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FORECAST

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Canadian Electric Power Technology Roadmap: Forecast

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1 OVERVIEW

In an increasingly deregulated and competitive marketplace, the Canadian electric power industry is facing new circumstances for which it needs to prepare. In the future, energy will be viewed as a commodity. Increased competition will lead to new players and partnerships, new products and businesses and, most importantly, a bottom-line imperative.

The industry is changing from focussing on supply that is mainly generation-dominated and characterized by a preoccupation with security and energy reserve to being a consumer-oriented, economic and ecologically optimized energy provider.

One of the crucial dimensions for ensuring success in this emerging market environment is technological preparedness. Every industrial context demands that increased attention be paid to technology as a critical force, and the Canadian electric power industry is no exception. The challenges facing the Canadian industry can be formulated into three main questions:

- How can we reduce the risk of investment in research and development (R&D)?
- How do we align R&D investment with true market potential?
- How can we sustain meaningful and commercial progress while building on existing competencies and capabilities?

Technology roadmaps provide a tool for finding answers to these questions. This forecast document provides a foundation for roadmapping Canadian electric power technologies.

1.1 Background

The Canadian Electric Power Technology Roadmap forecast exercise was launched at a workshop of senior Canadian utility executives in March 1998. See Appendix A for a list of the Canadian Electric Power Technology Roadmap launch participants. At that workshop, the concept of roadmapping was discussed, using the U.S. experience as a guide.

The first step in the roadmap forecast exercise was to select, for in-depth analysis, the major issues on which the Canadian industry needs to focus. The selection process began with an examination of extensive data collected from global Delphi surveys on an ongoing basis since 1995 by Professors Louis Lefebvre and Elisabeth Lefebvre of École Polytechnique in Montréal. Following analysis and synthesis of these studies on technological trends, markets and competition in the electric power industry, the main underlying issues driving markets, competition and technologies were identified. