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THE SMART GRID VISION FOR INDIA'S POWER SECTOR

A WHITE PAPER

March 2010

This publication was produced for review by the United States Agency for International Development. It was prepared by PA Government Services, Inc.

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Foreword

USAID/India and the Government of India's Ministry of Power provided the inspiration for this white paper for the electricity distribution sub-sector under the Distribution Reform, Upgrades and Management (DRUM) project. This paper is a by-product of the time, talent, effort and imagination that USAID, in collaboration with the Ministry of Power, invested over many years in initiatives involving energy, power sector reform, energy efficiency, and the market development of renewable energies as well as environmental and water-energy nexus issues. Collectively, these are vital to the future of India and the goal of crafting a sustainable model for high-growth, low-carbon economic development.

The smart grid vision is responsive to a need. Losses remain high and the industry continues to struggle with service quality and reliability in urban areas and electrification in rural areas. Climate change and a carbon crisis of global proportions have added to the urgency of finding a sustainable, high-growth, low carbon economic model.

One question is whether developing economies must move sequentially through the same stages as mature power sectors in order to be ready for a smart grid world? Or will the awesome challenge of providing sufficient supplies of clean energy to enable sustainable economic development inspire a breakthrough? Can the smart grid vision enable India to leapfrog into a new, different and better electricity environment?

The adaptation of the smart grid vision to the Indian context offers the potential to revolutionize electricity supply and increase the probability of achieving the Government of India's electricity sector goals sooner and more effectively. The immediate beneficiaries would be the people of India. The design of a sustainable smart grid model would also provide a blueprint for developing nations. And the reduction in carbon emissions along with potential technological innovations would benefit all nations, developed and developing alike.

Defining a smart grid vision for India's power sector is a worthy challenge. We hope this white paper advances the understanding of that vision and provides insight into the potential it offers.

Acknowledgments

The preparation of this white paper relied on observations, comments and inputs from a consultative process that involved a cross-section of knowledgeable industry experts and stakeholders in addition to USAID/India and the project team members and technical advisors from PA Government Services, Inc. In particular, we would like to acknowledge the guidance and support we received from Dr. Gaurav Bhatiani of USAID. His assistance in framing the issues, participating in stakeholder consultations and providing insightful comments on drafts of this white paper were invaluable. We are also especially grateful for the valuable time and useful insights provided by representatives of the Government of India, including the Ministry of Power, the Central Electricity Authority, the Power Finance Corporation and the Central Power Research Institute.

Many other organizations, including energy companies (both state-owned and private), universities and training institutes, software firms, information and communications technology consultancies, metering companies and engineering firms shared their knowledge and insights generously, including at a day-long workshop on smart grids sponsored by USAID/India. They include, in alphabetic order, AREVA, Autech Automation, Bangalore Electricity Supply Company, Centre For the Study of Science, Technology and Policy, CISCO, Dhiya Consulting, GE Energy, the Government of Karnataka, Honeywell Technology Solutions Lab Private Limited, IBM, Indian Electrical & Electronics Manufacturers Association, the Indian Institute of Technology (Kanpur), Infosys, the Institute of Engineering and Technology (Lucknow), Karnataka Electricity Regulatory Commission, Kalki Communications, Karnataka Power Transmission Company Limited, Karnataka Renewable Energy Development Limited, KEMA, Larson & Tubro, Maharashtra State Electricity Distribution Company Limited, Maharashtra Electricity Regulatory Commission, Mercom Communications, North Delhi Power Limited, ORACLE, Orb Energy, Patni Computers, the Public Affairs Foundation, Power Grid Corporation of India Limited, Quanta Technologies, Quanta Services, Reliance Communications, Reliance Energy, Reliance Energy Management Institute, Reliance Infrastructure, Secure Meters, SIEMENS (India), Tata Consulting Engineers, Tata BP Solar India, The Energy Research Institute, the U.S. Department of Agriculture's Rural Utilities Service and the Uttar Pradesh Electricity Regulatory Commission.

Additionally, we are grateful to the National Regulatory Research Institute (USA), PJM, and Puget Sound Energy for their help in providing invaluable research guidance and assistance. Two others who generously offered unique insights are Ashley Brown, executive director of the Harvard Electricity Policy Group, and Leonard Hyman of B&V Management Consulting.

Without the support we received from all these organizations and the many unnamed individuals who represent them, our task would have been much more difficult.

Executive Summary

Is electricity a commodity or a premium value-added service? The way this question is answered over the next decade will reshape, perhaps radically, the way electricity is produced, transported and used. That, in turn, will influence the way societies grow and the way people live their day-to-day lives. Recently, the concept known as "the smart grid" has been gaining momentum. The idea has captured the imagination of a widening circle of believers and — in part, due to the US Government's stimulus spending plan[1] — it is finding its way into the public consciousness.

The Smart Grid cannot be reduced to a simple formula or template. It is as much a vision as a blueprint. In its broadest interpretation, the smart grid vision sees the electric industry transformed by the introduction of two-way communications and ubiquitous metering and measurement. It will enable much finer control of energy flows and the integration and efficient use of renewable forms of energy, energy efficiency methodologies and technologies, as well as many other advanced technologies, techniques and processes that wouldn't have been practicable until now. It will also enable the creation of more reliable, more robust and more secure electrical infrastructure, and it will help optimize the enormous investments required to build and operate the physical infrastructure required.

There are some who say these ideas are not yet practicable or that the cost of implementing them will exceed the benefits. There are some thorny practical problems, too. Most notable are customer response and cost-benefit analysis (CBA). How customers will respond to time-of-use (TOU) rates — much of the potential benefit attributed to the smart grid hinges on the effectiveness of TOU rates — is a pivotal issue but difficult to estimate before the fact. If there is not wide adoption rate of TOU rates, the expected benefits could be anemic. That is also one of the issues that feeds into CBA, but not the only one. Regulators around the world have quickly honed in on both of these overlapping issues and they may become the litmus test for proposed smart grid projects around the world.

Our remit was not to take a position in this debate, but to sketch the "what is" of smart grids, including an overview of its various definitions[2] and comment on certain key issues, including technology and the subtleties involved in the economic analysis of this vision that is, as yet, mostly non-existent in the real world.

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[1] The American Reinvestment and Recovery Act (ARRA) allocated $4.5 billion to smart grid spending projects.

[2] We discovered that definitional differences are caused more by where one draws a boundary than any fundamental disagreement about the essence of the smart grid vision.

In today's world of sound bites and takeaways, we would suggest the following are essential points we learned in developing this white paper:

- Electricity is morphing from a commodity into a premium form of energy
- Demand for more high-quality electricity will continue growing unabated
- The link between economic prosperity and quality electricity is tightening
- Traditional fossil fuels will be increasingly scarce, expensive and polluting
- The smart grid vision offers unique solutions to meet customers' needs and society's need for a sustainable, high-growth, low-carbon economic model.

For India, the smart grid may offer a unique opportunity to leapfrog into a vastly improved electricity environment. We encourage the development of a smart grid vision tailored to India's unique needs and circumstances. A brief review of that vision suggests there is enormous potential for gain, but also some significant risks. The best course of action is to proceed with deliberate speed with a program that emphasizes front-end analysis, planning and goal setting.

India's robust economic growth and limited reserves of oil, gas or high-quality coal have also added energy security as a national imperative. In the words of Kirin Parikh, "… we are very short of oil, very short of gas. We need to find in the next 20, at the most 30 years, an alternative to coal-based power plants." [3] India's national interest could be directly affected — for better or for worse — by its success in defining and implementing a smart grid vision for the power sector and the nation. Thus, the specific conclusions for India are:

- One or more smart grid pilot projects would be a logical next step to build on the accomplishments of USAID's successful collaboration with the Government of India's Ministry of Power.

- The realities of India's power sector should determine the kind of pilot projects that are taken up, including high aggregate technical and commercial losses, reliability issues, and rural electrification and agricultural irrigation. Most of these suggest a focus on improving the distribution system or, especially in rural areas, of implementing micro-grids.

- Pilot projects should also consider the need for more renewable energy and energy efficiency measures and the need to confirm the commercial viability of new techniques, technologies and/or methodologies that would contribute to a sustainable, high-growth, low-carbon model for the power sector.

Some knowledgeable observers believe the smart grid will revolutionize the electricity business and forever change the business model that has been in place for the past 75 years and more. Although the extent of the coming transformation is difficult to predict,

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[3] Kirin Parikh, the head of a Government of India panel tasked with developing India's low-carbon strategy, as quoted in *The Economic Times*, 22 March 2010.

there is little question that much will have to change. That may well require changes in the boundary conditions and rules of the game to ensure there is a level playing field for all participants and to provide the incentives for market participants to get the best possible results.

Existing energy laws and regulations that address technical (e.g., reliability, service standards), economic (reasonable and economically efficient tariffs) and customer service issues were developed for a closed system that is now changing. Thus, regulations may have to be expanded and augmented to encourage innovation and provide incentives to adapt to a new paradigm and new market rules.

The economic model for the electric industry is still (mostly) based on maximizing revenue by maximizing the volume of electricity sales. As with demand-side management (DSM) initiatives several decades ago, this may put the increased emphasis on energy efficiency to be accomplished through a smarter grid, in conflict with a utility's bottom line. Of course, that assumes discoms are successful in reducing the extraordinary loss levels that are a more immediate and more potent threat to the financial viability of India's discoms.

New policies will also be needed to encourage innovation, to provide incentives for utilities to pursue energy efficiency, load management and conservation initiatives, to provide incentives to attract private players — with appropriate rewards and the assurance of a level playing field — and to empower consumers to manage energy usage more effectively. If the promotion of private investment in smart grid investments is deemed to be in the national interest, then a study of innovative financing techniques (e.g., tax incentives, accelerated depreciation,) would be warranted.

Evaluating the costs and benefits of proposed smart grid investments warrants a broad-gauged approach that incorporates societal benefits and externalities as well as the costs and benefits of more conventional utility investment proposals. This will require a delicate balance, but the transformational potential of the smart grid vision warrants it. A reduction in carbon emissions will contribute to improved public health. Some smart grid projects may create employment, enhance agricultural security, stimulate economic growth or provide other benefits that are outside the strict boundaries of traditional power sector projects. These should be taken into account.

The fact that such benefits are difficult to measure should not deter policy makers and regulators from developing a methodology to do it. India is uniquely well equipped to add to the conceptual foundation that has already been established and develop a workable cost-benefit methodology that encompasses the full range of potential benefits as well as the known and more easily quantifiable costs and risks.

It is difficult to explore the smart grid vision without thinking of the phrase "inflection point." The electric utility business is like a centenarian being reborn and there is a realistic possibility that the traditional business model could be changed radically, and quickly too. Although it is too early to predict how the smart grid vision will reshape the production, transportation and use of electricity, the potential is extraordinary.

Despite the appeal — and, admittedly, the glitter — attached to the smart grid vision, one serious practical problem is that it is difficult for customers to judge the value of something they can't envision. That has always been the case. This is equally true for policy makers, regulators and utility managers. Thus, education and capacity building will be essential enabling preconditions.

Fortunately, computing and telecommunications — key drivers of the smart grid — are the archetypes for a transformational technology. Nonetheless, it would be a mistake to underestimate the importance of communicating with and educating consumers, policy makers, regulators and utility managers. The electric industry is different. It is a slow-moving behemoth, steeped in an insular culture that is resistant to change. For their part, customers in India have been conditioned to expect the worst and to view electricity as a cheap public good.

The enlightenment of all stakeholders will be a vital first step.

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Acronyms

AMI	Advanced metering infrastructure
APDRP	Accelerated Power Development and Reform Programme
ARRA	American Recovery and Investment Act
AT&C	Aggregate technical and commercial
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
CBA	Cost-benefit analysis
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CER	Certified emission reduction
CERC	Central Electricity Regulatory Commission
CIP	Competitiveness and Innovation Framework Programme
CIS	Customer information system
CO_2	Carbon dioxide
CPP	Critical peak pricing
CPRI	Central Power Research Institute
CPUC	California Public Utilities Commission
CPUC	Colorado Public Utilities Commission
CRM	Customer relations management
DCA	Development Credit Authority (US)
DFID	Department for International Development (UK)
DMS	Distribution management systems
DNO	Distribution network operator
DOE	Department of Energy (US)
DR	Demand response
DSM	Demand-side management
EE	Energy efficiency
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESCO	Energy service company
EU ETS	European Union's Emission Trading Scheme
EV	Electric vehicle
FERC	Federal Energy Regulatory Commission (US)
GIS	Geographic information system

GOI	Government of India
GPRS	General packet radio service
GWAC	GridWise Architecture Council
ICT	Information and communications technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IED	Intelligent electronic device
ISO	Independent system operator
IVVC	Integrated Vol/VAR control
IPP	Independent power producer
JI	Joint Implementation
JUCCCE	Joint US-China Cooperation on Clean Energy
KPI	Key performance indicator
LEED	Leadership in Energy and Environmental Design
MoP	Ministry of Power
NERC	North American Electricity Reliability Council
O&M	Operations and maintenance
OE	Office of Electricity Delivery and Energy Reliability, DOE
NARUC	National Association of Regulatory Utility Commissioners (US)
NERC	North American Electric Reliability Corporation
NIST	National Institute of Standards and Technology (US)
PEV	Plug-in electric vehicle
PFC	Power Finance Corporation
PG&E	Pacific Gas and Electric Company
PHEV	Plug-in hybrid electric vehicle
PLC	Power line carrier
PLC	Programmable logic controller
PMU	Phasor measurement unit
PNNL	Pacific Northwest National Laboratory
PTR	Peak time rebate
PUCO	Public Utilities Commission of Ohio
R-APDRP	Restructured Accelerated Power Development and Reform Programme
RE	Renewable energy
ROI	Return on investment
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
SCE	Southern California Edison Company
SEB	State Electricity Board
SERC	State Electricity Regulatory Commissions

SPC	State Power Corporation (China)
T&D	Transmission and distribution
TERI	The Energy Research Institute
TOU	Time of use
USAID	US Agency for International Development
V2G	Vehicle to grid

Chapter 1
Overview and Background

Utilities around the world are rapidly making the "smart grid" the centerpiece of their infrastructure development plans. But the term "smart grid" seems to have many different meanings. In its *Position Paper on Smart Grids,* the European (Union) Regulators' Group for Electricity and Gas noted: "There is as yet no internationally unified definition of a smart grid." [4]

This chapter begins with an overview of the key forces driving the smart grid's development. It also touches on the role of smart grids in enabling sustainable, low-carbon/high-growth economies.

In the United States, the electric industry emerged as a grid-connected, central station network during the 1920s and 1930s. The shape of the industry had been set decades earlier when George Westinghouse won the battle with Thomas Edison over AC vs. DC power and large central station grid-connected vs. small-scale distributed generation networks. In the following fifty years, technological advances enabled ever-larger power plants to be built at ever lower unit costs. As the industry expanded, the enormous fixed costs of the grid-connected central station network could be spread over many more units of production, further reducing unit costs.

But that has changed.

Nobel laureate Lester Thurow made an interesting comparison between the technological revolution in computing and telecommunications that has been underway since the 1950s and an earlier technological upheaval that revolutionized the world. He was referring to the development of electricity in the late 19th century, or "the second industrial revolution," as he called it. [5]

The new electricity technology turned night into day by providing a better source of illumination and made it possible to locate power sources — and work that needed it — at great distances from rivers that for most of human existence had served as the

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4 *Position Paper on Smart Grids*, An ERGEG Public Consultation Paper, Ref: E09-EQS-30-04, December 10, 2009, p. 11.

5 "Building Wealth," *Atlantic Monthly*, June 1999, p. 57.

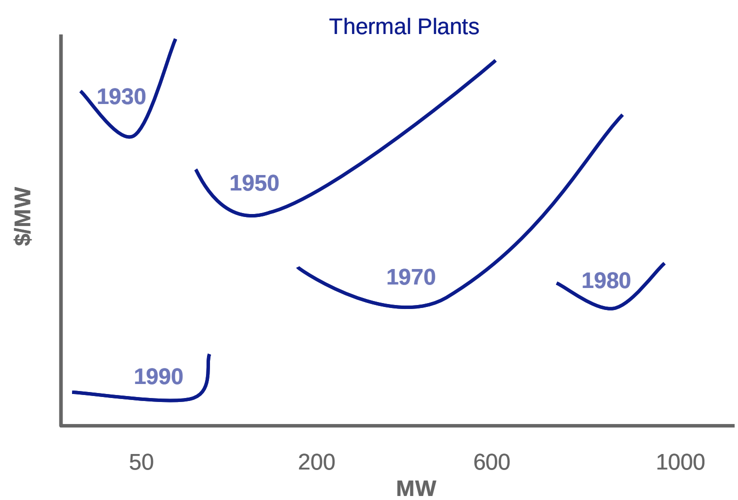
most important source of motive power. This miraculous new technology changed the nature of work radically:

> In the steam era, a giant engine powered a central rotating shaft, and machine tools ran off pulleys in long linear factories. In the new electric model of production, small motors could be arranged on the factory floor. It was an early industrial version of what is known today in the computer industry as distributive processing.[6]

After its financing needs were resolved either through the advent of regulated monopolies or direct government ownership, the electric supply industry enjoyed decades of almost uninterrupted growth.

This was the best of all worlds. Economies of scale, spurred by a string of technological breakthroughs, produced step-function improvements in productivity and continuous reductions in unit cost. The result was a string of ever-lower costs per megawatt to build ever-larger power plants, as Figure 1 shows.

Figure 1. Cost curves for optimal plant size per MW



Hunt, Sally and Graham Shuttleworth. *Competition and Choice in Electricity.* Chichester: John Wiley & Sons, 1999.

Each reduction in the price of electricity opened up new uses for it, which led to further reductions in unit prices because the high fixed costs of plant investment could be spread over greater sales volumes. This led to a continuing expansion in the application of electricity that resulted in historic growth in customers and sales. The parallels with today's growth in IT are compelling.

It is Lester Thurow (again) who pointed out that — after adjusting for such things as inflation, lumens emitted and bulb life, etc. — a 100-watt bulb has dropped from the equivalent of almost $1,500 in 1883 to about $1.50 today. In its infancy, electricity was a luxury. Today, it's a commodity.

[6] Ibid., p. 59.

In the mid-1960s, the first northeast blackout hit New York City and much of the northeastern part of the country, stunning the public. This led to a Congressional study and the formation of the North American Electricity Reliability Council (NERC) to coordinate the industry's planning efforts. It's easier to see in the rear view mirror of history that this event signaled the end of the longstanding trend of declining unit costs.

Next, the joint and reinforcing results of the OPEC cartel, coupled with high inflation and high interest rates, rocked the capital-intensive electricity business. The industry's then-latest technological development (nuclear power) failed to produce lower unit costs. Nuclear power was the largest failure of a technological innovation in electricity production since the earliest days of the industry.

The sharp run up in prices triggered by the OPEC oil embargo but compounded by the failure of nuclear power combined to reduce the average rate of sales growth to a fraction of what it had been. Sales growth plunged from roughly 7% to 9% a year to 2% or less. This led to a severe over capacity situation and, thus, upward pressure on unit costs.

What followed was a massive breakdown in pricing. Regulators and politicians found it difficult to raise prices to cover sharply higher costs. Keeping prices below economic levels contributed to the uneconomic consumption of electricity, the wasteful deployment of high-cost assets, and mounting economic losses.

Those companies operating as regulated monopolies discovered that regulation works better in declining cost environments than when conditions require successive and substantial price increases. Where governmental ownership was the norm, the industry discovered that governmental ownership and financing may have been a good at stimulating the development of early-stage growth but, here too, there was a massive failure in the pricing mechanism. If regulators had difficulty in imposing the necessary increases in tariffs, government-owned utilities found it almost impossible.

The OPEC oil embargo also signaled the finite nature of oil and gas, and unleashed a frenzy of inventiveness aimed at conservation and load management, as energy efficiency and demand-side management (DSM) were then known. Initially, in the face of industry resistance, DSM programs were mandated by regulators. Likewise, energy efficiency (EE) had a tumultuous beginning and many electric industry executives resisted it because it would reduce corporate revenues. As Upton Sinclair famously said, "It is difficult to get a man to understand something when his salary depends on his not understanding it." Ultimately, this too changed.

During the murky transition to liberalized markets after the mid-1980s, something else happened. There was another technological inflection point in power technology. This time, there was a major trend reversal in the link between greater plant size and lower cost per MW. Until then, the bigger the plant, the lower was the cost per MW to build it. Usually, this also meant the lower the cost per MW to operate. Instead of lower unit costs being associated with ever large plants, the optimal plant size (in terms of cost per MW) had dropped to a fraction of what it had been before.

Today, these revolutionizing technologies — electricity and information and communications technology (ICT) — are converging with the descendents of DSM (now considered a sophisticated marketing tool known as "demand response" or DR) and energy efficiency know-how. Collectively, cost-effective, small-scale distributed generation monitored by sophisticated electronic sensors and managed by advanced metering and control systems (all enabled by advances in ICT) are spurring more innovative and cost-effective applications of DR and EE to radically transform the way electricity is produced, delivered and used.

And just in time.

1.1 Key Drivers of the Smart Grid

Today, the electricity supply industry is wrestling with an unprecedented array of challenges, ranging from a supply-demand gap to rising costs and global warming. These and other forces are driving the need to reinvent the business. That, in turn, is driving the need for a smart grid.

There is an emerging consensus on the principal forces driving the transformation of the electricity network worldwide; these are discussed first in this section, followed by an examination of additional factors that spurred the smart grid in OECD countries. Here, the emphasis is on the United States where the smart grid experience has ramped up due to the government's $787 billion dollar stimulus plan, which includes a specific tranche of grant funding for smart grids.

India has limited experience with smart grid deployments and advanced metering, especially for small consumers and farmers. The factors that will drive India's adoption of smart grids include the need to reduce technical and commercial losses, resolve its the chronic supply-demand gap, and find a way to "leapfrog" into a more advanced electricity supply solution to satisfy its sustainable, low-carbon, high-growth economic development goals. The drivers for India are also discussed in this section.

Global drivers

Three main factors are driving utility deployments of the smart grid:

> **Electricity is the fastest growing form of end use energy**
> In the USA, power generation will increase by 77% between 2006 and 2030: from 18.0 to 31.8 trillion kilowatt hours. The fraction of US energy needs met by electricity increased from 20% in 1960 to 40% in 2000 and demand continues to outstrip the growth in production. Globally, non-OECD countries will account for 58% of world energy use by 2030.
> US Energy Information Administration, *International Energy Outlook, 2009*.

Unrelenting increases in electricity demand. Rising world population, the growing affluence of emerging nations, and escalating demand for goods and services that require ever more electricity, and the growing need for the unique properties of electricity in an increasingly digital world are all driving the demand for power to unprecedented levels. In India's high-growth economy, for example, the demand for electricity is forecast to grow by an estimated 10% per year until the existing supply-demand gap is closed. In the United States, the growth in peak demand for electricity has exceeded transmission growth by almost 25% per annum. As noted on the main page of the Edison Electric Institute's website, there has been serious under-investment in transmission networks for several decades.[7]

While many nations struggle to supply enough power to meet their peoples' basic needs, electricity has also emerged as a premium energy source, enabling the proliferation of electronic end-use devices, particularly for computing and communications. This spurred demand for more (and more reliable) electricity.

Global warming. There is broad consensus that global warming has already begun to cause serious and lasting damage to the world's ecology. Because electricity production is a major source of carbon emissions, "early adapters" around the world — both governments and corporations — have begun exploring ways to create sustainable, low-carbon, high-growth economies. The smart grid offers the potential to conserve energy, both through reducing demand at peak times and by its ability to deploy renewable energy sources, thus lessening the industry's contribution to climate change.

An upturn in the trend in unit costs of electricity. It is becoming more apparent that the long-term trend of rising unit costs of electricity began as long ago as the late 1960s, after nearly a half century of declining unit costs.

