changes within the U.S. electricity enterprise needed in response to the rapidly growing reliability and service value expectations of 21st century consumers and society. Just one possible approach to such a transformation is described there as an example. Ultimately, the Galvin Electricity Initiative will examine the broad range of potential technological innovations bearing on the future of the electricity enterprise, from both the supply and utilization perspective. Based on that broad objective examination, the Initiative will develop a comprehensive blueprint for elevating the reliability and value proposition of electric energy service.

Above all, such a transformed system must be able to remain robust in the face of future perturbations of all sorts. It should therefore incorporate mechanisms for learning, innovation, and creative problem solving well beyond the capabilities of the current electric energy service system. Robustness will also require that the Initiative and its participants consider the role of the system's evolutionary history in determining its current and future state, and the set of strategic options open to the system.[1]

> *Electrification is not an implacable force moving through history, but a social process that varies from one time period to another and from one culture to another. In the United States electrification was not a thing that came from outside society and had an impact; rather, it was an internal development shaped by its social context.*

Tables 1A and 1B summarize some recent basic statistics for the U.S. electricity enterprise.

Formation

Neither electricity nor electric lighting began with Edison. In 1808, Sir Humphrey Davey sent a battery-powered electric current between two carbon rods to produce an arc of light. In 1831, Michael Faraday invented the dynamo, which, when turned by a steam engine, supplied a cheap electric current by means of electromagnetic induction. Davey's arc lamp was used in a production of the Paris Opera in 1844 and was part of the Philadelphia Exposition in 1876. The development of the high vacuum Crookes tube served to kindle renewed interest in incandescent electric lamps that had begun in the 1820s.

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[1] *Robust Design: A Repertoire of Biological, Ecological and Engineering Case Studies*, edited by Erica Jen, Santa Fe Institute Studies in the Science of Complexity, Oxford University Press (2005). This book uses robustness as follows: "Robustness is an approach to feature persistence in systems that compels us to focus on perturbations, and assemblages of perturbations, to the system that are different from those considered in its design, or from those encountered in its prior history."

Table 1A. U.S. Electricity Industry Statistics (2002)

Generating Capacity & Generators	**Capacity (1000 MW)**	**Net Generation (Billion kWh)**
Investor-owned utility	398	1,740
Government & Cooperatives	204	807
Non-utility (unregulated producers)	380	1,294
Total	**982**	**3,841**

Total Net Generation By Fuel	**(Billion kWh)**	**%**
Coal	1,926	50
Nuclear	780	20
Natural Gas	695	18
Hydroelectric & Pumped Storage	253	7
Fuel Oil	92	2
Biomass	72	2
Geothermal	13	1
Wind	9	
Photovoltaic	1	
Total	**3,841**	**100**

Electricity Sales	**Customers (million)**	**Energy (Billion kWh)**
Residential	115	1,267
Commercial	15	1,122
Industrial	0.6	973
Other	1	109
Total	**132**	**3,471**

Revenues	**Sales ($Billion)**	**Percent Total Elec. Energy**	**Avg./kWh (cents)**
Residential	107	37%	8.4
Commercial	89	32%	7.9
Industrial	47	28%	4.8
Other	7	3%	6.6
Total	250		Avg. Price 7.2

Financial	**($Billion)**
Total Assets	598
Total Operating Revenues	250
Operating Expenses	220
Operating Income	30
Construction	25

Source: Edison Electric Institute (EEI) Statistical Yearbook (2002)

Table 1B. U.S. Consumption of Electricity (2001)

A.	**Residential**	**Billion kWh**	**%**
	Air Conditioning	183	16
	Refrigerators	156	14
	Space Heating	116	10
	Water Heating	104	9
	Lighting	101	9
	Ranges & Ovens	80	7
	Laundry	76	7
	Color TV, VCR/DVD, Stereos	55	5
	Freezers	39	3
	Furnace Fans	38	3
	Dishwashers	29	2
	Personal Computers & Communication	28	2
	Pools & Hot Tubs	17	2
	Other *	118	10
	Total	**1,140**	**100**
B.	**Commercial**	**Billion kWh**	**%**
	Space Cooling	288	26
	Lighting	255	23
	Office Equipment/Computing	200	18
	Refrigeration	100	9
	Ventilation	78	7
	Space Heating	56	5
	Cooking	22	2
	Water Heating	11	1
	Other	100	9
	Total	**1,110**	**100**
C.	**Manufacturing**	**Billion kWh**	**%**
	Machine Drive	512	53
	Process Heating	104	11
	Electro-Chemical	86	9
	HVAC	82	9
	Process Cooling & Refrigeration	63	7
	Lighting	62	6
	Other	61	6
	Total	**970**	**100**

* Composed of about 15 additional consumption categories, each representing less than 1% of residential electricity consumption.

Source: U.S. Energy Information Agency (EIA), Energy Consumption Survey

Edison, with a characteristic vision that distinguished him from his competitors, worked not only on the incandescent lamp but on the entire system powering the lamp. "The same wire that brings the light will also bring power and heat—with the power you can run an elevator, a sewing machine, or any mechanical contrivance, and by means of the heat you may cook your food." Scientists and rival investors predicted failure. In 1879, Edison had a working incandescent lamp and, within months, patented a direct current (DC) electric distribution system.

The next question was: who would buy the lights and equipment? Edison conceived the central power station that would distribute electricity through lines to the customers. On September 4, 1882, Edison's Pearl Street Station in New York City went into business to serve 85 customers with 400 lamps. This marked the beginning of the electric utility industry. Unfortunately, with Edison's low-voltage DC system, it was too expensive to distribute electricity more than a mile from the power plant. Transformers that could raise and lower voltage did not work with direct current.

In 1888, Nicola Tesla, who had been previously employed by Edison, announced his polyphase alternating current (AC) power system. That same year George Westinghouse bought the rights to Tesla's system. Westinghouse saw the potential for locating a central station at the source of water power or coal, shipping the power for great distances at high voltages, and then stepping down the power for distribution. But inventing a practical AC system created new problems. AC and DC systems could not be linked until Charles Bradley, another former Edison worker, invented the rotary converter in 1888 which converted DC to AC. Westinghouse also bought him out.

The Westinghouse engineers developed a universal system in which the polyphase AC generator at the central station produced electricity that went to a local substation where it was transformed to the voltage required by the user. The system had many advantages. First was a realization of economies of scale in generation. The second was the need for only one wiring grid. The third was that the generating stations could serve a wider area. The fourth was that the new system's productivity could benefit from load diversity; e.g., lighting in the evening, streetcars during rush hours, and factory motors during the periods in between. Interestingly, the introduction of practical electric streetcars in the late 1880s provided the major concentrated electricity demand that dramatically pushed the enterprise toward more powerful equipment and larger service areas favoring AC.

