Power Delivery System of the Future

A Preliminary Estimate of Costs and Benefits

Technical Report

Power Delivery System of the Future

A Preliminary Estimate of Costs and Benefits

1011001

Final Report, July 2004

EPRI Project Manager
R. Lordan

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Hoffman Marketing Communications

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520, (800) 313-3774, press 2 or internally x5379, (925) 609-9169, (925) 609-1310 (fax).

CITATIONS

This report was prepared by

Hoffman Marketing Communications
16360 Monterey Road, Suite 285
Morgan Hill, CA 95037

Principal Investigator
S. Hoffman

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Power Delivery System of the Future: A Preliminary Estimate of Costs and Benefits, EPRI, Palo Alto, CA: 2004. 1011001.

REPORT SUMMARY

This report documents the methodology, key assumptions, and results of a preliminary quantitative evaluation of the investment needed (costs) and value (benefits) of an envisioned power delivery system of the future (Future PDS). This report is not a definitive analysis of all attributes, costs, or benefits of enhancing the Future PDS; rather, it is a starting point for discussing possible levels of investment in the power delivery system and the value of enhancing this system.

Background

The Electricity Roadmap Initiative is an ongoing collaborative exploration of opportunities for electricity-based innovation in the foreseeable future. A critical part of this initiative involves a national imperative to modernize and enhance power delivery systems and electricity markets. The Future PDS is envisioned to provide high security, quality, reliability, and availability (SQRA) of electric power; enhance economic productivity and quality of life; and minimize environmental impact while maximizing safety. To achieve this vision, accelerated public/private research, design, and development (RD&D), investment, and careful policy analysis are needed to overcome barriers and vulnerabilities. The latter include the fact that the present electric power delivery infrastructure was not designed to meet the needs of a restructured power market and the increasing demands of a digital society. In addition, investment in expansion and maintenance of this infrastructure is lagging, and the existing infrastructure is vulnerable to various security threats.

Objectives

To initiate a discussion and debate of the investment needed and the benefits to be derived from enhancing the power delivery system.

Approach

The debate over the appropriate level of power delivery system investment requires some preliminary estimation of costs and benefits. For each key portion of the overall task, the project team selected methods based on the availability of credible information and the need to conduct a cost-effective and time-efficient study. The resulting estimates of costs and benefits are highly uncertain and open to debate.

Results

Over and above the investment to meet electric load growth and correct deficiencies in the existing power delivery system, the estimated *net* investment needed to realize the envisioned Future PDS is $165 billion ($38 billion for transmission and $127 billion for distribution). The total value estimate range of $638 - $802 billion compared to the Future PDS cost estimate of $165 billion results in a benefit-to-cost ratio range of 4:1 to 5:1. To put into perspective the magnitude of the net investment needed to realize the Future PDS, note that this net investment of $165 billion over 20 years equates to about $8.3 billion/year. By comparison, approximately $18 billion/year is currently being invested in the U.S. power delivery system.

EPRI Perspective

In addition to encouraging comments on this report, EPRI invites energy companies, universities, government and regulatory agencies, technology companies, associations, public advocacy organizations, and other interested parties throughout the world to participate in refining the vision and building the Roadmap. Only through collaboration can the resources and commitment be marshaled to achieve the vision described in the Roadmap. By taking the lead in this Roadmap endeavor, EPRI is acting as the catalyst in a process of engagement and consensus building among diverse parties within and outside the electricity enterprise. This effort will not be completed in 2004; by definition, the Roadmap is an iterative process that requires consistent attention and refinement.

Keywords

Power delivery system future cost benefit
Distribution
Transmission

ACKNOWLEDGMENTS

The EPRI project manager would like to acknowledge the contributions of the following individuals and organizations:

EPRI:
Clark W. Gellings
John Chan
Robert Schainker

EPRI Power Electronics Applications Center (PEAC):
Karen Forsten
Arshad Mansoor
Mark McGranaghan

Hoffman Marketing Communications, Inc:
Steve Hoffman

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
EXECUTIVE SUMMARY

Background

The Electricity Roadmap Initiative is an ongoing collaborative exploration of the opportunities for electricity-based innovation over the next 20 years and beyond. A critical part of this Initiative involves a national imperative to modernize and enhance power delivery systems and electricity markets. The power delivery system of the future is envisioned to provide high security, quality, reliability, and availability (SQRA) of electric power; enhance economic productivity and quality of life; and minimize environmental impact while maximizing safety. To achieve this vision, accelerated public/private research, design, and development (RD&D); investment; and careful policy analysis are needed to overcome barriers and vulnerabilities. The latter include the fact that the present electric power delivery infrastructure was not designed to meet the needs of a restructured power market and the increasing demands of a digital society; investment in expansion and maintenance of this infrastructure is lagging; and the existing infrastructure is vulnerable to various security threats.

Overcoming these challenges and meeting the needs of society requires the application of a combination of current and advanced technologies ranging throughout the electric power system from generation busbar to energy consuming devices. Developing and deploying these technologies will require a significant, sustained investment.

Purpose and Scope

This report documents the methodology, key assumptions, and results of a preliminary quantitative evaluation of the investment needed (costs), and value (benefits), of the envisioned future power delivery system. Not intended to be a definitive analysis of all attributes, costs, or benefits of enhancing the power delivery system, this report is a starting point for discussion of possible levels of investment in the power delivery system, and the value of enhancing this system. In short, this report acts as a point of departure for debate.

In addition to welcoming and encouraging comments on this report, EPRI invites the participation of energy companies, universities, government and regulatory agencies, technology companies, associations, public advocacy organizations, and other interested parties throughout the world in refining the vision and building the Roadmap. Only through collaboration can the resources and commitment be marshaled to achieve the vision described in the Roadmap process.

Summary of Results

Over and above the investment to meet electric load growth and correct deficiencies in the existing power delivery system, Table 1-1 shows that the estimated *net* investment needed to realize the envisioned power delivery system of the future ("Future PDS") is $165 billion ($38 billion for transmission and $127 billion for distribution). The total value estimate range of $638 - $802 billion[1] compared to the Future PDS cost estimate of $165 billion results in a benefit-to-cost ratio range of 4:1 to 5:1. Thus, based on the underlying assumptions, this comparison shows that the benefits of the envisioned Future PDS significantly outweigh the costs.

Table 1-1
Summary of Estimated Costs and Benefits of Power Delivery System of the Future

	20 year total ($billions)
Net Investment Required	$165
Net Benefit	$638 - $802
Benefit-to-Cost Ratio	4:1 - 5:1

To put into perspective the magnitude of the net investment needed to realize the Future PDS, note that this net investment of $165 billion over 20 years equates to about $8.3 billion/year. By comparison, approximately $18 billion/year is currently being invested in the power delivery system in the U.S.

[1] This range reflects a range of assumptions used in a Primen study to extrapolate power quality and reliability cost impacts from surveyed businesses to all other businesses. See page 4-4 for more information.

2
INTRODUCTION

The Electricity Roadmap Initiative is an ongoing collaborative exploration of the opportunities for electricity-based innovation over the next 20 years and beyond. Thus far, over 150 organizations have participated with EPRI, electricity industry stakeholders, and EPRI's members in shaping a comprehensive vision of how to further increase electricity's value to society.

In taking the lead in this Roadmap endeavor, EPRI is acting as the catalyst of a process of engagement and consensus building among diverse parties within and outside the electricity enterprise. This effort will not be completed in 2004; by definition, the Roadmap is an iterative process that requires consistent attention and refinement.

EPRI invites the participation of energy companies, universities, government and regulatory agencies, technology companies, associations, public advocacy organizations, and other interested parties throughout the world in refining the vision and building the Roadmap. Only through collaboration can the resources and commitment be marshaled to achieve the vision described in the Roadmap process.

The Envisioned Power Delivery System of the Future

A critical part of this Initiative involves a national imperative to modernize and enhance power delivery systems and electricity markets. The envisioned power delivery system and electricity markets of the future will enable achievement of the following goals:

- Extremely reliable delivery of the high quality "digital-grade" power needed by a growing number of critical electricity end-uses
- Availability of a wide range of "always-on, price-smart" electricity-related consumer and business services, including low-cost, high value energy services, that stimulate the economy and offer consumers greater control over energy usage and expenses
- Physical and information assets that are protected from man-made and natural threats, and a power delivery infrastructure that can be quickly restored in the event of attack
- Minimized environmental and societal impact by optimizing use of the existing infrastructure; promoting development, implementation, and use of energy efficient equipment and systems; and stimulating the development, implementation, and use of clean distributed energy resources and efficient combined heat and power technologies
- Improved productivity growth rates, increased economic growth rates, and decreased electricity intensity (the ratio of electricity use to gross domestic product)

Hence, this vision includes several dimensions. It extends beyond automating portions of the system, enhancing control, improving reliability, and integrating components to improve security. The ultimate vision is a fully-integrated, fully-functional power delivery system that enables maximum use of existing assets; improves reliability, security, and power quality; and fully integrates consumers with the power system.

Challenges to Achieving This Vision

To achieve this vision of the power delivery system and electricity markets, accelerated public/private research, design, and development (RD&D); investment; and careful policy analysis are needed to overcome the following challenges:

- The present electric power delivery infrastructure was not designed to meet, and is unable to meet, the needs of a digital society – a society that relies on microprocessor-based devices in homes, offices, commercial buildings, industrial facilities, and vehicles.
- Investment in expansion and maintenance of this aging infrastructure is lagging, while electricity demand grows and will continue to grow.
- This infrastructure is not being expanded or enhanced to meet the demands of wholesale competition in the electric power industry, and does not facilitate connectivity between consumers and markets.
- Under continued stress, the present infrastructure cannot support levels of power security, quality, reliability, and availability (SQRA) needed to facilitate higher levels of economic growth.
- The existing power delivery infrastructure is vulnerable to human error, natural disasters, and intentional physical and/or cyber attack.
- The infrastructure does not adequately accommodate emerging beneficial technologies, including distributed energy resources and energy storage, nor does it facilitate business opportunities in retail electricity/information services.

Purpose of This Report

The primary purpose of this report is to initiate a discussion and debate of the investment needed, and the benefits to be derived from, enhancing the power delivery system. To meet this objective, this report:

- Documents the methodology, key assumptions, and results of a preliminary quantitative estimate of the needed investment (cost) and value (benefit)
- Compares these benefits and costs of enhancing the power delivery system
- Provides a starting point that encourages stakeholder discussion of this topic.

The complexity of the power delivery system and wide range of potential technology applications and configurations to enhance it complicate the process of quantitatively estimating the needed investment and resulting benefits. In addition, due to the various types of information available, complexity of subparts of the analysis, and uncertainties associated with cost-benefit analyses and estimating techniques, no single approach can be applied to all portions of the evaluation. Nevertheless, the debate over the appropriate level of power delivery system investment cannot advance without some preliminary estimation of costs and benefits. Hence, for each key portion of the overall task, the project team selected methods based on the availability of credible information and the need to conduct a cost-effective and time-efficient study. The resulting estimates of costs and benefits are highly uncertain and open to debate.