Many factors will continue to put upward pressure on costs, including increased commodity prices, especially for oil and gas, plus "dispatchability" and thus lower plant load factors for renewable energy sources, among others. At the same time, a construction cycle of historic proportions is unfolding for utilities to replace and renew

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[7] The Edison Electric Institute is a trade organization representing the investor-owned utilities that provide 80% of the electricity sold in the United States.

the aging transmission and distribution infrastructure, and just as India, China and other high-growth developing economies are aggressively expanding their own power generation.

As a result of the construction boom, the competition for resources — from raw materials to capital and know-how — will continue to intensify, especially as economies emerge from the current downturn. If economies are to flourish, they must maximize output with a minimum of resources. The pressure to use assets wisely will only increase as the cost of capital rises, which is expected to occur when the current recession ends.

In the United States this is taking place against an ominous backdrop. The industry's aggregate credit rating is hovering one notch above junk bond status and the current worldwide recession has brought resistance by regulators, consumer advocates and the general public to rate increases.

Drivers in OECD countries

In addition to the universal factors above, certain changed realities and problems are setting the stage for smart grids in the mature economies of more developed nations.

Reliability. The electric utility industry is facing a decline in quality at the same time unit costs are rising. The United States, for example, has experienced 5 massive blackouts in the last 40 years (3 of them in the last 10 years) that have left a deep scar on the industry and, perhaps more so, society, as well as government and regulators. In the United States, these blackouts led to the codification of reliability standards[8] and the imposition of regulations with stiff penalties[9] to govern the reliability of bulk power supply networks. An important goal of the smart grid vision is a network that can improve outage management performance by responding faster to repair equipment before it fails unexpectedly.

Efficiency. The smart grid can improve load factors and reduce system losses. According to the US Department of Energy's (DOE) estimates, if the US electricity

[8] The US Energy Policy Act of 2005 authorized the FERC to approve and enforce mandatory reliability standards for the bulk power system. Section 215 of the Federal Power Act makes compliance with national and regional reliability standards mandatory and enforceable. In July 2006, FERC certified NERC as the authority to oversee development and enforcement these standards.

[9] In 2009 Florida Power & Light paid a $25 million fine (out of shareholders' equity) for a breach of NERC's Reliability Standards that caused a blackout for three million of its customers.

system were just 5% more efficient, the energy savings would be equivalent to eliminating the fuel and greenhouse gas emissions produced by 53 million cars.

Environment. Emerging and more stringent greenhouse gases limitations, renewable portfolio standards, and energy conservation requirements have become one of the key issues for utilities and are increasingly more ingrained in the environmental corporate responsibility commitments of vendors and industries.

Renewable energy use is becoming a necessity, but …
Using more renewable energy will put upward pressure on unit costs. Renewable energy doesn't have the same operating characteristics, load factors, cost-volume drivers, or "dispatchability" of conventional energy, especially base load plants. Renewable energy will stress transmission grids differently and significant investment will be needed to reconfigure bulk power networks.

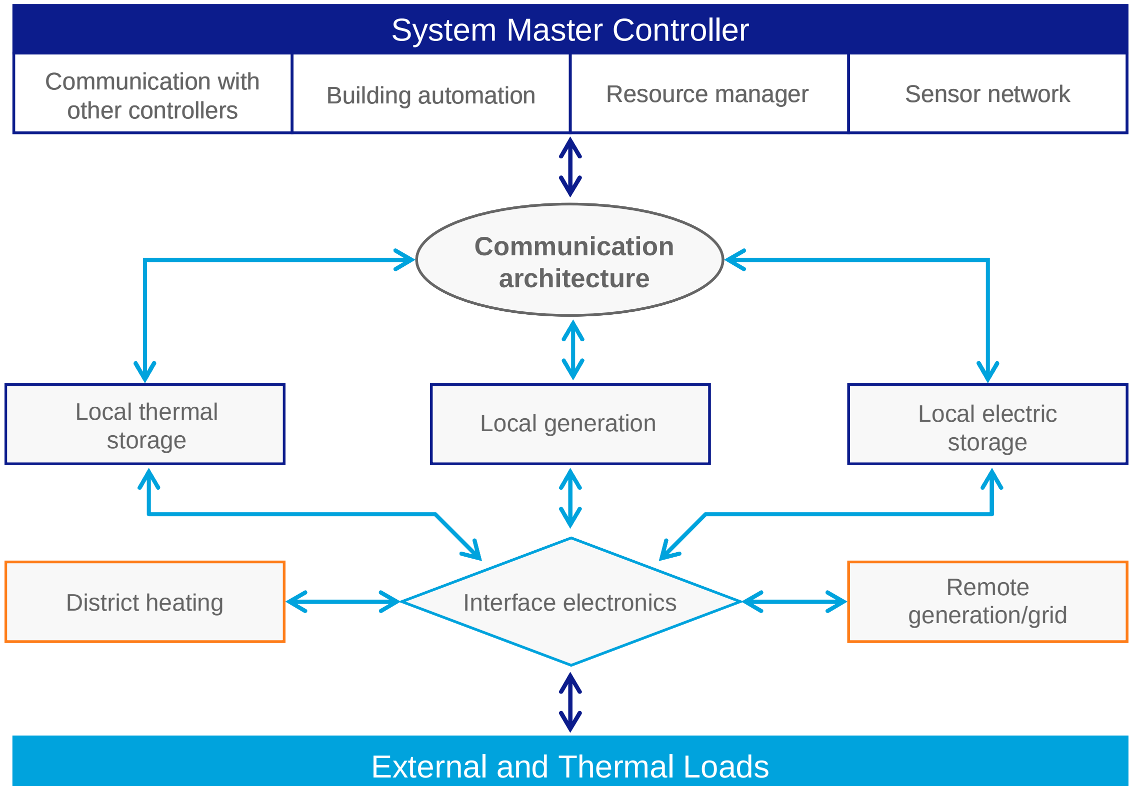
Renewable energy use has been growing rapidly, driven in part by renewable portfolio standards. Much of the recent thrust has been on larger-scale renewable systems, and owing to their variability and intermittency, require increased grid flexibility. Consumer-scale renewables such as rooftop photovoltaics are also expected to take off. On a distributed scale, these energy sources require "smarter" grids to meet safety, reliability, and control requirements.

As noted in a book jointly authored by the retired CEOs of Motorola and the Electric Power Research Institute, a smart grid should ideally consist of clusters of micro-grids that exist in a symbiotic relationship with the traditional large-scale grid. [10] These micro-grids could be — and, the authors argue, should be — based on small-scale renewable energy sources. Figure 2 depicts this concept.

The enabling ingredient consists of sensors and an electronic control system that would provide the communications and control capability for the smart micro-grid and that also would enable it to interact with the larger (host) grid. The two grid networks would work in concert to achieve maximum reliability and serve the unique needs of different customers at minimum cost.

[10] Galvin, Robert and Yeager, Kurt, *Perfect Power*, McGraw Hill, 2009.

Figure 2. Distributed micro-grid power system



Cost savings. Meter reading is a non-trivial component of a distribution utility's fixed monthly costs; typically, the costs of reading a meter are between US $0.50 and $3.00. Many US utilities do not read meters monthly. A common practice is to read bi-monthly and estimate usage in the interim month. If there is what is known as a CGI ("can't get in") problem because the meter is located inside the premises and nobody is home (a frequent occurrence in recent decades), the "estimating" could continue (legally) for up to a year. In addition to making meter reading nearly instantaneous, smart metering can synergize with gas and water meter readings, creating additional cost savings and, more important, greater convenience for customers.

With electricity prices set to continue rising sharply, the smart grid will also offer consumers choices that could reduce their bills. It can offer time-of-use and possibly even real-time pricing, as opposed to the flat rate retail tariffs most consumers now pay. When consumers respond to such tariffs through a smart grid, peak load would be reduced, which will improve asset utilization and in turn lower per-unit generating costs.

Grid improvement. Electricity demand in the United States is growing much faster than the transmission system. Deregulation has also increased the long-distance transmission of power, which is increasingly sourced from greater distances, driven by economics, rather than security and performance needs as in the past. In the words of one retired utility CEO: "The U.S. transmission system is under tremendous strain and only marginally stable. It was designed as a regional system and has been forced to function as a national system, a function for which it was not designed and does not handle very well."[11] The smart grid will improve the grid's resilience and robustness.

Technological advances. The advances in computing and telecommunications during the last half century have affected almost every facet of life. One reason the smart grid is taken seriously is because advanced computing and telecommunications have made it possible. As a network, the electricity industry has always required measurement, making it an ideal candidate for such advanced technology.

In a fundamental sense, the industry needs a breakthrough to enable it to rebalance the value equation it presents to customers. Costs are headed up while reliability is slipping. The recent advances in computing, telecommunications and metering have not arrived too soon. The smart grid also presents an opportunity to bundle "in-home intelligence" offerings, such as healthcare and home monitoring.

Improved customer satisfaction. If its costs cannot be driven down, the utility industry will need to improve the quality of service. As former Harvard Business School Professor Ted Levitt noted, it is possible to augment the commodity value of a utility service.[12] If done successfully, this will result in an increase in the "perceived" value of the product or service. The electric industry needs an increase in perceived value to improve its value offering. Because the smart grid promises to give customers more control over their use of electricity, it offers a way to increase perceived value. It could enable customers to minimize the total amount of their bills. So even though unit prices may not go down, the total size of a customer's bill could be minimized if not absolutely reduced. And the total amount of a bill, surveys show, has a much bigger impact on customer satisfaction than unit price.

Electric vehicles. According to the DOE, the smart grid's single biggest potential for delivering carbon savings is in providing cost-effective and increasingly clean energy for plug-in electric vehicles (PEVs) and their hybrids. PEVs can be plugged into a standard household electrical outlet to recharge their batteries. Capable of traveling up to 40 miles in electric-only mode, the majority of PEVs operating on battery power would meet the daily needs of most drivers.

Compared with a current hybrid, a PEV with an electric-only range of 20 miles could reduce fuel use by about one-third according to a report by the American Council for an Energy-Efficient Economy.[13] The Electric Power Research Institute estimates that the same PEVs could reduce fuel consumption by about 60% compared with non-hybrid vehicles.[14]

Although electric vehicles are not yet available on a large scale, a number of grid-connectible vehicles are anticipated to join the US fleet in the next five years. The

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[11] Wayne Brunetti, former CEO, Xcel Energy, 2002, quoted in Warren Causey, "Transmission Strains," *EnergyBiz Insider*, Feb. 8, 2010.

[12] Theodore Levitt, *The Marketing Imagination,* The Free Press, 1983.

[13] http://www.eei.org/ourissues/EnergyEfficiency/Pages/Technologies.aspx.

[14] Ibid.

technology is still expensive, mainly due to the cost of batteries, but the US Government is supporting the development of storage technology. An increase in production volumes would also help lower unit costs.

An intriguing addition to the potential of PEVs is that, while most of the discussion up to now has centered on "plugging the (electric) car into the house," there is a nascent but growing discussion about "plugging the house into the car." In other words, the collective storage capacity of PEVs could serve as reserve storage capacity for a micro-grid to help balance an unanticipated outage or shortfall in supply.

As ZigBee Alliance[15] chairman Bob Heile said, "American consumers are going to have to live with the interactive nature of the smart grid and the overwhelming fact that power generation will never keep up with future demand...Even if utilities pursued new power generation by every means, American attitudes towards nuclear power, not-in-my-backyard sentiments and demands of the Clean Air Act will constrain new generation to lag behind demand … We can't build new power plants fast enough, even without the transportation sector going electric. With EVs in the mix, demand will be huge." [16]

Drivers in India

Six factors will drive the adoption of the smart grid in India:

Supply shortfalls. Demand, especially peak demand, continues to outpace India's power supply. The increasing affordability of household appliances is adding to the burden on the grid. Official estimates of India's demand shortfall are 12% for total energy and 16% for peak demand. Managing growth and ensuring supply is a major driver for all programs of the Indian power sector.

Loss reduction. India's aggregate technical and commercial losses are thought to be about 25-30%, but could be higher given the substantial fraction of the population that is not metered and the lack of transparency. While a smart grid is not the only means of reducing losses, it could make a substantial contribution.

Managing the "human element" in system operations. Labor savings are not a prime driver for the smart grid in India, as contracts for outsourcing are inexpensive. However, automated meter reading would lower recording and other errors — including what are known elsewhere as "curbstone readings" or "shade tree" readings — or even deliberate errors, which are thought to be significant reasons for losses.

Peak load management. India's supply shortfalls are expected to persist for many years. A smart grid would allow more "intelligent" load control, either through direct

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[15] ZigBee is an open, global standard for low-power, wireless networks for monitoring and control products.

[16] As quoted in *intelligentutility*, February 12, 2010.

control or economic pricing incentives that are communicated to customers in a dynamic manner. Such measures would help mitigate the supply-demand gap.

Renewable energy. India has supported the implementation of renewable energy. Historically, much of its support was for wind power, but the newly announced National Solar Mission and its goal to add 20,000 MW of solar energy by 2020 should be an accelerant. Spurred by environmental concerns and the desire to tap into all available sources of power, this move can also be a smart grid driver.

Technological leapfrogging. Perhaps the most intriguing driver for India is the potential to "leapfrog" into a new future for electricity, as it did with telecommunications. Also, the "smart" in a smart grid is ICT — an area of unique capability in India.

1.2 What, Exactly, is a Smart Grid?

Simply put, a smart grid is the integration of information and communications technology into electric transmission and distribution networks. The smart grid delivers electricity to consumers using two-way digital technology to enable the more efficient management of consumers' end uses of electricity as well as the more efficient use of the grid to identify and correct supply demand-imbalances instantaneously and detect faults in a "self-healing" process that improves service quality, enhances reliability, and reduces costs. Thus, the smart grid concept is not confined to utilities only; it involves every stage of the electricity cycle, from the utility through electricity markets to customers' applications.

Key characteristics of the smart grid

- *Self-healing:* The grid rapidly detects, analyzes, responds, and restores
- *Empowers and incorporates the consumer*: Ability to incorporate consumer equipment and behavior in grid design and operation
- *Tolerant of attack:* The grid mitigates and is resilient to physical/cyber-attacks
- *Provides power quality needed by 21st-century users:* The grid provides quality power consistent with consumer and industry needs
- *Accommodates a wide variety of supply and demand:* The grid accommodates a variety of resources, including demand response, combined heat and power, wind, photovoltaics, and end-use efficiency
- *Fully enables and is supported by competitive electricity markets.*

Perfect Power, McGraw Hill, 2009, p. 82.

The emerging vision of the smart grid encompasses a broad set of applications, including software, hardware, and technologies that enable utilities to integrate, interface with, and intelligently control innovations.[17] Some of the enabling technologies that make smart grid deployments possible include:

- Meters
- Storage devices

[17] US Department of Energy, *The Smart Grid: An Introduction,* 2009.

- Distributed generation
- Renewable energy
- Energy efficiency
- Home area networks
- Demand response
- IT and back office computing
- Security
- Integrated communications systems
- Superconductive transmission lines.

1.3 Potential Benefits of the Smart Grid

The smart grid presents a wide range of potential benefits, including:

- Optimizing the value of existing production and transmission capacity
- Incorporating more renewable energy
- Enabling step-function improvements in energy efficiency
- Enabling broader penetration and use of energy storage options
- Reducing carbon emissions by increasing system, load and delivery efficiencies
- Improving power quality
- Improving a utility's power reliability, operational performance, asset management and overall productivity
- Enabling informed participation by consumers by empowering them to manage their energy usage
- Promoting energy independence.

1.4 Smart Grid and the Environment

There is a broad consensus that smart grid deployments will provide environmental benefits, including significant reductions in greenhouse gas emissions. EPRI has projected that by 2030, the implementation of a smart grid across the United States would reduce annual greenhouse gas emissions by 60-211 metric tons of carbon dioxide equivalent compared to "business as usual." This is equal to 2.5 to 9% of the greenhouse gas emissions of the US in 2006.[18]

> **Energy savings and carbon emission reductions enabled by a smart grid**
> An EPRI analysis indicates that the US energy sector will need to rely on a portfolio of technologies to meet future carbon reduction goals, including energy efficiency, renewables, nuclear, advanced coal, carbon capture and storage, plug-in hybrid vehicles, and distributed energy sources.
>
> The results show what most industry experts agree: energy efficiency is the most technically and economically viable near-term option for the electric power industry to reduce its carbon footprint.
>
> Electric Power Research Institute, *Prism Analysis,* 2008.

More than half of the potential emission reductions can be achieved through improvements in end-use efficiency and increased energy conservation enabled by the smart grid, as well as the integration of large-scale renewable energy projects into the grid. Smart grids can bring about environmental improvements by:

- ***Managing peak load*** through demand response rather than spinning reserves.

- ***Reducing transmission losses*** through better management of transmission and distribution networks. A recent study shows that a smart grid could reduce transmission and distribution losses by 30% from the business-as-usual case in 2020, the equivalent of $10.5 billion in energy savings and $2.9 billion in carbon costs.[19]

- ***Monitoring equipment in real time,*** which will enable the redirection of power flows in response to early warnings of system problems, detect and remedy faults in a "self-healing" mode and keep important system components operating at high efficiency.

- ***Increasing transparency in electricity prices*** to help consumers understand the true cost of electricity by time of day. Giving continuous feedback on electricity use could reduce annual CO_2 emissions by 31-114 million metric tons of CO_2 equivalent in 2030 as consumers adjust their usage in response to pricing and consumption information.[20]

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[18] http://www.pewclimate.org/technology/factsheet/SmartGrid.

[19] The Climate Group, Smart 2020: *Enabling the Low Carbon Economy in the Information Age*, 2009.

[20] http://www.pewclimate.org/technology/factsheet/SmartGrid.

- ***Reducing new infrastructure construction*** by helping optimize the use of existing generation and transmission and distribution capacity. Together with energy efficiency and conservation savings, this will reduce the pace at which new supply and delivery infrastructure must be built to satisfy increasing demand.

- ***Integrating more renewable energy sources and energy storage***, to support system operators by providing more real-time information to make decisions on selecting generation from clean energy sources, thus substituting renewable energy when possible. EPRI estimates increased renewable generation enabled by a smart grid could reduce US greenhouse gas emissions by 19-37 million metric tons of CO_2 equivalent per year in 2030.[21]

  Based on the rapid growth of renewable generation in a number of countries in Europe, Asia and the Americas, is clear that the role of smart grid enabling technologies will facilitate the integration of additional renewable energy resources at a faster pace than during the past decade. Figure 3 provides an indication of the significant growth rate of renewable generation.

Southern California Edison's plan for a clean energy future

- SCE is doing its part to reduce greenhouse gas emissions by providing customers with energy from renewable resources
- Smart power delivery is needed to manage greater diversity of supply and to optimize existing capacity
- Smart metering enables customers to increase energy conservation and reduce peaks while improving customer service and operational efficiency
- Plug-in electric vehicles will achieve transportation stability and enable distributed energy storage.

A study by the DOE's Pacific Northwest National Laboratory concluded that if 100% penetration of smart grid technologies could be achieved by 2030, a smart grid could reduce energy and CO_2 emissions from America's power sector by at least 12%. It identified nine mechanisms by which smart grids can lower energy use and carbon impacts, and quantified their effects. These mechanisms can be direct or indirect (Table 1):

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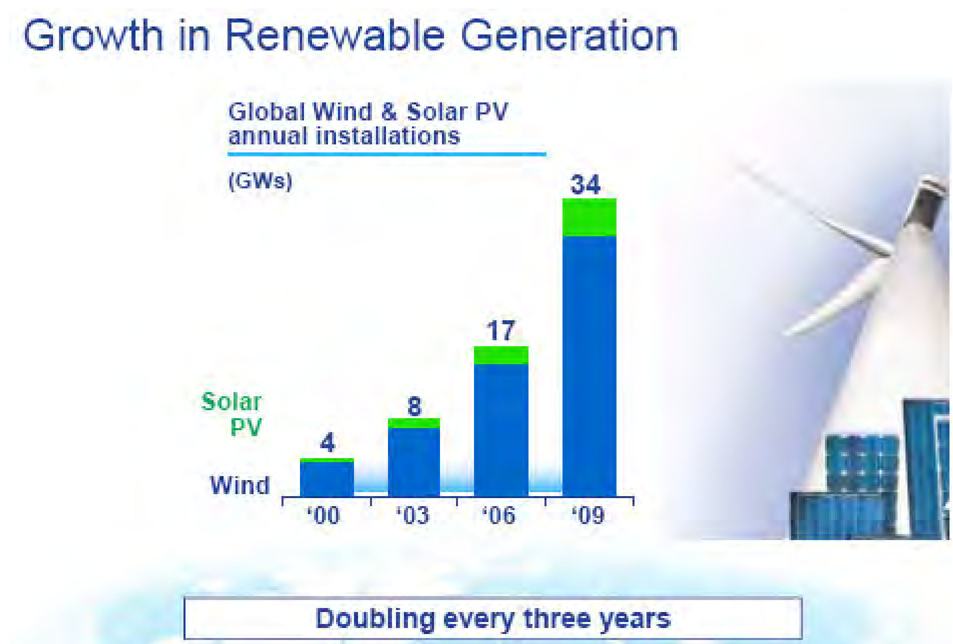
[21] EPRI, *The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid.* 1016905. Palo Alto, CA: 2008.

- Direct mechanisms include adding more plug-in hybrid vehicles and incorporating smart grid-enabled diagnostics in residential and commercial buildings.
- Indirect mechanisms are realized when smart grid capabilities are used to reduce the costs of energy efficiency and renewable energy. An example would be the use of demand-response methodologies and energy storage devices.

Figure 3



Source: GE T&D Marketing, The smart grid, May 2009.

Table 1: Smart grid mechanisms for reducing CO_2

Mechanism	Reductions in Electricity Sector Energy and CO_2 Emissions (%)*	
	Direct	Indirect
Conservation effect of consumer information and feedback systems	3	--
Joint marketing of energy efficiency and demand-response programs	--	0
Deployment of diagnostics in residential and small/medium commercial buildings	3	--
Measurement and verification for energy efficiency programs	1	0.5
Shifting load to more efficient generation	<0.1	--
Support for additional electric vehicles and plug-in hybrid electric vehicles	3	--
Conservation voltage reduction and advanced voltage control	2	--
Support the penetration of renewable wind and solar generation (25% renewable portfolio standard)	<0.1	5
Total reduction	**12**	**6**

Mechanism	Reductions in Electricity Sector Energy and CO_2 Emissions (%)*	
	Direct	Indirect

Assumes 100% penetration of smart grid technologies
Source: R.G. Pratt et al., *Smart Grid; An Estimation of the Energy and CO_2 Benefits,* Pacific Northwest National Laboratory, January 2010.

Also, smart grid deployments could provide added value for the utility industry due to the prospects of the costly emission control measures that many governments are now discussing.

Challenges to quantifying smart grid benefits. Environmental benefits will be difficult to quantify due to the complex dimensions of the smart grid and the fact that benefits are often dispersed and therefore not readily identifiable or easily quantifiable. Some other reasons for this concern include:

- Environmental benefits tend to occur due to avoided emissions or offset impacts, which are often difficult to quantify
- The benefits cannot always (or easily) be traced to a single organization
- Benefits will occur outside the boundary of the firm implementing the program
- Environmental benefits accrue over very long time periods.

> India's nearly 100 GW of thermal power generation currently accounts for nearly 60% of its net power generation and 57% of its total greenhouse gas emissions. Based on current expansion plans, this scenario is expected to persist until 2020.