In little more than a decade, Edison had put more than a half century of research into practical applications, conceived and invented an entire industry, and then became a reactionary who threatened to stagnate the industry at a primitive stage of development. In 1892, Edison's financier, J.P. Morgan, stepped in and forced a merger with Thompson-Houston and put their management in charge of Edison's

General Electric Co. In 1896, General Electric and Westinghouse exchanged patents, a move typical of the age of trusts, so even General Electric used Westinghouse concepts. The age of Edison had ended.

By 1892, Samuel Insull of Chicago Edison, another former Edison associate, had formulated an understanding of the economics of the electric utility business that was sustained through most of the 20th century. When Insull took over the Chicago Edison Co. in that year, it was just one of 20 electric companies in the city. Although Chicago had a population of more than one million, only 5,000 had electric lights. He vowed to serve the entire population. Insull and other leaders of the Association of Edison Illuminating Companies (AEIC) realized that the industry had high fixed costs because of the infrastructure investment needed. At the same time, the cost of operating the plants was fairly low. The question was how to translate that into profits, especially in an industry that had concluded it was selling a luxury item.

Insull began a sales campaign, cut prices as necessary to get customers, and wrote long-term contracts for large customers. He utilized a demand meter (invented in England) and set the price of electricity to cover both fixed and operating costs. Insull also concluded that profits were maximized by keeping the power plant running as much as possible to exploit diversity of load. As a result, the U.S. led the world in the rates of electrification. Insull in Chicago sold more electricity per capita, ran larger power stations, kept the plants running longer each day, and charged customers less. Insull also discovered that there were clear advantages to tying together urban and rural loads. For example, Chicago had a winter peak and the farm towns a summer peak.

By 1911, thanks to the development of the ductile metal filament lamp, electric lighting ceased to be a luxury, manufacturers developed new uses (e.g., refrigerators and sewing machines), and the demand for electricity skyrocketed. Also, Charles Parsons had recognized the limits of the reciprocating steam engine in 1884, and developed the steam turbine that produced rotary motion directly as high-pressure steam pushed against blades attached to a shaft. This elegantly simple machine occupied one-tenth the space, and cost one-third as much as the reciprocating engine of equivalent capacity. By 1911, 12,000 kW turbine generators also became the norm. Thus, the keys to the success of the traditional, declining cost commodity, grow-and-build electric utility business model were established, i.e., economies of increasing scale, rapidly rising consumer demand, and consumer diversity for load stabilization and higher capacity factors.

However, during much of this era of rapid sales growth and technological progress, electric utilities managed to earn unspectacular profits. This was addressed by consolidating the over-fragmented industry into ever-larger holding companies. Centralized ownership served to facilitate raising money and engineering the best systems. Also non-utility, industrial, electricity generation declined from more than 50% of the U.S. total as late as 1914 to 20% by 1932. Although states regulated the operating subsidiaries that sold electricity, none regulated the holding companies. By 1932 the eight largest holding companies controlled 73% of the investor-owned electric businesses. The Insull empire alone operated in 32 states and controlled at least a half billion dollars in assets with an investment of only $27 million. As a result of excesses committed, the electricity holding companies were condemned in the wake of the Depression, and controlling legislation was passed that created the present structure of the electric utility industry.

Under this legislation, interstate holding companies had to register with the SEC. This included any company that owned 10% or more of the voting securities of an electric or gas utility. The Act also broke up holding company systems that were not contiguous and eliminated intermediate holding companies from the financial structure. This Public Utility Holding Company Act of 1935 (PUHCA) also effectively marked the end of the formative period of the U.S. electricity enterprise. **Table 2** summarizes the rapid progress of the enterprise during this formation period.

Table 2. Electrification of the U.S. Economy

	1902	1932
% of Population in Electric-Lighted Dwellings	2	70
% Power in Industry (Horsepower equivalent)	5	73
Average Power Plant Size (MW)	0.5	8.5
Electricity Generation (10^9 kWh)	6	100
Residential Service Price (¢ per kWh – 1983$)	~ 40	15

Growth

In 1932 Franklin Roosevelt denounced the “Insull monstrosity” and proposed four Federal hydropower projects—The St. Lawrence, Muscle Shoals, Boulder Dam, and the Columbia. “Each of these in each of the four quarters of the United States will be forever a national yardstick to prevent extortion against the public and to encourage the wider use of that servant of the people—electric power.” In the same general time frame, Lenin also underscored the universal impact of electricity by declaring that “Communism equals the Soviet power plus electrification.”

Even during the Depression and through World War II, the U.S. electric utility industry continued to expand and to cut its costs. Government-supported entities, such as the Rural Electrification Administration, brought electricity to the farms. Although investor-owned utilities lost territory to governmentally owned (public power) utilities, the most significant change was the devolution of operating control from holding companies to locally operated utilities. These were incented to concentrate on customer service rather than on complex financial frameworks. Between 1935 and 1950, 759 companies were separated from holding company systems, and the number of registered holding companies declined from over 200 to 18.

During this period of industry consolidation and growth, utilities desired three features from new technology: reliability, greater power at lower costs, and higher thermal efficiency. As a result of this demanding market, manufacturers initially developed their new machines using a “design-by-experience” incremental technique. As with many other engineering endeavors then, the people who built these complex machines learned as they went along. This was reflected by steady increases in steam pressure and temperature in boilers and generators, providing corresponding improvements in thermal efficiency. Steam temperature and pressure in 1903 were typically 530°F and 180 PSI respectively. By 1930, water-cooled furnace walls permitted the production of steam at 750°F and up to 1,400 PSI. By 1960, these parameters had increased to 1,000°F and 3,000 PSI, turning water into dry, unsaturated, supercritical steam, effectively exploiting the full potential of the Rankine steam cycle.

Improvements in transmission systems also occurred stepwise during the power industry’s first several decades. While comprising a relatively small portion of a power system’s total capital cost, transmission systems nevertheless contributed significantly to providing lower cost and more reliable service. They did this by operating at ever-increasing voltages and by permitting interconnections among different power plants owned by contiguous power companies. Transmission voltage increased from 60,000 volts in 1900 to 240,000 volts in 1930 and up to 760,000 volts by 1960. Increased voltage, like higher water pressure in a pipe, allows more electricity to pass through a transmission wire. Doubling the voltage, for example, increased a line’s volt-ampere capacity by a factor of four. In short, the development of high-voltage transmission systems contributed as much to the steady increase in capacity of power production units as did advances in turbine speed or generator-cooling techniques.

U.S. energy consumption grew in lock-step with the economy after World War II, but electricity sales rose at double that rate until about 1970. The result, over the period of 1935 to 1970, was an 18-fold increase in electricity sales to ultimate customers with a corresponding 12-fold increase in electric utility revenues. This growth was stimulated by the dramatic and continuing drop in the real price of electricity, compared to other fuels. Much of the success in reducing costs was due to these continued improvements in the generating process and in higher voltage, longer distance transmission, which together more than offset the impact of the break up of the holding companies. Over the post-war (1945-1965) period, the average size of a steam power plant rose five-fold, providing significant economy-of-scale advantages.

Efficiency improvements (heat-rate) did not, however, keep pace after the late 1950s, even with higher operating steam temperatures and pressures. The inherent limitations of the Rankine steam cycle coupled with metallurgical constraints caused this efficiency plateau. Electricity distribution system expense per customer year also increased over 100% during this period, from $8 to $17.

After World War II, the accelerated growth of the industry caused manufacturers to modify their incremental, design-by-experience approach to one of “design-by-extrapolation.” This enabled manufacturers to produce larger technologies more rapidly. The push for larger unit sizes reflected the postwar U.S. economic prosperity and the introduction of major new electricity uses including air conditioning, electrical space-heating, and television. The all-electric home loomed large on the horizon. The biggest concerted promotional push began in 1956 with the “Live Better Electrically” campaign employing celebrities such as Ronald Reagan, on the heels of the very successful “Reddy Kilowatt” mascot for modern electric living.

While the best steam turbine generating units only improved in thermal efficiency from 32% to a 40% plateau in the postwar period, turbine unit sizes jumped from about 160 MW in 1945 to over 1,000 MW in 1965 through the design-by-extrapolation approach. Correspondingly, new plant construction costs declined from $173/kW in 1950 to $101/kW in 1965. Between 1956 and 1970, utilities operated 58 fewer plants to produce 179% more electricity. As regulated monopolies, electric utilities could not compete with each other for market share, but competition existed during this period as engineer-managers strived for technical leadership among their peers. This type of competitive environment contributed to rapid technological advances and production efficiencies. Utility managers encouraged manufacturers to build more elegant technology so they could get credit for using the “best” machines. The risks to gain customized technological supremacy often meant an economic tradeoff, but this was a price readily paid in the 1950s and 1960s by utility managers who retained their engineering values and goals as they became leaders of large business enterprises.

During this period of rapid expansion and success, a third participant—in addition to electric utilities and manufacturers—played a largely invisible supporting role. This third party consisted of the state regulatory bodies, which performed two tasks relative to electricity. First, they protected the public from abusive monopoly practices while assuring reasonably priced, reliable utility service. Second, they guaranteed the financial integrity of the utility companies. Conflicts rarely arose because utilities were steadily reducing their marginal costs of producing power, and they passed along some of these savings to consumers. Thus, few people complained about a service where declining costs countered the general trend toward cost-of-living increases. Regulatory actions also tended to reinforce the industry's grow-and-build strategy by permitting utilities to earn a return only on capital expenditures. This "social contract" served the industry and its stakeholders well for more than half a century providing a robust, state-of-the-art infrastructure. Although not articulated at the time, these stakeholders had forged an implicit consensus concerning the design, management, and regulation of a national technological system. As long as benefits continued to accrue to everyone, the consensus remained intact.

For electric utilities, this consolidation and growth period was, in summary, one of reorganization out of the holding companies, minimal need for rate relief, declining costs and prices, an average doubling in electricity demand every decade, incentives to add to the rate base, satisfied customers and investors, and acceptable returns for owners. That environment of few operating problems and little need to question the prevailing regulatory structure left the electricity enterprise and its stakeholders unprepared to either anticipate, or respond quickly to, the challenges that rapidly followed.

Table 3 summarizes the progress of the electricity enterprise during this period of growth and consolidation.

Table 3. Electricity Enterprise Growth

	1932	1950	1968
Ultimate Customers (million)	24	43	70
Net Generation (10^9 kWh)	100	389	1,436
Installed Generating Capacity (10^3 MW)	43	83	310
Average Power Plant Size (MW)	8.5	18	85
Circuit Miles of Hi-Voltage Line* (10^3 miles)	N/A	236	425
Residential Service Price (¢ per kWh – 1983$)	15	10	7.1

* 22,000 volts and above

Maturity and Stasis

By the mid 1960s, the electricity enterprise and its stakeholders were beginning to experience the first cracks in the traditional business model and its associated regulatory compact. The fundamental concepts of the enterprise began to be challenged and investment started to erode. The most notable initial event was the November 9, 1965 Northeast Blackout that spread over 80,000 square miles affecting 30 million people. This, and other outages that followed, forced utilities to redirect expenditures from building new facilities to improving the existing. Specifically, they had to upgrade the fragile transmission and distribution (T&D) system in order to handle larger power pools and more frequent sales among utilities. These new costs led to higher rates—literally for the first time in decades—and despite expensive image advertisements, the public grew increasingly critical of utility monopolies.

1967 marked a second major turning point for the U.S. electricity enterprise—generation efficiency peaked. Rather than lower the average cost of electricity, a new steam power plant would henceforth increase it. Economies of scale ceased to apply (bigger was no longer necessarily better or cheaper) and continued expansion in the traditional manner no longer held the same consumer benefits. The grow and build strategy had seemingly reached the end of the line. A third turning point was Earth Day in 1970. This launched environmental activism and focused fresh attention on electric utilities, ultimately leading to further investment redirection for environmental control equipment, most notably for sulfur dioxide scrubbing on the industry’s coal-fired power plant fleet. The Clean Air Act of 1970 made environmental concerns an integral part of the utility planning process while planning for growth became more difficult.

The fourth major enterprise turning point event was the Oil Embargo of 1973. OPEC’s actions led to a rapid rise in the cost of all fuels, including coal. Accelerated inflation and interest rates resulting from the Vietnam War economy also led to higher borrowing rates for utilities. The sum of these turning-point issues led to ever-higher electricity prices, reducing the growth of U.S. electricity sales in 1974 for the first time since World War II. Consolidated Edison missed its dividend and utility stock prices fell by 36%, the greatest drop since the Depression.