3
POWER DELIVERY SYSTEM OF THE FUTURE: COSTS

Overview

The power delivery system includes the busbar located at the generating plant (where the power delivery system begins) and extends to the energy consuming device or appliance at the end user (where the power delivery system ends). This means that the power delivery system encompasses generation step-up transformers; the generation switchyard; transmission substations, lines and equipment; distribution substations, lines, and equipment; distributed energy resources located at end users; power quality mitigation devices and uninterruptible power supplies; and other equipment.

Present and projected future inadequacies in the power delivery system are manifested in the form of poor reliability, excessive occurrences of degraded power quality, vulnerability to mischief or terrorist attack, and the inability to provide enhanced services to consumers. "Gold plating" the present power delivery system (e.g., simply pouring more money into the power delivery system in the form of duplicative or redundant facilities) is not a feasible way to provide the level of SQRA that is required.

Meeting the energy requirements of society will require the application across the entire power delivery system of a combination of current and advanced technologies, including but not limited to the following:

- Automation: the heart of a "smart power delivery system"
- Communication architecture: the foundation of the power delivery system of the future
- Distributed energy resources and storage development and integration
- Power electronics-based controllers
- Power market tools
- Technology innovation in electricity use
- A consumer portal that connects consumers and their equipment with energy service and communications entities

For more information on these and other technologies, refer to EPRI report 1009321, "Electricity Technology Roadmap: 2003 Summary and Synthesis, Power Delivery and Markets."

Developing an optimal combination of these technologies will require a significant, sustained RD&D investment. Making such an investment in a critical industry like the U.S. electric power industry is not unprecedented. According to a June 2003 report by the National Science Foundation, RD&D spending in the U.S. as a percent of net sales was about 10 percent in the computer and electronic products industry and 12 percent for the communication equipment industry in 1999. Conversely, RD&D investment by electric utilities was more than an order of magnitude lower – less than 0.5 percent during the same period. RD&D investment in most other industries is also significantly greater than that in the electric power industry.

To conduct a preliminary quantitative estimate of the level of investment needed over the next 20 years to enable the envisioned power delivery system, the project team first decided to treat transmission and distribution separately. This is due to fundamental differences, which are discussed on page 3-10, in the nature of these two portions of the power delivery system.[2] The team also decided to further subdivide the estimating process into the following three segments:

- **Load Growth.** Via equipment installation, upgrading, and replacement, transmission and distribution system owners invest in the power delivery system to accommodate new customers (so-called “new connects”) and to meet the increasing energy needs of existing customers as their load grows.
- **Correct Deficiencies.** The project team estimated the investment needed to correct deficiencies (e.g., correct power flow bottlenecks and limit high fault currents that damage critical grid equipment) due to lack of investment in the power delivery system in the past.[3]
- **Power Delivery System of the Future (“Future PDS”).** The project team estimated the investment needed to develop and deploy advanced technologies needed to realize the vision of the power delivery system (both transmission and distribution) described above.

The first two segments represent investments required to maintain adequate capacity and functioning of the power delivery system, while the third segment is the additional cost to elevate this system to the power delivery system of the future.

Transmission System Costs and Expenditures

Overview

The high voltage transmission system is the “backbone” of the power delivery system. It transmits very large amounts of electric energy between multiple regions and sub-regions. Transmission system equipment fails and causes power outages much less frequently than distribution equipment. But when transmission equipment fails, many more customers are affected, and outage costs can be much higher, compared to the impact of a distribution

[2] There are, however, substantial areas in which distribution technology enhancements will greatly affect the operation and potentially the configuration of the transmission system. There interactions were not considered in this evaluation.
[3] Transmission and distribution asset owners currently invest limited funds to correct deficiencies. In today’s market, these investments are generally restricted to replacing failed equipment or correcting only serious deficiencies.

equipment-related outage. This fact, combined with the high cost per mile or per piece of transmission equipment, and its high visibility has historically led to greater attention to transmission system reliability. However, in the last 15-20 years, a variety of factors has led to a significant decrease in investment in transmission system expansion.

To estimate the investment needed in the transmission system or "grid," a top-down approach was used for the "load growth" and "correct deficiencies" segments, while a bottom-up approach was used for estimating the investment needed for the Future PDS.

Load Growth – Transmission Portion

Most of today's transmission expenditures are directed at meeting load growth needs.[4] Hence, for a preliminary estimation of the investment needed to meet future load growth, the team used the annual level of investment in transmission (see Figure 3-1). Based on data from the Edison Electric Institute (EEI) and the U.S. Department of Energy's Energy Information Agency (EIA), Figure 3-1 shows that annual transmission investment was at least $2.5 billion in the 1950s and 1960s. The industry experienced a transmission building expansion in the 1970s and early 1980s, with annual investment of $7-$8 billion. From 1985 to 1999, investment decreased to about $3 billion per year, failing to keep pace with load growth. Subsequently, operating margins tightened considerably. Based on discussions with team members and industry experts, the team concluded that an annual investment of about $5 billion is needed to meet load growth. Assuming continued consumer load growth, the investment needed to serve load growth over 20 years is approximately $100 billion (constant dollars).[5]

[4] While it can be argued that some of these transmission expenditures serve to connect merchant plants to the grid, these expenditures are ultimately likely to also accommodate new load.

[5] To verify this approach, the project team examined the area under the transmission curve in Figure 3-1, which represents the cumulative investment in transmission. Assuming that almost all of the investment was made in transmission over the last 50 years, the area under the curve from 1950 to 1999 is about $250 billion. (Note that this number is more than twice as high as the oft-quoted book value, or depreciated value, of $100 billion for transmission assets in place in the United States. This higher number is expected since replacement value is much higher than book value.) Various agencies have projected long-term load growth of about 2 percent per year. Compounding this growth factor over 20 years results in a needed growth in transmission investment of about 44 percent over that period just to keep pace with load growth. Forty-four percent of the total investment in transmission over the last 50 years is $110 billion. This means that the $100 billion number calculated assuming $5 billion per year is reasonable.

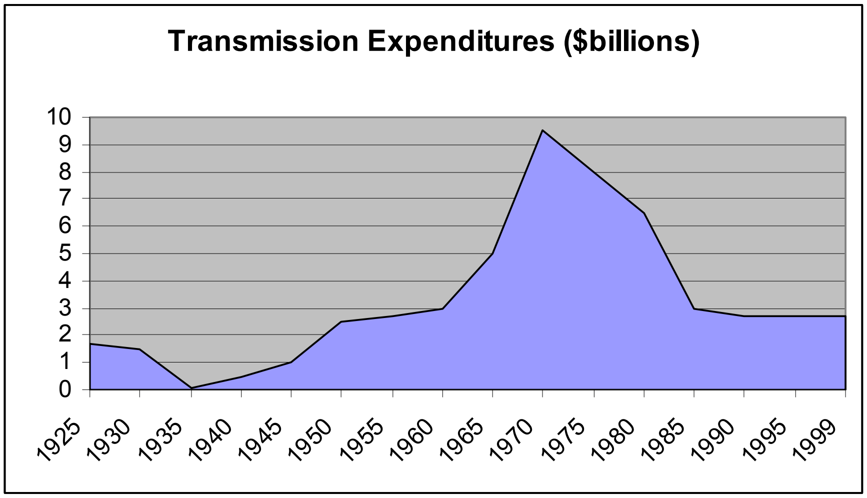

Figure 3-1
Annual Investment in the U.S. Electric Power Delivery System (2003 Dollars) Sources: Edison Electric Institute, DOE's Energy Information Administration

Correct Deficiencies – Transmission Portion

Investing in the transmission system to ameliorate bottlenecks and correct other deficiencies will involve the following:

- Build transmission lines and substations to improve power flow
- Plan and operate the transmission system to meet required equipment outage contingency conditions
- Improve and standardize the communication and data protocol infrastructure
- Upgrade supervisory control and data acquisition (SCADA) equipment, upgrade energy management control center equipment, and train control center personnel
- Update protection schemes and relays so that outages will not cascade into neighboring grid systems
- Perform transmission line and right-of-way maintenance (e.g., tree trimming) that is consistent with agreed upon industry standards.

To estimate the investment needed to correct deficiencies due to lack of investment in the transmission system in the past, the project team also used the data in Figure 3-1. From 1985-1999, transmission investment was fairly stable at the low level of about $3 billion per year. During a large part of this latter period, the decrease in transmission investment is generally attributed to overcapacity and sufficient reserve margins. However, in the late 1990s, the transmission portion of the electric power industry in the United States was restructured and re-regulated. During this period, the decrease in transmission investment was principally due to uncertainty in the rate of return on investment (and whether it would be modified or disallowed in future years) offered to transmission owners/investors. This sustained decrease in transmission investment has at least partially led to the creation of significant transmission bottlenecks and other transmission deficiencies throughout North America.[6]

Assuming that $5 billion per year (instead of $3 billion per year) should have been spent from 1985-1999 (which is consistent with the earlier assumption that $5 billion per year is needed to meet load growth), about $2 billion per year is needed to correct the deficiency over the 15-year period. This $30 billion can be invested at a rate of $1.5 billion per year over the next 20 years.[7]

Future Power Delivery System – Transmission Portion

To estimate the investment to develop and deploy advanced technologies for the transmission portion of the future power delivery system ("Future PDS"), the team first assembled a list of 14 technology categories that would be needed (see Table 3-1). (These categories are similar to those described in the Roadmap 2003 Summary and Synthesis Report for Power Delivery and Markets.) The team estimates that development and deployment of these technologies could improve transmission system reliability by as much as 30-40 percent, while improving network efficiency, reducing grid blackout vulnerability, and improving security.

[6] Examples of these deficiencies are revealed in the reports of the August 2003 Midwest-Northeast blackout. While these reports explain that some very old circuit breakers and substation transformers operated properly under stress, much of the power delivery equipment in this part of North America uses outdated mechanical (rather than microprocessor-based) methods and is beyond its predicted useful life.

[7] In describing these changes in expenditures in various forums, the authors have been asked to justify this approach. Some assert that the period from 1965-1980 represented an overinvestment resulting in an infrastructure that was "overbuilt." They suggest that due to development of improved planning tools, past high expenditures on the transmission system may not be necessary. However, there is substantial evidence that today's power delivery system is under stress and inadequate. For more information, refer to "Electricity Technology Roadmap: 2003 Summary and Synthesis, Power Delivery and Markets," EPRI report no. 1009321, November 2003.