The Indian context. Even with a population of over a billion, India is a relatively low carbon economy — ranking 63rd worldwide in per capita emissions and 48th in CO_2 emissions per unit of GDP. Furthermore, recent studies commissioned by the Ministry of Environment and Forests have found evidence that India is improving the energy intensity of its GDP: in 1980, it used 0.30 kilograms of oil equivalent per $ of GDP in purchasing power parity terms; today, the comparable figure is 0.16. Most independent projections indicate that India's CO_2 intensity is likely to continue to decline over the 2030-2050 timeframe.[22]

Nonetheless, the potential for offsetting CO_2 emissions in India is high owing to the large opportunities to both lower energy intensity and improve the carbon intensity of its fuel mix. India's commitment to a low-carbon economy will involve major changes to the way it supplies and uses energy. Modernizing and improving the operational efficiency and increasing the proportion of renewable energy in its fuel mix while

[22] Ghosh, Pradit, Ph.D. Distinguished Fellow, The Energy & Resource Institute, *India's GHG Emissions Profile: Results of Five Climate Modeling Studies*. Ministry of Environment and Forests, Government of India, 2009. Also, see *Climate Change Negotiations; India's Submissions to the United Nations Framework Convention on Climate Change*, August 2009.

reducing peak demand (especially for electricity created from fossil fuels) will remain central to achieving the objective of a lower carbon footprint.

Meeting this objective will require a development strategy to design smart grids at the outset, spur more consumer-driven energy efficiency, optimize the sector's fuel mix, and speed the deployment of grid-connected renewable energy sources.

The ideal outcome would be a plan to enable India to "leapfrog" into an advanced electricity supply system without going through the life cycle of the power sectors in mature industrial and post-industrial economies.

Chapter 2
The Technology of Smart Grids

A variety of computing and telecommunications technologies can make many of the smart grid's envisioned benefits a reality. A few of these include detecting and quickly responding to power outages, providing consumers with near real-time information on the amount and cost of the power they use, improving the security of the system, and linking all elements of the grid to enable better decision making on resource use. As these technologies advance, they will produce more and better-quality data, which will give utilities new opportunities to improve their analyses of, for example, customer load patterns and tariffs, and thus offer better services to their customers.

After a brief overview of the electricity value chain and a review of the evolving role of the independent system operator (ISO), this chapter's discussion of smart grid technologies follows the path data will take within the utility system's architecture: from the field device to the computer system at a central location (e.g., the data management system at the utility's headquarters, the customer information and billing system, the dispatch center). For some applications, such as control, data also flow in the opposite direction, from the head of the system to the field device.

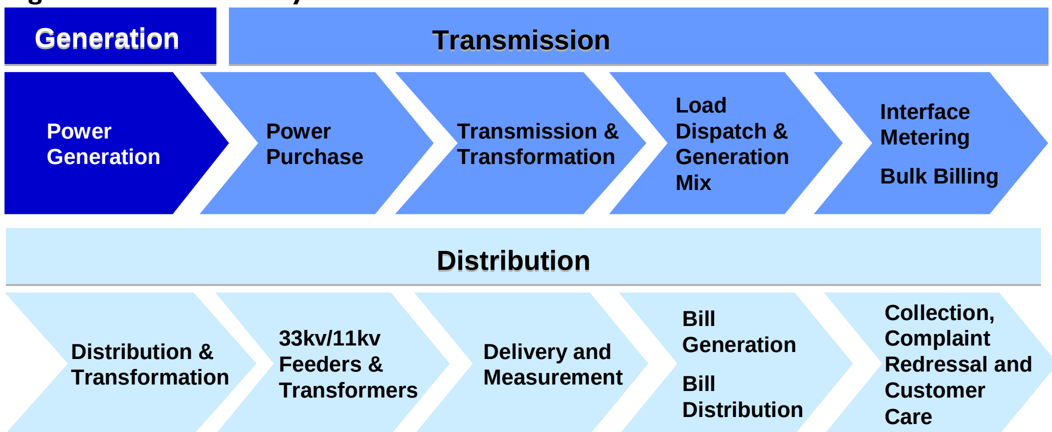
2.1 The Electricity Value Chain

The process for generating electricity and transporting it through the bulk power supply network (the transmission grid) has been in place for many decades. A critical early step was the adoption of AC power to enable the cost-effective transportation of bulk power over long distances.

This enabled the technical structure of the electric industry that was set almost 100 years ago, namely, large, central-station power plants connected to a transmission grid (the superhighway of the electric system) to move power to load centers where transformers reduced voltage levels to distribution levels for use by customers.

The core process remained largely unchanged, except for technical advances that allowed for ever-larger plants producing power at ever-lower unit costs as well as the continuous enhancement of transmission technology. Figure 4 shows the major elements of the value chain.

Figure 4: The Electricity Value Chain



For more than a half century, the vertical integration of all elements of the value chain was under the ownership and control of individual, vertically-integrated companies. This enabled the industry to optimize the economies of scale inherent in the capital-intensive electric supply industry.

Once this began to change, in the 1970s and 1980s, the dynamics of the business began to change as well. Market liberalization, functional unbundling and competition are common features of the changes that are taking place in the power sector in most countries around the world.

Today, the convergence of several major forces is changing the historical structure of the industry. These include: technological advances in ICT, the growing scarcity and increasing price of fuel, and the advent of cost-effective, small-scale distributed generation. The increasing technical efficiency and cost-effectiveness of renewable energy sources, coupled with growing public concern about the effects of climate change, have also brought about change. These are the underpinnings of what is known as the smart grid.

The heart of the smart grid vision relates to metering (and the technical enhancements that have been a work-in-progress for the past 35 years and more) and the distribution sub-sector. Thus, this white paper will focus on them. However, that is not the entire story. As discussed elsewhere in this report, the array of generation options, in terms of fuel sources and sizes, is greater than ever before. The consensus view seems to be that the smart grid will not replace the "legacy" grid, but rather will augment it with micro-grids, with the traditional grid serving as the host.

Nonetheless, the way an integrated smart grid will operate will be different — radically different in the view of many — from the way the industry operated historically. One feature that will change but remain central to the smooth functioning of the electricity supply industry is network operations, or system operations and dispatch, as it was commonly known in the past.

Network Operations

The most visible differences between today's power networks and the smart grid of tomorrow will be in the distribution area at the customer/network interfaces. However, in the generation and transmission areas, the role of the system operator (which today is already complex) will become even more complex and critical as it will have to ensure the reliable, efficient, and more integrated operation of many additional energy resources.

These additional energy resources include increasing amounts of intermittent solar and wind generation, distributed generation, and demand response options (DR) that are expected to become an integral part of the power system of tomorrow, thanks to the smart grid enabling technologies currently under development and implementation.

System operators will play a crucial role in tomorrow's smart grid. They will need to be supported by even more advanced and sophisticated energy management systems to oversee and mange all available energy resources and transmission constraints in every part of the system under a broad variety of operating and market conditions and possible future scenarios.

Evolutionary changes in network operations

The traditional system network operation model has evolved from the cost-based, supply-side system dispatch paradigm when companies operated as vertically-integrated utilities. Electric utilities operated large, remote power stations, long transmission lines, and a distribution system primarily designed to deliver power to a fairly static load.

This will change to a more sophisticated market-driven system dispatch with multiple-asset owners with a wide range of commercial interests. This evolution has been underway for several decades and will continue; the pace of change may accelerate. The new approach will have to accommodate more demand-side resources, generation and storage resources on the distribution system, and considerably higher levels of wind, solar and other types of renewable generation.

The traditional or classical system dispatch focused mainly on:

- Unit commitment scheduling
- Economic dispatch
- Automatic generation control
- Grid security
- Local dispatch with some regional implications.

The more sophisticated market-based system dispatch has additional focus areas including:

- Formal day-ahead and real-time tasks

- Unit commitment/economic dispatch with more explicit transmission security constraints
- Checks and balances to ensure transparency and consistency
- Large-scale system dispatch that is regional and multiregional in scope.

The evolution into a smart grid system dispatch environment will add even more dimensions, which include the following:

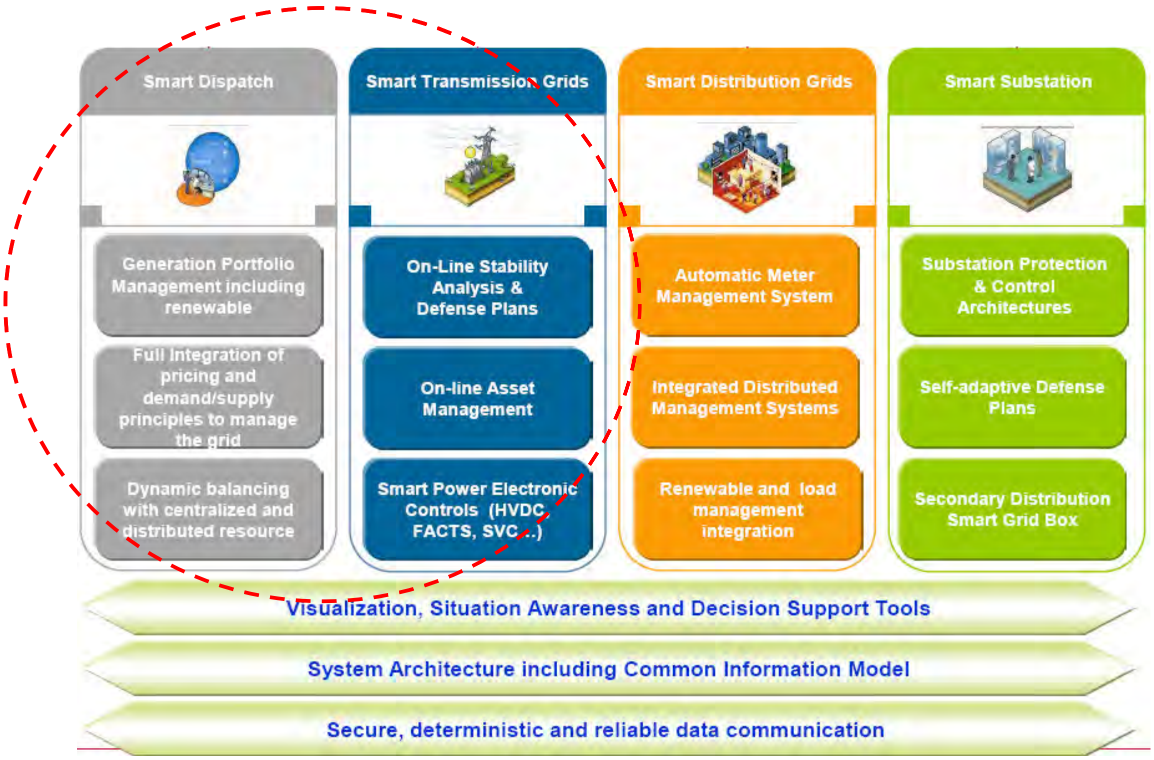
- Dynamic balancing of centralized and distributed resources.
- Integration of distributed energy resources and demand response resources.
- Integrating large-scale intermittent renewable generation.
- Increased coordination of renewable generation and storage resources. Given the variability of some renewable generation (e.g., wind, solar), more real-time control will be needed to instantaneously balance supply and demand. New forms of storage resources, such as plug-in electric vehicles, could provide a critical buffer.
- Shifting loads to more efficient generation using demand response and distributed generation and storage with the aim of saving energy and reducing carbon emissions, depending upon the mix of base, intermediate, and peak load generating resources in use at any given time.
- Integrating technological advances in transmission to control power flows (FACTS, SVC, etc.).

Figure 5 illustrates the smart grid environment in which transmission and generation operations are evolving. It provides a view of the supply chain from generation, through transmission and distribution without getting into the purely customer end of the smart grid spectrum.

These changes may require changes to the power system capacity and capabilities. They will also have a significant impact on systems operators and the IT needed to monitor and control the reliable operation of the power system in an optimal economic manner.

In the future, the range of possible scenarios that system operators face will increase dramatically. Electrical variables such as current and voltage will need to be monitored extensively across the network, even at the lowest voltages, and on-line network analysis will have to be included so that automatic or manual actions can be taken to ensure that circuit capacities are not exceeded. These network data will be used locally or regionally to balance generators and demand response resources in real-time.

Figure 5: The smart grid environment



Source: Generation Dispatch, AREVA – IEEE Smart Grid Conference January 2010.

Smart grid technologies will allow better management of network flows. Specific network operation solutions include:[23]

- More accurate monitoring of the network and analysis of the operational state of the network, including lower voltage levels
- Increasingly efficient allocation of cross-border interconnection capacity
- Power flow control (e.g., by phase shifting transformers, FACTS and HVDC devices)
- Improved coordination of operations across countries
- Exploitation of real-time thermal monitoring for power cables and/or critical overhead lines
- Increasingly intelligent post-contingency corrective actions and defense schemes
- Activation of pre-contingency preventive actions after exceeding pre-defined stability limits and thresholds
- Improved automation in distribution grids and optimal use of grid reconfiguration after faults.

Table 2 summarizes how smart grid could affect some of the generation and transmission functions of systems operators to ensure reliable and efficient performance of the network.

[23] Source: "Position Paper on Smart Grids," An ERGEG Public Consultation Paper, December 2009

Table 2: How the smart grid can affect generation and transmission

Primary Function	Description of Functions	How the smart grid affects these functions	How an intelligent communications infrastructure enables and amplifies the smart grid impact
		Generation	
Load control and dispatch	Economical load dispatch scheduling and optimization help to select the right dispatch for the right load at the right time, reducing the cost of generation (startup, operations, and wind down)	The smart grid helps with the scheduling of committed generating units so as to meet the required load demand at minimum operating cost while satisfying all units and system equality and inequality constraints	Economic load dispatch during unforeseen events warrants robust real-time communication infrastructure between the demand and generation functions
Load shaping	Shaping the load during peak demand times reduces the idle and standby generating capacity	Demand-side management helps to manage and accurately estimate demand to as to meet demand without extra generation	Load shaping with DSM involves reliable communication between AMI and CIS (customer information systems) and generation functions
Distributed, renewable generation	The integration of micro-grids as well as customer premises with the utility infrastructure	The smart grid enables distributed generation and automated adjustment of feed-in tariff regulation to receive premiums in the case of forced switch-off of distributed-generation asset for balancing	Infrastructure is needed to confirm, analyze, and dispatch available load to distribution generation sources
Generation equipment maintenance	Diagnoses and maintenance of the generation equipment reduces faults and prevents their propagation	The smart grid helps asset management and conditioning in preventive maintenance. It also helps accessing newly sensed data.	Data from utilities need to be transferred to the generation control center for better equipment conditioning and monitoring.
		Distribution	
Transmission-grid monitoring and control	Energy management systems and transmission SCADA for data acquisition needed for the following functions: 1) outage management, 2) Volt/VAR management, 3) state estimation, 4) network sensitivity analysis, 5) automatic generation control, and 6) phasor data analysis.	Automatic regulation of load tap changer and capacitor banks for voltage regulation. Wide-area phasor management and control for grid optimization and control. Volt/VAR management using capacitor switches and controls.	Substation automation results in two-way communication between transmission SCADA equipment and the energy management system. Communication between transmission and generation units is necessary for automatic generation control.
Maintenance of	The transmission control center is the	Automated operations eliminate human	Real-time communication between primary and backup

Primary Function	Description of Functions	How the smart grid affects these functions	How an intelligent communications infrastructure enables and amplifies the smart grid impact
transmission control center	first line of defense for transmission fault detection and prevention	interventions in fault prevention, detection, isolation, and correction	transmission control center, transmission, generation, and distribution units is necessary for control center operations. Security technology deployment provides for secure data sharing between transmission and other utility functions.
Equipment maintenance	Maintenance of transmission equipment, including breakers, relays, switchers, transformers, and regulators, prevention of faults	The smart grid helps asset management and conditioning for preventive maintenance	Data from transmission equipment need to be transferred to the generation control center for better equipment conditioning and monitoring

Source: Smart Grid - Leveraging Intelligent Communications to Transform the Power Infrastructure

What are ISOs doing about the smart grid?

In the USA, independent system operators (ISO) are already taking leading roles or specific steps in the coordination and or implementation of smart grid projects that would enhance their operations.

The ISO New England will receive $3.7 million in federal funding to develop a smarter, more efficient energy grid. The U.S. Department of Energy chose ISO New England as one of 100 companies nationwide to receive federal stimulus funds as part of the American Recovery and Reinvestment Act of 2009.

The project's focus is to install 30 synchrophasors to provide enhanced real-time visibility of the electric grid. As a result of this project, systems operators in New England will be connected to increase response time to real time system events and reduce congestion by being able to collect and share synchrophasor and disturbance data with other regions for wide area monitoring.[24]

- Transmission owners in New England will install smart-grid devices at 30 locations across the region to enable enhanced monitoring and control by ISO system operators
- "Synchrophasor" technology will be used as a foundation for the next generation of power-grid situational awareness
- Phasor measurement units will observe system conditions 30 times per second—much faster than conventional technology.

Synchrophasor Monitoring

Most monitoring of the grid is based on non-simultaneous average values of measurements taken over a period of several seconds. This is valuable in assessing the steady-state condition of the grid. The monitoring of line voltage phase angles (phasors) can fill that gap, providing the instantaneous measurement of electrical magnitudes and angles that can reveal emerging instability. The deployment of phasor measurement units (PMUs) is growing, along with the development of predictive algorithms that can assess system risk. For example, the Center for Energy Advancement through Technology Innovation has initiated a project to directly input phasor data into an ultra-fast load flow to identify thermal overloads, voltage constraints, and voltage instabilities. Reliable broadband communication channels are needed to accommodate the system-wide deployment of this tool.

Source: National Energy Technology Laboratory, *The Transmission Smart Grid Imperative,* developed for the US Department of Energy Office of Electricity Delivery and Energy Reliability, September 2009.

The New England ISO is also implementing several other smart grid projects. One initiative that already is being implemented in New England is demand response. The North American Energy Standards Board is developing demand-response standards, and FERC and the North American Electric Reliability Corporation (NERC) have issued regulations that provide guidance to implement DR capabilities. An ISO New England pilot program on using demand-response resources for ancillary services (e.g., reserves) is just beginning, and the region's ongoing demand response programs continue to deliver results.

In addition, the ISO's Forward Capacity Auction for 2010 produced approximately 1,100 new "negawatts" of capacity obligations from demand resources (representing almost two-thirds of the new capacity that will come online in 2010).[25] Table 3 lists the ISO's current demand-response programs, as well as other types of smart grid projects. While

[24] George, Anne, VP, Corporate Communications and External Affairs, ISO New England, Inc., "Improving Reliability and Integrating New Resources with Smart Grid Technology in New England," February 25, 2010.

[25] ISO New England, Inc., "Overview of the Smart Grid – Policies, Initiatives, and Needs," February 17, 2009.

some of the demand-response programs are well underway, some of the R&D projects will take time to mature.[26]

Table 3: ISO New England smart grid projects

Project	Description
Integration of demand resources within ISO/Regional Transmission Organization operations	A project to develop real-time dispatch and telemetering capabilities for demand-response resources with capacity obligations for 2010 obtained via the forward capacity market.
Demand-Response Reserves Pilot Program – Phase II	Thirty-minute real-time demand response program to provide load reduction capability of less than 5 MW.
Demand-Response Programs	Consists of reliability programs where customers respond to system reliability conditions, as determined by the ISO New England control room, and price programs where customers respond to wholesale spot prices, as determined by the market.
Rig Replacement Project	A project to replace the proprietary Qualitrol Remote Intelligent Gateway master communication equipment located at ISO New England with equipment that supports interfacing with industry standard equipment for substation automation.
Alternative Technology Regulation Pilot Program (ATR)	An 18-month program in response to FERC Order 890 that will test the impact of non-generating technologies on the regulation market and allow owners of ATR resources to evaluate the technical and economic suitability of their technologies as possible regulation-service sources. The ATR Pilot Program is limited to 13 MW of participation, and no single entity will be allowed to provide more than 5 MW of regulation service. Eligible non-generating resources include flywheel technology, battery technology, and certain demand-response resources. Resources must be commercially on line by November 1, 2009.
North America Synchrophasor Initiative (NAPSI)	A program sponsored by PNNL to improve the planning, operation, and reliability of the electric power system through wide-area measurement, monitoring, and control. The mission of the group is to create a robust, widely available and secure synchronized data measurement infrastructure for the integrated North American electric power system with associated analysis and monitoring tools. Under NAPSI, over 40 synchronized phasor measurement units (PMUs) have been disbursed across the eastern United States. A super phasor data concentrator collects real-time phasor data at the Tennessee Valley Authority which makes tools available to view and analyze the information. ISO New England has installed two PMUs and is planning to install more as part of this project. Control room operators will be able to view the accurate phasor information, which will assist in understanding system dynamics in real time. The phasor data also will be integrated with the state estimator (SE) to improve the performance of the SE.
Situational awareness (SA)/visualization	The ISO's implementation of advanced alarm management and wide-area power system visualization, for example, and new technologies such as PMUs, interactive 3D and Google Earth, help operators better assess and visualize system operation states. System operators' situational awareness and monitoring capability are important to the reliability and security of power systems. Many advanced technologies in SA and visualization exist, although they have not been used in the power industry.

[26] Ibid.

Project	Description
Real time stability analysis and control	A planned, day-ahead automated and real-time (voltage and transient stability) assessment to improve the accuracy of stability analysis and control options available to operators when instability conditions occur. Currently, the stability limits used in daily operations are based on off-line studies, which are conservative and have numerous uncertainties.
System Black Start and Restoration Automation	A planned on-line decision support tool to help operators to restore the system in real time. System restoration is primarily based on off-line planning and manual work by system operators. An actual blackout may have different characteristics from the off-line studied system.
Advanced Grid Simulator Project	A project to create a simulator based on the current dispatcher simulator, which will simulate the operational characteristics of the grid of the future. It is envisioned that this tool will be built using a 2020 calendar year Network model of the electric grid and will analyze the operational impacts of various alternative resources and smart grid technologies tied to the grid. The tool could also be used to conduct economic analysis at a higher level of detail than what was done in ISO's *2007 Scenario Analysis*.

ISO New England is sponsoring two smart-grid initiatives with the ISO/RTO Council:

1. Plug-In Electric Vehicles (PEV) Integration Project will:
   - Identify products and services that PEVs could provide under existing market and reliability structures within ISO/RTO markets

2. Smart Grid Standards Development Project will develop a straw standard:
   - Describing smart grid end-to-end process flows, from all service providers between customers and the ISO/RTO
   - Defining and prioritizing the applications and functions that have the most urgent need for standards
   - Developing draft architecture and standards to support information between ISO/RTOs and smart grid aggregators.

Other ISOs like the California ISO and the Electric Reliability Council of Texas (ERCOT) are also actively evaluating options to deal with the expected increased penetration of renewable generation resources, which increases the need for regulation services.

The regulation (of electricity flows) is one form of ancillary services needed to stabilize the grid during normal operations, and the need for regulation is expected to increase in order to manage the planned high penetrations of renewables. An illustrative example of this occurred in February 2008, when the ERCOT had to curtail power to many interruptible customers because wind production unexpectedly and suddenly dropped by 1700 megawatts.

The drop in output had been forecast, but occurred several hours earlier than expected, so base load power plants had not been scheduled for dispatch to provide the replacement energy and the ramping up services to manage the transition. Some generation capacity is always held back and kept "hot" to handle a sudden contingency (known as spinning reserves), but this event exceeded the capacity of the spinning reserves and fast-start, non-spinning reserves (e.g., gas turbines) to pick up the deficit in output. The situation was made more difficult by the fact that it occurred in February. That is during the off-peak-load season in Texas and many power plants were down for scheduled maintenance.

As a result of the sudden deficit, grid frequency dropped quickly and emergency curtailment contracts, mostly with large industrial customers, were called on to drop load to prevent a potential blackout until additional power plants could be brought online.[27]

2.2 Intelligent Electronic Devices

Utilities have used electromechanical devices such as land lines and power line carriers for many years. But today, many of these devices are taking on enhanced, and even new, features and functions in the form of intelligent electronic devices (IEDs). For example, the old single-function electromechanical meters have given way to multi-function electronic meters that can communicate with a central computer. Also, the addition of electronics to the control units of reclosers has enabled them to communicate with a utility's central computers, which automatically store the outage data (e.g., number, duration) needed for reliability and availability indices (SAIDI, CAIFI, SAIFI, etc.).