In spite of these troubling events, the electricity enterprise commitment to growth was slow to respond. In 1973 electric utilities issued $4.7 billion in new stock, almost seven times that sold by all U.S. manufacturing companies combined. Finally in 1975, capital expenditures declined for the first time since 1962. The traumatic decade of the 1970s concluded with perhaps the most strategically serious turning point issue of all—Three Mile Island. On March 28, 1979 a cooling system malfunction at the Three Mile Island nuclear plant in Pennsylvania destroyed public and political confidence in nuclear power, which had been seen as a technological solution to restoring the declining commodity cost and financial strength of the electricity enterprise. This event fell immediately on the heels of the nuclear accident movie—*The China Syndrome*—and seemed to validate nuclear power plant risks in the public mind. Although the lack of any core meltdown or even radiation leakage was testament to the quality and integrity of nuclear power plant design and construction, the demand for stricter safety regulations led to rapid cost escalation.

The first commercial nuclear power unit built in 1957 had a rating of 60 MW. By 1966, utilities were ordering units larger than 1,000 MW, even though manufacturers had no experience with units larger than 200 MW at the time. This arguably over-aggressive design-by-extrapolation, plus uneven utility operations and maintenance (O&M) training and management, led to reactor cost overruns that were sending power companies to the brink of bankruptcy while average power prices soared 60% between 1969 and 1984. Utilities and manufacturers in 1965 predicted that 1,000 reactors would be operating by 2000 and providing electricity "too cheap to meter." The reality was that only 82 nuclear plants were operating in 2000, and no new U.S. orders had been placed in two decades.

These issues were profoundly impacting the electricity enterprise in the 1980s. The very ways electricity was generated and priced were being challenged for the first time in nearly a century. No longer could planners count on a steady rise in electricity demand. No longer could utilities count on low-cost fuels or the promise of the atom. They could no longer construct larger and more efficient generation, nor could they avoid the costs associated with environmental emissions. Competition from innovative technologies and hustling entrepreneurs could no longer be blocked, and the long-standing social contract consensus among the stakeholders of the electricity enterprise began to unravel.

The push for open power markets started when energy-intensive businesses began demanding the right to choose their suppliers in the face of rising electricity prices. Recognizing this pressure, the Energy Policy Act of 1992 also greased the skids for greater competition. The Act let new unregulated players enter the electricity generation market and opened up the use of utilities' transmission lines to support wholesale competition. The deregulation of natural gas in the 1980s made gas a more available, affordable, and cleaner fuel for electricity generation. This, coupled with rapid advancements in aircraft-derivative combustion turbines, provided an attractive vehicle for new independent power producers to enter the market with low capital investment. Notably, non-utility sources as late as 1983 supplied only 3% of the U.S. generation market. By 2003, however, unregulated non-utility generators had captured nearly 30% of the U.S. generation market, exceeding the combined share from rural coops, the federal government, and municipal utilities. Wholesale electricity trading also soared—from approximately 100 million kWh in 1996 to 4,500 million kWh in 2000.

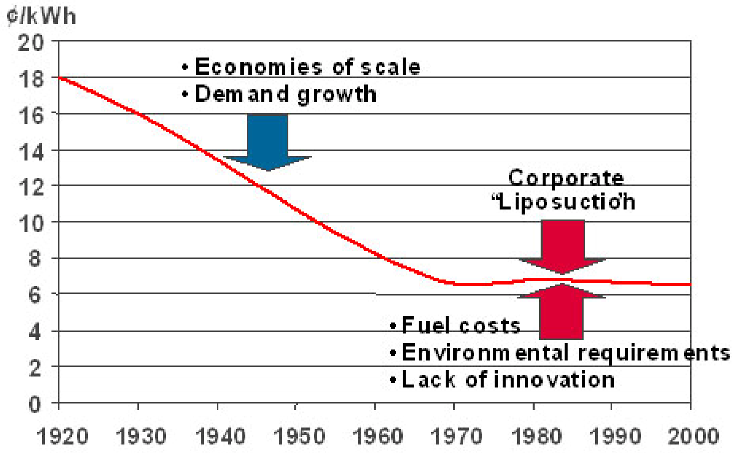
Between 2000 and 2003, about 200,000 MW of new natural gas-fired combustion turbine capacity were added to the U.S. electricity generating fleet. 65% of this new deregulated generating capacity utilizes combined cycle technology. However, the rate of new combustion turbine-based capacity addition has dropped off dramatically since then. In addition, the performance of this new capacity has suffered in terms of both heat rate and capacity factor. These are all symptoms of the boom-bust cycle in power generation that now exists in the restructured industry. For example, the average capacity factor for the fleet of new combined cycle power plants dropped from 50% in 2001 to below 30% in 2004 as electricity supply capability significantly exceeded demand, market access was physically limited by transmission constraints, and natural gas prices rose dramatically.

The 21st century has not begun well for the performance and integrity of the U.S. electricity enterprise. The biggest power marketer, Enron, collapsed amid scandal while facing a slew of lawsuits. Pacific Gas and Electric, one of the largest investor-owned utilities, filed for bankruptcy amid the chaotic power markets in California. 50 million people in the Northeast and Midwest lost electricity because of a cascading power failure in 2003 that could have been prevented by better coordination among utility operators. High natural gas prices and the U.S. economy's overall slowdown caused electricity demand to falter and wholesale prices to fall. As noted, the natural gas-fired combustion turbine boom collapsed, carrying many independent generation companies with it.

The end result was a $238 billion loss in market valuation for the electricity enterprise by early 2003 and the worst credit environment in more than 70 years. Those companies able to maintain good credit ratings and stable stock prices bought nearly $100 billion in assets from weaker firms. Since the Energy Policy Act of 1992, competitive electricity generators have been able to charge market rates, while the transmission and distribution sides of the enterprise have remained regulated with relatively low investment returns. As a result, more power is being produced, but it is being sent over virtually a frozen grid system. The U.S. Department of Energy predicts that transmission investment is only likely to expand 6% compared to the 20% growth in electricity demand expected over the coming decade. Another rising controversy pits residential against business customers as electricity rates increase.

In summary, as shown in **Figure 3**, the past 30 years have focused on efforts to restore the electricity enterprise's declining cost commodity tradition. All have failed to meet this challenge and there are no "silver bullets" on the horizon that are likely to change this reality within the context of today's aging electricity supply infrastructure. At the same time, electricity has become increasingly politicized as an essential retail entitlement where market price volatility is effectively allowed to operate only in one direction – downward. Thus, the essential foundation for restoring vitality to the electricity enterprise rests first and foremost on innovation, principally in the consumer/delivery interface and in end-use electro-technologies. This represents a profound transformational challenge for the enterprise, which, throughout its history following the Edisonian beginning, has focused on supply-side technology as the wellspring of progress.