Table 3-1
Estimated Cost of Developing and Deploying Advanced Transmission Technologies

Transmission Technology Category	Development and Deployment Avg. Cost/Unit ($million)	Number of Units	Cost ($billion)
Automation of transmission/substation systems	1	10,000	$10
Sensors/monitors & communication systems	0.01	400,000	$4
Reliability centered/predictive maintenance	1	20,000	$20
Self diagnostic transformers & other substation equipment	0.1	50,000	$5
High current/superconducting wires & cables	150	200	$30
Higher voltage lines/substations	100	100	$10
Power electronics controllers, current limiters, & circuit breakers	50	200	$10
Energy storage shock absorbers	20	300	$6
Emergency operation controllers, relays, and tools	0.1	20,000	$2
Emergency restoration equipment/tools	1	10,000	$10
Faster than real-time simulation tools	1	1,000	$1
Probabilistic vulnerability assessment	1	1,000	$1
Dynamic thermal circuit rating	0.5	1,000	$1
Power delivery system planning tools	1	500	$1
Total Cost ($billion)			$110

For each of the technology categories in Table 3-1, assumptions were made as to 1) the cost per unit to develop and deploy the technology (the first column in Table 3-1), and 2) the total number of units needed to realize the envisioned power delivery system (the second column of Table 3-1). The product of these two numbers yields the total estimated investment needed over the 20-year period for this technology category (the third column in Table 3-1). For example, for the technology category of "power electronics-based flow controllers," the team assumed a per unit investment of $50 million per unit, and a need for 200 of such devices, yielding a total investment of approximately $10 billion. Using this approach, the total projected cost of developing and deploying transmission technologies to realize the envisioned power delivery system in the United States is approximately $110 billion (about $5.5 billion per year).

Figure 3-2 aggregates these 14 technology categories into six groups to illustrate the relative investment magnitude for various types of technologies. Figure 3-3 apportions this $110 billion investment across the following three types of improvements:

- **An adaptable "self healing" transmission grid** refers to a transmission system that senses power disturbances and counteracts them, or reconfigures the flow of power to cordon off a disturbance before it propagates. More broadly, this term refers to an integrated, 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.

- The emergence of **open power markets** increases power flows across the grid to levels at which the power delivery system was not originally designed to operate. Various advanced technologies will enable the voltage and transient stability performance on the grid that is needed for open power markets.
- **Increased efficiency** at the transmission level is achieved in part by building and operating lines and substations at higher voltage and by using superconducting wires and cables. Higher efficiency in the power delivery process will enable consumer load to be served with less generated power, which results in less emissions and **reduced environmental impacts**.

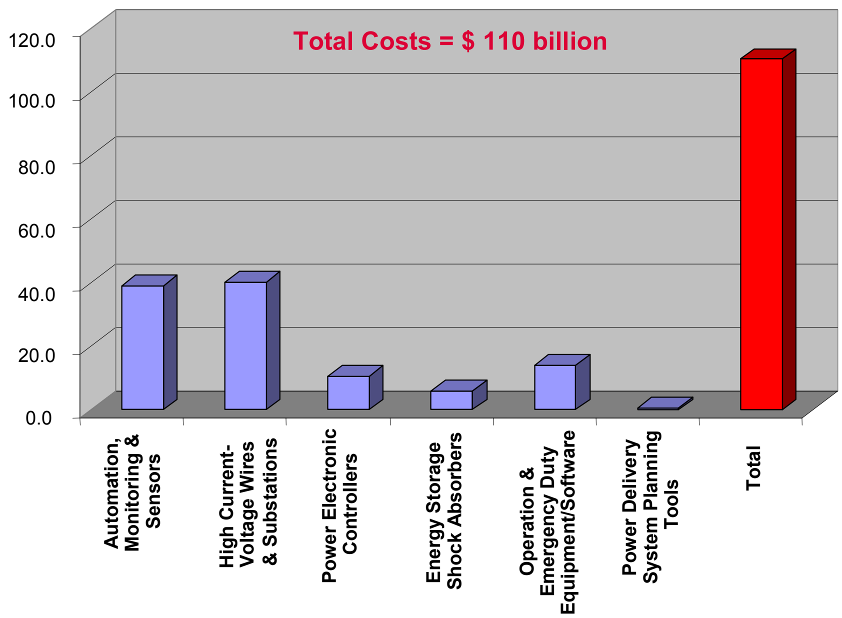

Figure 3-2
Grouping the 14 Technology Categories Shows the Estimated Relative Investment Magnitude of Various Transmission Technology Types Needed for the Future PDS.

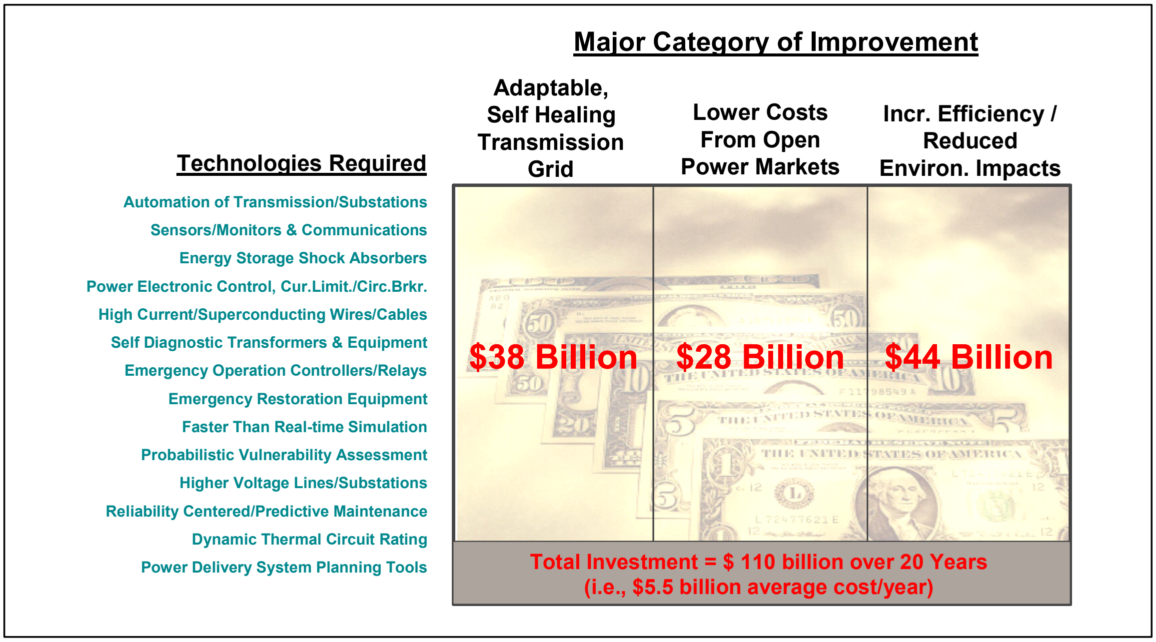

Figure 3-3
Investing in the Transmission System of the Future Leads to Projected Improvements in the Three Categories Shown.

Synergies – Transmission Portion

After estimating the investment needed to meet load growth, correct deficiencies, and develop/deploy the transmission portion of the Future PDS, the project team assessed potential synergies between these three segments. For example, current investments to meet load growth and correct deficiencies on the transmission system usually only address the need to serve the particular load or correct the specific deficiency. These investments are typically not part of a strategy to enhance the functionality of the overall power delivery system. However, with little or no additional investment, such investments could be coordinated to aid realization of the transmission portion of the Future PDS. Conversely, advanced technologies aimed at establishing the Future PDS will also help to meet load growth and correct deficiencies.

To account for synergies like these, the team first examined more closely the 14 technology categories shown in Table 3-1, which are needed to realize the Future PDS. To develop a preliminary estimate of the extent to which these technologies also help meet load growth and correct deficiencies, the team allocated the fraction that each of the 14 technology categories would contribute to 1) meeting load growth needs, 2) correcting deficiencies, and 3) helping realize the Future PDS. Summing these contributions across all 14 technology categories revealed that an estimated $55 billion of the $110 billion “Future PDS” total can also contribute to meeting load growth, and that about $17 billion of the $110 billion total can also contribute to correcting deficiencies. Using a similar approach, the team estimated that about $5 billion of the $100 billion load growth investment can also help correct deficiencies.

Figure 3-4 illustrates these synergies. Without consideration of synergies, the total estimated transmission investment over the next 20 years is $110 billion for the future power delivery system, $100 billion to meet load growth, and $30 billion to correct deficiencies. In Figure 3-4, these three values are indicated in brackets outside the three circles and represent the areas of the circles. The areas where the circles overlap represent the synergies described above. Hence, for example, the overlap of the $110 billion circle and $100 billion circle is the $55 billion synergism between technologies to realize the Future PDS and meet load growth.

Without considering synergies, the total cost is $240 billion ($110 billion + $100 billion + $30 billion). The synergies sum to about $77 billion ($55 billion + $17 billion + $5 billion). Subtracting the synergies from the total shows that, after accounting for synergies, the total investment is reduced from $240 billion to $163 billion.

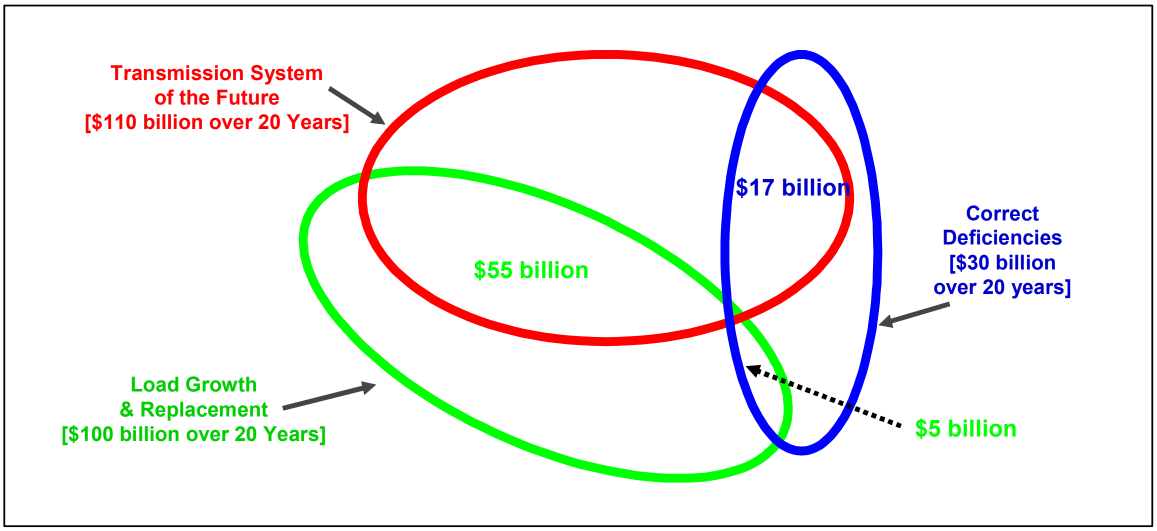

Figure 3-4
Synergies in the Three Categories of Needed Transmission Investment Reduce the Total Investment From $240 Billion (Sum of Total Area of Three Circles) by $77 Billion (Overlapping Areas of Circles) to About $163 Billion Over the Next 20 Years.