Remote terminal units (RTUs) for supervisory control and data acquisition systems (SCADA) are smaller and less expensive than before. For this reason, the use of SCADA RTUs is expanding out from the transmission system to the distribution system.

Modern digital relays perform the detection and tripping algorithms that were impossible to implement with electromechanical relays. These relays have hundreds of set points and a broad range of storage history. While this can be addressed with internet protocols, relays still require ongoing operational technology to manage security, firm-ware changes, configuration changes, maintenance, health checks, version control, compatibility testing, and more. Thus, the enterprise information management system must evolve for relays.

Some of the advances India is making in the area of intelligent electronic devices include:

- The Restructured-Accelerated Power Development and Reforms Programme (R-APDRP) is stimulating progress toward 100% metering on distribution transformers and feeders.

- The conversion from electromechanical to static (electronic) metering is progressing at the low-tension level (400/220 Volts) to residential and small commercial customers.

[27] Pacific Northwest National Laboratory, *The Smart Grid: An Estimation of the Energy and CO_2 Benefits*, January 2010.

- The Bureau of Indian Standards is scheduled to issue a standardized meter protocol in March 2010 to address meter interoperability. The Meter Inter-Operability Solution being promoted by the Indian Electrical and Electronics Manufacturers Association and Device Language Message Specification are also gaining ground.

- Although meter data acquisition and management are still within the purview of meter vendors, which is hindering the interoperability of the products of different meter suppliers, R-APDRP is working on a holistic approach to meter data management.

2.3 Telecommunications

The core of the smart grid transformation is the use of intelligent communications networks and systems as the platform that enables grid instrumentation, analysis, and control of utility operations from power generation to trading, and from transmission and distribution to retail.

Telecommunications channels can be divided into four categories:

- Land line: this includes analog subscriber lines, digital subscriber lines, coaxial cable, and fiber optics

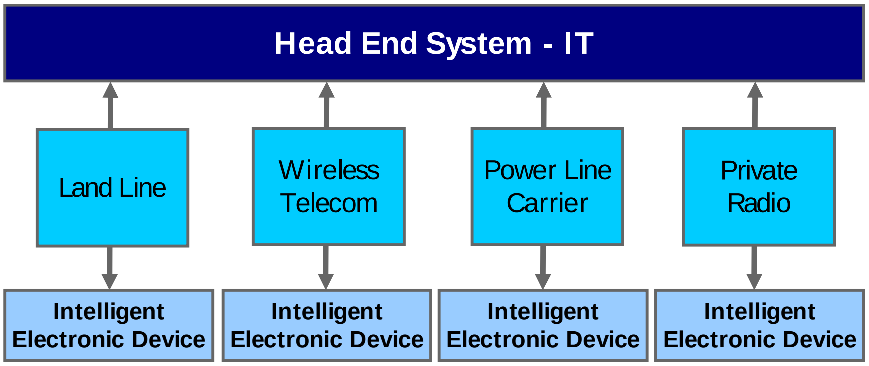
- Wireless: this includes cell phone communications systems (both the GSM/GPRS/EDGE method and the CDMA method) and Wi-Fi

- Private radio: this includes trunk mobile dispatching channels and meshed meter networks

- Power Line Carrier: this encompasses traditional power line carriers between substations and the new technology of broadband-over-power line at the distribution voltage.

A smart grid system could be constructed from just one of these telecommunications technologies, but a utility will often use two or three in order to add more reliability to its service territory coverage.

Figure 6. Telecommunication technologies for the smart grid



Considerations in selecting telecommunications technologies

Telecommunications is critical to a power system because it serves as a backbone for information exchange, which helps the utility's delivery performance and resilience. Combined with distributed intelligence, telecommunications make it possible to report and resolve grid issues in real time (self-healing). In addition, the information communicated by intelligent electronic devices alerts operators to problems. It is thus important to evaluate the system's reliability, security and availability, as well as technology cost, when choosing telecommunication methods.

Scalability is another important consideration in choosing telecommunications technologies. With smart metering, an advanced infrastructure of interval meters and two-way communication systems serves as a gateway for distribution company-customer interaction. This integration brings with it an exponential growth in the amount of data that must be gathered, stored, and transformed in near real-time for intelligent responses and decision support. Thus, the ability to scale a communications method also becomes an important parameter.

Telecommunications in India

The telecommunications emphasis in India is on mobile phones, which are more reliable and have good coverage in urban areas, but do not have full coverage or enjoy network reliability in rural areas. In urban areas, mobile network congestion (the spectrum for unlicensed radio bands is also becoming crowded) is a challenge because the smart grid requires voluminous data over short intervals. Although communication costs, especially those for general packet radio service (GPRS), have dropped dramatically, the overall quality of the infrastructure to support them is improving only slowly. However, it is possible to transmit smart grid and smart meter data during off-peak times in the mobile network, thus improving the load factor of the mobile telecommunications network. India's electric utilities can explore time-of-use tariffs with their mobile phone counterparts in order to shift the mobile phone load.

Programmable logic controllers[28] (PLCs) present their own set of challenges due to the quality of cable and joints, resulting in poor communication speeds. PLCs do, however, have an advantage when an electric utility has a good PLC network and owns these assets. Because the utility is responsible for maintaining the PLCs and the PLC signal goes everywhere the electric utility wants it to, it could use the PLC as the option to install a smart grid device or smart meter and save on recurring costs.

Wide Area Network and expanded advanced metering infrastructure implementations are also underway in India. R-APDRP will be able help demonstrate the reach, reliability and scalability of communication systems to meet these requirements. This will help define gaps and requirements for smart grid telecommunications. In addition, it will help define the migration path from legacy systems to standards based on smart infrastructure, leading to the most cost-effective hybrid model.

Both government-owned and private telecommunication service providers are taking single ownership of their telecommunications systems and will require an approach for gearing up to meet the needs of the distribution companies. This will be critical in large-scale smart grid implementations, which need integrated communications networks.

With telecom utilities learning to adapt and industry supporting them to develop end-to-end networking solutions, a fundamental platform will evolve for utilities to improve their energy efficiency, security and service innovations for electrical grids. Companies like Cisco are sharing their networking expertise with leading utility providers around the world to build standards based on interoperable platforms to provide efficient backhaul communications smart meters that will integrate proprietary solutions in the overall smart grid platform.

According to Carnegie Mellon University and other leading research centers, 49% of cyber security breaches involve physical security. Secure standards-based data center portfolios are being enabled to use sophisticated data collection techniques and storage solutions for grid analysis and subsequent optimization. Software development companies such as Accenture, Capgemini, HCL, Infosys, IBM, OATI, Oracle, and Wipro, along with power and utility integrators such as Areva, General Electric, Schneider Electric and Siemens, are working with a host of smart metering, grid automation, business and home automation technology companies in collaboration with connectivity and transport service providers such as Cable and Wireless, and Verizon, to develop solutions.

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[28] A power line communication or power line carrier (PLC), also known as power digital subscriber line, is a system for carrying data on a conductor that is also used for electric power transmission. Broadband over power lines use PLC by sending and receiving information-bearing signals over power lines to provide access to the Internet.
Electrical power is transmitted over high-voltage transmission lines, distributed over medium voltage, and used inside buildings at lower voltages. Power line communications can be applied at each stage. Most PLC technologies limit themselves to one set of wires (for example, premises wiring), but some can cross between two levels (for example, both the distribution network and premises wiring). Typically, the transformer prevents propagating the signal so multiple PLC technologies are bridged to form very large networks.

Table 4 presents the key characteristics of the major telecommunications technologies available in India.

Table 4: Features of major telecommunications options in India

Technology Capability	Land Line	Wireless Telecom	Power Line Carrier	Private Radio
Infrastructure available in India	Remote area connectivity not available everywhere	Available also in remote areas. Connectivity improving	Not widely used in India until now	Remote area connectivity may not be available and point-to-point networks would need to be established
Cost of transferring data	Low	Low (based on transmission during off-peak time)	Low (different standards must be implemented first so initial cost may be high)	Free
Reliability	Low (due to risk of physical damage)	High	Low (due to use of newer and untested technologies)	High
Risk involved	Physical damage	High traffic during day-time	Newer, relatively untested technology	Onsite support
Scalability	High (major investment needed)	Low (bandwidth in wireless domain is limited, but with 3G near this may not be a concern)	High (major investment needed)	High (regulatory concerns and initial high costs are barriers, technology is not a barrier)

2.4 Information Technology

The head-end system is the apex node of the network; it consists of the telecommunication system and field devices. The role and function of the head-end system vary depending on the system's application (for example, metering for billing, SCADA, automatic generation control with economic dispatch, metering for load research, demand-side and load management, load shedding, disconnection and reconnection as part of billing, energy accounting, and SAIDI, SAIFI, and CAIDI indices).

The size of the head-end system is usually in proportion to its position within the utility hierarchy, with systems at the apex usually being the largest. System size (number of file servers, amount of storage, etc.) decreases for systems in the second and third tiers of the hierarchy.

This combination of growing technology in distribution management and operations is leading to an emerging need to support the integration of micro grids, open-access energy systems, and the use of network-controlled devices, and hence, a need for a converged security infrastructure for all. The first priority is securing these assets of electric power delivery systems, from the control center to the substation, to the feeders and even to the customer meters. This will require an end-to-end secure infrastructure that protects the web of communication assets (control center-based SCADA, RTUs, PLCs, power meters, digital relays and bay control) used to operate, monitor and control power flow and measurement.

Physical and cyber security

Smart grid communications will play a critical role in maintaining high levels of electric system reliability, performance and manageability. But at the same time, the grid is increasingly subject to attack, as many of the technologies being deployed to support smart grid projects (such as smart meters, sensors, and advanced communication networks) are interoperable and open.

Meeting the critical need for an integrated security infrastructure will require the establishment and implementation of a security framework for managing both physical and cyber security, as well as an accompanying security policy. In addition to reducing the system's vulnerability to physical or cyber attacks, a comprehensive approach to security will help utilities better manage their systems, keep costs lower, and improve the system's resilience against security disruptions and data privacy invasions. This framework should cover:

- Physical safety and security
- Generation plant security
- Substation security
- Utility regulatory compliance
- Identity management
- Access control
- Threat defense
- Wide Area Network security
- Security management and monitoring.

Cyber security encompasses privacy. The Government in India has yet not demonstrated superior cyber security enforcement, and its standards for security are limited.

Business applications and services

The first priorities in smart grid development are addressing the transmission and distribution infrastructure, the telecommunications network, and data centers (computing platforms). Next, attention should turn to building the right operational systems for automated metering infrastructure, outage information, customer information, geographic information systems (GIS), meter data management, asset management and distribution management. Currently the R-APDRP does not adequately address these systems, which should be viewed from the perspective of overall business applications and workforce management so that India can evolve into transmission and distribution automation, smart meter communications, and business and home energy management applications.

As discussed above, several software companies are working to develop these infrastructures. However, in India infrastructure developments have been restricted to micro grids and pilots in which a zone is ring fenced and then preliminary analytics are done to make business cases for smart metering. Hopefully in R-APDRP, 100%

distribution transformer and feeder metering will be completed, although interoperability issues may still need to be addressed. The Ministry of Power has appointed a task force on the adoption of smart grid technology, and has charged the Central Power Research Institute with helping to finalize standards; the Ministry is conducting capacity building and awareness programs for the adoption of standards, which should be released during 2010.

Indian companies that are developing products for world markets have adopted a standards-based approach for software integration. Significant contributions towards integrated applications are also being made as a result of the focus on utility business applications in R-APDRP, such as enterprise resource planning systems, customer relations management, and meter data analysis solutions. This, in turn, will encourage standards-based provisions for backward compatibility so that it becomes easier to migrate from one technology to another and to make those technologies interoperable.

Software standardization in the distribution sector is being based on International Electrotechnical Commission standards (IEC SG / IEEE SG P 2030), which will help ensure:

- **Interoperability:** The capability of "plug and play" devices and software is important for the field devices, telecommunication channels, and IT system of the head-end equipment.

- **Open architecture:** A service-oriented architecture produces savings in both capital and life cycle costs. Adopting a non-proprietary architecture will eliminate vendor lock-in, be easier to maintain than the architectures of disparate proprietary systems, and will help in the development of uniform systems across enterprises because when vendors compete, innovations result.

- **Based on industry- accepted standards**: Architectures that conform to such standards protect the utility's investment, reduce the risk of obsolescence, and ensure a smooth migration to future technologies.

Unfortunately, India's utilities lack the basic hardware and software required to deploy a smart grid. India's utilities have not adopted large-scale basic enterprise systems or followed a broad IT strategy (the few exceptions are mainly found in private distribution utilities). Most deployments are limited to a few functionalities such as computerized billings and setting up control centers. Several pilot projects have been implemented and most deployments have delivered results, but an integrated approach and road map for taking these pilots to the utility scale are still needed to enable smart grid implementations.

A major hurdle to be overcome in India is that the asset and customer repositories are not being updated. A GIS-based approach is being adopted in R-APDRP, which will require validating and migrating current data to create an integrated customer asset profile. Several aspects of a comprehensive strategy and plan have been addressed in R-APDRP, but successful implementation and a utility-wide scaling plan are absent.

R-APDRP partially addresses customer relationship management, outage management, and work management. From a smart grid perspective, however, power resource management (trading and contracts, settlement and risk) needs to be addressed on a functional level, as do network management at the operations level and home area networks for communications.

At the infrastructure level, the smart home infrastructure (smart thermostats, load control devices, gateways, etc.) has also not been addressed. Government support for these technologies, through incentives and subsidies, will help build meaningful volumes and spur adoption. In summary, India is some distance away from the time when peak power demand loads can be assessed at the customer and cluster levels.

2.5 Customer Relations Management

Customer management, particularly regarding increased availability and reduced commercial losses, is key driver for the smart grid. India has a long way to go in customer management because most of its distribution companies are in various stages of updating and organizing their customer information. Under R-APDRP they are investing in business applications that will help integrate the various pieces of customer information over various customer databases.

Utility customers are becoming more demanding and impatient. They expect utilities to produce such benefits as:

- Reduced outages
- Lower bills
- Increased awareness and control over energy consumption through better information on usage patterns (the telecom industry has achieved something akin to this)
- More choices for energy sources along with options to supply energy to the grid
- More green and renewable choices to increase environmental sustainability (this pressure is greater now that the price gap between peak power, solar and diesel generation alternatives is closing).

Integrating customer relations management (CRM) and advanced metering infrastructure (AMI) data will be a key enabler here, as it will help derive the benefits of optimized capacity utilization and system performance. Up-to-date load data at each feeder section are required along with customer load profiles in order to develop auto fault detection, location isolation, and service restoration. In addition such data will help evolve fault isolation and service restoration switching sequences for premium customers. This integration will also enable utilities to set up quick response teams that will improve demand response (DR) and lead to the integration of AMI/DR in systems planning and engineering. Coincident load data for optimized load balancing and the potential for using AMI for end voltage monitoring will help complete the load profile data for estimating and minimizing technical losses.

Currently meter vendors in many Indian states own the meter data. A holistic approach for meter data management will help bridge this gap and build the ability to conduct end voltage monitoring. Thus, knowledge of customers' profiles with their usage requirements and patterns is critical for utilities wishing to implement a smart grid.

Complete knowledge of customers and their needs will also allow utilities to influence consumers to shift peak demand consumption and protect customers from over-consumption. In addition, it will enable utilities to help customers comply with contract fulfillments, environmental and security regulations. This, in turn, will help utilities to manage their assets, improve customer service, and control costs.

An important aspect of CRM is customer awareness (education) and participation. Customers will be important stakeholders in the smart grid and they will need to be more aware of the risks involved. For example, unless availability-based tariff customers modify their usage patterns, they will see higher bills. Also, because smart meters will be more accurate than current electromechanical meters, customers' usage will be tracked more accurately and they may see higher bills. Last, the energy savings accrued through smart grids will need to be distributed and incentives to conserve energy will be needed. Customer participation will be important in all of these activities and will also help improve the smart grid's overall governance and utility-wide implementations.

Automated call centers

The infrastructure set up for automated call centers is being developed under the R-APDRP. These centers will allow utilities to integrate customer information, address customer queries and complaints, and provide basic information about office locations, billing information, bill payment centers, modes, connection status, service levels, planned outages, and information on efficiency programs, among others. These initiatives will help utilities measure and drive customer satisfaction, and make customers more aware of opportunities for energy efficiency. They will also help utilities track consumption patterns and payments. In addition, the databases maintained by the centers would enable quick-start smart grid implementations, through targeted programs for home area networks and smart appliances projects to increase availability and reduce commercial losses.

At present, the complaint handling process in India is weak, resulting in decreased customer satisfaction. However, these centers are helping build better processes and more accountability within the utilities.

Utility portals

Utility portals (interactive websites that are linked to the call center databases and help customers log directly into websites) are being enhanced under R- APDRP. Their objectives are similar to those of the automated call centers and give customers another medium for interacting with the utility. Again, private utilities are leading in this area in

India. Government-owned utilities are also implementing portals, but a few of these have failed due to a lack of training staff and integration of IT into the workflow. Because of this lack of integration, many state-owned utilities find it necessary to maintain a paper-based system as well, resulting in a duplication of effort.

Informing customers before and during meter change-out

The change-out of an existing meter is often a contentious issue for customers, especially when the new electronic meter registers a higher bill. The reasons why customers' bills can be higher after a meter change-out are well known and are not repeated here. In addition, the customer may have to bear some of the costs of the change-out. For example, the customer's electrical installation may not comply with electrical safety codes, and the installation may have be the rehabilitated at the customer's expense.

A customer relations program is needed to alert customers to the upcoming meter change-out. It should spell out what the customer's rights are, explain the long-run benefits of smart meters, and describe how the change-out will be conducted.

Resolving bill complaints

When a new, accurate meter replaces an old, inaccurate or tampered meter, the customer will receive a higher bill. The customer relations program of the utility needs to be ready to address this collateral effect of the re-metering program.

2.6 Some Illustrative Applications

This section presents some examples of the application of smart grid and smart metering, and the issues that will likely arise with their implementation in India. The extant literature provides numerous examples and offerings of the features and benefits of smart grids and smart metering. Annex A lists some of the more salient literature.

Automatic meter reading

Automatic meter reading is often the most widely implemented smart system in a utility. Its contribution to making the grid smarter is that meter data are rapidly and accurately collected. Many countries have adopted this technology to save labor costs, but labor costs are not an important factor in India. However, in India, as in other countries, automatic meter reading facilitates the collection of data that are critical for utility planning and implementation. Such data also improve the inputs to the retail tariff structure, help with regulatory compliance, and help customers better understand their consumption and plan their usage accordingly.

Remote disconnect and reconnect

The remote disconnection and reconnection of customers who do not pay their bills is an extension of automated meter reading. The meter contains, or controls, a large contactor (relay) that disconnects or reconnects the customer from the head-end system, most often the billing system.

Outage monitoring and evaluation

SAIDI, SAIFI, and CAIDI are common measures of the power system network's availability and reliability. The collection of the field data to perform these measurements is time consuming, tedious, prone to arithmetic errors, and open to manipulation by personnel who collect the data. Smart devices on the distribution system (meters, reclosers, circuit breaker controllers, etc.) that are equipped with remote reading capability make the collection of field data automatic and accurate. This will help the utility improve its planning process and optimize the resources deployed in power restoration.

Mini-SCADA

In the past, the high cost and large size of RTUs for SCADA limited SCADA systems to the transmission network. As the size of RTUs increases and their costs decrease, SCADA is penetrating the distribution networks.

Demand-side management and load management

Like automated meter reading, demand-side management and load management have long been features of the utility system. As the cost of the field devices for demand-side and load management drops and their functionality increases, these devices will become increasingly integrated into customers' lives.

Renewable energy

Wind generation, small hydro, micro hydro, bio gas generation, bio gas fuel cells, solar and similar supply-side technologies need to be integrated into the power system network. Smart control devices are needed to connect these renewable energy sources to the power grid, and exchange information and commands with the energy dispatch center.

Distributed, standby, mini-grids, and off-grid generation

A large portion of India's energy comes from distributed, standby, mini-grid, and off-grid generation sources. However, as rural electrification extends farther into un-electrified areas, there is a concern that the arrival of relatively inexpensive national grid energy will lead to the abandonment of much off-grid generation. Since there may not be a corresponding increase in national generation, the sudden addition of off-grid load to the national grid will increase load shedding.

The smart grid offers a way to incorporate these sources of energy into the national grid in a rational and balanced way. For example, off-grid generation could be dispatched by the central control center and used only during peak times. Appropriate feed-in tariffs would compensate the off-grid generator for costs, and would shield the pool of customers from adverse pricing by blending the cost of off-grid generation with the average weighted price of electricity used in the tariff. The smart grid can convert this problem into an advantage for India, and changes in regulations and feed-in tariffs can manage the societal aspects.

Time-of-use rates

Time-of-use (TOU) tariffs involve a sharing of some risks between the utility and the customer. During those times of the day when energy is cheap for the utility (early morning hours and weekends), the savings are passed on to the customer. When energy is expensive for the utility (peak times) the customer experiences the high cost. The objective is for customers to shift their utilization in response to a price signal,

For over two decades electronic static meters have been available to handle TOU tariffs. In fact, they handle very complicated and very extensive tariffs (on peak, shoulder peak, and off peak; fixed and variable holidays; seasonal data capture; etc.). A difficulty that a smart grid can overcome is the effort needed to re-configure the meters on a regular basis, which will allow TOU tariffs to change as rapidly as desired by the utility and customer. The smart grid, with its telecommunication link between the customer information (billing) computer system and the meter in the field, overcomes this.

Islanding

At the transmission level, large sections of a utility, state, or region may be cut off from other sections in order to preserve the electrical system during major system disturbances and block cascading outages. Such systems have been used for many decades, having been perfected and extensively implemented in Russia before 1990. These protection systems operate very fast, and keep generation and load in balance; when a generating unit trips, a corresponding block of load is immediately tripped. Within minutes other generators increase their output and when spinning reserve and frequency are strong, the load that was shed is reconnected, usually within minutes. The philosophy behind this is to keep most of the electric system operating so that power can be restored quickly and efficiently.

The smart grid can do the same thing at the distribution level, rapidly isolating failed portions of the network and restoring service automatically and rapidly.

Capacitor control

Capacitor control in the distribution network has a direct and significant effect on customer satisfaction. It also improves utilities' financial performance by reducing a component of technical losses. If capacitor control is implemented poorly, there will be insufficient capacitor support during periods of high demand and low voltage (peak times), and over-compensation during periods of light load and high voltage (midnight to dawn, and weekends).

When integrated into a smart grid, advanced capacitor control by the utility (not the customer) allows the utility to provide the right amount of capacitor injection at the right time. This approach also removes a requirement on customers to install, operate, control, and maintain their own capacitors.

Demand response

Smart grid applications allow electricity producers and customers to communicate with one another and make decisions about how and when to produce and consume. This emerging technology will allow customers to shift from an event-based demand response where the utility requests the shedding of load, towards a more 24/7-based demand response where the customer sees incentives for controlling load at all times. Although this utility-customer dialogue increases the opportunities for demand response, customers are still largely influenced by behavioral as well as economic incentives and many have demonstrated reluctance to relinquish total control of their assets to utility companies.

One advantage of a smart grid application is time-based pricing. Customers who traditionally pay a fixed rate for kWh and kW/month can set their threshold and adjust their usage to take advantage of fluctuating prices. This may require the use of an energy management system to control appliances and equipment, and can involve economies of scale. Another advantage, mainly for large customers with generation, is being able to closely monitor, shift, and balance load in a way that allows the customer to save during times of peak load, not only kWh.

Smart grid applications increase the opportunities for demand response by providing real-time data to producers and consumers, but economic and environmental incentives remain the driving force behind this practice. The foundation for this would again be having accurate customer profiles with load, consumption pattern and asset data so as to be able to evolve customer segmentation and develop business cases for supporting each of those categories with different plans and incentives.

