Keeping the lights on – Sustainable scenarios for the future

By Carl J. Weinberg

Electricity has become an essential ingredient of our lives and has vast social implications. CARL J. WEINBERG looks at scenarios that will enable the electricity system to provide electricity that we require to maintain our quality of life in a sustainable manner, and to perform all the duties we assign to it.

Electricity and the associated system and organization have been considered one of the most important developments of the 20th century. Our lives are touched daily by electricity. Economic development has been intrinsically coupled to electricity use. The lack of electricity, or insufficient electricity, is a concern of governments. If people who don't have it live close to 'wires' that carry it, they find ways to steal it. Its absence is usually associated with poverty and reduced quality of life. The information revolution would not be possible without a stream of electrons. It is clearly an integral part of our lives and has a large component of public benefit associated with it. The question of 'keeping the lights on' must be interpreted in the broader context. How will the electricity system provide electricity to maintain our quality of life in a sustainable manner and perform all the duties we assign to it? This question in its various aspects has been widely discussed and continues to be discussed.[1]

The existing system

The existing system encompasses not only the technology, but also all the associated organizations, structures, politicians, consumers and users. The concept of technological systems is described by Thomas P. Hughes in *Networks of Power: Electrification in Western Society*.[2] Hughes demonstrates how the complex of power plants, transmission lines, individuals and institutions interacted to create unique electric utility networks in different countries using similar hardware. In each country the system builders wove a variety of considerations that could be labeled economic, political, educational, legal, managerial and technical. Though the overall systems differed, each used similar technology and succeeded within its particular social constraint to transform raw energy resources into electricity for expanding uses.

In political science there is a concept called the 'elitist perspective' to explain how individuals and groups amass power for organizing and controlling social institutions.[3] Elitism holds that a minority dominates society and presides over its governing institutions. Elites exert power through the manipulation of individuals and governmental institutions to obtain results that directly profit them. To maintain authority they often argue that their actions are in the public interest. Occasionally, they create an ideology that unites the dominant parties and persuades the populace of the legitimacy of the elite rule. The widespread belief was that the electric power business was a natural monopoly, and the associated power relationship established among stakeholders legitimized the rule of the elite, the utility managers. These concepts are more elegantly explored by Professor Richard F. Hirsh in his recent book *Power Loss*.[4]

Those that had the most to gain from the growth of the system tried to close it. Utility managers worked to decrease outside influences so that they could achieve greater control over elements that may decrease their authority. Power company executives achieved closure partly by encouraging the creation of conservative innovation, which originated within the system, while discouraging radical innovation emerging from outside the system. Combining the elitist perspective with the technical systems approach, politicians and utility executives were the prominent parties that established the utility structure early in the 20th century. Politicians lost interest and utility managers found they could exploit the institutions which protected their firms from competition, while offering valuable benefits. They gained widespread support and were allowed to rule a closed system essentially insulated from external forces. The utility managers did an excellent job until their basic assumptions came under scrutiny and their responses did not appear adequate. However, major forces beginning in the later part of the 20th century reopened the system and led to the present turmoil in the electrical utility world.

Major forces opening the system

The start of the new millennium brings to an end a remarkable 100 years, a time-span that saw major changes in the philosophy of people, their relationship to each other and their relationship with nature. There were major changes in concepts of governance and major changes in technologies that continue to push, pull and shape our lives.

The major forces introducing new criteria into the design of the system of the future are:

Governance	competition and the increased use of market based approaches
Environment	sustainability and increasing emphasis on environmental impacts, both local and global
Technology	shifting from large, central station constructed energy to smaller more modular, flexible, manufactured energy, managed with information technology.

These forces are creating changes with different speeds, in different industries and in different parts of the world. And they are changing the electric industry. This is part of the major global changes taking place this century, and changes that will continue to take place over the next hundred years. A recent insert in a fortune cookie expressed this most succinctly: ‘The philosophy of one century is the common sense of the next.’