Distribution System Costs and Expenditures

Overview

While a small percentage of consumers are served directly from the transmission system, the vast majority of consumers are served by the distribution system. Compared to the transmission system, the greater complexity, exposure, and extent of the distribution system (e.g., more miles of wire and more poles or conduits) result in inherently lower reliability, reduced power quality, and greater vulnerability to disruptions of any kind.

Power disturbances experienced by consumers are most influenced by distribution system characteristics and performance. Reliability performance is often measured as the average total duration of interruptions (i.e., "minutes lost") experienced by a consumer in a year. Using this measure, over 90 percent of the minutes lost for consumers are attributable to distribution events. Hence, investments in the distribution system are required to achieve higher levels of reliability and quality; these investments will have the following additional important advantages:

- Integration of electric energy services and communications with consumer facilities and equipment, providing a vast array of consumer services
- Improved asset management
- Reduced losses on the distribution system (via better voltage/VAR management)
- Complete integration of distributed energy resources (DER) to provide more flexibility in overall system energy management

Load Growth – Distribution Portion

Like transmission, most of today's distribution capital expenditures are directed at meeting load growth (both "new connects" and upgrades to serve increasing load for existing customers). Hence, to estimate the continued investment to meet load growth and normal equipment replacement requirements, the team used historical EIA data on annual capital expenditures for distribution since 1988, adjusted to 2002 dollars (see Figure 3-5).[8] The trend line for these data shows that the annual capital costs are increasing at about 1 percent per year, and the trend line is at about $15 billion annually for capital expenditures in 2002 (actual expenditures in 2002 were below the line). Assuming that this capital investment in distribution continues to increase at 1 percent per year, the total cost over the next 20 years will be about $330 billion – simply to keep pace with normal system investment requirements for load growth and equipment replacement.[9]

[8] Utilities report and expend capital and O&M distribution funds in a wide variety of ways, depending on budgetary constraints, local practices, and other factors; this increases the uncertainty in this data.
[9] Despite concerns voiced by some stakeholders that distribution O&M expenses have declined, this EIA data show that they are also increasing by 1 percent per year.

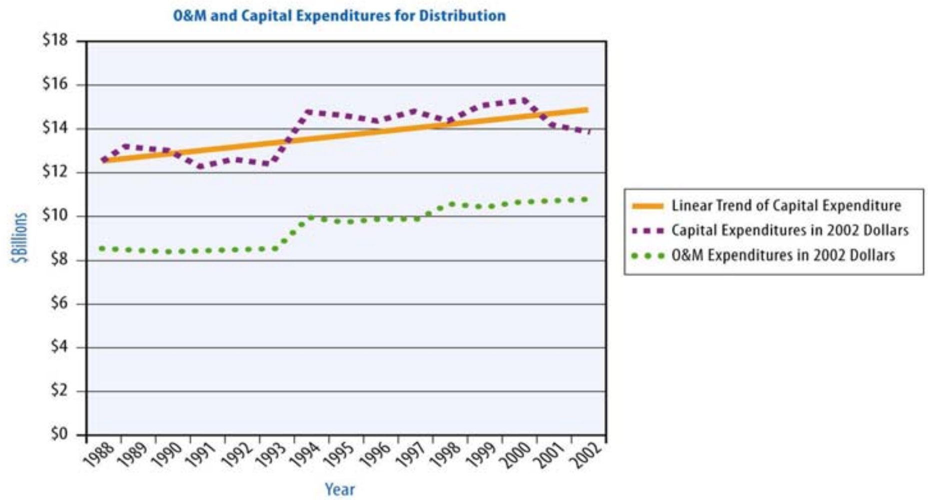

Figure 3-5
Historical Distribution System Investment (Adjusted to 2002 Dollars)
Source: DOE's Energy Information Administration Database, 2002

This $15 billion annual cost is about twice as high as the average investment in transmission from 1965-1980 (about $7 billion), and five times larger than the average transmission investment from 1985-1999 (see Figure 3-1).

Distribution versus Transmission Investment

There are four main reasons why investment in distribution is significantly greater than investment in transmission:

- Distribution serves every home and business in the United States. By contrast, the transmission system is far more concentrated – transmitting power over long distances. Even though the transmission system is more expensive per mile, this is more than compensated by the higher number of miles and larger number of devices on the distribution system.
- There is less diversity on distribution systems than on transmission systems. The distribution equipment on a particular feeder is sized to meet the peak electrical load in that defined location. Transmission equipment, conversely, feeds power to a larger area, and hence, must only meet the peak load of that larger area. Because peak loads vary from area to area at any given time based on weather, customer mix, and other factors, the transmission equipment can generally have a smaller capacity than the sum of all of the distribution equipment in that area.
- Because of the lower load carrying capability and reduced load diversity of distribution compared to transmission, distribution is typically upgraded more frequently and quickly than transmission for relatively low load increases. For example, for new commercial or residential construction (e.g., shopping centers and subdivisions), distribution upgrades can be completed before the new consumer facility materializes. Also, relocation of distribution lines and equipment for road work and other public works projects must be done promptly.
- Transmission systems operate at higher voltages than distribution systems. At higher voltages, a given cross-sectional area of wire will accommodate considerably more power flow. Similarly, at higher voltages, transformers require less mass to transform power from one voltage to another.

Correct Deficiencies – Distribution Portion

Figure 3-5 shows that actual distribution capital expenditures in recent years have been lower than the historical trend. During this period, various state regulatory agencies have implemented requirements for the upgrading of poorly performing portions of the distribution system. The project team concludes that some accelerated level of capital expenditure is needed to correct these deficiencies and maintain traditional reliability levels, in addition to the proposed investment to achieve the Future PDS. The team estimated that a deficiency of approximately $6 billion exists. Due to the more short-term nature of needed distribution expenses, the team assumed that this total investment would correct these deficiencies in at most five years.

Future Power Delivery System – Distribution Portion

The project team estimates that the fully automated distribution system can improve reliability levels by 40 percent, compared to traditional distribution systems, reduce losses, and decrease the costs required to maintain and operate the system. This distribution system of the future will also facilitate connectivity with consumer facilities and equipment. The latter capability will, in turn, provide consumer access to a variety of value-added services, including advanced electricity billing information, real-time electricity pricing, home security and appliance monitoring, data services, and many others.

These distribution system investments will occur in the following three overlapping areas:

- Increasing **automation of distribution substations** is underway and will continue.
- **Distribution feeder circuits** will increasingly be automated. New topologies will allow automatic reconfiguration and full integration of distributed energy resources (DER). New technologies will be applied to improve performance (e.g., power electronics-based controllers).
- The distribution system will be extended to provide **connectivity to consumer facilities and equipment**. Examples of the wide range of impacts of this integration include consumer-owned DER into the distribution system, and beneficial load control of consumers' end-use appliances and devices (e.g., to decrease the need for distribution capacity upgrades). Advanced pricing systems, consumer portal technologies to provide enhanced services, and new equipment technologies (e.g., the intelligent universal transformer) will provide enhanced quality and reliability.

Automating distribution substations, automating feeders, and complete integration of intelligent monitoring systems (e.g., fault location, equipment diagnostics, and integration with operations and asset management systems) can result in a 30-40 percent improvement in reliability levels.

Distribution Substation Automation

The initial investments to increasingly automate distribution substations will provide high bandwidth communications to all substations; implement intelligent electronic devices (IEDs) that provide adaptable control and protection systems; provide complete monitoring that is integrated with asset management systems; and incorporate intelligence to help mitigate power quality events, improve reliability and system operations. The following four important investment categories are needed to achieve substation automation:

- **Implementing high bandwidth communications to the distribution substations and integrating this communication capability with substation intelligent electronic devices (IEDs) and monitoring systems.** Although high speed communications have been implemented for some distribution substations, a high percentage of substations still need to be upgraded. In addition, the communications architecture must be implemented to allow convenient integration of individual components in the substation. Communication costs continue to decrease but an investment requirement of $75,000 per average substation is assumed.
- **Implementing IEDs.** These devices include smart relays and protection systems that provide adaptable controls needed to support reconfigurable systems and integration of DER. Average investment per distribution substation is estimated to be $350,000.
- **Intelligent monitoring systems**. These systems need to be integrated with system operations and asset management to improve system performance, extend asset life, and reduce operating costs. IEDs will provide much of the actual monitoring capability, but additional monitoring and intelligent processing of the distribution substation data is required. An investment of $75,000 per substation is assumed for this function.

- **Advanced controls and diagnostics**. These technologies are needed to optimize system performance and reliability based on real-time and analyzed information from distribution substation monitoring and intelligence. These controls will include both distributed controls and centralized controls for integration with energy management systems. The average investment per substation is assumed to be $100,000.

Figure 3-6 illustrates these components and shows that the total investment per distribution substation is estimated to be approximately $600,000. The project team assumed that these upgrades will be needed in 40,000 distribution substations over the next 20 years, resulting in a total distribution substation automation investment of $24 billion.

Distribution Feeder Circuit Automation

The second area of distribution system investment is to extend automation to individual feeder circuits. This means automating switches on the distribution system to allow automatic reconfiguration, automating protection and adapting it to facilitate reconfiguration and integration of DER, implementing new technologies where necessary to improve reliability and system performance (e.g., power electronics-based controllers), and optimizing system performance through voltage and volt-ampere reactive (VAR) control to reduce losses and improve power quality.