Table 5 summarizes the areas in which each of the technologies discussed above makes its greatest contribution.

Phasor Measurement Units

Phasor measurement units (PMUs) are the most accurate and advanced technology available for wide area monitoring, protection and control. A well-planned, system-wide PMU deployment over optimal system architecture provides several unique advantages, including the avoidance of outages as the result of a true early warning system, congestion mitigation through better system margin management and better "state estimation" for the location marginal pricing that will be increasingly required to enable transmission grids that optimize competitive markets.

Invisible smarts: Let's talk synchrophasors

Synchrophasors, aka synchrophasor measurement units, or PMUs, have been upgraded with the advent of the civilian use of global positioning system (GPS) to provide near real-time data on wide areas of the grid and its behavior. Before that, PMUs provided forensic data on past events such as blackouts. Today, they can provide the basis for making decisions that could prevent blackouts.

PMUs measure grid conditions about 30 times per second, a considerable improvement over the once per four seconds possible in the past. Each measurement is "time stamped" using GPS so that different utility grids in an interconnection can be compared and realigned. Those comparisons are expressed in degrees, as in a compass bearing. If two interconnected grids are seriously out of phase, for example, there may be trouble ahead an PMUs can provide operators with timely data to suggest a correction.

PMUs can be discreet, dedicated devices installed at the substation or they can be digital fault recorders (DFRs0 or relays already in place and optimized to provide analogous data. So thepatchwork of grids that make up an interconnection such as the Western interconnection already have some PMUs in place. Now, more than 800 additional PMUs will be added to the North American bulk power system over three years using federal investment grants.

The transmission operator employing PMUs collects the raw data and "pushes it up" to a regional data concentrator (CAISO in the West, TVA in the East, etc.) that archives and time-aligns the data. That data is fed to applications that translate it into actionable intelligence such as the Real time Dynamics Monitoring System (RTDMS), a phasor application program.

30 March 2010
Phil Carson
Intelligent Utility Daily

Table 5: Technology contributions to the smart grid

	Availability	**Reliability**	**Reduce operating costs**	**Reduce commercial losses**	**Increase electricity supply**	**CRM applicable**
Automated meter reading			■	■	■	■
Remote disconnection and reconnection			■	■		■
Outage monitoring and evaluation	■	■				
Mini-SCADA	■	■	■		■	
DSM and LM			■		■	■
Renewable energy					■	■
Distributed, standby and off-grid generation					■	■
Time-of-use tariffs			■		■	■
Islanding	■	■	■		■	
Capacitor control		■	■		■	
Demand response			■	■		■
Phasor Measurement Unit	■	■	■			

Chapter 3 Engineering Economics and Financing

Since the early 2000s, the Government of India's policy has been to balance the development of generation, transmission, and distribution. This policy has served as the touchstone for a number of financing innovations to deal with the power sector's large capital investment deficit: unbundling the vertically-integrated power companies to improve their performance and accountability, attracting increasing private sector participation, expanding all sources of capital market financing (bonds, listings and privatizations), and continuing public and multilateral investments in strengthening and expanding transmission and distribution, in particular. These new capital sources are expected to play a role in smart grid roll-outs in India.

> In the United States, the Electric Power Research Institute developed a *Methodological Approach for Estimating Benefits and Costs of Smart Grid Demonstration Projects*, with joint funding from the US Department of Energy (DOE). The report, issued in January 2010, shows the importance EPRI and DOE place on cost-benefit analysis (CBA). Our interpretation of this action is that they (correctly) realized that CBA may well become the pivot point in the assessment of proposed smart grid projects. If too narrow an approach is taken, some otherwise worthy projects may be rejected. The comments in this engineering economics chapter are consistent with the findings of EPRI's report.

A number of problems, however, will continue to hamper smart grid deployments and must be factored in during project design, including the determination of the financial feasibility of investing in projects.

The poor balance sheets of many electric utilities, coupled with the lack of an efficient procurement and project management culture at most State Electricity Boards, has resulted in inadequate investments in state transmission and distribution systems. In addition, many of the utilities that are undertaking projects under the Restructured Accelerated Power Development and Reform Programme lack management experience with R-APDRP; this lack of experience spans the full project cycle, from formulation to appraisal, procurement, construction supervision and commissioning. As a result of the lack of automation (computerization and telecommunications) in their businesses, the discoms also have a serious skills deficit in information and communications technology (ICT). Many will also be hard pressed to attract qualified talent to join bureaucracies that are still dominated by work cultures and practices of the past.

The barriers to implementing smart grid concepts in India are much the same as the barriers that have slowed power sector reform since market liberalization was first announced almost 20 years ago. With the government already running severe losses on its current power subsidies, the additional cost of moving to a smart grid will be problematic. If there are only limited fiscal benefits from smart grid investments in the short term, it will be a challenge to get a commitment for significant additional funds from the government. Hence, innovative financing alternatives will have to be explored.

Some possible avenues for funding include a combination of grants, self-funding, and public-private partnerships. Ultimately, however, the widespread implementation of a broad interpretation of the smart grid vision may be held back by the sector's lack of commercial viability.

In India, smart grid projects will be subject to the same issues that face conventional utility capital projects. Cost-benefit methodologies have been established for energy efficiency and renewable energy projects, and these can serve as a starting point for determining the viability of smart grid projects.

3.1 Engineering Economic Issues

The smart grid is a system that enables two-way communication between consumers and electric power companies. In this system, electric power companies receive consumer's information in order to provide the most efficient electric network operations. At the same time, consumers get better access to data to help them make intelligent decisions about their consumption. Thus, project economics will need to reflect the benefits to both consumers and utilities.

A top-down review of "typical" smart grid projects reveals that a large capital outlay will usually be required to fund the various aspects of implementation. The primary costs will include automated metering infrastructure, customer systems such as in-home displays and digitally controlled appliances, and electric distribution and transmission system grid automation.

The primary benefits include lower operating and maintenance costs, lower peak demand, increased reliability and power quality, reductions in carbon emissions, expansion of access to electricity, and lower energy costs from fuel switching and home automation.

3.2 Traditional Cost-Benefit Analysis

Although many countries have been discussing the concept of a smart grid for several years, projects are only now beginning to move forward. In the United States, where many projects are in various stages of preparation, most project sponsors are using traditional cost-benefit approaches to gauge their projects' viability.[29]

The suggested cost-benefit analysis methodology described here has three main objectives:

- Develop a common cost-benefit methodology that can be applied across all smart grid demonstrations (approved by financing sources and regulators)
- Publish an agreed upon methodology, including underlying rules and assumptions
- Ensure that the methodology can easily accommodate changes and expansion.

In order to work out the engineering economics of smart grid projects, one needs to consider various scenarios with selected elements being implemented in a phased manner.

This section presents a high-level framework for identifying the typical costs attached to the various elements of smart grid and the potential benefits associated with its projects. This framework must be customized for each project.

While still new enough to lack a universally agreed upon definition, some typical project components of a smart grid include:

- ***Smart power meters*** featuring two-way communications between consumers and power providers to automate billing data collection, detect outages, and dispatch repair crews to the correct location faster. This one element — sensors and two-way communication and control equipment — is central to most definitions. Smart measurement and metering also often embrace smart substation and smart distribution (together known as distribution automation). Collectively, these elements represent the *de facto* core of most programs that are being proposed or implemented.

- ***Smart substations*** include the monitoring and control of critical and non-critical operational data such as power factor performance, security, and breaker, transformer and battery status.

- ***Smart distribution*** is self-healing, self-balancing and self-optimizing, including superconducting cables for long-distance transmission, and automated monitoring and analysis tools capable of detecting or even predicting cable and other failures based on real-time data on weather, outage history, etc.

- ***Smart generation*** capable of "learning" the unique behavior of power generation resources to optimize energy production, and to automatically maintain voltage, frequency and power factor standards based on feedback from

[29] The American Recovery and Reinvestment Act (ARRA), known as the Stimulus Plan, provided $4.5 billion in grant funding for smart grid investments for qualified applications that were approved by the US Department of Energy.

multiple points in the grid.

- ***Universal access to affordable, low-carbon electrical power generation*** (e.g., wind turbines, concentrating solar power systems, photovoltaic panels) and storage (e.g., in batteries, flywheels or super-capacitors or in plug-in hybrid electric vehicles).

- ***Intelligent appliances*** capable of deciding when to use power based on pre-set customer preferences. This can go a long way toward reducing peak loads, which has a major impact on electricity generation costs by alleviating the need for new power plants and cutting down on damaging greenhouse gas emissions. Early tests with smart grids show that consumers can save up to 25% on their energy usage by simply providing them with information on that usage and the tools to manage it.

Cost analysis

The typical costs associated with the smart grid are categorized according to the elements and functions they provide. The major cost items are:

- Cost of project design and feasibility studies
- Cost of program management
- Cost of setting up infrastructure to enable two-way communications between the consumer and the utility; this will include the costs of the communications medium (e.g., fiber optic, PLC), installing sensors, monitoring equipment, and software, and an online tracking mechanism
- Cost of purchasing and installing the smart meters
- Costs for in-home devices and customer information systems
- Training and development of key staff.

It is difficult to provide a more specific sense of costs because most of the utilities in the US and Europe are still in the initial stages of implementing smart metering, so the actual costs of deployment are not available. However, from the estimated cost proposals submitted by various US utilities (such as PG&E and Allegheny Power), the total capital invested tends to vary from ***$250 to $600 per meter installed.*** It is notable that the range provided by utilities is wide and hence estimating a reasonable cost based on this range is not prudent.[30]

Some key variables that can have a major impact on costs are also worth noting:

- Size of the project, which is determined by the number of transmission and distribution lines in the grid, and number of buildings to be covered
- Strength and compatibility of the existing infrastructure, if the project is not a green field project

[30] Furthermore, it may be possible to manufacture meters with comparable features and functionality, but at a much lower cost, in India.

- Ability to forecast the schedule of generation for that area.

Benefits analysis

The move to a smarter grid promises to change the power industry's entire business model and its relationship with all stakeholders, involving and affecting utilities, regulators, energy service providers, technology and automation vendors, and all consumers of electric power.

The smart grid envisages providing choices to every customer and enabling them to control the timing and amount of power they consume based upon the price of the power at a particular moment of time. Some basic benefits of a smart grid are:

- ***Peak load reduction.*** Smart grids can use time-of-day price signals to reduce peak load – this benefit has particular importance for Indian utilities coping with urban loads.

- ***AT& C loss reduction***. For Indian utilities, this is a major driver from a commercial and regulatory point of view. For distribution operations with high losses that are upgrading meters and other equipment, companies may consider smart grid components as a way to build in additional communication technology and upgrades.

- ***Self-healing.*** A smart grid automatically detects and responds to routine problems and quickly recovers if they occur, minimizing downtime and financial loss.

- ***Consumer motivation.*** A smart grid gives all consumers – industrial, commercial, and residential – visibility into real-time pricing, and affords them the opportunity to choose the volume of consumption and price that best suits their needs.

- ***Attack resistance.*** A smart grid has security built-in from the ground up.

- ***Improved power quality.*** A smart grid provides power free of sags, spikes, disturbances and interruptions. It is suitable for use by the data center, computers, electronics and robotic manufacturing that power an economy.

- ***Accommodation of all generation and storage options.*** A smart grid enables "plug-and-play" interconnection to multiple and distributed sources of power and storage (e.g., wind, solar, battery storage).

- ***Enabled markets.*** By providing consistently dependable operation, a smart grid supports energy markets that encourage both investment and innovation.

- ***Optimized assets and operating efficiently.*** A smart grid enables the construction of less new infrastructure and the transmittal of more power through existing systems, thereby requiring less spending to operate and maintain the grid.

These benefits can be combined under three broad categories:

Economic benefits. Five types of economic benefits can be derived from the smart grid.

- ***Cost savings from peak load reduction.*** Smart grids bring about a reduction in per-unit production costs due to demand response / load management programs.

- ***Reductions in capacity costs.*** These can be attributed *to* residential customer reductions in demand during the 50 to 100 hours of highest system demand each year (critical peak periods) in response to some form of dynamic pricing, either peak time rebates or critical peak pricing.

- ***Deferred capital spending for generation, transmission, and distribution investments.*** By reducing peak demand, a smart grid can reduce the need for additional transmission lines and power plants that would otherwise be needed to meet that demand.

- ***Reduced operations and maintenance costs.*** Smart grid technologies allow for remote and automated disconnections and reconnections, which eliminate unneeded field trips, reduce consumer outage and high-bill calls, and ultimately reduce O&M costs. Reduced costs can also result from near real-time remote asset monitoring, enabling utilities to move from time-based maintenance practices to equipment condition-based maintenance.

- ***Reduced industrial consumer costs.*** Industrial and commercial consumers could benefit significantly from a smart grid. Electric motors account for about 65% of industrial electricity usage because they power virtually every moving process necessary for process industries, including power generation, oil and mining extraction, and pharmaceuticals, as well as for the compression and pumping needed for heating and cooling buildings. Motors are also essential to India's growing manufacturing sector for automobiles and other products. Small improvements in motor efficiency can generate significant savings in energy costs, but more sophisticated motors require higher-quality power.

Service benefits. The smart grid will bring benefits to residential, commercial, and industrial consumers alike:

- ***Improved reliability.*** A smart grid enables significant improvements in power quality and reliability. Smart meters will allow utilities to confirm more easily that meters are working properly. Two-way communications all across the grid will let utilities remotely identify, locate, isolate, and restore power outages more quickly without having to send field crews on trouble calls. A smart grid could eliminate up to 50% of trouble calls in a mature power sector.

- ***Increased efficiency of power delivery.*** Up to a 30% reduction in distribution losses is possible from optimal power factor performance and system balancing. Today, this problem is managed to some extent by controlled or automated capacitor banks on distribution circuits and in substations. But the control of these devices can be greatly improved with better real-time information through a smart grid.

- ***Consumption management.*** Smart grid technologies offer consumers the knowledge and ability to manage their own consumption habits through in-home or building automation. Advanced meters tell consumers how energy is used within their home or business, what that usage costs them, and what kind of impact that usage has on the environment. They can manage their usage interactively or set preferences that tell the utility to automatically make adjustments based on those choices.

- ***Improved system security.*** Utilities are increasingly employing digital devices in substations to improve protection, enable substation automation, and increase reliability and control.

- ***Enhanced business and residential consumer service.*** The smart grid will allow automatic monitoring and proactive maintenance of end-use equipment, which can be an avenue for energy savings and reduced carbon emissions. Equipment is sometimes not properly commissioned when it is first installed or replaced. With the two-way communications of a smart grid infrastructure in place, a utility could monitor the performance of major consumer equipment through advanced interval metering and on-premise energy management control systems. The utility would thus be able to advise the consumer on the condition of specific facilities.

Environmental benefits. According to recent studies, the smart grid can reduce emissions at a lower cost than many of the newest clean energy technologies. The smart grid will reduce emissions in four ways:

- Enabling the integration of clean, renewable generation sources
- Reducing electrical losses
- Increasing the penetration of distributed energy resources
- Increasing energy conservation through feedback to consumers.

More specifically, emission reductions will come from:

- Expanded renewable resource integration, enabled by a smart grid through its "plug and play" capability.

- Reduced transmission and distribution electrical losses, as generation is placed closer to the load, load curves are flattened, flow patterns are optimized, more efficient components are deployed, and as power quality (e.g., harmonics and phase balance) are improved. Reduced losses translate to a corresponding reduction in gross generation, and hence, less emissions.

- Improved central generation efficiency, as units face flatter load curves.

- Increased penetration of distributed energy resources, including combined heat and power, and plug-in hybrid electric vehicles. These resources could provide fine-tuned support for the grid and ancillary services to increase efficiency and reduce energy-consuming spinning reserves.

- Increased conservation, as software provides feedback information about emissions to the marketplace and customers. This will also encourage consumers to invest in energy efficiency and demand response options to save money.

- Reductions in other major pollutants (e.g., nitrous and sulfur oxides, particulate matter, ozone) due to conservation and the use of cleaner energy sources.

Calculating project costs and benefits

The methodological approach for calculating smart grid project costs and benefits has several steps:

- Identify the assets/elements that are deployed for the smart grid's systems
- Assess the principal characteristics of the smart grid; each will have one or more metrics that are reflected in the project
- Identify, from a standardized set, the smart grid functions that each project element/asset could provide and what will be demonstrated
- Estimate benefits
- Map each function onto a standardized set of benefit categories
- Define the project baseline and how it is to be estimated
- Identify and obtain the baseline and project data needed to calculate each type of benefit
- Quantify the benefits
- Monetize the benefits
- Estimate the relevant, annualized costs
- Compare costs to benefits.

An insightful point noted in EPRI's Cost Methodology is that there is third dimension to cost-benefit analysis (CBA) in the form of the level of precision. Since the biggest risk with CBA relates to the accuracy of the assumptions made, it makes sense to attempt to measure the precision of estimates. For smart grid projects, an ongoing data base of projects and project studies could be maintained to enable users to hone their estimates on the basis of experience. The importance of accurate estimates may also warrant a focused study of early implementers and/or a review of earlier studies of the experience of other "first time" implementations.

3.3 Estimating Technology Costs for a "First Time" Implementation

Five major types of technology costs will be incurred for a first-time implementation of a typical smart grid project:

- ***Integrated communications*** include data acquisition, protection, and control, and enable users to interact with intelligent electronic devices in an integrated system.
- ***Sensing and measurement technologies*** support acquiring data to evaluate the health and integrity of the grid. They support automatic meter reading, eliminate billing estimates, and prevent energy theft.
- ***Advanced components*** are used to determine the electrical behavior of the grid and can be applied in either standalone applications or connected together to create complex systems such as micrcogrids. The success, availability, and affordability of these components will be based on fundamental research and development gains in power electronics, superconductivity, materials, chemistry, and microelectronics.
- ***Advanced control methods*** are the devices and algorithms that will analyze, diagnose, and predict grid conditions, and autonomously take appropriate corrective actions to eliminate, mitigate, and prevent outages and power quality disturbances.
- ***Improved interfaces and decision support*** convert complex power-system data into information that can be easily understood by grid operators.

The categories of costs associated with these technologies are listed in Table 6.

Table 6: Typical cost categories for a smart grid implementation

Smart Grid Elements and Functionality	Prerequisites	Attached costs
Program design and appraisal		
Project feasibility and management	Need for project design team, feasibility studies, pilot projects and reporting requirements	Initial concept and pilot studies Feasibility studies Program management Measurement and verification
Demand-side management an energy efficiency		
Smart metering	Smart meter capable of two-way communication with control facility	Cost of smart meter and installation
	Automated meter infrastructure, including software	Cost of actual software and installation

Smart Grid Elements and Functionality	Prerequisites	Attached costs
	Display at consumer premises	Cost of display equipment
	Operational readiness	Cost of preparing the existing infrastructure compatible with the new metering
Load research	Meter having load survey capability for every category of consumers	Cost of smart meter or cost of upgrading a meter to provide this functionality
	Software capable of storing and processing data, and producing results in different scenarios	Software cost
	Facilitation through which load curve can be flattened including peak curtailment	Cost of man hours and training
Load control	Remote equipment control	Cost of equipment
	Adequate advance technological communication infrastructure	Cost of infrastructure including wiring, etc.
	Energy efficient appliances with remote control facility	Appliance costs
Integration of renewable energy sources		
Technically strong	Integration of renewable sources at any voltage	Cost of integrating the renewable source to the new grid
	Promotion of energy storage devices	Cost of running workshops to build consumer awareness for purchasing energy storage devices
	Adequate and robust protection system	Cost of installing the protection system
Plug-in hybrid electric vehicles	Market development of electrical vehicles	Cost of electrical vehicles and cost associated with bringing these to market
	Charging stations	Cost of building charging stations
	Advance information on charging price as per time-of-use pricing	Cost of monitoring equipment required to record time of use
Net metering	Regulatory insight and passage of tariff order	Regulatory intervention
	Promotion of solar roof top and other models	Promotion costs
Energy storage	Energy storage devices	Cost of energy storage devices and installation costs
	Batteries	Cost of batteries

Smart Grid Elements and Functionality	Prerequisites	Attached costs
Self-healing power quality		
Safety	Network sensors	Cost of network sensors
	Closed loop control system to detect and take appropriate preventive measures	Cost of loop control systems
	Automatic adjustment and curtailing of load through smart grid software	Cost of installing smart grid software
Online monitoring of network health vis-à-vis improving reliability indices	Network sensors	Cost of network sensors
	Preventive maintenance	Cost of monitoring and maintaining the system
Loss minimization		
Available transfer capability loss reduction	Online monitoring of energy audit	Cost of online systems
	Smart meter having control and bidirectional control facility	Cost of smart meter and installation
	Smart grid software integration with billing and other software	Cost of software
Asset optimization		
Increase power throughput on transmission and distribution assets	Online monitoring of asset utilization	Cost of installing an online monitoring system
	Network reconfiguration as per informed decision	Cost of reconfiguring the network
Workforce management		
Workforce effectiveness	Advance visualization and control system to support and automate decision making	Cost of visualization and control system
	Usage of emerging field technologies to improve crew safety and efficiency	Cost of using new field technologies
Consumer web portal		
Consumer awareness and control	Repository of consumer information (not data)	Cost of designing and running a consumer web portal

3.4 Risks Associated with Smart Grid Projects

Because of the lack of experience with the full-scale deployment of advanced metering infrastructure (AMI) and dynamic pricing, there are a number of uncertainties associated with certain of a smart grid's projected benefits and costs.

Assessing the Impact of a Project's Scale and Complexity, and the Impact of Resources Constraints

These uncertainties create a financial risk that the actual benefits from a smart meter plan may prove to be even less than the stated projections.

A number of AMI projects have not been approved in US and Europe due to the unclear projections and the lack of a contingency plan in case the utility becomes cash strapped. A recent example from US is the smart grid project by Xcel Energy in Colorado, where projected capital expenditures for the SmartGridCity went up from an initial estimate of $15.3 million in March 2008 to $27.9 million in May 2009. As of February 2010, the company believes the total bill will reach $42.1 million, not including the costs of operating and maintaining the new grid.

A large part of the increased price tag is associated with the unanticipated difficulty of the scale and resources required in constructing the system's fiber network. (See Annex B for a description of this program.)

Hence, it is important to plan in advance for unanticipated resource constraints while budgeting for a smart grid project.

The Effect of "Fast Tracking" on Project Schedules and Cost

The rapid development of both the technologies and rate designs and related AMI functionalities makes the job of the system planner complicated and challenging. Best practices require that the designers of the hardware, software and communications networks engineer the system to a well-defined end-state of functionalities. When evaluating project costs, they must determine exactly what the information will do, and who needs it for what purpose, at what time.

Utilities such as PG&E and Oncor in US have experienced difficulties because when they were attempting to fast track a project, they chose technologies that turned out not to have certain desired functionalities (in these cases, desired by the regulators). PG&E customers are paying incremental costs for functions that conceivably could have been integrated less expensively had the utility started with those specifications in mind before designing and bidding out its metering project. Oncor finds itself trying to recover the costs of a metering choice that was rendered obsolete when the state of Texas determined that utilities must provide different functionalities in their smart meters. Inasmuch as proponents of the smart grid point to the possibility of benefits not yet imagined, the continuing evolution of the smart grid presents challenges to system planners, especially at this early stage in its development.

"Systems Integration" Effect

The costs of information technology integration and software are the largest component in a smart grid project. A utility attempts to recover this cost through smart pricing techniques, which help in peak load management, thus reducing the utility's cost of generation and service. Response programs and rate offerings are provided to all ratepayers in the form of lower generation service costs due to the impacts of reductions in peak load wholesale capacity and energy prices.

However, the cost recovery aspects of a company's proposed smart grid plan include the level of annual revenue requirements to be recovered, the allocation of those revenue requirements among rate classes, and the design of the specific rates by rate class to recover those allocated revenue requirements. There is a minimum level of revenue requirements the utility banks on for this recovery. This is where the "systems integration" effect kicks in, when partial and isolated smart grid projects are planned. Such standalone projects typically cannot meet the minimum required level of revenue requirements because of their smaller scale, which leads to a more complex, more complicated and, sometimes, somewhat convoluted cost-benefit ratio.