During the last century there was a struggle between governance by so-called ‘market-based’ systems and so-called ‘centrally planned’ systems. The phrase ‘so-called’ is used to prevent an ideological argument on pure definitions. They are descriptors of systems that use market based approaches versus those that use central planning approaches. Both elements are used in both systems but the emphasis is what differentiates them. Market-based governance systems are emerging in a variety of forms, but all require that individuals play a greater role, and that governments relinquish actions to markets where feasible. The emphasis on market-based approaches has introduced competition to many other monopoly industries, and has spawned the restructuring of the utility industry. This of course requires that there is a movement closer to democratic principles. The emergence of customers and voters will increase the importance of choice, not only in energy but also in the form of governance. It implies that energy will increasingly be considered a quality of life issue, requiring greater involvement of individuals in the future of energy choices. The method of production and delivery will increasingly be of importance to the almost 2 billion people who do not have electrical service, as well as the billions that do.

The last century was also a time when doubts arose that our function, as humans, on this planet was to conquer nature. The environmental movement began to evaluate the need to live in a symbiotic relationship with nature. There are limitations on what we could do to this earth. The environment will become increasingly important as this new century progresses. Action is often possible when problems are local, but dealing with them when they are global is more difficult. It does not seem probable that the impact of global climate change will bring forth rapid and co-ordinated action between governments. If policymakers are smart, there will be a movement from conquering nature to living in harmony with nature, which is the underlying concept of sustainability. The electrical utility industry will increasingly come under environmental scrutiny, as it is a major contributor to atmospheric pollution and waste disposal. That concern will not disappear. Nature has provided us with a Faustian bargain: it has provided relatively cheap fossil fuels, available in some form or other for at least the next 200 years, but is asking us not to use them as the atmosphere cannot absorb the effluents. The predictions are that technologies with diminished environmental impact will play an increasingly larger role.

The provision of electrical energy and energy services is also undergoing technological change. These technological changes are calling into question the structure and the delivery systems of the traditional utility. The technology is changing from the dominance of large central station constructed energy to the more modular, flexible, manufactured energy. Photovoltaics, in particular, is the premier example of this new kind of technology. These new technologies provide a means for electrical service to move toward the user, in many cases to the user's premises, and be tailored to their needs and ability to pay. Modern information technology has also provided a means to monitor and manage widely different and dispersed services. The conceptual model of a utility as large central station power plants connected to their customers by wires may well not be the model for the future. This is particularly true for developing countries.

Designing a future system

What should be the vision for the electrical system of the future, considering these forces? *A system that provides energy services that are clean, sufficient, affordable and tailored to 'smart' efficient customers worldwide:*

Clean	environmental impacts are minimal, system sustainable for future generations
Sufficient	enough exists to maintain a good quality of life
Affordable	all people can have access
Tailored	has the reliability and quality needed for that customer and use
'Smart'	information technology has been utilized to provide meaningful choice and the ability to manage multiple resources
Efficient	all buildings, appliances, equipment or processes use electricity efficiently.

The main system design trade-offs are vertically integrated, regulated vs. competitive market-driven, clean vs. dirty, central vs. distributed, and affordable vs. expensive.

Vertically integrated, regulated vs. competitive market-driven

Putting economic and political theory aside, it would be possible to introduce a new ideology for designing such a system under a regulated structure. In fact, such an instrument was introduced in the United States, called the Integrated Resource Plan (IRP) in its various forms. Its flaw is that history tells us that there are not that many smart governments around. It also flies against the ideology of market-based governance. Market-based governance has produced the greatest availability of goods for the greatest number of people and there does not appear to be any reason why that ideology cannot be applied to the electrical energy sector; the UK was an early adopter of that ideology. Experience also tells us that developing a market for electricity that maintains public interest is not as easy as it sounds. California is a prime example of a badly designed market trampling on public interest. To quote George Soros, ‘A system based purely on greed will not lead to social cohesion’.[5] It is also difficult for existing organizations to respond to radical or disruptive technologies. It would require extraordinary governmental oversight to force utilities into a new structure. There does not appear to be a way that the industry can maintain its vertically integrated structure and deliver the envisioned system. This theme is also explored by Walt Patterson in his book *Transforming Electricity*.[6]

Clean vs. dirty

Energy is a major component of the quality of life and it is becoming increasingly evident that renewables coupled with energy efficiency are important elements of a sustainable future. There are really only three approaches:

1. high-efficiency conversion of clean (low carbon) fuels, or sequestering waste (CO_2/nuclear)
2. renewables
3. efficient use.

There are varying opinions on the ratios of the three.