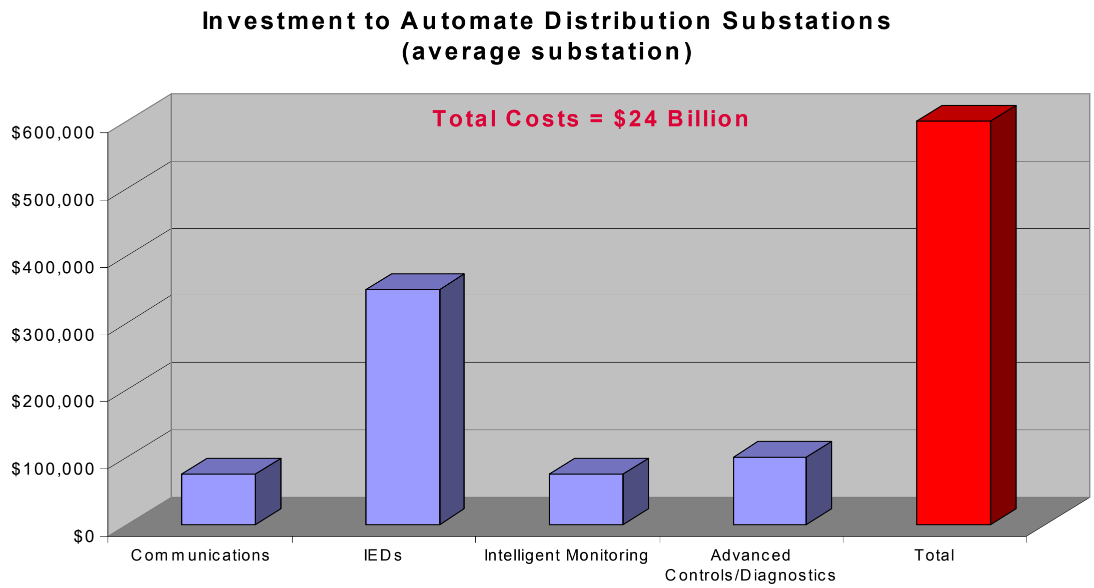

Figure 3-6
This Technology Category for Distribution – Automating Distribution Substations – Illustrates the Process of Estimating Future PDS Investment for Distribution.

Figure 3-7 shows the results of a similar estimation process for this technology category of automating distribution feeder circuits. Assuming an investment of $540,000 per feeder on about 320,000 feeder circuits in the U.S. yields a total estimated cost of $173 billion over 20 years.

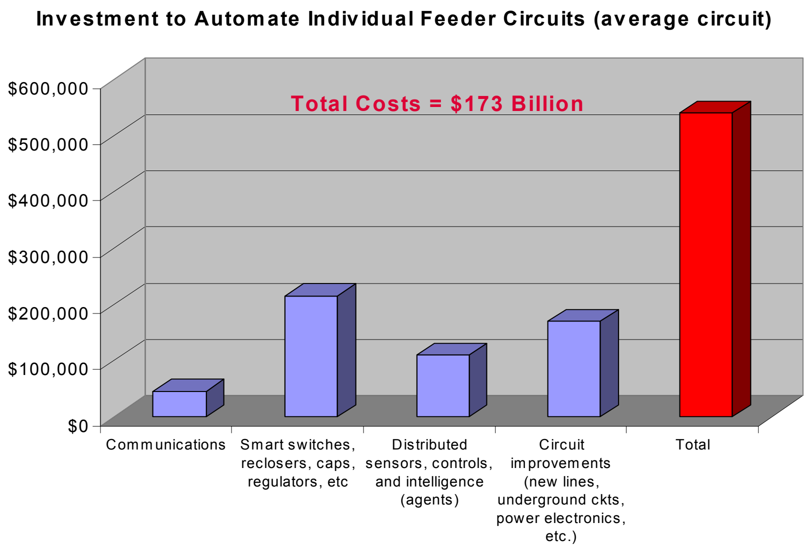

Figure 3-7
The Feeder Automation Technology Category for Distribution Contributes the Largest Investment to the Future PDS From the Distribution Side.

Integration With Consumer Systems

The third aspect of the distribution system of the future is complete integration and connectivity with consumer facilities and equipment. A system is needed that integrates the distribution system with a communication system, enabling customer connectivity. This enhancement will allow three new areas of functionality:

- Related directly to electricity services (e.g., added billing information or real-time pricing)
- Services related to electricity (e.g., home security or appliance monitoring)
- Communications services (e.g., data services).

Called the ElectricWindow^{SM},[10] this concept represents the technology, data standards and protocols that enables two-way communication of electronic messages with consumer owned networks and intelligent equipment and provides a pathway to the full development and implementation of a variety of energy-related services. Substantial value can be added by leveraging the ability to communicate with consumer owned energy management systems and intelligent energy consuming equipment. For more information, refer to "The ElectricWindow^{SM}: A Consumer Portal at the Junction of Electricity, Communications, and Consumer Energy Services," by Clark Gellings.

[10] ElectricWindow is a servicemark of the Electric Power Research Institute (EPRI)

To estimate the investment needed for this third technology category – complete integration with consumer systems – the team estimated the integration investment by sector (residential, commercial, and industrial), assuming a cost per consumer and the number of consumers in each sector. For example, the commercial sector is a current focus because of opportunities to interface with intelligent building energy management systems and the amount of load that could be influenced through these applications. The incremental cost per facility for the interface (assuming communications is available and the applications are developed to maximize the usefulness of the systems) is estimated at $1500 per commercial consumer. There are about 15 million commercial consumers, resulting in a total investment of $23 billion for commercial consumer integration.

For residential systems, the cost per consumer is based on numerous studies related to automated meter reading and other advanced applications for the consumer interface. It is estimated that the cost per consumer is on the order of $300 for residential consumers to allow the flexibility of two-way high speed communication with advanced pricing, load control, and flexible service offerings. Based on 113 million residential consumers, this results in a total investment of $34 billion.

Industrial systems are the most sophisticated but may also be the most important for integration. The needed investment associated with reliability and quality problems can be the highest of any consumer sector, and the actual load available for control and optimization is the greatest of all the sectors. The estimated investment per consumer for the interface is $10,000, assuming that communications is available and consumer equipment can be interfaced through standardized information models. Based on 500,000 industrial consumers, this results in a total investment of $5 billion. The total investment for all sectors is $62 billion (see Figure 3-8).

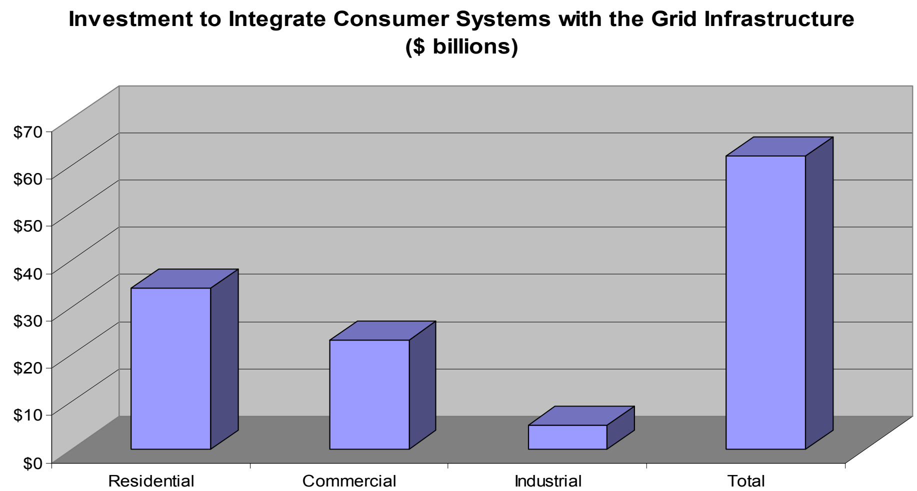

Figure 3-8
The Investment Needed to Integrate Consumers With the Future PDS Was Estimated by Consumer Sector.

This analysis results in an investment to upgrade and automate the distribution system of $259 billion over 20 years ($24 billion for distribution substations + $173 billion for feeder automation + $62 billion for consumer system integration – see Figure 3-9).

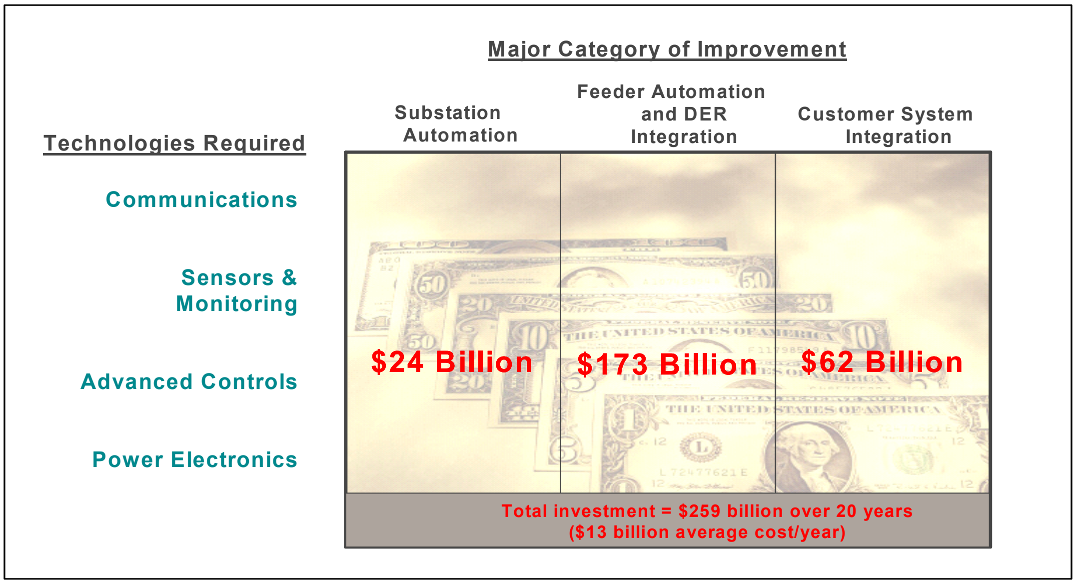

Figure 3-9
Investing in the Distribution System of the Future (Total Investment of $259 Billion) Leads to Projected Improvements in the Three Categories Shown.

Synergies – Distribution Portion

Current investments on the distribution system to meet load growth may be used only to address the need to serve the particular load. These investments may not be part of a strategy to enhance the functionality of the overall power delivery system. However, with little or no additional investment, such investments could be coordinated to aid realization of the distribution portion of the Future PDS. This involves intelligent application of the overall investments by contributing to the automation and control objectives for the future system. This can be done, for example, by purchasing equipment (e.g., switchgear, protection equipment, regulators, transformers, controls, and monitoring equipment) that can be easily integrated with the automated distribution system.

The project team estimated that about 40 percent of the $330 billion estimate to meet load growth will also help realize the distribution portion of the Future PDS. Figure 3-10 represents this savings due to synergism of about $132 billion as overlap between two circles.[11] The large circle in the figure represents the $330 billion needed to meet load growth needs on the distribution system, and the smaller circle represents the $259 billion investment needed for the distribution portion of the Future PDS. Figure 3-10 shows that the *incremental* investment (after accounting for synergies) to realize the Future PDS is $127 billion. Figure 3-10 also shows the $6 billion investment needed to correct deficiencies on the distribution system.

[11] This $132 billion consists of savings due to synergies in the following areas: distribution substation automation ($16 billion); distribution feeder circuit automation ($96 billion); and integration with consumer systems ($20 billion).