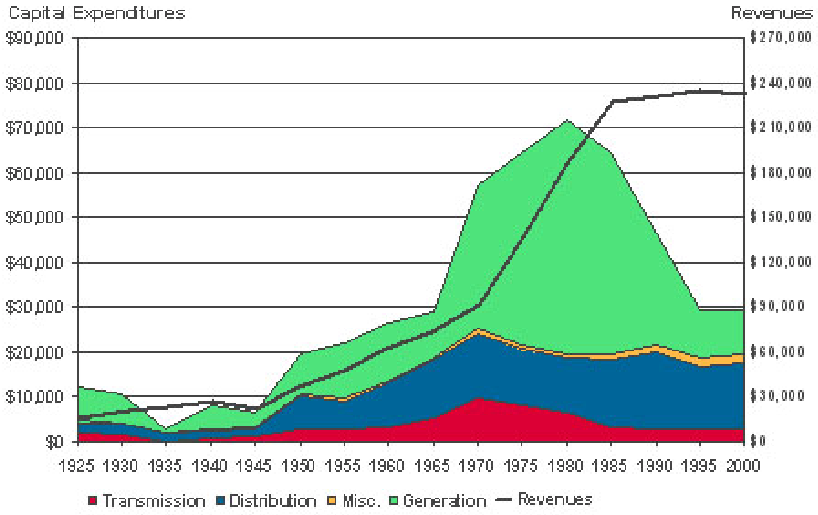
Figure 3. Average U.S. Price of Residential Electricity Service (1984 $)



This combination of rising costs and artificially constrained price creates an economic vise on electricity supply that is squeezing out more and more value from the enterprise and the nation. Unfortunately, the dominant financial imperative has been to contain immediate costs at the expense of infrastructure development and investment. Unless the resulting standstill is ended and the assets of the enterprise are urgently reinvented, they risk being left behind as industrial relics of the 20th century. For example, the total capital expenditure rate of the electricity enterprise, both regulated and unregulated, as a fraction of its electricity revenues is now about 10%, less than one-half of the historic minimum levels and, in fact, a percentage only briefly approached during the depths of the Depression (**Figure 4**).

Unfortunately, this emphasis on controlling costs at all cost has also resulted in a period of profound technological stasis throughout the grid-based electricity enterprise. This has not been for lack of innovative opportunity but rather the lack of financial incentives. Every aspect of the enterprise has both the need and opportunity for technological renewal. For example, although coal remains the backbone of the power generation fleet producing over half the nation's electricity, the outdated technology being used is both inefficient and unable to keep pace with rising environmental demands, including carbon control. Integrated coal gasification-combined cycle (IGCC) technology which, in effect, refines coal into a clean synthesis gas for both electric power generation and synthetic petroleum production, could fundamentally address these constraints. Similarly, advanced nuclear power cycles could resolve the waste management, proliferation, and efficiency problems limiting the use of this essential clean energy source. Without considerably greater R&D emphasis and modernization of the power delivery system, renewable energy will also remain a theoretically attractive but commercially limited resource opportunity. The same is true of electricity storage.

Figure 4. Electric Utility Revenues & Capital Expenditures (2003 $m), 1925–1999



Throughout the history of commercial electrification, large-scale storage, the long-sought after "philosopher's stone" of electricity, has remained elusive and thus a fundamental constraint on addressing optimal load management and asset utilization. Pumped storage, the use of off-peak electricity to pump water behind dedicated hydroelectric dams, has gained acceptance where feasible within geologic and environmental constraints. Demonstrations of compressed air storage using evacuated salt domes and aquifers were also successful, although this technology has not yet achieved significant commercial acceptance. At the other end of the spectrum of electricity storage, small-scale devices, including batteries and capacitors, are used for short-term load stability purposes and to dampen current fluctuations affecting reliability. A variety of advances in storage, including superconducting magnetic energy storage (SMES) and flywheels are being explored, but all have suffered from the general technological malaise constraining the grid-based electricity enterprise.

Only in applications for power portability has innovation in electricity storage made significant technical and commercial progress during this period. This progress also represents a quite different set of players than those of the traditional electric utility-based industry. Also indicative of new players taking advantage of the growing value gaps in the nation's traditional electricity supply capability is the trend toward distributed power resources. Consumers with urgent needs for high quality power are increasingly taking advantage of the emergence of practical on-site generation technologies. These include diesel power sets, microturbines utilizing natural gas or landfill methane, fuel cells, and hybrid power systems incorporating photovoltaics. All of these are, in effect, competitors with the power grid, although ideally they could be integrated as grid assets within a truly modernized national electricity service system.

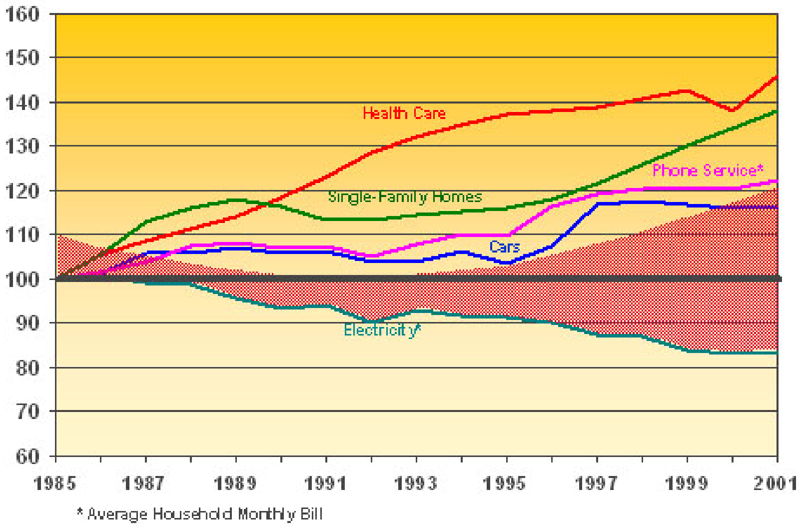
Similarly, in terms of power delivery technology, a wide array of thyristor-based digital control systems (e.g., FACTS), wide-area monitoring and communications, and highly sensitive anticipatory condition monitors, have been demonstrated and could revolutionize the reliability, capacity, and operability of the nation's electricity transmission and distribution network. Superconductivity represents another potential breakthrough technology that could fundamentally improve the efficiency of both power delivery and end use. This has been enabled by the recent development of so-called "high-temperature" superconductive materials operating at relatively modest liquid nitrogen temperatures. These materials, in effect, have no electrical resistance, thus eliminating transmission distance limitations, and are capable of significantly increasing the electrical capacity of existing distribution systems. The primary constraint today is the brittle ceramic nature of these superconducting materials and the resulting difficulties in manufacturing durable wiring, etc.