There is no silver bullet, only silver buckshot

A number of mechanisms are being considered that range from taxes to buydowns as a means of providing value to ‘clean’ energy sources, so that businesses can operate according to known economic principles. No one has been successful in designating a value for externalities and have it used consistently in business decision making. Rather a variety of fiscal instruments are being experimented with. In England, the Non Fossil Fuel Obligation (NFFO) has been successful in bringing renewables into use and in reducing the price in the process. The German feed laws have stimulated the market in Germany. Specific government requirements and financial support have expanded the market for roof top PV systems in Japan.

All of these methods however, can be summarized as two main concepts:

- create the market and let capital flow to it
- create the capital and buy from the market.

The methods used are extensive (Table 1). All of these approaches play the role of balancing the economic equation in an attempt to move these technologies into use.

Table 1. General methods for speeding innovation

Create the market	Create the capital
Renewable Portfolio Standard	Non Fossil Fuel Obligation
Standard offer contracts	Cost buydowns
Electricity feed laws	Production credits
Efficiency standards	Tax policies

Tags/Green market certificates	Climate change levies
Wind development concessions	Energy efficient mortgages
Fuel price risk avoidance standards	System benefit charges

A Renewable Portfolio Standard (RPS) that stipulates an amount of renewables is an example of creation of a market place. The NFFO, collecting an amount of capital and buying competitively, is an example of creation of capital. Every methodology devised so far falls into one of these two categories. Each of them has strengths and weaknesses, but both categories can accomplish the task of adding additional renewables into the generation mix. My own experience indicates to me that creating a market works best at a wholesale or central generation level, and that creating capital is more effective at the retail or distributed level. Both work, though, to bring renewables into the generation mix. These approaches can be applied to either regulated or unregulated business structures.

In the USA several states are experimenting with Renewable Portfolio Standards (RPS). The RPS requires a certain percentage of the generation to be composed of renewable generation. The USA has also provided System Benefit Charges (SBC) to assist both renewables and energy efficiency into the market. In some cases these are coupled to customer choice and a green power market. The emergence of this market has startled utilities and revealed a latent desire of people to choose ‘green’, even if their governments do not.

The latest and as yet untested methodology is the separate valuation of the clean attributes and the electrical attributes. This is the green coupons or Green Market Certificate (GMC) approach. One renewable supplier in the USA has even tried to go further by separating out the CO_2 attributes, in addition to the clean attributes – in essence, selling two certificates for each ‘green’ attribute. The combined GMC/RPS requires that each electricity provider either produces renewable electricity or purchases renewable credits (green certificates) in a credit trading market. This is presently a hotly debated subject in the USA, and under consideration in OECD countries. The main criticisms centre on potential abuse and on what is really being sold or traded, and whether the public would understand the value of reducing global emissions but not necessarily alleviating local conditions.

There is another attribute of renewables that has not been seriously considered, but that has become a major issue in California – the potential for fossil fuel price risk mitigation. Renewables have the potential to provide the equivalent of ‘fixed rate mortgages’ vs. the ‘variable rate mortgages’ of fossil fuels. Some studies have been done to analyse the reduction in risk by the addition of renewables in various fossil fuel portfolios.[7] As an example, while the California market was being buffeted by increased natural gas prices and out-of-control electricity prices, rising as high as 40–50 ¢/kWh, a green power marketeer offered an 8.5 ¢/kWh fixed price product for 3 years and sold out the available supply rapidly.[8] While California was in the crisis, long-term contracts for wind (10–25 years) were being negotiated in other states at around 3–4 ¢/kWh, with no or limited escalation clauses. This ability to mitigate fossil fuel price volatility may well be an attractive attribute for a market in which there is customer choice and price volatility. It may turn out to be the real driver for the inclusion of renewables in a generation mix

For energy efficiency, creating the market through standards has been an extremely effective mechanism. Creating capital and then buying additional efficiency by integrating technologies has been the approach to create measures beyond those that can be obtained by standards. The electron saved is clearly the cleanest option, and society should always attempt to save as the first option if the cost is reasonable compared with producing the electron. On the other hand, energy efficiency also poses a serious challenge for traditional utilities. If their revenue streams are based on electricity sales, then efficiency reduces revenues and profits.[9] This is also true of distributed resources.