Accelerated depreciation of technology

For many decades, once a utility plant was constructed or equipment installed, it could be reliably expected to remain in service for its estimated useful life. Many of these ranged from 10 to 40 years. Meters, for example, had useful lives of 10 to 15 years. However, advanced meters and metering systems employ computing technology.

The technological and cost curves for computers may be very different from the equipment historically used in the electric utility industry. If advanced metering systems exhibit technological and cost behaviors that are similar to those of computers, then their useful lives may turn out to be shorter than estimated.

Smart grid technology is classified among the high-technology systems and hence requires faster depreciation than traditional meters. For tax purposes, the use of accelerated depreciation would be an incentive for utilities to promote the technology.

Utilities with advanced meter and related programs already underway would benefit from the acceleration of depreciation, as their cash flows would increase as a result. But it may not be a powerful enough incentive to spur utilities that have not yet launched a smart grid initiative to undertake a smart grid program.

Accelerated depreciation could increase regulatory and political difficulties if it means higher expenses and, thus, a higher revenue requirement and increased upward pressure on tariffs. Governments could find that this adds to the difficulty of approving smart grid capital requests.

Although that could heighten resistance to smart grids, it should be evaluated in a larger context that considers externalities, e.g. carbon reduction, and the long-term benefits, including societal benefits. In India, this might be best done as part of a holistic assessment of the costs and benefits of smart grids. That could, and probably should, include an examination of innovative financing techniques and ways to provide incentives to spur smart grid development.

Risk of stranded assets

This could, as an example, involve equipment that was, at the point of installation, the state-of-the art, but (before it reached the end of its useful life) it was eclipsed by a newer technology that might cost significantly less. As (formerly) staid electric utilities take on some of the characteristics of high-tech industries, utility managers and regulators may have to deal with the unique challenge of cost recovery of significant asset values where the actual experience differs greatly from the assumed technological and economically useful life.

This is an example of a "known unknown." The more utilities take on the characteristics of a high-tech business, the greater will be the probability that the industry — as well as policy makers and regulators — will have to balance the competing needs of stability (i.e., allowing companies to recover investments over a long time to minimize rates) vs. the volatility (and potential write downs) associated with companies in competitive markets.

Deployment of smart grid technology will be piecemeal and utilities that do not install smart meters will still need to install conventional meters. This clearly establishes the risk of creating stranded assets, as the smart roll-out could make them redundant before the end of their asset life.

3.5 Examples of Recent Smart Grid Analyses

The experience with smart grids is recent in the United States and Europe; most of the projects have been implemented only within the last two years or so. In Asia (China and India), full smart grid projects are not underway, but there are a number of efforts toward a smart grid.

United States and Europe

In the US, most recent smart grid projects (e.g., smart metering) are driven by utility operational needs. In order to fund these upgrades, regulators and utilities propose to use the value of demand response programs such as load control and pricing-responsive rates to bridge the gap between operational savings and project cost. A complexity in this approach is that operational savings are difficult to pass on to consumers and utility regulators are more comfortable using traditional project valuation methodologies. Thus, these efficiency benefits might not garner the same weight as do operational

> The *Boulder Daily Camera* recently reported that the costs of Xcel's high-visibility smart grid pilot project in Boulder had increased to about $42 million, or almost three times the original estimate of two years ago. By itself, this is not a matter of grave concern, but it has attracted the attention of the state regulator because it raises the possibility that additional ratepayer funds may be required to for the introduction of the new technology.

benefits. Utilities are also beginning to attempt to value carbon reduction.

Benefits can also include emission reductions from the particular utility's generation mix taken against the price of carbon credits. While sometimes significant, these costs are not likely to bridge the gap that can run upwards of hundreds of millions of dollars on large smart metering projects. Carbon reduction may represent a growth opportunity, but current prices are at historic lows, although they are predicted to rise. Some examples of smart grid initiatives include:

Xcel Energy, USA. In May 2008, Xcel began implementing a smart grid network in Boulder, Colorado. SmartGridCityTM is a multi-phase project that will run through 2011. It is expected to provide customers with a portfolio of smart grid technologies designed to provide environmental, financial and operational benefits.

Centerpoint Energy, USA. In May 2008, CenterPoint Energy filed its advanced metering system initial deployment plan with the Texas Public Utilities Commission. The company anticipates that it will begin deploying up to 250,000 interactive meters and related infrastructure over a three-year period.

Oncor, USA. In March 2007, Oncor became the world's first utility to install S&C Electric Company's new TripSaver Dropout Recloser™ as a part of a smart grid initiative in which the electric grid will monitor, think, act, repair and prepare itself to respond quickly to consumer needs. The smart grid will heal itself, sense outages as they occur, monitor equipment performance, report back on needed maintenance, and more, all of which will result in an increase in reliability and service quality.

Southern California Edison, USA. Between 2009 and 2012, SCE plans to replace more than 5 million traditional electric meters with next-generation smart devices, making possible money-saving time-differentiated rates and demand response options as well as home area connectivity with appliances of the future. The new meter system will allow customers to set smart, communicating thermostats and appliances to respond automatically to periods of peak pricing and grid emergencies, potentially reducing overall peak demand on SCE's grid by as much as 1,000 MW – the output of a major power plant. The company also has a joint program with the Ford Motor Company to explore plug-in hybrid vehicles and vehicle-to-grid technology.

Pacific Gas & Electric, USA. PG&E is partnering with Tesla Motors to further evolve vehicle-to-grid (V2G) technology by researching smart charging (a form of V2G designed to allow remote control charging of electric vehicles connected to the power grid).

American Electric Power, USA. AEP is deploying advanced metering and an enhanced infrastructure. Initially, the systems are expected to be in place by 2010, and to be fully deployed by 2015 for more than 5 million customers. The company is also collaborating with General Electric to address the full energy pathway from the power plant to the customer's home.

San Agustin del Guadalix, Spain. This pilot includes both residential and commercial consumers. It consists of power supplied to building loads as well as to an experimental grid that supports the installation and re-configuration of a number of distributed components, and incorporates a variety of different power generating units such as photovoltaic panels, wind turbines and diesel generators. The energy management system enables power quality to be monitored and tested with varying configurations of distributed generators, storage systems and loads.

Supply Centre East, Germany. This pilot incorporates both commercial and industrial loads in six different buildings. Power sources include a battery system with a bi-directional inverter and a 5.5 kW co-generation plant. It also includes a high-bit-rate communication system that supports messaging between units solely via their power line connections. The utility can readily check to see how much it saves by managing the battery operation, and it can thereby benchmark future pricing to a privately owned combined heat and power facility.

Asia

Rabirashmi Abasan, Kolkata, India. In July 2008, Rabirashmi Abasan became the first housing project in India where residents have the option of generating power from rooftop solar photovoltaic panels, and selling it to the power grid utility. From now on, their electricity bills will reflect the difference between the energy consumed from the utility and how much they send to the grid.

BESCOM, Bangalore, India. The Karnataka Government will soon deliberate on the State's 2009 Renewable Energy Policy, whose aim is to "enhance the contribution of Renewable Energy in the total installed capacity of the state from 2400 MW to about 6600 MW by 2014." BESCOM is in talks with information companies to start a pilot project for a smart grid that could be replicated in other parts of the State.

SA Habitat and Valence Energy, India. In January 2009, a partnership project between property developer SA Habitat, and solar company Valence Energy, located on the outskirts of Hyderabad, incorporated renewable, decentralized energy production, smart grids, and home automation. Under this scheme, 18 of the 330 houses that make up this residential complex are equipped with a 4.2 kW solar photovoltaic system (it comes equipped with solar water heaters) on their roof, which will provide 40% of the complex's electricity needs. All of the equipment for this project is fully automated ("smart").

China: In April 2007, the MIT Forum on the Future of Energy in China took place in Shanghai. This led to the formation of the Joint US-China Cooperation on Clean Energy (JUCCCE), a non-government organization dedicated to bringing together international expertise and technologies to accelerate the use of clean and efficient energy in China. Since a third of particulate matter pollution in California comes from China, one of JUCCCE's primary goals is to identify and catalyze a regional pilot for a smart grid in China. In addition, JUCCCE will be giving away 10 million light bulbs at no cost to households in Shanghai, the pilot city for a clean lighting conversion program. This project alone will result in the reduction of over 2 million tons of CO_2 emissions over the five-year lifespan of the bulbs.

3.6 Challenges for the Smart Grid

Several challenges present themselves for smart grid development, and may affect the results of a cost-benefit analysis.

Financial resources. The business case for a self-healing grid is good, particularly if it includes societal benefits. But regulators will require extensive proof before authorizing major investments based heavily on societal benefits.

Government support. The industry may not have the financial capacity to fund new technologies without the aid of government programs to provide incentives for investment. The utility industry is capital-intensive, but has been sustaining exorbitant losses due to thefts and subsidization.

Compatible equipment. Some older equipment must be replaced as it cannot be retrofitted to be compatible with smart grid technologies. This may present a problem for utilities and regulators since keeping equipment beyond its depreciated life minimizes the capital cost to consumers. The early retirement of equipment may become an issue.

Speed of technology development. The solar shingle, the basement fuel cell, and the chimney wind generator were predicted 50 years ago as an integral part of the home of the future. This modest historical progress will need to accelerate.

Lack of policy and regulation. No defined standards and guidelines exist for the regulation of smart grid initiatives in India.

Capacity to absorb advanced technology. Most discoms have limited experience with even basic information and communications technology and, as a result, they have weak internal skills to manage this critical component of smart grids. R-APDRP aims to provide some redress, but it is relatively recent and has not yet had a major impact on the industry. The industry's reluctance to implement ICT appears to have been a by-product of a desire to avoid transparency, especially in meter-billing-collection processes. Now, the lack of automation and the heavy dependence on outsiders for ICT know-how is an unavoidable penalty for any effort to implement a smart grid vision. This suggests that 1) policy makers actively discourage the organizational culture that fostered a lack of transparency, 2) recruiting and capacity building in these areas should be accelerated, and 3) partnerships with leading Indian ICT organizations should be considered as a means to accelerate implementation of smart grid concepts.

Consumer education. "Customer response" is the phrase used to describe the reaction of customers to the new features and functionality enabled by the smart grid. If, for example, a company installs advanced metering and two-way communication along with time-of-use rates, the question is "Will customers use it?" If there aren't enough customers who use the features, the benefits of a smart grid will not be achieved. Thus, two critical and often overlooked components of a smart grid implementations are 1) sufficient marketing analysis and product design to optimize the likelihood that customers will use the new technology, and 2) an education, communication and public relations program aimed at creating an understanding of smart grids, the associated benefits and the potential implementation issues. The program should be aimed at customers but also policy makers, opinion leaders, regulators and financial institutions.

Cooperation. The challenge for diverse State utilities will be the cooperation needed to install critical circuit ties and freely exchange information to implement smart grid concepts.

Cost assessment. Costs could ultimately be higher than projected because the standards and protocols needed to design and operate an advanced metering infrastructure are still in a state of flux. Thus, investments made now, before the standards are settled, have a higher risk of obsolescence. Failure to include estimates of the costs for the control equipment customers will install to automate their response to time-differentiated pricing could put smart grid investments at risk. Other risks include 1) no demonstration that the proposed project is more cost-effective than alternative approaches that will achieve the same major energy cost reduction objectives at less cost and 2) exclusion of incremental costs of "stranded" existing meters (i.e., accelerated depreciation).

According to Anil Razdan, Secretary of Union Power Ministry, India's power demand is increasing at 8-10% per year. In October 2008, the Smart Grids India Conference was held to discuss the infrastructure needed to modernize the grid and to turn a "dumb grid' into a "smart grid." Indian utilities have been challenged to achieve the ambitious target set by the MOP to provide "power to all by 2012." According to California-based Echelon, this will take roughly an investment of $100 billion in technologies for generation, distribution, transmission, and monitoring.

Rate design. Many utilities are proposing to recover these costs via a customer surcharge. This is not reasonable, based on the view of cost causation, and will have disproportionate adverse impacts on low-usage customers.

Consumer protection. Privacy concerns about customer usage data and other personal data are real, but it is not clear how such data will be protected. Also, the installation of smart meters will open the door to remote involuntary disconnection and the use of service limiters, all of which limit customer access to and control over electricity service. Even unfounded concerns about a "spy in the house" may affect consumer attitudes. Thus, issues related to consumer privacy will likely be submitted to regulators and consumer protection agencies as soon as new technologies are planned.

Lack of empirical evidence. Utilities have done a number of pilot projects to test AMI and dynamic pricing on a limited basis, but it is only recently that several US utilities received regulatory approval to deploy AMI and dynamic pricing tariffs on a wide scale. In fact, most of those utilities are still in the process of completing deployment. The absence of robust empirical evidence regarding the performance and economics of AMI and dynamic pricing on a system-wide basis over time is a source of uncertainty over both long-term technical performance and the magnitude of peak load reductions that will actually be sustained in the long term in response to dynamic pricing.

Funding issues for India

Historically, building the grid through transmission and distribution lines has been undertaken by PowerGrid Corp. and various state-regulated distribution companies. Central programs such as APDRP and R-APDRP provided some support in modernizing and rationalizing the billing and metering systems, but there have been relatively few such programs.

While no one has estimated with any level of detail the costs required for India to upgrade to a smart grid, estimates range widely depending on the utilities involved and the timing.

Given the large investment required to build out the current set of plans, Indian utilities will need to experiment with how best to fund such projects. Based on a survey by the authors, most utilities are proposing to recover all of these costs via a fully reconcilable surcharge. Many are proposing to allocate these costs among rate classes according to the number of customers in each class. Some utilities are also proposing to recover these costs via a monthly customer surcharge.

With the introduction of smart grid technology at the distribution level, consumers will have more incentive to switch to a new tariff. The existing tariff structure will have to be rationalized and time-of-day tariffs must be introduced to provide incentives to consumers. Similarly, for new renewable generation, more system integration will be required to ensure system security.

Some possible alternatives for funding are presented below. However, these are only illustrative in nature. Detailed rounds of talks with government, banks and the private sector will need to be undertaken to rationalize and validate the plausibility of these alternatives.

For central sector lending, develop a new appraisal process for smart grid projects. Grant and loan funding for the smart grid can come through traditional sources (e.g., PFC), but a revised project appraisal process that incorporates operational benefits will be needed to evaluate project submittals.

Reach self-funding. Following the lead of on-going loss reduction projects, many smart grid projects will become self-funded by exceeding the stipulated payback periods.

Attract new players and bring in vendor financing. Information and communication technology companies such as IBM, Infosys, and Wipro have started smart grid programs and are developing commercial models. Some examples of pilot projects include those with real estate developers to implement small-scale smart grid projects for residential and commercial complexes.

Expand bank understanding of the smart grid. Banks that are already lending to the power sector will see the business case for the smart grid quickly and can act to increase funding directly to projects, or indirectly to companies and utilities.

The most prudent route is however, a combination of these sources through public-private partnerships. State utilities can take the lead on developing the business case for pilot implementations of smart grids and then invite private players to participate by providing both technical know-how and funding. Private players can further approach the banks to fund their investment.

Regulatory issues

India's electric power delivery system is much like the telecommunications network of the past – dated and increasingly costly for consumers. Like the telecommunications revolution, which created new technologies, choices and improved service levels, there is a need for a similar revolution in the power sector.

Being a highly regulated sector, regulatory intervention is imperative for successful smart grid implementation across the following key areas:

- Funding
- Consumer awareness
- Establishing common standards
- Playing the role of a "watchdog"
- Cyber-security
- Interoperability.

The Government of India is keen to prepare the power sector for the introduction of the smart grid. Indian utilities are showing initial interest and starting to explore the subject. The private sector, especially companies with global experience in smart grid technology, is helping the Indian market understand the concept of the smart grid.

Based on technical presentations and discussions held during a recent seminar on the subject of "Smart Power Grid," the following recommendations are being considered by the Government of India.

- India's Ministry of Power may appoint a task force consisting of various stakeholder representatives to study the status of smart grid implementations in other countries. It will consider various issues relevant to India in examining the introduction of smart grid technology and make suitable recommendations for introducing smart grids in the country at different levels.

- The Central Power Research Institute (CPRI), Bangalore, could be appointed as a nodal agency for the collection of data / information from other countries and assist the task force in its study and finalization of recommendations. CPRI could even coordinate with other agencies on the development of smart grid technologies.

- Institutions such as CPRI, IITs, technological universities like JNTU, IT industries etc., may be identified to conduct further research on the "smart grid" technology for implementation suitable for the Indian environment.

- Since the IT sector in distribution companies is being developed under R-APDRP, the scope of funding could be increased to introduce smart grid technology in distribution wherever distribution control centers are already in operation. One distribution company in each region may be selected to implement pilot projects, as recommended by the task force.

- A small region in a central location like Bangalore or Hyderabad could be selected to implement the concepts of the smart grid as a pilot project in order to update the status of the smart grid's design and implementation in a phased manner.

Other considerations

The potential benefits of the smart grid vision extend well beyond the power sector value chain. Thus, a utility-centric approach is too narrow and too parochial, and it probably won't produce the best results for customers and society. The only reason a state-owned utility deserves to exist is to benefit customers and the commonweal. Shaping a smart grid vision should begin with customers and customer solutions. The utility will play an important role in achieving these benefits – at least, it could play an important role – but the beneficiaries are the customers and commonweal of India.

It is difficult to monetize some of the gains or benefits of a smart grid. An improvement in the health of citizens due to a reduction in carbon emissions is one such benefit. Given the wide impact of smart grids, an innovative methodology for guiding CBA and project appraisals will be needed. In the United States, EPRI and DOE have recognized this need. They organized a high-level group for this purpose, but even with the very substantial work accomplished to date, their efforts are ongoing.

Certain of the benefits of smart grids can be monetized, but for others, the current regulatory framework or accounting rules may not be supportive. For example, utilities benefit from the increased sale of electricity, so there is no incentive to reduce sales by implementing DSM[31] – even though that would help reduce the supply-demand gap and benefit customers and society. Another example is the incentive utilities have to increase the absolute value of their earnings by expanding their asset base.[32] Perversely,

[31] Decoupling or, more specifically, revenue decoupling, has been proposed as an alternative. A decoupling mechanism seeks to provide an opportunity for a regulated power company to earn a fair return but in a way that "decouples" its earnings ability from sales volume.

[32] The phenomenon known as the Averch-Johnson Theorem is that utilities that are regulated under a "rate base, rate-of-return" approach demonstrate an observable tendency to over-invest in assets that can be included in rate base.

there is no incentive to deliver a high volume of electricity with existing assets. These issues suggest that some modifications to India's regulatory framework or accounting rules may be warranted.

Communications infrastructure is costly, yet is at the heart of the smart grid vision. As we move deeper into a smart grid world, communication will play an ever-larger role in the power sector. Often, utilities will argue that they should build their own communication infrastructure owing to reliability and security concerns. This could result in the duplication of infrastructure, and as noted earlier, the electricity sector may not have the bandwidth in term of ICT skills to engineer, procure and implement this technology. This suggests that it might be advantageous to encourage close coordination between the telecommunication and power sectors, with the participation of policy makers and regulators.

Chapter 4 Recommendations

The still-evolving concept of the smart grid is a vision of an industry transformed. The electric industry's historic business model will be changed, perhaps as much as the long-successful business model of the telephone industry was. For the electric industry, technology is the key enabling factor, but the situation is more complicated.

Whatever else might be said, the ultimate reality is that the electric industry desperately needs a new business model. Companies must learn how to prosper in an era of increasing unit costs, when their primary measures of service quality are either high but declining (as in the United States) or low and stagnant (as in India). As one industry observer recently put it:

> The electric industry is unique. Its real "customer"[33]… (has been the) regulator … An industry facing increasing costs per unit for the foreseeable future … (but without any) … obvious productivity gains to offset them and (that also) must ask permission to raise prices … (is not in) an enviable position.[34]

The smart grid concept results from the convergence of a number of trends that have been evolving for up to a half century, including:

- **Information and communications technology (ICT)** – Moore's Law continues in effect and ever-cheaper computer chips, sensors and controllers, coupled with increasingly sophisticated mobile and WiFi capabilities, have already begun to radically transform the data-intensive electric business.

- **Advances in metering technology** – Likewise, digital meters are increasingly affordable and rugged, and they have begun to replace electro-mechanical meters on a wholesale basis, even in some developing countries.

- **Costs** – The trend in the unit cost of electricity turned upward several decades ago, although that wasn't clear until more recently. The reality is that electric companies need to learn how to prosper during an era of increasing costs and

[33] In India, the state politician might be the "real" customer.

[34] Judith Warrick, in a speech at a clean technology conference in Palm Springs, California, on January 10, 2010 and as published in Morgan Stanley's Energy *Insight, January 25, 2010*

declining service quality. That may well require a "next new thing." If the smart grid is not the answer, the industry's future could be unpleasant as well as unprofitable.

- **The dawning of the digital age** – The automation of almost everything is occurring at a breathtaking pace. Likewise, the expansion of high-tech electronic manufacturing has spread in response to mushrooming demand. One side effect of the digital age is the increased demand for electricity as the premium form of energy (as the authors of *Perfect Power* put it, "Try running your laptop on a lump of coal") and the need for higher-quality power to run everything from delicate precision machinery to advanced household appliances.[35]

- **Growing prosperity** – It is difficult to acknowledge in the midst of the most serious recession in 75 years, but the world is becoming more affluent. There are significant risks attached to recent economic developments but, with the exception of a worst-case scenario, the long-term trend is still up. And customer expectations are rising in tandem with individual affluence.

- **Climate Change** – Mounting evidence is reinforcing the consensus of leading scientists that global warming is real, that it is a function of historic amounts of carbon that have been released to the environment as the result of human behavior. The reality of global warming and the increasing public concern it has triggered — and the close link between electricity production and carbon emissions — add an accelerant to the technological, utility cost and behavioral economic influences that are converging.

In the West, the smart grid vision is compelling, even though it may sound a bit like science fiction to some today. Of course, the early days of mobile telephones were characterized by "mobile" phones that were bigger than many laptop computers today. Despite the reality of the "convergence" of the historic forces discussed above, there are also some daunting hurdles, including:

- **Initial cost** – The utility sector is steeped in the concepts of return on investment (ROI) and cost-benefit analysis (CBA). The American Recovery and Reinvestment Act of 2009 (ARRA), also known as the stimulus package, set aside $4.5 billion for qualifying smart grid projects. This resulted in the telescoping forward of projects that otherwise would have been pursued over a longer time frame.

  Our study of smart grids, including discussions with knowledgeable experts on the cost of implementing smart grid technology, suggests that the initial stage may experience a significant increase in costs but without a commensurate near-term reduction in O&M costs from savings. Unknowns surrounding actual vs. projected costs and the nature and value of benefits may be difficult to quantify (fully) and assign a value. The engineering-economics chapter discusses several factors that

[35] Robert Galvin and Kurt Yeager, *Perfect Power: How the Microgrid Revolution Will Unleash Cleaner, Greener, More Abundant Energy,* McGraw-Hill Companies, 2008.

will complicate CBA. The significance of this issue is reflected in the fact that EPRI has been developing a CBA methodology tailored to smart grid projects.[36]

If the full benefits of the smart grid vision will not be realized until the full "system integration" effect kicks in, the debate may gravitate towards a battle between believers (i.e., in the potential of the smart grid vision) vs. skeptics. Unfortunately, regulators have an institutional responsibility to be skeptics.

- **Policy and regulatory** – The power sector is composed of an institutional complex that includes companies, regulators, governmental agencies, politicians and more. The laws, policies and regulations governing the behaviors of various actors are elaborate and detailed, and were developed over very long periods. The further the industry must move away from the traditional model in order to deploy a smart grid vision, the more it will require changes to existing policies and regulations. When policy, law and regulation must be changed as a precondition, the time frame to accomplish the desired result will be lengthened.