However, unless and until the electricity system advances from its current "life-support" level of infrastructure investment, all these potential advances remain, at best, on-the-shelf novelties. (These and others will be addressed further in the following section on Transformation.) This investment gap is exacting a significant cost that is just the tip of the iceberg in terms of the electricity infrastructure's growing vulnerability to reliability, capacity, security, and service challenges. In fact, since the mid-1990s, the electric utility industry's annual depreciation expenses have exceeded construction expenditures. This is typical of an industry in a "harvest the assets" rather than an "invest in the future of the business" mode.

An even more dramatic measure of stasis is the minimal R&D investment by the electricity enterprise. In the wake of restructuring in the early 1990s, the enterprise's R&D investment rate has declined to about 0.2% of annual net revenues. This compares to the U.S. industry-wide average of about 4%. Even with inclusion of federal electricity-related R&D, the total is still only equivalent to a fraction of one percent of annual electricity sales revenues. The bill for this mortgaging of the future has come due and will, unless promptly paid, impose a heavy price on the nation's productivity, economy, and the welfare of its citizens.

Figure 5 compares recent relative price trends among a variety of essential retail consumer goods and services. On the surface, the trend for electricity looks quite favorable but, after factoring in the rapidly growing cost of service unreliability (the shaded area), the real cost of electricity service has been increasing significantly and continues to do so at an escalating rate. This is an indelible reminder that it is only the **lack** of quality that adds to cost.

Figure 5. Relative Consumer Prices, 1985-2001



Prices calculated in 2001$, 1985=100

There is also significant and growing stakeholder concern that the electricity enterprise, as currently constituted, is out of step with the nation at large. As economic growth resumes, will the enterprise be able to keep pace with energy quantity and quality needs, and can it also satisfy investor expectations without again resorting to questionable, high-risk financial schemes?

Table 4 summarizes the course of the enterprise during the maturity and stasis period of the last 35 years.

Table 4. Maturity and Stasis

	1968	1985	2002
Ultimate Customers (million)	70	101	132
Net Generation (10^9 kWh)	1,436	2,545	3,841
Installed Generating Capacity (10^3 MW)	310	712	981
Average Power Plant Size (MW)	85	227	300
Circuit Miles of High-Voltage Line* (10^3 miles)	425	605	730
Residential Service Price (¢ per kWh – 1983$)	7.1	6.8	6.8

*22,000 volts and above

Transformation

The first step in restoring the integrity and building the value of the electricity enterprise, in the context of 21st century needs, is to focus on the fundamentals that broad stakeholder input has helped to highlight:

1. Electricity is more than a form of commodity energy; it is the underpinning of the modern quality of life, and the nation’s indispensable engine of prosperity and growth.

2. Electricity is a service-based enterprise whose value to consumers depends on the most technically complex machine ever built.

3. The opportunities for technology to relieve cost pressures are principally in its ability to increase the service value of electricity. Building service value, over and above electricity’s historic commodity energy value, is essential to every element of, and participant in, the electricity value chain.

4. The ability to capitalize on these new value opportunities requires a transformation of today’s electricity infrastructure. This transformation must enable all consumers to become active participants in, and benefactors of, the electricity enterprise, rather than remaining captive to the historic commodity model. Consumers want more choice and control.

The stakeholder messages also underscore that this “forward-to-fundamentals” transformation of the electricity enterprise is a process, not an event. It should proceed based on local benefits and costs—just as the nation’s highway system was developed in the 20th century. It will also be a process because it requires a transformation of the institutional as well as physical infrastructure.

This “reinvention” of the electricity enterprise is likely to be as daunting as it is essential. Indeed, it is more typical for incumbents to consider innovative transformation as a greater threat to their status instead of an opportunity. However, the current conditions prevailing in the enterprise, and the growing service-value gap created by these conditions, provide a situation in which transformative change is rapidly becoming a matter of survival for many incumbents, in addition to being a national productivity imperative.

Unfortunately, there are very few examples of successful transformative reinvention by established incumbents in any endeavor. The issue is even more challenging in the case of the electricity enterprise because of the significant barriers to entry by new players. Although the Public Utility Holding Company Act (PUHCA) was repealed in the just-passed Energy Policy Act of 2005, this is unlikely to attract significant new entrants unless and until the prevailing regulatory conflicts, uncertainties, and other disincentives are resolved that effectively create an impenetrable “iron curtain” around the enterprise, and transformational change leadership is mobilized.

Transformation requires that both the industry and its regulators move beyond their traditional cost-plus (or minus) commodity culture in terms of electricity’s value proposition to consumers and society. A compelling, unified leadership vision is needed that conveys the fact that electricity, through innovative technology, provides a service value to consumers and society that is significantly greater than its basic commodity value. In order to realize this vision, regulatory policy must facilitate true consumer participation by urgently resolving the tension in the changing role of regulation from one primarily of protecting to one of enabling.

The foundation for confidence in this enterprise transformation stems from the revolution underway in the enabling technologies affecting all network infrastructures. A portfolio of innovative technologies can comprehensively resolve the vulnerability of today’s power supply system in terms of its capacity, reliability, security, and consumer service value. These “smart technologies” will also open the door to fully integrating distributed resources and central station power into a single network, in a manner than can reduce system vulnerability rather than add to it—as is typically the case today—while also steadily improving the efficiency and environmental performance of the system.

Since 1980, the electricity intensity (kilowatt-hours per dollar GDP) of the U.S. economy has declined about 10%, leaving the intensity today about where it was three and a half decades ago. Is this the result of real efficiency improvement or just another measure of stasis? The electricity enterprise stands at a critical fork in its road of progress. Today its stakeholders have the necessity, the opportunity, and the means to make a clear choice about the future value of the enterprise. The decisions made and the path taken will make a profound difference, not only to the destiny of the electricity enterprise, but also to the nation, and ultimately to the world.