Radical and disruptive technologies
Sustainable energy requires the increased use of the short-term flux of the sun rather than the stored flux of aeons represented by fossil fuel. The shorter the flux of the sun the more the electricity generation is dispatched by nature and not by man. The more dispatched by nature the more radical or disruptive from a central station electrical utility viewpoint, is the technology. Renewable technologies in general are smaller and more modular. They work as well or better distributed rather then centralized. The more modular and the more distributed, the more radical is the technology to a traditional utility. Photovoltaics is an example that is both immediately dispatched by nature and is the most modular and the most widely dispersed of the renewable technologies, and therefore easily qualifies as a radical innovation. Some renewables, those with characteristics of central station power plants, can be applied by utilities in a traditional manner.[10] The other issue that brings in the question of radical or disruptive technologies is the idea of distributed resources, more fully discussed in the following section. Distributed generation would be dispatched locally – a radical notion for power control centres and utility power control operators. Numerous studies of technical innovation have shown that, radical innovation has never been introduced by market leaders.[11] This does not mean that market leaders cannot change their strategy to encompass radical innovation, but few do. Some examples include Microsoft – in shifting focus to the Internet – and Intel – in shifting from DRAMS to microprocessors. Yet electric utilities have not shown that sort of adaptation. The technical innovations are not only introducing new technologies, but are introducing radical new technologies. Introduction of radical technologies implies that they will have to be accompanied by new organizational structures.

Central vs. distributed
Distributed resources encompass not only generation but also efficiency technologies. While generation has traditionally been centralized, energy efficiency has always been integrated with and located at the point of use. Combined heat and power (CHP) or cogeneration also has attributes of distributed resources. There is not yet an agreed-upon definition of distributed resources. The definition I use is that distributed resources are located at a user's premises and/or connected to the distribution grid.

Most people in the electric industry have recognized the trend toward smaller scale power plants (Figure 1). In the USA the average size unit grew steadily from World War I through World World II at an annual rate of 5.5%. Then the rate of growth increased rapidly in the following decade at 17% a year. The 1970s continued the trend with the average nameplate capacity leaping to 150 MW. This peak was the result of new large-scale nuclear and coal technology. The advent of gas turbine technology with innovation primarily from outside the industry, and the demise of the nuclear era coupled with the advent of independent power producers, initiated a significant reversal. The average size of plant dropped to below 90 MW, then to 40 MW and on to 29 MW in the first half of the 1990s. These data include 99.9% of all 13,583 known units brought on line in the USA during 75 years.[12] This change in plant size indicates a fundamental change in economy of scale. An excellent history of this change and the underlying technology stasis in boiler type power plants is chronicled in Hirsh's book Technology and Transformation in the American Electric Utility Industry.[13]

Power plants that were primarily 'constructed' are now being 'manufactured'. Smaller engines and microturbines are joining solar and wind power plants. All are assembly line produced power plants that will be available to small and medium-sized businesses and to individual residences. Fuel cell technologies will then follow these initial forays into distributed generation. This is not just a new way of generating electricity but also a new way of distributing it. This requires different analysis techniques, and approaches. The important cost, or price to a customer, are services at point of delivery, not cost of power at the power plant. The traditional analysis is dependent upon the calculation of that cost at the power plant, the bus-bar energy cost. But actually what is important is the cost at the point of delivery.

One important added consideration is the value set of the customer. More and more managers and politicians now realize that customers do want cleaner energy and, with customer choice, that desire has a means to be expressed. In addition, distributed generation allows the inclusion of other user values such as reliability and quality. This development threatens the very physical structure of the electric utility. A significant wild card would be the development of small-scale storage devices, such as flywheels or advanced batteries. The ability of individual customers to store electricity cost-effectively threatens not only the underlying physical structure, but also the underlying economic structure of the utility.

In addition, the continued movement toward ‘knowledge’ economies vs. ‘resource’ economies gives the concept of reliability greater significance. This is true for both information-dependent industries (financial markets) and production-oriented industries using microprocessor controls, where both reliability and power quality are of increasing importance. This is referred to in the USA as the 7/9th problem. The grid can only provide 4/9th reliability (99.99%) not the 99.99999% required (7/9th). The cost of down time can be large (Table 2).