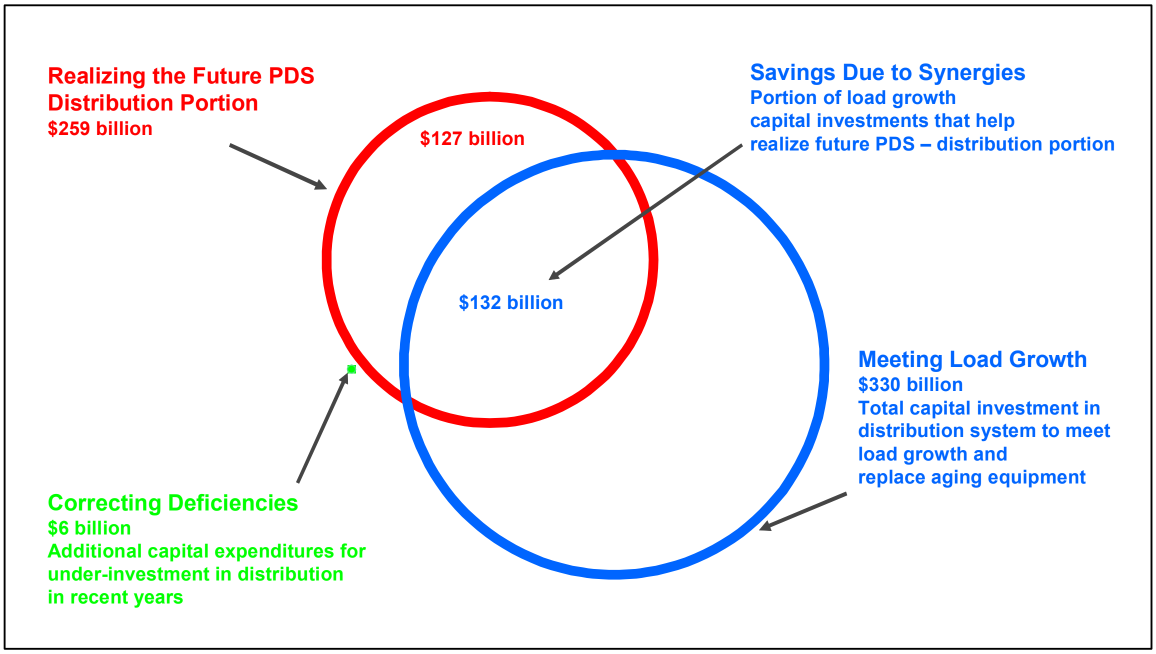

Figure 3-10
A Large Portion ($132 Billion) of the $330 Billion Investment Needed to Meet Load Growth Contributes to Realizing the Distribution Portion of the Future PDS (Constant 2002 Dollars). Hence, the Incremental Investment Needed to Realize the Future PDS is $127 Billion.

Summary of Total Investment Required – Transmission and Distribution

The right column of Table 3-2 shows that the total 20-year investment needed in the distribution system (without considering synergies) sums to $595 billion ($330 billion for load growth + $6 billion to correct deficiencies + $259 billion for the *total* Future PDS). Subtracting the savings due to synergies ($132 billion) yields the investment needed of $463 billion. Using estimates from Figure 3-4, the left column of the table shows the corresponding estimated investment for the transmission system ($163 billion considering synergies). The equivalent annual investment for both transmission and distribution is also shown. This tabulation shows about a 3:1 ratio of needed investment between distribution and transmission, which reflects historical investment ratios.

Further examination of this data reveals the estimated *net* investment needed to realize the Future PDS, over and above the investment to meet load growth and correct deficiencies. In other words, assuming that the investments are made to meet load growth and correct deficiencies, Table 3-3 shows the net additional investment required to realize the Future PDS. To calculate this investment, the team began with the *total* investment to realize the Future PDS from Table 3-2 ($110 billion for transmission and $259 billion for distribution) and subtracted the synergistic investments that overlap with this investment ($55 billion for load growth in transmission and $17 billion to correct deficiencies in transmission from Figure 3-4; and $132 billion to meet load growth in distribution). This indicates that the *net* investment to realize the Future PDS is $38 billion for transmission and $127 billion for distribution, for a total of $165 billion (about $8 billion per year).

Table 3-2
Comparison of Transmission and Distribution Investment Needs With and Without Synergies

	Transmission investment (20 year total $billions)	Distribution investment (20 year total $billions)
Meeting load growth	$100	$330
Correcting deficiencies	$30	$6
Realizing the Future PDS	$110	$259
Total without synergies	**$240**	**$595**
Savings due to synergies	$77	$132
Total considering synergies	**$163**	**$463**
Equivalent annual investment over 20 years	$8	$23

Table 3-3
Estimate of the Net Investment Needed to Realize the Future PDS

	Transmission investment (20 year total $billions)	Distribution investment (20 year total $billions)	Total
Realizing Future PDS	$110	$259	
minus Load Growth Synergy	$55	$132	
minus Correcting Deficiencies Synergy	$17	$0	
Net investment to realize Future PDS	$38	$127	$165

4
POWER DELIVERY SYSTEM OF THE FUTURE: BENEFITS

Overview

To estimate the *value* (benefits) of the power delivery system of the future, the project team developed a framework that consists of a series of interconnected spreadsheets. The framework is flexible, in that input assumptions are centralized on a single spreadsheet; this enables users to change input assumptions and assess the impact on the calculated value. This was done to encourage ongoing changes to the assumptions underlying the estimation process.

The fundamental approach that the team used involves the identification of *attributes* of the power system (e.g., cost of energy, capacity, security, quality, reliability, environment, safety, quality of life, and productivity). The team then developed the framework to quantitatively estimate the dollar value of improving each of these attributes by a defined amount (i.e., percentage improvement). The section below on power quality and reliability illustrates this approach.

Existing, documented data sources were used for this estimation process for each attribute. These sources included the U.S. Energy Information Administration, the U.S. Department of Energy's Policy Office Electricity Modeling System, the Federal Energy Regulatory Commission's transmission constraint study, the U.S. Labor Department's Bureau of Labor Statistics, and many more.

The approach did not definitively assess *how* the assumed improvement in each attribute will be attained. In other words, no assumptions were made as to what technologies or how much of each technology will be developed and deployed. Instead, a percent improvement in each attribute was assumed, without regard to how it will be attained. By developing the flexible framework, these assumed percentage improvements can be changed, and the resulting changes in the results can be examined.

The team did, however, apply its collective wisdom to these assumptions. Based on a combined 150^{+} years of power systems experience, the team estimated what improvements may result from the technologies described in the previous section on costs.

While scenarios were not explicitly defined in this approach, implicit in the approach are two assumed scenarios – a reasonable status quo scenario, and a more desirable future scenario. The improvement in each attribute defines the *difference* between the two scenarios. Generally, the status quo meets load growth requirements, prevents more deficiencies in the power delivery system from emerging, and to some extent, reduces existing deficiencies (although not completely).

Hence, the assumed quantified improvements in attributes can be thought of as targets to be achieved via development and deployment of a diverse portfolio of technological advances. Determining this technology portfolio, as a function of various combinations of quantified attribute improvements, remains a task to be completed. Tasks like these are best achieved via collaborative public/private discourse.

Attributes

Table 4-1 shows the various types of improvements that correspond to each of the attribute types. A key aspect of the value estimation process in general is its consideration of improvements to the power delivery system (see the left column of Table 4-1), as well as improvements that consumers directly realize (see the right column of Table 4-1). This was done to ensure that emerging and foreseen benefits to consumers in the form of a broad range of value-added services (e.g., via the ElectricWindow[SM]) are addressed in the estimation of value.

Table 4-1
Attributes and Types of Improvements Assumed in the Value Estimation of the Future Power Delivery System (Left: Power Delivery System Improvements; Right: Improvements That Consumers Realize)

Power Delivery (Improvements/ Benefits) 	Attributes	 Consumer (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
EMF Management 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

The "cost of energy" attribute is the total cost to deliver electricity to customers, including capital costs, O&M costs, and the cost of line losses on the system. Therefore the value of this attribute derives from any system improvement that lowers the direct cost of supplying this electricity. "SQRA" is the sum of the power security, quality, and reliability attributes, because the availability part of SQRA is embedded in the power quality and reliability attributes. (Refer to the section below on power quality and reliability for more information on SQRA.) The quality of life attribute refers to the integration of access to multiple services, including electricity, the Internet, telephone, cable, and natural gas. This involves integration of the power delivery and knowledge networks into a single intelligent electric power/communications system, which sets the stage for a growing variety of products and services designed around energy and communications.

To quantify the benefit of these improvements for various attributes, the project team developed various spreadsheet-based "benefit calculator tools." Figure 4-1 shows the relationship of these benefit calculator tools, the attributes, and the overall value. Note that science and technology drivers feed generally into the process.

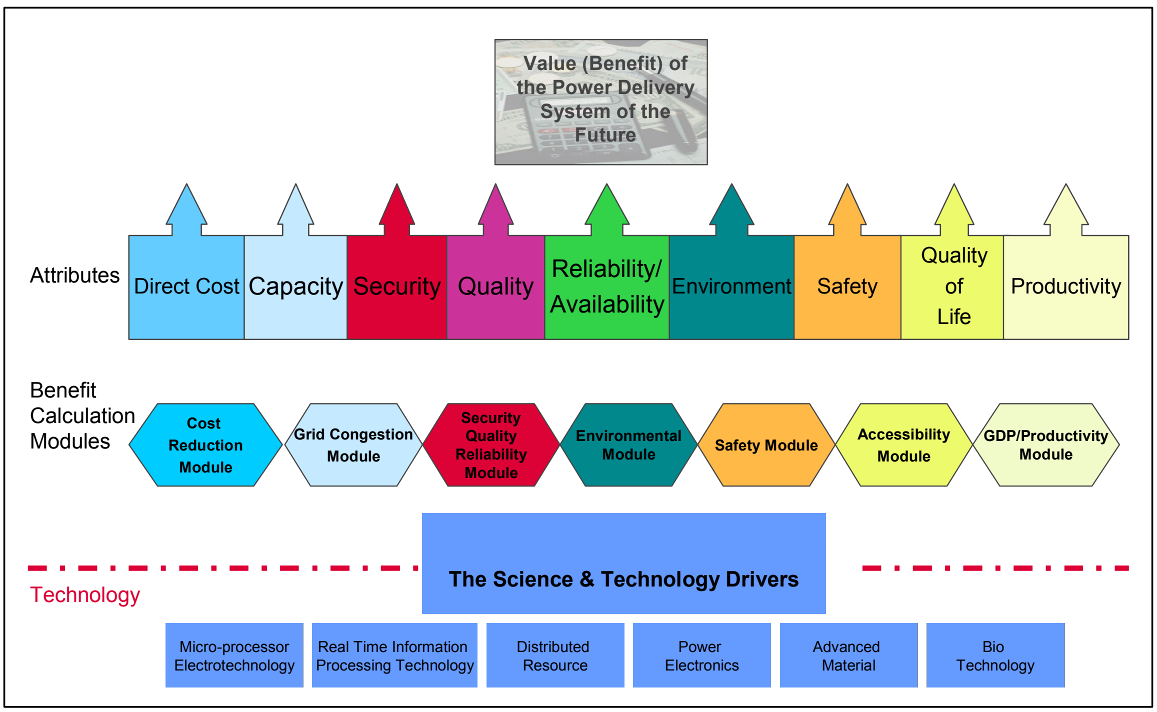

Figure 4-1
Relationship Between Value, Attributes, and Benefit Calculator Tools in the Value Estimation Process

The study did not evaluate the effect of interactions between the improvements in various attributes. However, it is likely that interactions between these improvements would have a positive multiplier effect, increasing the total value of the improvements. An example of this effect is Moore's Law, in which continuing levels of innovation that provide faster microprocessors are projected without identifying all specific guiding technologies and their interactions. This innovation can also lead to macroeconomic interactions, such as an increase in economic productivity. Jorgenson, Ho and Stiroh (2002) explain that there is a residual component of economic growth via increased productivity (after accounting for contributions of labor and investment) that is largely credited to innovation. In their study, this innovation-related effect on economic growth was estimated at 0.63 percent of the 4.2 percent average economic growth during 1995-2000.