  One of the challenges for regulators and policymakers will be dealing with the societal benefits of smart grids. This will influence the cost-benefit analyses that must be done and it could become a difficult issue. For example, a reduction in utility O&M costs would offset the higher cost of installing advanced meters. However, discoms in India will not have a net gain from the reduction in labor-intensive meter reading activities, as will utilities in the West. But one benefit would be the increased transparency in consumption, billing and payment, and a reduction in aggregate technical and commercial losses.

  Other societal benefits will accrue once a more robust smart grid comes into existence, including micro-grids powered by renewable energy sources and more advanced variations of energy efficiency. Some of these will be quantifiable, but others will be more difficult, and there are some that may not materialize until the "system integration" effect comes into play.

  Costs will probably be easier to quantify. The full range of benefits, including some elusive societal benefits, will need to be properly valued too.

- **Technology** – How will the smart grid work? Within living memory, the electric industry was in the throes of an earlier transforming technology that was lauded by advocates as having the potential to produce energy that was "too cheap to meter." Alas, nuclear power is not the only or even the most recent "next new thing" that didn't deliver on its initial promise. Even though nuclear power has since become a vital part of a sustainable energy solution, the hype surrounding its introduction is not dissimilar to that surrounding the smart grid vision today. One question about the implementation of smart grid technology is whether a robust foundation must first be built before jumping into the new world of smart grids?

[36] US Department of Energy and the Electric Power Research Institute, *Methodological Approach for Estimating Benefits and Costs of Smart Grid Demonstration Projects*, January 2010.

For India, a critical question is: "How can you implement a smart grid when the existing grid isn't yet capable of providing reliable service to half the population?"

While this over-simplifies the issue, it does help frame an important question about the "how to" of adopting smart grid concepts. Pondering this issue can help develop an understanding of how the smart grid vision could be used to leapfrog into an entirely different future than the conventional path would lead to.

- **Customer response** – The most unique "human factor" in business is customer response. The electric industry's historic term for a customer ("ratepayer") says something about how they are still perceived in what has long been a centralized, bureaucratic, supply-side business. In competitive retail industries, marketing — developing customer solutions — is where strategy begins. Not so in the electricity business. Not yet.

  That may change even with powerful institutional forces aligned against it.

  In a business-as-usual case, India's state-owned monopolies may be evolving in a "Swiss cheese" pattern where high-profit customers with the ability to solve their own problems (e.g.,, industrials) are abandoning the SEBs for SEZs with captive power. Market liberalizations in other countries saw industrials become "first movers," but it didn't stop there. It probably won't in India either.

  For smart grid expenditures, proposed projects will have to pass rigorous CBA tests. However, even for those who are persuaded that the benefits of the smart grid vision will ultimately justify the costs incurred, there is still a question of the transition. Another question is who will bear the risks and costs relative to potential benefits. Customer response — specifically whether customers will pay extra for early smart grid features — has become a much-discussed issue for smart grids. The answer for some customers is "no," but it's difficult to judge consumer response to a service they have never experienced. Nonetheless, it's clear that cost will be important in shaping customer sentiment.

- **AT&C losses** – In India, the issue of aggregate technical and commercial (AT&C) losses must be added. A reduction in AT&C losses is central to reducing cost, improving cash flow and, thus, enhancing the financial viability of discoms so they can pursue measurable service quality improvements. Loss levels of 32% of total electricity produced are ruinous.

  Any effort to capitalize on the smart grid vision should build on India's continuing program to reduce AT&C losses. A smart grid initiative should begin with an enlargement of the R-APDRP program to link R-APDRP to the achievement of specific service quality improvements as measured by key performance indicators (KPIs) such as those developed by four discoms[37] under the MOP's distribution reform initiatives.

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[37] Banglaore Electricity Supply Company (BESCO) in Karnataka, MGVDCL in Gujarat, MSEDCL in Maharashtra, and North Delhi Power, Ltd. in New Delhi.

Electrification – Another key driver in India is electrification. Urban areas are expanding access to electricity, although considerable unevenness and significant power quality issues remain. In rural areas, access to electricity is lagging seriously. About 50% of rural households lack electricity and even where service is available, the rationing of supply with daily outages lasting for hours is the norm. The GOI is committed to an ambitious plan to make electric service universally available to all. The smart grid vision can help achieve that goal.

4.1 How Should India Respond to the Smart Grid Vision?

Does the smart grid vision make sense for India? We believe the answer is, "Absolutely." Nonetheless, an across-the-board implementation should not be attempted right away. While India's power sector needs a "next new thing" more than the power sectors in mature economies need a new business model, a selective and flexible approach will yield a better result than a "one size fits all" approach. Generally, the following are basic preconditions for the successful implementation of the smart grid:

- Commercially viable and self-sufficient discoms
- Public awareness and acceptance of the smart grid
- A national smart grid vision and a flexible plan
- Appropriate smart grid standards.

Optimally, these should all be in place before smart grid implementation is launched. These preconditions do not yet exist in India and it is likely that their achievement will be uneven going forward. In 2007-08, AT&C losses averaged 32% of total generation and, in 6 of 30 states, discom AT&C losses were above 50%.

Some might conclude that India should defer pursuing a smart grid vision. However, the same elements that are regarded as preconditions to the smart grid are also the ones that benefit most from the adoption of smart grid elements and principles. For instance, improved metering through the deployment of remote measurement and monitoring of energy use will help utilities better monitor energy use across the grid and allow them to trace the source of energy losses. The resulting improvement in transparency will lead to reduced losses and improved financial health of the sector. Smart grid technologies can enable improvement in meter-billing-collection systems and help reduce line losses.

ARRA's fast track approach in the USA

The American Recovery and Reinvestment Act of 2009 allocated $4.5 billion in grants for smart grids. A recent survey showed that 70% of utility managers said their companies would apply for a grant even though less than 45% felt the projects would achieve the desired results cost-effectively. It appears that ARRA has caused spending on smart grid projects to be telescoped forward. That is quite understandable (and a more reasonable risk in the US), but it has also resulted in a "fast track" situation that brings certain risks. The fast tracking of complex, large-scale projects brings a higher risk of cost and schedule overruns. By moving slowly, India will be able to learn from the experience of others, and possibly avoid some costly missteps.

Furthermore, investment in a smart grid today may enable India to leapfrog into a vastly improved electricity scenario. Even under a business-as-usual case, the GOI will have to invest heavily in the power sector over the next two decades and beyond. Smart grid technologies could enable India to leapfrog into a much more advanced grid infrastructure and electricity market, and more quickly achieve parity with developed economies.

Nonetheless, there is much unfinished business to be taken care of before adopting the more advanced features of smart grids on a broad scale. A strong follow through on earlier programs will be necessary to build the foundation needed for more advanced features of the smart grid vision. But that doesn't mean action should be deferred until a foundation is fully in place. Transitioning to a smart grid vision tailored to India's unique circumstances would have a number of dimensions:

- Develop a national vision and frame a flexible plan for pursuing smart grid benefits.
- Build on the R-APDRP program and link it to improvements in service quality as defined by measurable KPIs.
- Identify and implement smart grid concepts that reinforce the operational efficiency of discoms.
- Conduct customer and marketing surveys to develop a more refined understanding of what drives customer satisfaction, and analyses to develop a better understanding of demand and consumption (e.g.,, an analysis of the actual cost of "free" power and a profile of who receives agricultural power and how much, among other analyses).
- Develop policies and regulations to create a more receptive environment for smart grids, by encouraging innovation, establishing standards for interoperability, and allowing more market-oriented and entrepreneurial solutions.
- Implement techno-commercial "proof of concept" pilot projects for initiatives that have potentially high impacts and that can be implemented independently of the grid.

As part of its approach to adopting smart grid concepts, India should give priority to customers and customer solutions over the creation of another high-level commission.

The need for a commission is unavoidable given the structure of the power sector, but its convenors should make a conscious effort to limit the temptation to develop a top-down, "one size fits all" solution.

4.2 What are the Barriers to Smart Grid Implementation in India?

The barriers to implementing the so-called smart grid in India are much the same as those that have stymied power sector reform ever since market liberalization was first announced nearly 20 years ago. The problems that afflict India's power sector are many and serious, and are very well known to policy makers, industry experts and, indeed, the general public.

The loss of 32% of total electricity generated, the sector's legendary voltage fluctuations, chronic blackouts in rural areas, the lack of electricity connections for almost half the population, and so-called "free" power to the 25-30% of farmers with irrigation pumps are not simply unfortunate happenstance.

All these outcomes persist despite the GOI's Rs. 25,000 crore annual subsidy to the sector and what must now be the equivalent of many billions of dollars in time, effort and capital that have been invested in power sector reforms since the early 1990s. There are causes for these effects and, if left unaddressed, they could dampen the impact of any smart grid scheme as they did in the past for other initiatives.

The power sector's chronic problems must be acknowledged, but not accepted. Despite the troubled state of the industry, there have been some notable successes, including the Delhi public-private partnership, under which discoms operated by Tata Power's NDPL and two Reliance-owned discoms are revitalizing one of the most intractable electricity distribution systems in the country, and the franchise concept that offers intriguing potential[38] as does an early trial of an agricultural demand-side management (DSM)[39] project currently under contract with an electricity service company (ESCO) with BESCOM in Karnataka. In addition to BESCOM, several other state-owned discoms are moving forward with impressive accomplishments, including MSEDCL in Maharashtra, MGVDCL in Gujarat and APCPDCL in Andhra Pradesh.

But even with these successes, the pace of change is too slow. The world is moving faster and one insightful report on smart grids repeated a finding of other studies done in recent years: "… in India … the network's inefficiencies are severely impeding economic growth."[40] Globally, the trend in unit prices of electricity has turned upward

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[38] Early experiences with electricity franchising suggest that contractual terms and pricing must be revised to make the concept commercially viable.

[39] Designed under USAID's WENEXA II Project to reduce 22-30% of the electricity provided "free" for irrigation pumping.

[40] The Climate Group and the Global e-Sustainability Group, *SMART 2000,* with analytic support provided by McKinsey & Company.

and, in India, the penalty for delaying the step-function improvements needed to achieve the country's growth potential will continue to rise.

To add perspective, we note that the pay gap between India and the West seems to be shrinking as fast as the polar ice cap. On a fundamental level, this is a very positive development, but one that could expose India's soaring knowledge economy to a "productivity penalty" that won't be offset as easily as in the past by global labor rate differentials.

As experienced by other economies, electricity is an ever-more prized form of energy, especially for high-tech industries but, increasingly in manufacturing and other old-line industries too. It would be dangerous for India to be complacent about the importance of world-class electricity as an enabler of world-beating growth.

These conclusions are echoed by other reports, including The Climate Group's report, which includes a section on India's power sector as an example of how ICT as the enabling technology for a smart grid can help accomplish major reductions in carbon emissions. As the report states, the major hurdles are:

- No proven commercial viability for large-scale smart grid roll outs
- Poor financial health of most state-owned T&D companies
- Low awareness of technological developments in the utility sector
- No coordinated national road map for smart grid deployment
- A fragmented industry.[41]

These are daunting hurdles and the report's assessment reinforces the fact that the first step toward achieving the smart grid vision is to follow through on what has already been started. That doesn't mean the smart grid vision should not be pursued, but it would be equally dangerous to lose sight of the need to follow through on fundamental initiatives.

4.3 A Needs-Based Methodology[42]

Even for an individual electric company, setting a comprehensive smart grid strategy involves a complex mix of internal and external challenges:

- The technical challenges of new systems, new devices, new communications technologies, and a deluge of new data can be overwhelming

- The impact on existing business processes needs to be identified, with new business processes defined. The organization has to make itself ready for the significant and perhaps radical changes that will take place.

[41] Ibid., p. 49.

[42] This section draws on PA Consulting Group's *Smart Grid Executive Insights* and its "Connecting the Smart Grid Dots™ approach to developing a smart grid strategy.

- Customers, regulators and investors need to understand the change and be convinced that it is beneficial. A successful migration to a smart grid environment will require that all of them embrace the vision, not merely accept it.

Practically speaking, the organization has to assess how its end-to-end delivery and operational value chains will be affected and determine how smart grid enhancements can add value to the customer and other stakeholders. Given sufficient time and effort, all of these challenges are manageable. The test for corporate leaders is to create a shared vision and engage internal and external stakeholders in a common focus to collaborate and ensure that smart grid benefits are delivered cost effectively.

Accomplishing these aims for the entire power sector in India will be a much more daunting challenge than for any single entity.

The development and clear communication of a credible strategy is the single-most important thing to "get right" early. PA's "Connecting the Smart Grid Dots™" provides a framework to help define and communicate why the strategy is essential, how it can be achieved, and that it represents a well-designed program of change. The approach is shown in Figure 7.

The "takeaway" from this exhibit is that the complexity involved in migrating to a smart grid environment warrants a careful approach. "Connecting the Smart Grid Dots" can provide a framework to evaluate the needs and priorities of the sector, but achieving it will require a coordinated effort among a broad range of stakeholders.

Before proceeding with the detailed implementation, some questions must be answered. These relate to basic efficiency as well as the need to reduce carbon emissions.

"Electricity generation currently accounts for 57% of India's total emissions and will continue to do so until 2020. India's power network is highly inefficient and much of the generated electricity is wasted. The lack of transparency in the grid makes losses difficult to measure, but it is estimated that in 2007 India lost 32% of total generation."[43]

Thus, anything that reduces the need for power production and, in particular, anything that reduces AT&C losses, will have a large potential impact on reducing emissions.

Based on analysis by McKinsey & Company, the *SMART 2020* report identifies four high-impact activities for carbon emissions that can be achieved in India's power sector:

- Reduction in T&D losses
- Integration of renewable energy sources
- Reduction in consumption through user information
- Demand-side management.

Although *SMART 2020* is focused on carbon emissions and how the ICT industry can reduce its carbon footprint, the observations about India's power sector are pertinent

[43] The Climate Group, *SMART 2020*, op. cit., p. 47.

to the industry's migration to a smart grid vision since the underlying analysis focused on how ICT could help the ultimate users reduce their carbon footprint. Furthermore, there is a high correlation between generation and carbon emissions in the power sector. For those reasons, we use this framework as a starting point to identify the high-need/high-impact areas for potential pilot projects, as shown in Table 7. Certain institutional and policy matters will be critical to success, as will the need to improve service quality.

One-page summaries of the possible pilot projects are included at the end of this chapter. In addition to a basic requirement that each possible pilot mitigate carbon emissions, the first priority in developing them was to identify ways to contribute to the reduction in AT&C losses. Other priorities were to support demand response/energy efficiency and to enhance customer value/ease the demand for electricity on discoms (to facilitate improvement in their commercial/financial position). Another consideration went to possible pilot projects that could help accelerate the pace of reform.

Figure 7: PA Consulting Group's connecting the smart grid dots™ framework

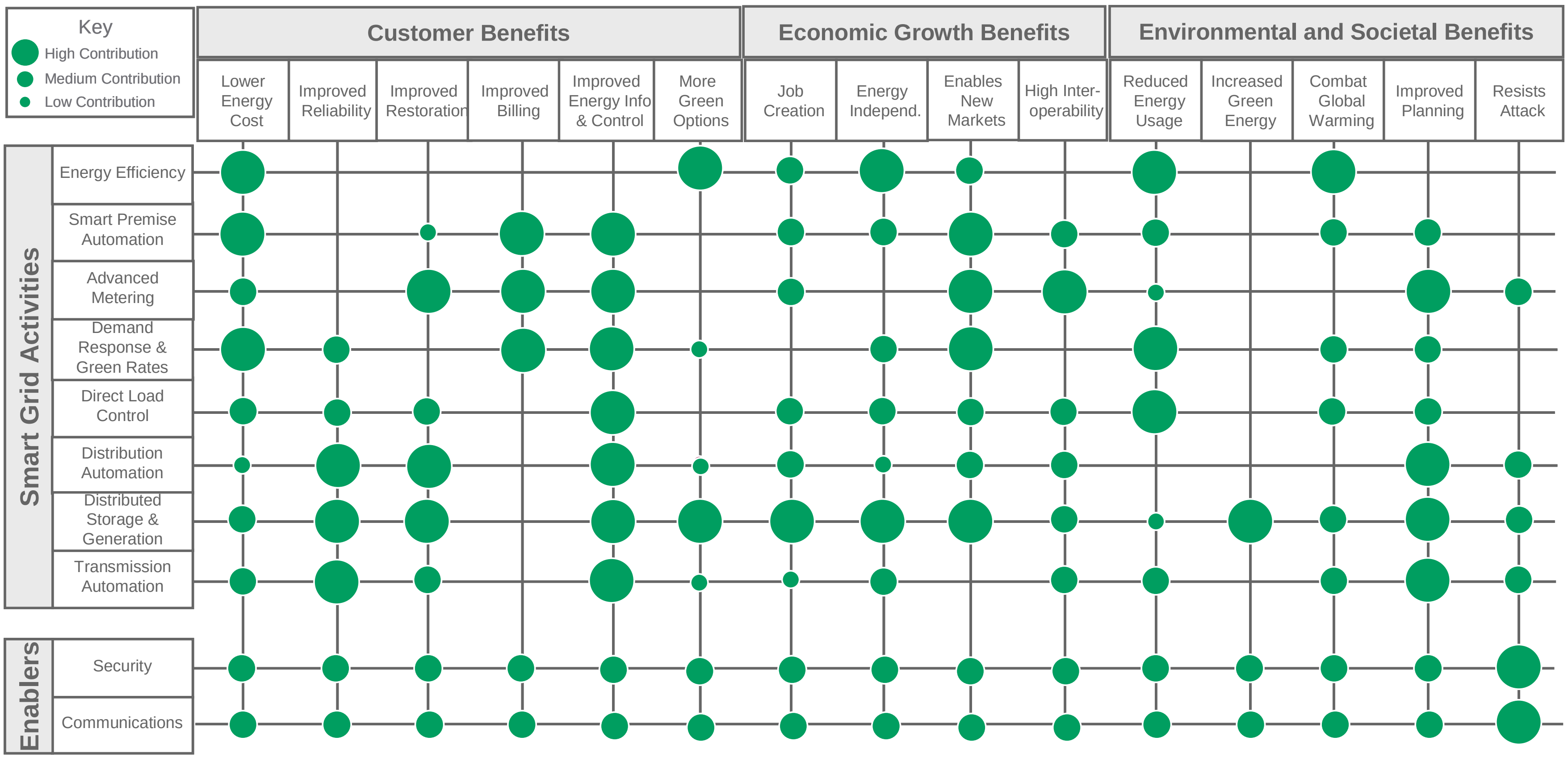

Table 7: Smart grid focus areas in India

Possible Pilot Project/Study	Reduce AT&C Losses / Improve Efficiency	Reduce / Mitigate Carbon Emissions	Improve Service Quality / Enhance Transparency	Facilitate Demand Response and Energy Efficiency	Reduce Demand on Discoms	Transform the Biz Model / Accelerate Reform
1. Link R-APDRP to measurable service-quality KPIs	High potential impact	High potential impact				High potential impact
2. Smart green apartment complex		Contributing impact	Contributing impact	Contributing impact	High potential impact	Contributing impact
3. PHEVs		High potential impact		Contributing impact		Contributing impact
4. Replacement of small-scale gensets with renewable energy		Contributing impact				Contributing impact
5. Off-grid renewable energy for irrigation pumping	High potential impact	Contributing impact	High potential impact		High potential impact	Contributing impact
.6. Smart grid pilot in BESCOM	High potential impact	Contributing impact		High potential impact		High potential impact
7. Wastewater methane generation	High potential impact	Contributing impact			High potential impact	Contributing impact
8. Distributed RE generation in remote rural villages			High potential impact		Contributing impact	Contributing impact
9. TOU rate pilot project		Contributing impact	High potential impact	Enabling precondition	Enabling precondition	Enabling precondition
10. Advanced Volt/ VAR support	Contributing impact	Contributing impact	Contributing impact			
11. Direct debit delivery of subsidies coupled with cost-based tariffs	Enabling precondition		High potential impact	Contributing impact	Enabling precondition	High potential impact

High potential impact — Contributing impact — Enabling precondition

4.4 Moving Forward

Techno-commercial pilot projects offer interesting potential demonstrations of ways to improve results for customers and utilities alike. However, achieving a smart grid vision goes well beyond any individual pilot and, in fact, all of them collectively. Overall, the major elements include:

- Developing a smart grid vision
- Conducting appropriate communication to educate and develop consensus
- Identifying viable funding options
- Implementing appropriate policy and regulatory actions to set common standards and encourage innovation.

In tandem with these actions, certain techno-commercial pilot projects could be implemented to demonstrate their commercial viability. A high-level view of the next steps is presented in Table 8.

Table 8: Summary of suggested smart grid elements and components for India (2010-2020)

			Adoption Level		
Element	Components	Timing	National	Utility	Customer
1. Develop National Smart Grid Vision	Set up a smart grid task force (multidisciplinary, with major ICT focus)	1	■		
	Confirm target loss reduction curve for AT&C losses at discoms	1	■		
	Confirm impact estimates for renewable energy, carbon emissions, cost reduction and service quality improvement	1	■	■	
	Conduct customer and market surveys to confirm objectives and get feedback from key reform participants	1		■	■
	Draft proposed vision and indicative plan identifying roles and responsibilities	1	■		■
2. Develop Flexible Smart Grid Approach for India	Link R-APDRP to service quality improvements to service quality & operational improvements demonstrated by KPIs	2	■	■	
	Identify smart grid elements for introduction to the discom business model and internal operations program using KPIs	2	■	■	
	Foster partnerships between ICT and power sector players	2		■	■
3. Develop Legal and Regulatory Framework	Amendments in Electricity Act 2003, National Tariff Policy and National Electricity Policy	1	■	■	■
	Regulatory approach for energy security and societal value	2	■	■	
	Higher return to utilities for higher risk and use of cutting-edge technology efficiency and better service delivery	1	■	■	
4. Support Development of Smart Grid Infrastucture	Develop a policy approach for cost recovery	2	■	■	■
	Identify funding source for ICT backbone infrastructure for qualified projects	2	■	■	
	Identify funding source for electric grid infrastructure for qualified projects	2	■	■	
	Develop standards and protocols for interoperability	2,3	■	■	
5. Conduct Techno-commercial Pilot Projects	Confirm and rank order commercial viability and environmental impacts and launch projects with strong monitoring and verification protocols	2	■	■	
	Develop case studies, customer education and outreach to all major stakeholders to build commitment	3	■	■	■

Timing/Phases: **1** – Immediate / as soon as feasible; **2** – As soon as preconditions are met; **3** – Continuous

The role of USAID/India

USAID/India is uniquely well equipped to assist the GOI through the Ministry of Power (MOP) and the Bureau of Energy Efficiency (BEE) to develop and successfully implement a smart grid vision appropriate to India's circumstances. Such a vision would optimize the benefits achieved in terms of mitigating carbon emissions and optimizing the value equation for electricity customers by creating a framework for sustainable, low-carbon, high-growth economic development. USAID/India's role could include:

- Evaluate ways to integrate results-based KPIs into the R-APDRP program
- Help develop target loss-reduction curves and AT&C loss reduction programs for discoms
- Explore the potential impact of and prospects for implementing micro grids
- Conduct studies of market needs and customer behavior
- Assess the potential impact of renewable energy and energy efficiency on electricity demand
- Organize US-India collaborations and studies on technical issues and legal, regulatory and financial policies
- Help develop retail electricity tariff designs to promote DSM, tap renewable energy potential, and flatten the load curve
- Assist in developing/adapting an appropriate cost-benefit analysis methodology for the Indian context
- Help develop a methodology to estimate the cost of externalities tailored to the Indian context for use in conducting cost-benefit analyses
- Implement techno-commercial pilot projects, as agreed with the MOP, and provide feedback as appropriate
- Conduct other studies to assist with the development/implementation of a smart grid vision adapted to the Indian context
- Develop and implement consumer outreach and education programs
- Implement capacity building initiatives with regulators and policymakers on time-of-use tariffs, feed-in tariffs and other issues related to the implementation of pilots or the smart grid
- Build the capacity of discoms to absorb new smart grid technologies.