Table2. Price and value of electricity reliability in the information age

Industry	Average cost of down time
Average small business	$7500/day
Cellular communication	$41,000/hour
Telephone ticket sales	$72,000/hour
Airline reservations	$90,000/hour
Credit card operations	$2,580,000/hour
Brokerage operations	$6,480,000/hour

Distributed resources pose a problem to traditional utilities

Distributed generation poses a serious problem to traditional utilities. All of these technologies are a threat to the revenues of utilities since most utility revenues are derived from the sale of electricity. This means that the application of these technologies will be bitterly opposed by traditional utilities. This battle is in full swing in the USA in the establishment of interconnections to the distribution grid. Interconnection requirements fall into two categories, technical and administrative.

Technical standards deal mostly with safety issues, the impact on the distribution system and the prevention of harmonics for power quality. It appears that the technical issues are being solved by the appropriate standards committees, and the ability of solid state devices to deal with islanding and cut-off concerns.

The administrative issues are proving much more contentious. What studies need to be done, how must the system be certified and inspected, who has air quality jurisdiction, what contracts or permits to sign, who inspects – these are all contentious issues presently under discussion in the USA. Horror stories abound.[14] So far, Texas, New York and California have produced regulations covering these issues, and their application is just beginning. In addition, the concept of 'net metering' has been passed by 32 states in the USA. Net metering allows distributed generation to turn the meter backwards. This is equivalent to the utility buying power at the same price it is selling it. The interconnection rules are important in letting the market of distributed generation thrive. A philosophy of approach scale that runs from 'plug and play' to 'hesitate and hassle' appears to be evolving. In 'plug and play', the system must meet technical standards for installation and operation. The burden of proof in the issue that customers using their own equipment are harming the distribution system is on the utility. In 'hesitate and hassle', the distributed generator must meet the technical standards while also suffering the burden of proof that it is not harming the utility distribution system. The ability to install distributed generation varies greatly depending on these administrative interconnection requirements. It is an interesting exercise, and in some ways amusing, to place various utilities along this scale. Consideration of interconnection standards is already pointing out the need for a national standard – and eventually an international standard – if one really wants to capture the cost-effectiveness of mass production. The advent of distributed generation will also have a significant impact on distribution system design.

Distributed resources are the only hope of providing electricity to the billions of people that presently do not have access to it. It just does not make sense, nor is there capital available, to provide electricity in the traditional fashion. So 'keeping the lights on' for this population cannot be a choice between tradition and innovation – it has to be innovation. A considerable amount of capital and attention are being expended to deal with this concern. It has been recognized that the private sector will have to try to provide these services. The traditional utility has not been able provide these services in any sort of cost-effective way. They have no experience in off-grid systems and the traditional concepts are not applicable. The problem is not one of technology but business models that can operate in these environments. It becomes critical to fix the cost, and design the best services, rather than fix the level of service and provide them at least cost. While this seems like just a minor adjustment it is an almost insurmountable barrier for traditional utilities. In the off-grid developing world, the progression of electricity service is from individual home systems to village mini-grids and maybe in the future connection to a grid. It is ironic that in the developed world we are now discussing moving from connection to a grid to include generation locally and at the home level.

Efficiency – demand reduction

A slightly different set of issues concerns the technologies that deal with the demand side of electricity. The underlying philosophy is relatively simple: if one can get the same service for less electricity, one ought to be able to save money and the environment at the same time. There is extensive literature, extensive NGO advocacy, and many programmes dealing with the successes and the failures of implementing energy efficiency. We have not yet devised the business structure that will thrive in what has been called the 'negawatt' market. But sufficient experiments are underway around the world for one to assume that such a structure will evolve.

The results of technological innovation have significantly reduced the power requirements of motors, lighting, refrigerators, air conditioners, computers and other apparatus. This has been achieved primarily by technology forcing through standards, and through so-called market transformation programmes. More difficult has been the integration of advanced technologies into system designs. Integration of improved building materials, highly efficient windows and added insulation to significantly reduce building energy use has been more difficult to accomplish. Experiments by PG&E in the early 1990s showed that it was possible to decrease energy use in a variety of buildings, from personal residences to office buildings, by 60–80% with no or little increase in overall cost. It is even possible to conceive of buildings that satisfy all their energy needs or require very little electricity from the grid, such as by integration of photovoltaics with efficient building design. The traditional utility has not been very successful in providing energy efficiency programmes without government or regulatory impetus. These programmes run into the same basic problems if the utility revenues are based on electricity sales, in which case efficiency measures reduce sales and therefore revenues. Distributed resources, both generation and efficiency, not only threaten the structure of the traditional utility, but their fundamental economic basis.