Summary of Benefits

Rather than conclude that the estimated value of the Future PDS is a single definitive present worth number, the project team decided to provide a range of values to reflect the impact of one key assumption that has a significant impact on the study results. The assumption itself relates to the estimation of the value of two particular attributes – power quality and reliability – as calculated by a 2001 Primen study. More specifically, the assumption involves the approach used to extrapolate from power outage costs incurred by *surveyed* businesses, compared to *all other* businesses. Since the surveyed businesses are particularly sensitive to power disturbances, the Primen study assumed that all other businesses incur 25 percent or 50 percent of these outage costs. These two numbers represent the "Primen lower bound" and "Primen upper bound" assumptions, respectively.

For the set of assumptions used in this study, the present worth (at a 5 percent discount rate) over the 20-year study period of the improvements due to the various attributes ranges from $638 billion to $802 billion. The corresponding annualized values range from $51 billion/year to $64 billion/year.

For the Primen upper bound assumption, Figure 4-2 shows the contribution of each attribute to the total 20-year present worth ($802 billion). Figure 4-3 shows how each attribute contributes to this annualized value, and Figure 4-4 shows the value stream from 2005-2025 for the various attributes.

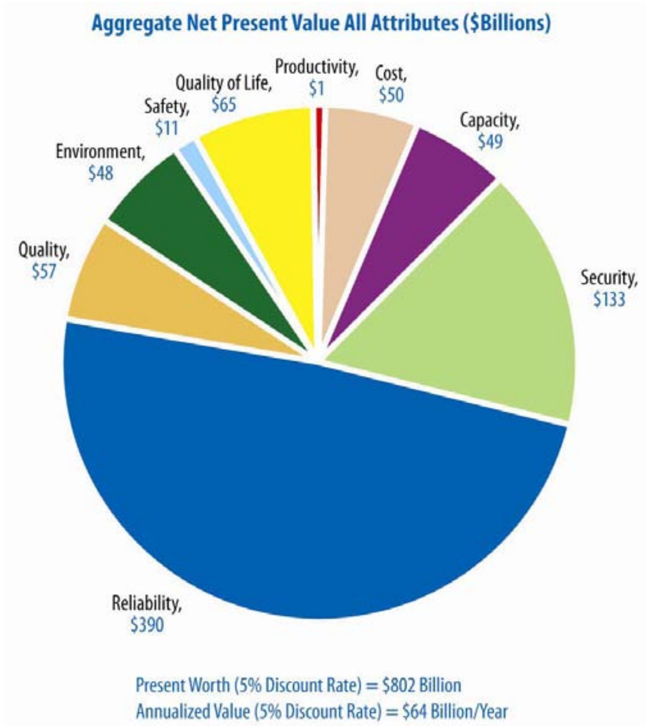

Figure 4-2
Estimated Net Present Worth ($ Billions) of the Improvements for all Attributes Over the 20-Year Study Period (Assuming Primen Upper Bound)

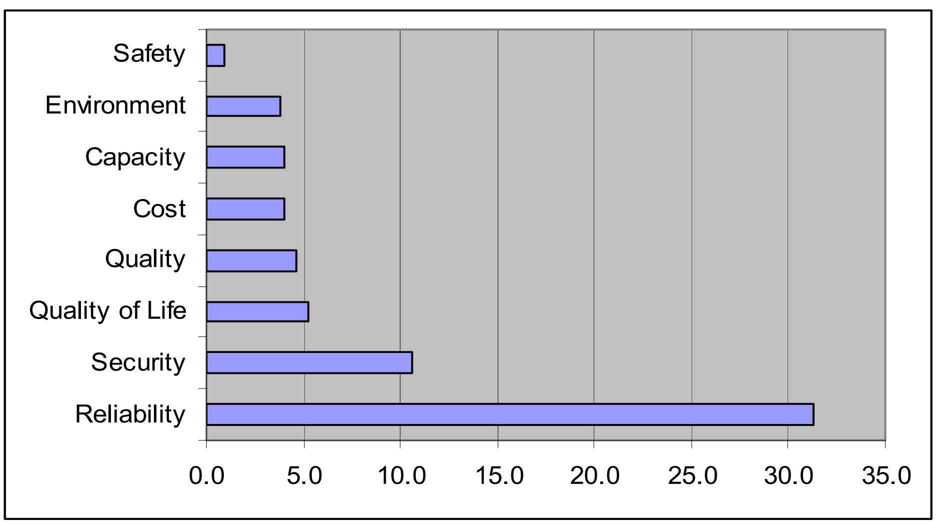

Figure 4-3
Estimated Annualized Value ($ Billions) of Each Attribute (Assuming Primen Upper Bound)

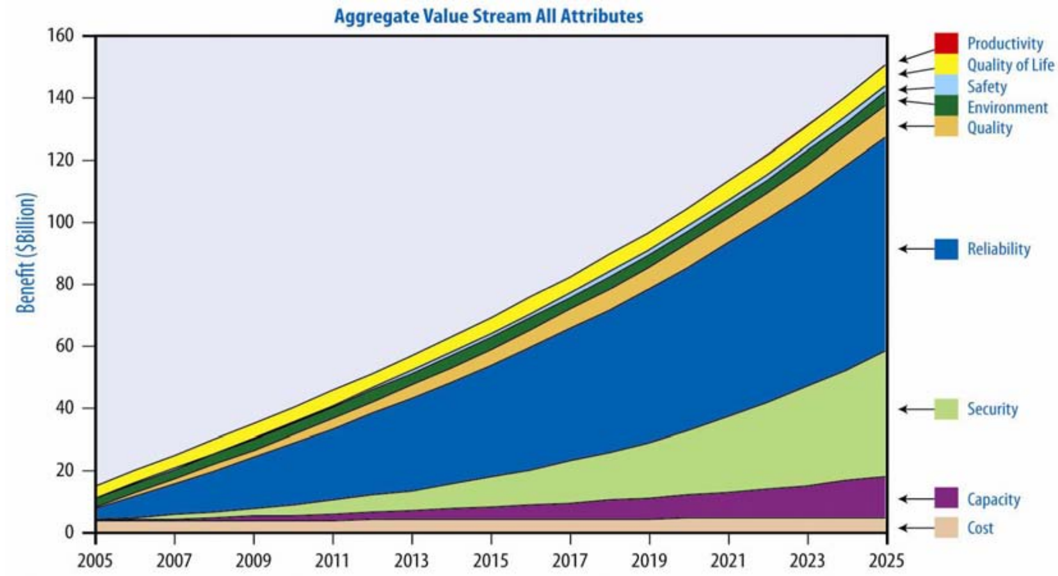

Figure 4-4
Estimated Contribution of Each Attribute to the Value Stream ($ Billions) of the Future PDS Over the 20-Year Study Period (Assuming Primen Upper Bound)

For the Primen lower bound assumption, Figure 4-5 shows the contribution of each attribute to the total 20-year present worth ($638 billion). Figure 4-6 shows the value stream from 2005-2025 for the various attributes.

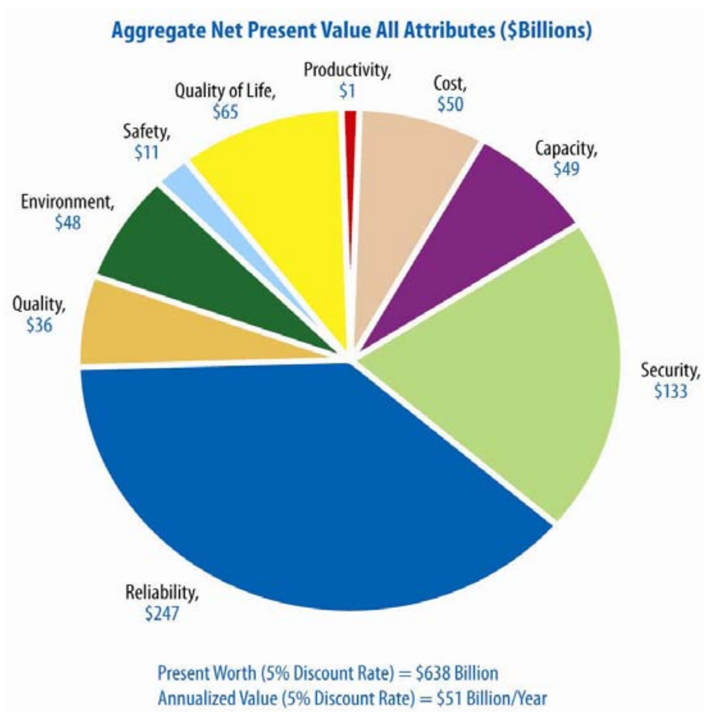

Figure 4-5
Estimated Net Present Worth ($ Billions) of the Improvements for All Attributes Over the 20-Year Study Period (Assuming Primen Lower Bound)