Opportunities for US-India collaboration

There are some interesting possible opportunities for the exchange of knowledge, including:

- Electric Power Research Institute – seminars and/or a joint task force to adapt EPRI's Smart Grid CBA methodology to the Indian context
- National Association of Regulatory Utility Commissioners and/or National Regulatory Research Institute – collaborations on studies and workshops on policy and regulatory issues related to the smart grid
- US and Indian electric companies – information exchanges on pilot projects, e.g., Southern California Edison's smart grid pilot and/or PJM's program with the University of Delaware to purchase backup EV energy for system stabilization
- Exchange programs organized by US Energy Association
- Exchange programs with the US Department of Agriculture's Rural Utility Service
- NIST collaboration with Government of India agencies, e.g., BIS.

A flexible implementation approach is required

A national-level task force will be required, but it should focus not only on policy issues as outlined above but also on customers. Table 8 presented a high-level assessment of the next steps for developing a smart grid vision and implementing it. It should be emphasized that any plan must be adaptable to the unique needs, cultural and political realities, and resource constraints of different regions, states and localities. Perhaps the gravest error at this early stage of smart grid development would be to adopt a rigid, top-down and "one size fits all" approach to achieving a smart grid vision.

4.5 Eleven Potential Pilot Projects for India

Link R-APDRP to Service Quality KPIs

Business Case	
The GOI's Revised Accelerated Power Development and Reforms Programme (R-APDRP) can be viewed as a forerunner to the implementation of a smart grid vision. It encompasses the introduction of ICT into the distribution business and, as such, should be linked with improvements in service quality as measured by KPIs. The measurement and continuous reporting of the universal KPIs for service quality in the electricity business (e.g., SAIDI, SIAFI, CAIFI) and also some logically linked KPIs (e.g., transformer failure rates, percent of energy metered, percent of metered energy that is billed and collected) would help to emphasize the linkage between inputs, activities and results	
Implementation Approach	**Key Challenges and Questions**
• Survey global practice and practice in India, including CERC, State Electricity Regulatory Commissions, State Electricity Boards and Discoms to identify the state of reporting of KPIs for service quality. • Develop a best practice set of KPIs • Present the results in a white paper and at a national conference • Establish an industry benchmarking forum to report results and to conduct joint studies to improve KPI results.	• The cause and effect link between the implementation of ICT in the electricity distribution business and the achievement of results as measured by KPIs (see the list above) is often influenced by other factors, especially management actions or inactions. Thus, management's commitment to achieving the results defined by the KPIs will be critical.
Benefits	**Costs**
• A better platform for smart grid initiatives. • Improved metering, billing and collection • Reduced AT&C losses • Reduced carbon emissions.	• The additional cost of defining the KPIs, developing consensus and establishing an industry benchmarking forum should be modest since they can build on existing programs.

Smart Green Apartment Complex

Business Case
The value of a Leadership in Energy and Environmental Design (LEED)-certified green building is well established and growing in popularity around the world.[44] Although the construction cost of a green building is about 15-20% higher than conventional construction, the higher first cost is more than offset by the reduction in annual operating costs. This project would explore using smart grid automation to optimize the LEED green building concept. It could include tasks to focus on the potential in residential apartments. The growth in apartment housing in Indian urban pockets is creating an increasing number of "city within a city" developments. For example, Dwarka township in Delhi and Lavasa city near Pune are nearly self-contained developments but with good infrastructure for rapid mass transport, educational and public facilities. The Dwarka mini-city covers more than 5,000 hectares and is estimated to house half a million families.[45] Similarly, Lavasa city, when completed, will cover 10,000 hectares, almost one fourth the size of Mumbai[46] and Gurgaon is a separate high-growth, high-tech "new city" on the outskirts of Delhi. The discoms serving these areas cannot provide adequate supplies of reliable electricity to satisfy the expectations of the more affluent people moving into these areas. Some community organizations have organized backup generators to provide power when adequate power is not available from the discom. More can be expected to be built even though power from a diesel genset is very expensive. A developer could improve the marketability of apartments by offering a secure source of backup power that, when blended with local discom prices, will lower total bills. Adding established energy efficiency concepts to minimize electricity usage would further minimize energy costs. Another option would be to include renewable energy and storage capacity to provide clean backup power. Another intriguing possibility – especially in view of the number of mini-cities to be developed over the next 20 years *and* the number of new cars to be sold – is integrating houses and cars in a holistic approach to optimizing energy use.

Implementation Approach	Key Challenges and Questions

44 World Economic Forum, *Accelerating Smart Grid Investments*. Geneva. 2009.

45 http://www.dwarkaparichay.com and http://en.wikipedia.org/wiki/Dwarka_Sub_City

46 http://www.lavasahillcity.com

• Analysis of EA03 and state regulations to identify preconditions for success • Develop a detailed business case, including a solution to the higher funding needs • Identify a developer interested in participating in a pilot project • Develop a cost hierarchy of smart-grid technologies to install on a least-cost basis.	• Conduct a detailed cost / benefit analysis demonstrating the business case • Educate developers on smart grid benefits • Develop a compelling marketing plan for prospective buyers • Develop smart-banks to finance smart grid solutions, perhaps with a DCA loan guarantee / mortgage buy-down
Benefits	**Costs**
• Lower electricity use and carbon emissions • Better value-for-money for smart housing	• Long-term O&M costs for smart apartments need to be determined.

Plug-in Hybrid Electric Vehicles

Business Case	
Because of the number of new mini-cities that will be developed in India over the next 20 years *and* the number of new cars to be sold, one intriguing possibility is the idea of integrating "smart" houses and plug-in hybrid electric cars (PHEVs) in a holistic approach to optimize energy use and storage. In the words[47] of Willett Kempton, director of the Center for Carbon-free Power Integration and a professor at the University of Delaware: "The long-term vision is to charge electric vehicles at night, off-peak, when intermittent but huge amounts of wind power are available. More valuable in the short term is frequency regulation, involving short bursts of charging and discharging on command by PJM."[48] The net draw on the battery over time is close to zero, according to Kempton. "Electric drive vehicles cost roughly one-quarter as much as gasoline-driven vehicles per mile. Their operating pollution is negligible." PJM is paying the University of Delaware because the cars offer cheap control of electricity that PJM needs for frequency regulation, to balance shifts between generation and demand. The technology currently is also suitable for spinning reserves. In both applications, PJM ordinarily would use power plants, with significant capital and operating costs that V2G could replace. "What's new," according to Kempton is that "money is changing hands." The question for India is what might be made of the potential for similar applications?	
Implementation Approach	**Key Challenges and Questions**
• Integrate the smart-grid concept at the urban planning stage.	• Developing a smart bank to subsidize smart grid solutions.

[47] As reported by Phil Carson, editor-in-chief, *Intelligent Utility Daily,* February 25, 2009.

[48] PJM coordinates the generation and transmission of wholesale electricity in all or parts of 13 states in the US, from the Mid-Atlantic to Chicago, and the District of Columbia.

Benefits	Costs
• Competing developers would embrace smart-grid concepts and hence trigger a cascading effect on smart apartment housing development • Enables a low-carbon pathway consistent with national goals.	• Energy efficiency measures with 2-5 year paybacks and distributed renewable energy technologies with 7-10 year paybacks could be financed • The operation and maintenance costs of smart apartment housing are not fully established and long-term O&M costs need to be identified.

Replacement of Small-scale Gensets with Renewable Energy and Connect them to the Grid

Business Case

India has about 20,000 MW of captive capacity that is not connected to grid; most is stand-by generation for mostly small industrial companies. These units range from 100 kW to 500 kW with, we estimate, an average size of 200 kW. The plant load factors are low (approximately 33% at maximum). Industrial firms, shopping malls, large-scale apartment complexes and some "vest pocket" IPP operators in affluent residential enclaves represent an enormous untapped potential. Finding a way connect even a portion of this captive capacity to the grid would help close India's supply-demand gap. The problem is that most of this capacity uses diesel for fuel and, as such, is a high carbon emitter.

The goal would be to determine whether and to what extent these distributed generators could 1) be replaced with renewable energy-fueled generation, perhaps in conjunction with storage and 2) connected to the grid. The initial capital cost would likely be significant and obtaining the appropriate policy support and regulatory approval might be a test case for evaluating the societal benefits of the conversion. A pilot project could and probably should be funded at least partly by a GOI grant, but ongoing operating costs would have to be paid on a commercial basis. Another dimension to this project could be the study of so-called "feed in" tariffs to mobilize private investment to fund the conversion of these small-scale generators to RE. How to share, if at all, the cost of linking these small gensets to the grid would have to be determined and sanctioned by policy and approved by regulation.

Implementation Approach	Key Challenges and Questions
• Study the potential and segment the existing stock of distributed gensets by location, size, age, fuel type and customer group (e.g., industrial, shopping malls, apartments). Assess the potential for 1) converting generation to RE, and 2) connecting supply to the grid. Map the potential geographically • Develop an economic model, evaluate costs and benefits, and assess funding options • Evaluate the need for / potential of a feed-in tariff to attract private investment • Assess the potential to package storage with the conversion to RE	• Involvement of private owners • Getting buy-in from discoms, political support and regulatory approval • Sustainability of model • Are feed-in tariffs workable? Needed? • Who will bear the cost of connecting to the grid? • Roll out on larger scale after successful pilots.

• Plan demonstration pilots for different regions with good solar / wind potential.	
Benefits	**Costs**
• Links to the grid capacity for which there is demand and need • Reduces carbon emissions • Creates entrepreneurial opportunities and generates employment.	• The initial capital cost could be significant • Installation and O&M costs are unknown.

Off-Grid Renewable Energy for Irrigation Pumping

Business Case
Many of India's 10,000,000 irrigation pumps are powered by electricity that is provided free or at a nominal tariff. These dysfunctional but politically correct tariffs have caused the wasteful use of water and electricity. Underground aquifers are being depleted at an ever-increasing rate and estimates of electricity used for irrigation pumping range from 20 to 30% of total. Distributed renewable energy (e.g., wind, solar) could be used to provide power to operate pumps that could irrigate fields directly or pump water to storage tanks for later use or, alternatively, energize batteries. A one-time capital grant to offset the installation cost of such a system might be justified in terms of the value of subsidies to the power sector that could be discontinued. This could be integrated as part of an ESCO Agricultural DSM solution as is being tested at Doddaballapur, Karnataka or with other models considered (e.g.,, farmer cooperative), including the franchise model to improve the economic viability of franchises with significant agricultural demand.

Implementation Approach	Key Challenges and Questions
• Analyze EA03 and state regulations, etc. to identify the preconditions for successful implementation • Survey RE and high-efficiency pump manufacturers to identify the technology options and estimated costs • Study the results of Ag DSM pumping pilots and franchising experiments • Develop an economic model, evaluate costs and benefits, and assess funding options • Plan demonstration pilots for several regions (e.g., those with good solar potential, good wind).	• A intensive program to educate farmers will likely be required • Regulatory approval and assent by a discom may be required if an ESCO (with a contract with the local discom) will own the RE source • Vested interests who get free electricity under Ag tariffs may oppose something that reduces the known benefit they now receive • The economic viability of the program might require metering and possibly a cost-recover mechanism, e.g., tariff.

Benefits	Costs
• Reliable electricity for irrigation pumping • Enhanced control of ability to irrigate crops for farmers • Improved agricultural outcomes, i.e., quality of crops, farmer incomes • Reduction in power sector subsidies • May justify the implementation of (transformer) metering if farmers are assured of adequate electricity for pumping.	• The initial capital cost could be significant • Installation and O&M costs are unknown.

Smart Grid Pilot in BESCOM

Business Case	
Bangalore Electricity Supply Company (BESCOM) is one of India's leading distribution companies. It has been a pioneer in many fields of technological implementation, especially distribution automation. With a vision to continue its leadership in the electricity distribution sector, BESCOM is keen to develop a smart grid pilot project. BESCOM's smart grid pilot will be implemented in the Electronic City area. A hub for large IT companies, the pilot area comprises 17,409 consumers of all types with a relatively sophisticated consumer profile. A workshop on the smart grid was organized on 5 January 2010, with leading technology providers participating. IT companies expressed their willingness to support BESCOM in its venture by providing the right mix of technology free of cost as well as the support needed to integrate renewable energy and captive generation with the grid. As per workshop the smart grid pilot in electronic city area will cost about 100 corer. The Ministry of Power (MoP) has already approved the creation of a smart grid task force. It has set aside approximately Rs 200 crores for pilot projects. Fifty percent will be contributed by the MoP and the remainder must be arranged by a distribution company. BESCOM has already submitted an application requesting their support for this activity.	
Implementation Approach	**Key Challenges and Questions**
• Evaluate costs and benefits, and assess funding options • Develop a public-private partnership model • Quantify robust baseline data prior to implementation so that benefits can be verified and documented • Focus on urban areas during first phase of implementation • BESCOM to solicit support from the Ministry of Power and private sector vendors and service providers for the installation of a communication network, hardware and software.	• Selecting the right technological partner and consultants • Regulatory approval for a variable-rate tariff based on BESCOM's power purchase price • Upgrading the existing network • Consumer education on participating in this pilot • BESCOM employee knowledge and skills development • Detailed cost/benefit analysis demonstrating the business case • Rolling the project out on a larger scale after the pilots have proven successful.
Benefits	**Costs**

• Peak curtailment/levelling and time-of-use pricing – load adjustment • Power quality improvement and grid self-healing • Integration of renewable/captive generation • Tariff options to consumers – monthly reduction in consumer bill • Better and advanced customer services • Reduced technical and commercial losses to a level of international standard.	• Network upgrade costs would be significant • While the cost side equation is well known and focused within the utility, the benefits are often unclear and societal in nature.

Wastewater Treatment Plant Methane Capture

Business Case	
Electricity is one of the largest factor inputs for wastewater treatment plants, which must operate 24 hours a day, 365 days a year. Methane, a by-product of wastewater treatment, can be used to produce electricity. In India, municipal treatment plants are among the largest non-payers of electricity. It is difficult to force them to pay due to the essential nature of the service. If a cost-effective way can be found to build new wastewater facilities using methane capture to fuel an on-site generator, it could reduce the amount of electricity the local discom would have to provide and lessen the financial impact of non-payment by the municipal treatment plant. The retrofit of a power generation facility at an existing wastewater treatment plant could achieve similar results. Also, the facility could be operated under a management contract by a private operator. If suitable payment guarantees could be arranged (e.g., a contract with a power trader who could sell the output on power trading markets and pay the proceeds to the plant operator and the wastewater municipality), it might be possible to create a viable private investment.	
Implementation Approach	**Key Challenges and Questions**
• Assess construction and O&M costs of suitable plant sizes from manufacturers of on-site generation equipment • Survey overseas wastewater treatment plants with methane on-site generation to identify the characteristics required for a viable plant, e.g., processing volumes, off-take prices, construction costs, O&M expenses • Analyze the power trading potential of India's power markets and transmission grids to identify high-potential areas • Develop an economic model, evaluate costs and benefits (including the value of carbon credits) and assess funding options (including possible loans from multilateral banks • Plan and implement a demonstration.	• A municipal authority with the ability to assure backing of a payment guarantee mechanism • Financing, especially if a private owner / operator is desired • An enforceable contractual arrangement regarding delivery of electricity to a power trader, perhaps including a take-or-pay provision to ensure that the power trader would be receive power (or payment in lieu) to enable payment to the private operator. • Regulatory approval and assent by a discom may be required • A government guarantee may be necessary.

Benefits	Costs
• Reliable source of electricity for wastewater treatment plants • Increased ability to build wastewater treatment plants in urban areas • Reduction in power sector subsidies • Methane's high carbon credit value could defray capital cost.	• The initial capital cost could be significant • Installation and O&M costs are unknown.

Distributed RE Generation in Remote Rural Villages

Business Case	
One of the most incorrigible problems in India's power sector is the rural-urban divide. The low customer density in rural areas, and more so in remote rural areas, creates an inherent disincentive to expand the grid. And when the grid is extended, this phenomenon (coupled with low income levels) creates a disincentive for utilities to "extensify" electricity access to more people. The purpose of this pilot would be to identify low-cost energy solutions that do not require grid access and promote them in rural areas. Applications could include existing technologies (e.g., solar water heating, but also other limited techniques to provide high-impact access to electricity, such as community internet access for medical and educational purposes) to enable farmers to check commodity prices, etc. The concept would be to install an RE source (e.g., a solar panel) that would provide sufficient power to operate a laptop. The initial capital cost could be funded at least partly by a GOI grant program, but ongoing operating costs would have to be paid on a commercial basis.	
Implementation Approach	**Key Challenges and Questions**
• Create a micro grid • Use 90% capital subsidy from GOI in RGGVY scheme • Develop an economic model, evaluate costs and benefits, and assess funding options • Plan demonstration pilots for several different regions, e.g., those with good solar potential, good wind, etc.	• Involvement of local community • Sustainability of model • Roll out on larger scale after successful pilots.
Benefits	**Costs**

• Basic source of electricity for remote rural villages • Access to basic health care knowledge • Remote learning capability (e.g., farming techniques, health care) • Mobile phone recharging • TV use for communication, entertainment and education • Creates entrepreneurial opportunities and generates employment.	• The initial capital cost could be significant • Installation and O&M costs are unknown.

Time-of-Use (TOU) Rate Pilot Project

<table>
<tr><th colspan="2">Business Case</th></tr>
<tr><td colspan="2">The implementation of smart meters is central to the smart grid vision. The two-way communication capability that is implicit in what seems to be a universal assumption only makes sense in an operating environment where TOU rates are in effect. Without a means to signal the changing cost (and, thus, price) by time of day, it will not be possible to achieve the most basic of benefits of the smart grid vision. TOU rates make good sense from an economic and business perspective, but the process of developing them, getting them approved by regulators and accepted by customers has been fraught with difficulties, and progress has been slow. This has also been the case in India. Getting results from a valid TOU pilot is essential for the power sector – including companies, regulators and customers – to understand this concept and learn about the benefits TOU can enable.</td></tr>
<tr><th>Implementation Approach</th><th>Key Challenges and Questions</th></tr>
<tr><td>• Develop a concept note and plan, including costs and the approach to measuring results
• Identify potential pilot sites with the discom and ERC support
• Conduct cost-of-service study to determine costs by time of use and obtain ERC approval
• Conduct a customer survey and a consumer education program
• Compile baseline data
• Implement and test meters and implement the demonstration pilot
• Collect data from the pilot, make course corrections as needed, and analyze results
• Conduct a follow-up customer survey.</td><td>• Customer acceptance
• Political support
• Regulatory approval.</td></tr>
<tr><th>Benefits</th><th>Costs</th></tr>
<tr><td>• A successful TOU pilot will enable an assessment of the potential to</td><td>• The initial capital cost could be estimated on the basis of prior</td></tr>
</table>

flatten the load curve and reduce the total amount of customer bills from a demand response program using time-of-use price signals • Flattening of the peak • Reduction in the size of customer bills.	attempted TOU pilot projects.

Increase the Efficiency of Electricity Delivery through Advanced Volt/VAR Control

Business Case
Distribution management systems (DMS) have varying degrees of sophistication. Some companies handle their distribution system operations using manual and paper-based systems using static data and prevailing conditions of the network and customers. Others manage their operations using more sophisticated systems that provide operators with more real-time circuit and customer data by adopting DMS applications including distribution power flow, fault detection and restoration, voltage/VAR control, and contingency analysis. The use of advanced DMS systems can increase efficiency in electricity delivery by reducing distribution system losses and end-user energy consumption through advanced voltage/VAR control. Distribution losses increase as voltage levels in feeders drop because motors and other types of connected loads draw more current to compensate for a drop in voltage. Since electricity losses are a function of the square of the current, they increase. Today, distribution operators try to maintain customers' voltage levels by adjusting transformers at substations and perhaps voltage regulators at the beginning of the feeders. Many utilities also need to add capacitors to provide the VAR support required to avoid excessive voltage drops along the feeders. Such capacitors are often constantly connected and manually switched on/off. Smart grid technologies, by continuous monitoring, controlling and acquiring data, can be used to dynamically optimize the required VAR support needed on distribution feeders according to their changing load conditions. Integrated Vol/VAR control (IVVC) can provide coordinated and dynamic control of substation transformer tap changers, feeder voltage regulators and capacitor banks to ensure appropriate voltage profiles in distribution feeders.

Implementation Approach	**Key Challenges and Questions**
• Analyze discos' current conditions to identify preconditions for success • Develop a detailed business case, identifying loss reduction potential and peak load reduction resulting in lower fuel generation costs, and deferral of generation capacity • Identify a developer interested in participating in a pilot project • Develop cost hierarchy of DMS and smart-grid technologies to implement on a least-cost basis.	• Detailed cost / benefit analysis demonstrating the business case • Educate discos on the benefits of DMS and value of IVVC using smart-grid applications and technologies • DMS requires detailed electric system modeling including connectivity, impedance, equipment, load distribution, and often geographic coordinates for all elements. Getting such data requires access to GIS/AM-FM, CIS/billing, and system load flow packages, which may not be in place.

Benefits	Costs
• Reduced electricity distribution losses • No need to manually control and inspect capacitor banks • Real-time monitoring of voltage on circuits • Lower electricity use and carbon emissions.	• The operation and maintenance of DMS and IVVC extended from the network to the pole-mounted transformer. The individual customer may not be identified and long-term O&M costs need to be established.

Direct Debit Delivery of Subsidies

Business Case	
One of the continuing challenges for India's power sector relates to subsidies and how to ensure that 1) they are delivered to the intended customer groups – mostly small consumers and farmers – and also that 2) a high proportion of the subsidy fund is delivered to the target customers. These phenomena are known as "targeting" and "penetration." A related problem is the effect on customer behavior when subsidies are delivered through tariffs. These issues cause distortions in consumption and potentially significant misdirection of subsidies. If discoms and SEBs set tariffs based on economically efficient cost-of-service principles – and if subsidies were delivered directly to customers – they (customers) would have an incentive to respond to price signals while also receiving the intended value of their subsidy. In fact, these customers would have an incentive to minimize their electricity consumption if the system allowed them to keep any unused portion of the subsidy (i.e., beyond what was needed to pay their electricity bill) and apply it to other economic goods. Given the sophisticated ICT available in India and its robust financial system, it may be possible to provide debit cards to some, most, or even all customers who receive an electricity subsidy and allow payment to be made by that card. If that card could also be used for other purchases (up to the available balance), it would create an incentive to use electricity more carefully while also creating funds that could provide some measure of financial flexibility for small, mostly rural, customers.	
Implementation Approach	**Key Challenges and Questions**
• Analyze subsidy flows and recipients by geography, occupation, age and income • Discuss the potential for issuing debit cards with financial institutions and mobile phone operators. Assess implementation steps, costs, barriers and risks, and evaluate potential impacts of a successful roll-out • Conduct a road show to review the idea with government policy makers and regulators at the State and Centre as well as the MOP and other stakeholders • Enlist the participation of a financial institution and/or mobile operator • Obtain funding, if and as required	• The data on the size of subsidies and the data subsidy flows are murky and may be difficult to obtain as well as sensitive • Financial institutions and/or mobile telephone operators would need a high degree of confidence that the program would not be subverted; thus, a thorough risk analysis would be important • A viable transition plan would have to be developed • The potential that cash subsidy requirements might exceed the notional value of subsidies embodied in tariffs would have to be analyzed and a mitigation / transition plan developed.

• Plan and implement a pilot project • Measure results and make a recommendation for moving forward.	
Benefits	**Costs**
• Price signals based on economically efficient tariffs would be introduced to the electricity market.	• The financial institution / mobile operator would pay the debit card system costs • Other costs should be transition costs for discoms / regulators.