Options for service

Many options are available to serve a customer. Providing either supply or efficiency close to the customer is, in many cases, the least cost of service solution. The least cost of service for each customer provides a means for a broader evaluation of options including those technologies the customer chooses to include in his value consideration. Cost or price will not be the only values that a customer may consider. The rather amazing emergence of a ‘green market’ was clearly not a consideration in the initial theories of restructuring.

From the viewpoint of the customer, the traditional utility can be characterized as follows:

Cost or price = $\$G+\$S+\$T+\$D$, where
G is central generation
S large storage
T transmission wires
D distribution wires.

A more generalized form is:

Cost or price = $\$G+\$S+\$T+\$D+\$DR(\pm gs)$, where
+g is small generation
–g is energy efficiency
s is small storage.

There are three generalized situations:

1. $\$G+\$T+\$D \lll \$DR\ (\pm gs)$
Centralized operation based on central generation (large load centres). Cost of central generation plus the cost of T&D is much less than the cost of distributed resources.

2. $\$G+\$T+\$D \ggg \$DR\ (\pm gs)$
Distributed operation (islands/villages/off-grid) based on distributed resources. Cost of distributed resources is less than the cost of generation, transmission, and distribution.

3. $G+$T+$D ~~~$DR (± gs)
A mix of resources depending on localized costs, conditions and choices (niches). Cost of distributed resources is approximately equal to the cost of generation, transmission, and distribution and other values become important.

The wholesale or commodity market is characterized by:

$G+$T+$D <<< $DR (± gs)

This market is the traditional utility market. It revolves around the development of central station generation and its associated grid. Emerging for this market is a regulated or nationally operated power pool and an open access transmission grid with private companies building the generation systems. This market is focused around bus-bar costs without regard to cost of delivery. It is assumed that the cost of delivery is roughly equal for all sources of generation in the same geographic area or no other delivery mechanism exists.

The situation in which

$G+$T+$D >>> $DR (± gs)

describes the case in which there usually is no utility structure and the central station concept does not fit. It represents 2 billion people without electricity, the off-grid market, or limited grid market. In this case there is a relatively unknown demand and an indeterminate ability to pay. Attempts to fit this situation into the classical utility model have not been successful.

There is also a subtle difference in approach between these two situations. In the centralized approach, the question is ‘at a given level of service, what is the least cost at which services can be provided using traditional technologies?’ In the decentralized approach, the design question is ‘given a cost (or ability to pay), what are the levels of service that can be provided with the distributed technologies?’ The starting point of the analysis is quite different.

The situation

$G+$T+$D ~~~ $DR (± gs)

in which they are roughly equal, describes the evolving energy services industry of the future. It combines central station generation with a mixture of small generation, storage and energy-efficiency technologies located at specific distribution or dispersed sites.

All of these situations imply a dynamic process that will continually change, and they will define the market for distributed resources. This market will emerge in areas where peaking loads and high transmission and distribution costs coincide. Roughly, the peaks in the US are twice the baseload and last for half a day. This represents an energy requirement of approximately 20% of the total energy demand. This does not take into consideration the markets in which distributed resources are cheaper because there is no need for wires, or where it is more cost-effective to bury pipe than to string wires. Distributed resources, assuming they provide 20–40% of the demand, are not a small market.

There is a certain symmetry between the off-grid market in developing countries and the distributed market in developed countries. The developing country market starts with off-grid specific applications and single home systems, then with increased wealth creation moves to a village or mini-grid market. This may appear to be the final configuration but one can envision that a number of mini-grids could be connected to a grid. For developed countries the grid already exists, but then the market moves to mini-grids, specific applications and single home systems. In both future systems, the mini-grid becomes the dominant element. By moving to a mini-grid concept, one can manage the demand and supply balance in a local area, and take from the grid only under specified conditions. Simply stated, one removes the peaks locally and uses central station generation only for baseload requirements. This would also allow loose coupling to the grid and not the tight coupling presently required.[6] Loose coupling would allow failure in the grid to be limited and the rest of the grid to have islands that continue to operate.