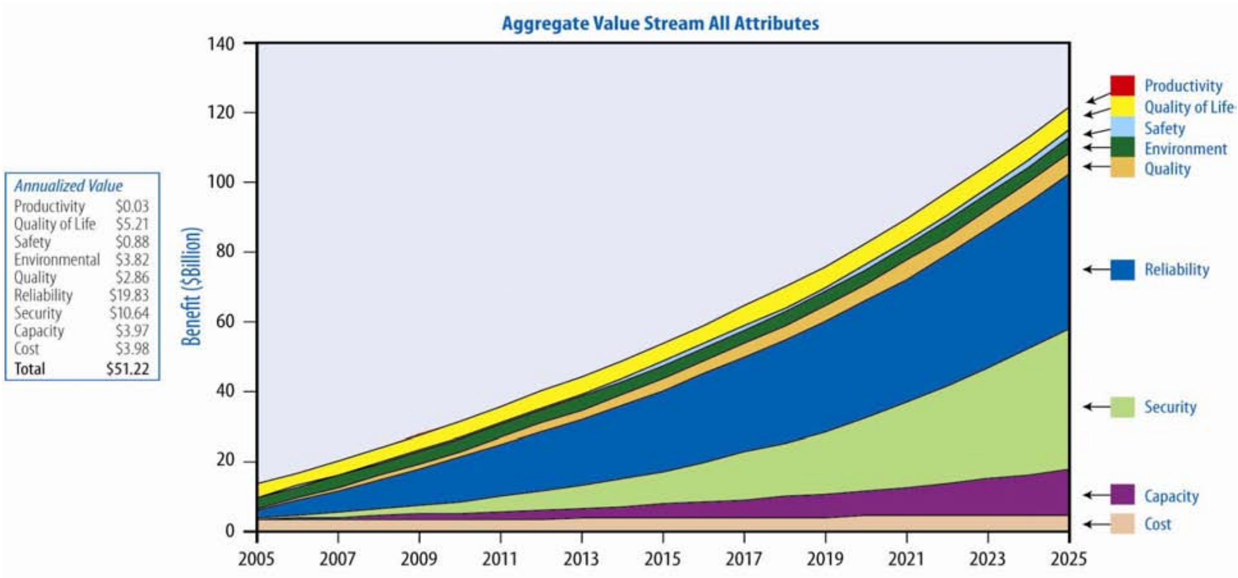

Figure 4-6
Estimated Contribution of Each Attribute ($ Billions) to the Value Stream of the Future PDS Over the 20-Year Study Period (Assuming Primen Lower Bound)

Power Quality and Reliability

The single largest contribution to overall value is the reliability attribute, which accounts for 49 percent of the total in the upper bound case, and 39 percent in the lower bound case. Closely related to the reliability attribute is the power quality attribute, which contributes another 7-8 percent to the total. The central role of power quality and reliability is not surprising, as economic losses from power disturbances and power outages include production downtime, loss of raw material, damaged product and equipment, disrupted supply chains, and failed businesses. The costs of power disturbances are parasitic in nature, yet are largely unreported, and are passed on by businesses of all types to consumers in the cost of goods and services. Conversely, improving power quality and reliability will result in productivity improvement, decreased costs, and increased consumer comfort and convenience.

According to Primen, poor power quality and outages cost U.S. consumers $119-188 billion *per year*. The critical assumption when estimating the value of the Future PDS in terms of poor reliability and power quality is the percentage that these costs will be reduced. In this study, the project team assumed that, in the status quo scenario, these costs will increase by 1 percent per year over the study period. For the desired future scenario with the Future PDS, the team assumed that these costs would *decrease* by 1 percent per year. Hence, the difference between the two scenarios in the first year is 2 percent, in the second year it is 4 percent, and so on.[12]

[12] In the desired future scenario, an implicit assumption is that consumers will be willing to pay for higher reliability and power quality. In 2000, Primen conducted a large-scale national survey to estimate consumer response to various retail energy offers, including power reliability and quality guarantees. The analysis found that a broad cross-section of energy users are willing to pay more for enhanced reliability and power quality. For more info, see "Retail Service Offerings: Thinking Beyond Price," David C. Lineweber and Patricia B. Garber, *EPRI Journal*, Fall 2000.

Assuming the Primen upper bound cost numbers ($188 billion for 100 percent of the reliability and power quality costs), Figure 4-7 shows the stream of savings. The combination of these two attributes results in a present worth savings of $447 billion and an annualized benefit of $36 billion per year. Assuming the Primen lower bound cost numbers ($119 billion for 100 percent of the reliability and power quality costs), Figure 4-8 shows the stream of savings. The combination of these two attributes results in a present worth savings of $283 billion and an annualized benefit of $23 billion per year. Of course, the framework allows analysts to change the assumed percentages for the status quo and Future PDS scenarios, change the assumed initial 100 percent cost number, or even use different starting assumptions.

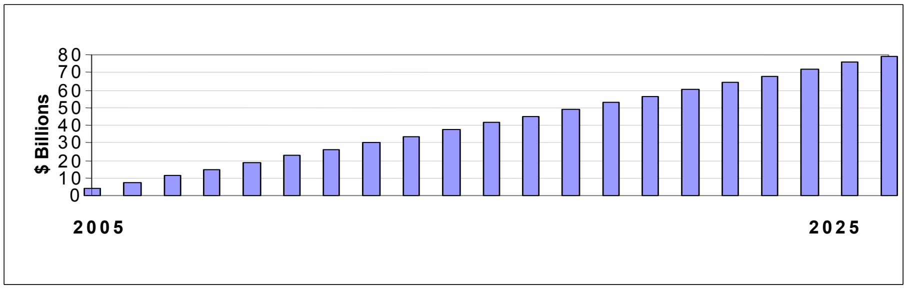

Figure 4-7
Assuming the High Primen Annual Cost Estimate of $188 Billion for the Quality, Reliability, and Availability (QRA) Problems, a 2 Percent Improvement Per Year Yields this Value Stream, a Present Worth of $447 Billion, and Annualized Benefit of $36 Billion/Year.

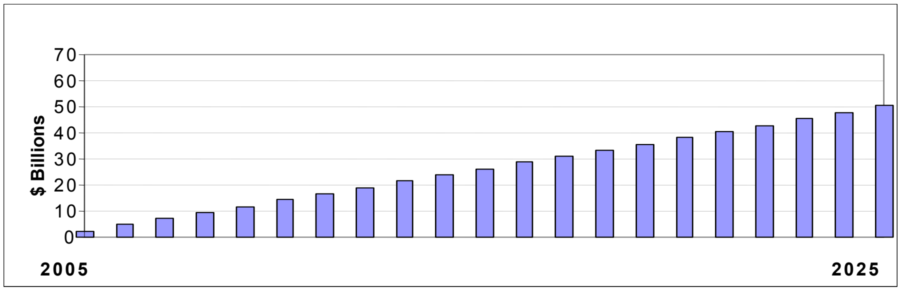

Figure 4-8
Assuming the Low Primen Annual Cost Estimate of $119 Billion for all Quality, Reliability and Availability (QRA) Problems, a 2 Percent Improvement Per Year Yields this Value Stream, a Present Worth of $283 Billion, and an Annualized Benefit of $23 Billion Per Year.

5
COMPARISON OF COSTS AND BENEFITS

From one perspective, the value (benefit) estimate can be compared with the investment (cost) estimate described earlier. The value estimation approach assumes that load growth and deficiencies are generally handled in the status quo scenario. Hence, the value estimation method attempts to quantify the benefit of the Future PDS only, not the additional benefit of meeting load growth and correcting deficiencies. This means that the result of this value estimation can be roughly compared to the Future PDS segment only of the investment evaluation – not the total of meeting load growth, correcting deficiencies, and providing the Future PDS.

To make this comparison, Table 5-1 shows that the estimated *net* investment needed to realize the Future PDS is $165 billion ($38 billion for transmission and $127 billion for distribution). The total value estimate range of $638 - $802 billion compared to the Future PDS cost estimate of $165 billion results in a benefit-to-cost ratio range of about 4:1 to 5:1. Thus, based on the underlying assumptions, this comparison shows that the benefits of the envisioned Future PDS significantly outweigh the costs.

To put into perspective the magnitude of the estimated net investment needed to realize the Future PDS, note that this investment of $165 billion over 20 years equates to about $8.3 billion/year. By comparison, approximately $18 billion/year is currently being invested in the power delivery system in the U.S.

Table 5-1
Summary of Estimated Costs and Benefits of Power Delivery System of the Future

	20 year total ($billions)
Net Investment Required	$165
Net Benefit	$638 - $802
Benefit-to-Cost Ratio	4:1 - 5:1

Due to the information available, the investment estimation and the value estimation used different approaches. One method (the investment estimation) explicitly examined a portfolio of technologies, while the other method (the value estimation) did not. Hence, comparisons between the results of these two analysis parts must be done understanding their differences. Subsequent work will be needed to consistently address the impact of various technology portfolios on both of these approaches, as well as to conduct analyses of the sensitivity of the results to project assumptions.

6
FOR MORE INFORMATION

For more information, refer to the following documents:

EPRI, March 2004. “Electricity Technology Roadmap: 2003 Summary and Synthesis,” EPRI, March 2004.

EPRI, 2004. “The ElectricWindow[SM]: A Consumer Portal at the Junction of Electricity, Communications, and Consumer Energy Services,” Clark Gellings, EPRI, 2004.

EPRI, November 2003. “Electricity Technology Roadmap: 2003 Summary and Synthesis, Power Delivery and Markets,” EPRI report no. 1009321, November 2003.

EPRI, 2003. “Electricity Sector Framework for the Future,” EPRI reports 1009078 (summary), 1009079 (vol. 1), 1009080 (vol. 2), August 6, 2003.

EPRI, 2000. “Retail Service Offerings: Thinking Beyond Price,” David C. Lineweber and Patricia B. Garber, *EPRI Journal*, Fall 2000.

Jorgenson, Dale W., Mun Ho, and Kevin J. Stiroh. 2002. “Projecting Productivity Growth: Lessons from the U.S. Growth Resurgence.” Economic Review. Federal Reserve Bank of Atlanta.

National Science Foundation, 2000. “Research and Development in Industry: 2000,” NSF Division of Science Resources Statistics, Arlington, VA (NSF 03-318), June 2003, http://www.nsf.gov/sbe/srs/nsf03318/pdf/taba19.pdf.

Primen, 2001. David Lineweber and Shawn McNulty, “The Cost of Power Disturbances to Industrial and Digital Economy Companies,” Primen report no. 1006274, June 2001.

Programs:

1011001

Power Quality Analysis Tools
Power Quality Solutions for Transmission and Distribution
Value and Risk in Energy Markets
Electric Transportation
Underground Distribution Infrastructure
Overhead Transmission
Underground Transmission Systems
Substations
Increased Transmission Capacity
Grid Operations and Planning
Electromagnetic Compatibility (EMC)
Enterprise Information Security (EIS)
Energy Storage for Transmission or Distribution Applications
Power Quality Knowledge-Based Services
Power Quality Mitigative Solutions
Global Electricity Market Restructuring
Transmission Operations
Power Delivery Asset Management
Strategic Management of Security, Quality, Reliability, and Availability
Power Delivery Applications for Superconductivity
Generation Switchyards
Distribution Operations
Metering, Measurement, and Customer Integration
Global Power Quality Issues and Solutions

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

Printed on recycled paper in the United States of America

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com