A primary rationale behind the restructuring of the electric utility industry 10 years ago was that competitive markets manage supply and demand, incent innovation, and allocate investment more effectively than centrally regulated monopolies. While fundamentally sound in principle, the policy implementation of this rationale has not adequately reflected either the unique physics or the public entitlement characteristics of electricity. The consequence has been a breakdown in the traditional public/private partnership built around the obligation to reliably serve, and upon which the value and reputation of the electricity enterprise was built. The decision to begin the competitive market transformation of electricity with the wholesale supply function rather than with retail service has proven to be particularly counterproductive. As a result, most of the potential consumer benefits of innovation have been left on the table thus seriously compromising the consumer value of transformation.

In short, the electricity enterprise has tended through restructuring to become a victim of its historic success in maintaining universal service reliability at ever-lower cost. The essential foundation for restoring enterprise vitality in the coming decade is rebuilding this fundamental public/private partnership, based on technology innovations that can increase the quality and value of electricity service, particularly providing higher levels of reliability and security. This transformation of the traditional electricity supply network into tailored, multi-functional service networks should also result in significant new business growth opportunities, reinforced by greater consumer satisfaction.

A modernized electricity enterprise would provide widespread benefits for the economy and society. In this enhanced scenario, productivity growth rates are higher and the economy expands more rapidly, while energy consumption, intensity, and carbon emissions are reduced relative to business as usual. Higher productivity rates can be sustained because a more reliable digital power delivery infrastructure would enable workers to perform existing and new functions more accurately and efficiently. This accelerated productivity growth has been demonstrated and established selectively in the economy, but its potential could be expanded dramatically through a smart power supply system. In effect, improved electricity reliability and quality would enable the digital economy to expand at a broader and faster rate—an essential factor for successful U.S. competition in a global economy.

The Digital Revolution is the third major economic transformation in the last 100 years, and each has increasingly depended on electricity. Each also has created substantial new levels of wealth, as well as winners and losers at the scale of individuals, corporations, and nations—all depending on the effectiveness with which the innovative technology underpinning the economic transformation is exploited. In this new electricity business environment, it is the quality of customer connectivity and responsiveness that increasingly will differentiate the winners from the losers. The most precious business asset becomes the customer access portal. Every electricity supply function preceding it will be under relentless cost pressure, only moderated by the value that each consumer ultimately receives.

This transformed electricity infrastructure and business model will also serve to catalyze entirely new capabilities for consumer participation in the electricity marketplace, while significantly reducing the parasitic costs of power disturbances characteristic of today's system. This technological innovation will finally break open the commodity box currently constraining both the electricity enterprise and consumers, and will usher in an era of ever-higher valued energy/information services even beyond our imaginations. The payoff from this economic progress could easily exceed $1 trillion per year in additional U.S. GDP within a decade. This accelerated economic expansion is essential to meeting the nation's growing debt, security, and aging population costs.

Above all, this modernized electricity system would provide much greater functionality and service value for consumers. From a business perspective, this additional value is increasingly necessary to compensate for the expected significant rise in the cost of electricity. A number of upward cost trends are likely to increase electricity cost by at least 30% during the coming decade. These upward cost pressures largely occur because of forces beyond the control of the electricity enterprise, including fuel price, environmental protection, and protection of the physical and cyber infrastructures against potential incursions.

The prices of fuels—natural gas, coal and uranium—are rising, and are likely to remain significantly elevated. As a result, fuel costs are expected to account for at least half of the net increase in the price of electricity over this period.

Similarly, the cost of compliance with steadily tightening environmental regulations also continues to increase. In addition, there is a growing possibility that mandatory carbon control requirements will be instituted, possibly in the coming decade. This would have significant additional impact on electricity costs, including the need for major strategic investment in cleaner replacement generation facilities using natural gas and nuclear, Integrated Gasification Combined Cycle (IGCC) for coal, and renewables.

Security improvements, both to discourage terrorist attacks and to recover from them, may further add to the cost of electricity. A fully functional security program would, for example, combine enhanced physical security systems with self-healing grid capabilities and cyber security advances. Cyber security would focus on increasing the security of communications, data monitoring, and automated system control functions, plus provide vulnerability assessments supporting the self-correcting grid and related adaptive islanding capabilities. Rising fears of terrorist attacks also may fuel political pressure to further escalate infrastructure security measures, regardless of their value. On the other hand, a modern digitally monitored and controlled power supply system would comprehensively and confidently address these concerns as part of the process of technical modernization.

The need to improve the reliability and quality of power is another important reason the cost of electricity likely will increase through 2015. Mandatory reliability standards have been endorsed widely and were moving through Congress until stalled with the rest of the 2003 Energy Policy Act legislation. However, to be relevant to the needs of the new century, these standards will need to move beyond the traditional “keep the lights on” level of reliability to reflect the more stringent requirements of the digital economy.

Probably the greatest long-term challenge to the electricity sector is the fact that even as the demand for power is growing, the nature of electricity demand is undergoing a profound shift due to digital technology. Twenty years ago when the personal computer was introduced, few foresaw the widespread proliferation of “smart” devices. Today, for every microprocessor inside a computer, there are 30 more in stand-alone applications, resulting in the digitization of society. In applications ranging from industrial sensors to home appliances, microprocessors now number more than 12 billion in the United States alone.

These digital devices are highly sensitive to even the slightest disruption in power (an outage of less than a fraction of a single cycle can disrupt performance), as well as to variations in power quality due to transients, harmonics, and voltage surges and sags. “Digital quality power,” with sufficient reliability and quality to serve these growing digital loads, now represents about 10% of total electrical load in the United States, for example. It is expected to reach 30% by 2020 under business-as-usual conditions, and as much as 50% in a scenario where the power system is revitalized to provide universal digital-grade service.

However, the current electricity infrastructure in the United States, designed decades ago to serve analog (continuously varying) electric loads, is unable to consistently provide the level of digital quality power required by our digital manufacturing assembly lines, information systems, and soon even our home appliances. The economic loss of power disturbances mentioned earlier is attributable in part to the sensitivity of digital technology.

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 "Intelligrid" electricity supply system that provides the same reliability, efficiency, precision and interconnectivity as the billions—ultimately trillions—of microprocessors that it will power. The following summarizes a potential set of key steps in this performance transformation:

- **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 would sense disturbances and instantaneously counteract them, or reconfigure the flow of power to cordon off any damage before it can propagate. To realize the vision of the smart power delivery system, standardized communications architecture must first be developed and overlaid on today's power delivery system. This "integrated energy and communications system architecture" should reflect an open

standards-based architecture for data communications and distributed computing infrastructure.