Affordable vs. costly

Because of the integral role of energy in our quality of life it becomes politically imperative that the benefits become available to most of the world's citizens. This becomes an extremely important issue for those that have no electricity today and little wealth. This brings us back to a concept that has been discussed over the years. Is the focus on cost of electricity or on the integrated cost of energy services (rates vs. bills)? It is only by balancing both supply and demand that a system moves toward cleaner and affordable. Yet Energy Service Companies have not blossomed in the way Independent Power Producers have. We have not devised a business structure to make this integration occur easily. Our business models and policies are much better at producing supply than reducing demand.

We need to be more aggressive in introducing 'smartness'. Information technology has the capability of managing the supply and demand of individual customers. The development in information technology also allows the management of large numbers of distributed resources without central control. It is dealing with both the demand and supply that can maintain affordability for all involved.

Reconciling tradition and innovation

We are now faced with a dilemma. We must design a system that not only keeps the lights on but turns them on for billions of people in this world, tailors it to individual needs and preserves the environment. The solution isn't a choice between tradition and innovation, it is *both* tradition and innovation.

Innovation is not a static concept. Innovation implies a steady stream of research and development. Most of the innovative effort relating to energy is concentrated in a small number of industrialized countries. Despite the importance of electricity investments are modest. Total R&D expenditures in industrialized countries are low relative to other economically important sectors. Private sector R&D support tends to be comparable to 'smokestack' industries and much less than for high-tech industries. In the United States, private sector R&D in 1995 averaged 0.4% of net sales compared to 6% for service industries and 10% for drugs and medicines.[15] Private sector R&D is not only low but declining. In the USA, spending has declined from $7 billion in 1980 to $3 billion in 1996. There has also been a decline in public sector support. In the United States, public sector investment in R&D fell from $5 billion (0.1% of GDP) in 1980 to $1.3 billion in 1996 (0.02% of GDP). This trend seems to be applicable to all developing countries. If one decides that innovation needs to be introduced in the electricity industry then R&D investments and continual innovation are a necessary input.

Dynamics in the industry

Tradition is already in flux (Figure 2). The introduction of competition and the rise of independent power producers is already changing the organizational structure. The traditional system cannot survive in the traditional configuration, and must evolve to encompass the radical technical innovations presently outside the system. Methodologies exist to increase the portion of renewables and energy efficiency in either a regulated or market-based system. The opening of distribution systems to distributed generation is a harder task. The experiments for accomplishing this are just beginning. There is little experience of designing optimal policies and approaches. In both cases government involvement is required. In the regulated case, it requires wise planning for long timeframes, in the restructured case, carefully constructed and monitored market policies.

Scenarios for the future

There are four possible scenarios for the electrical industry (Figure 3). These are slightly different from the two 'traditia' and 'innovatia' proposed by Walt Patterson.[6] These scenarios have two axes: structure and technology. The structure axis has regulated, vertically integrated at one end and fragmented, competitive, market-driven at the other. The technology axis encompasses the environmental criteria, and has central station generation at one end and smaller, distributed systems at the other. This leads to four scenarios:

- triumph of the good old boys
- new gladiators – old weapons
- teaching old dogs new tricks
- supermarket of choices.

On a global basis, each of these scenarios exists or is starting to evolve. The mergers of electrical utilities, the rise of power brokers, and worldwide independent power producers, are all part of the 'New gladiators–old weapons' scenario. The offering of green power and energy efficiency approaches by some utilities move them into the 'Teaching old dogs new tricks' scenario. The attempts to bring electricity to the off-grid world by small entrepreneurial businesses and by equipment manufacturers that sell distributed generation from a few MW to a few kW, moves into the 'Supermarket of choices'. These last two scenarios have the potential to redesign the electricity system into the future system required. But both of these worlds require active private sector involvement, and a heavy dose of public interest participation.

Teaching old dogs new tricks

This scenario would require heavy command and control and new regulatory policies to force existing traditional utilities into a new mould. The difficulty is not so much at the wholesale generation level but at the retail energy services level. It requires the inclusion of renewables in the generation mix. Such inclusion can be spurred by integrated resource plans and requirement for utilities to purchase or develop the designated resources. It also treats energy efficiency as a resource. The risk is then taken at the government or regulator level. This is not significantly different to what some utilities in a variety of countries are doing or have done.