- **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

  To a power system operator, automation means a self-healing, self-optimizing smart power delivery system that automatically anticipates and quickly responds to disturbances, thus minimizing if not ultimately eliminating power disruptions altogether.

- **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 gateway or portal through today's opaque electric service "iron curtain" provides the tool for moving beyond the commodity paradigm of 20th century electricity service. The result will quite possibly usher in a set of new energy/information services at least as diverse as those in today's telecommunications. This portal would sit between consumers' "in-building" communications network and wide-area "access" networks, enabling two-way, secure and managed communications between consumers' equipment and energy service and/or communications entities.

- **Integrating distributed energy resources.** The new system would also be able to seamlessly integrate an array of locally installed, distributed power generation units (such as fuel cells and renewables) as power system assets addressing a variety of challenges. These challenges include the needs to increase the resiliency and reliability of the power delivery infrastructure, provide high-quality power, facilitate provision of a range of services to consumers, and provide consumers lower-cost, higher-quality power. These distributed power sources could be deployed on both the supply and consumer side of the energy/ information portal as essential assets dispatching reliability, capacity, and efficiency. Unfortunately, today's electrical 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.
- **Expanding portable power.** The added value of individualized consumer electricity services is exemplified by the rapidly proliferating market for portable electricity devices and power supplies. These are likely to capture more and more of the higher-value electricity uses. More efficient power usage is reducing the overall power demands of these devices while new cell chemistries are expected to double usable power densities.

  Lithium-ion battery technology is rapidly leading the demand for powering portable devices, while the market for nickel-cadmium (NiCad) is shrinking under environmental pressures. The price of lithium-ion batteries has also dropped by 20-50% during the last few years, while NiCad and nickel-metal hydride battery prices have declined by 10-20%. Primary batteries can be stored up to 10 years and have much higher energy densities than rechargeable secondary batteries.

  Fuel cells are a particularly attractive alternative for greater power portability. However, until major cost, size, and performance breakthroughs are achieved, fuel cell use will remain limited in portable applications. Fortunately, this is an area of technology that is receiving substantial developmental investment to resolve these constraints.

With the switch to electronic automobile braking and steering by wire, the 3 kW capability of the rechargeable lead-acid and the single 12-volt battery will no longer be sufficient, and is likely to usher in the 42-volt system. Hybrid vehicles require a high-voltage battery of about 150 volts. This is currently provided by connecting nickel-metal-hydride cells in series. Battery life in this service is key since replacement costs as much as a new motor.

Conclusion

The overarching priority of the electricity enterprise and all its stakeholders is to pursue the policies and actions needed to stimulate system modernization. The current rate of investment in the power delivery system alone, some $18–20 billion per year, is barely enough to replace failed equipment. To correct deficiencies in the existing system and to enable the smart power delivery system of the future will require double this amount annually. The result would be an electricity supply system fully capable of meeting the escalating needs and aspirations of 21st century society. In summary, these needs and aspirations dictate a future where:

- The electricity enterprise confidently provides the nation’s most essential platform for technical innovation, productivity growth, and continued economic prosperity. Eventually, it is expected that this platform will enable every end-use electrical process and device to be linked in real time with the open marketplace for goods and services, including, but not limited to, electric power.
- Economic productivity increases substantially as a result of the transformation of the electricity enterprise, generating additional wealth to deal with the large societal, security, and environmental challenges of the 21st century.
- The roles, responsibilities, and rules governing the electricity enterprise have been clarified, enabling a revitalized public/private partnership that maintains confidence and stability in electricity sector financing. As a result, the rate of investment in the essential electricity infrastructure is substantially increased.
- The role of regulation has evolved from oversight of company operations and “protection” of ratepayers to oversight of markets, as well as enabling and guiding market transparency and specific public-

good services (i.e., reliability standards, provider-of-last-resort, market transformation, etc.).

- National security and energy policies emphasize U.S. fuel diversity, placing electricity at the center of a strategic thrust to 1) create a clean, robust portfolio of domestic energy options including fossil, nuclear, and renewable energy sources, along with enhanced end-use efficiency; 2) develop a sustainable electric energy system providing the highest value to all consumers with perfect reliability; and 3) electrify transportation to reduce dependence on foreign oil.

The cost/benefits of electricity system modernization will be profoundly positive. For example, the cost to the average household would be less than $5 per month, taking no credit for the considerable energy-savings opportunities that each consumer would be empowered to achieve through a modernized, more functional power system. In return, as power reliability and quality improve, each consumer would save hundreds of dollars a year in the price of purchased goods and services. Even more financially significant would be the income potential added to each household as the nation’s productivity, security, and competitiveness increase. Thus the service quality improvements from electricity system modernization would not result in higher costs, but are the genesis of cost savings for all consumers. Again, **improving quality always costs less**.

In support of this more positive future, a proactive technology development program will be necessary. This should emphasize power system reliability and functionality, management of greenhouse gases, and the development of higher-value, more efficient, smart electricity end-use devices and services. Technological innovation will remain, as it has been throughout the history of commercial electricity enterprise, the essential asset determining the destiny of the electricity sector and its value to society.

The result is likely to be a profoundly transformed, multi-dimensional electricity service capability incorporating an array of distributed, stored, and portable power resources as assets. At the same time, this infrastructure transformation will enable the convergence of electricity, telecommunications, and sensors into a smart, sustainably robust, mega-infrastructure powering a universal digital society with absolute reliability. Most importantly, this transformation will enable an array of innovations in electricity service that is only limited by our imaginations.

In closing, The Galvin Electricity Initiative seeks to urgently catalyze this performance and value transformation. It will do so through a two-phase effort that first explores and evaluates the most promising opportunities for technological innovation throughout the electricity value chain, as seen from the broad consumer perspective. The goal here is demonstrable and compelling perfection in electricity service quality that will mobilize the broad community of stakeholders to demand the necessary performance and value transformation. In its second phase, the Initiative will develop the comprehensive change leadership plan for most effectively stimulating this electricity service and supply transformation. This plan will broadly consider and specifically recommend the essential policies, institutions, standards, and incentives, etc. needed to break today's pervasive innovation/investment logjam in the electricity enterprise. The results will truly electrify the nation and the world in the full meaning of the word.

A message of enduring vision:

> *So long as there remains a single task being done by men or women which electricity could do as well, so long will that development (of electrification) be incomplete. What this development will mean in comfort, leisure, and in the opportunity for the larger life of the spirit, we have only begun to realize.*
>
> —Thomas Edison, 1928

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