The real changes, though, occur at the retail level. These changes would require utilities to open up the distribution grid to distributed generation. In essence, this approach requires that utilities become regulated energy services providers. This requires fundamental changes to the utilities' economic basis, the revenue stream. If the revenue stream, hence profits, are dependent on the sale of electricity, then distributed generation and energy efficiency decreases revenues and profits. If utilities are not in the central generation business the impact becomes large.[9] One means of dealing with this issue is to base the revenues on customers served and not electricity sold. This has been referred to as requiring revenue caps not rate caps. If total revenues are capped and customers can be served by either supply or demand, then the utilities should choose the cheaper approach in order to maximize profits. Experience with this type of regulation is limited.

There are a number of difficulties in realizing this scenario.

1. Old dogs are smart. Managers of utilities are politically powerful and could easily manipulate the system to their advantage.
2. It is hard for old dogs to learn new tricks. It would require utility managers to become proficient in the application of radical or disruptive technologies. History's lessons are that few companies that are good at traditional technologies can make that switch.
3. We don't know how to teach old dogs. No one yet knows how to create a system of performance-based regulation with cost per customer vs. cost of electricity.
4. Not only is it hard for old dogs to learn new tricks, they must also forget their old ones. Utilities would have to relinquish a culture of control and enter a culture of customer service. It would be hard for them to put the customer first.

All these problems could be overcome, but not easily. It would require political will and patience to face a snarling dog while trying to teach it new tricks.

Supermarket of choices
In this scenario the traditional utility industry is totally dismantled. Competing businesses provide a multitude of products tailored to customer requirements and desires. Markets are continuously monitored and rapidly adjusted if they do not produce public benefits.
There are a number of difficulties in this scenario also:

1. Nimble competitors quickly find loopholes in the market. This scenario requires significant restructuring of the existing utility industry, and forcing rigorous competition at both the wholesale and retail level. It requires continual monitoring of the markets to prevent gaming.
2. Nimble distribution grid operation will be vital. This requires the opening of the distribution grid to a variety of distributed systems with a 'plug and play' philosophy, as well as management at electrical sub-station level. This may require a totally redesigned distribution system.
3. Meaningful choices require information and informed customers. Increased information flow would be required at both the wholesale and retail level. The full capabilities of information technologies would be applied to real-time pricing, smart energy system management, control of all electric equipment, and educating customers.
4**. All the elements of a consumer market structure must be avai**lable. Customers must be allowed to aggregate in order to increase purchasing power. Aspects of consumer markets, such as warranties and complaint systems, must be available.

To achieve this scenario requires the fashioning of a variety of markets and assuring a host of competitors, along with the capability to oversee these markets for some time.

Prospects

Both of these scenarios are achievable, but they follow different paths. More needs to be done to explore, and to learn from the ongoing experiments, the advantages and disadvantages of the two pathways. A reminder is in order: scenarios do not predict the future, they merely postulate potential futures. The real world that evolves may even be a mixture of postulated worlds. The value of scenarios is in working back to the present and understanding the actions that would cause a shift to one world or another. In many cases there are actions that are meaningful in either world. Moving renewables and energy efficiency into the resource mix is prudent in both worlds. Beginning to open up the distribution grid is also a prelude to both scenarios. Developing business models for the off-grid, unserved world will teach both worlds how competition and business structures might evolve.

My 'gedanken' experiment, which is purely heuristic, is that

- teaching old dogs new tricks will be a slow and continuous innovation-forcing process, but has a better chance of 'keeping the lights on'
- the supermarket of choices provides more and faster innovation but has a higher risk, initially, of not 'keeping the lights on'.

But the decision is really not between 'tradition' and 'innovation'. Rather, the decision is how to reconcile these apparently opposite concepts. Tradition cannot provide the energy system the world needs in the future, nor provide electricity to those that do not have it. Innovation will be required, in both the structure of the industry and the technologies employed. We must ask how society will achieve that reconciliation – through the use of regulation or by competition, by push or by pull. One of the difficulties is that there is not global agreement on the design criteria for the future electrical system. There may be many paths.
There are some common elements in both pathways:

- increased inclusion of renewables and efficiency
- ·opening the distribution grid to distributed resources.

There is no way today to know the right path. Though policymakers and technologists are currently undertaking many experiments, it appears that the new electric utility system – one that equitably and responsibly brings electricity to the world's billions of people – will require a combination of both regulation and competition.

Governments do not have all the answers, and markets do not have all the solutions.

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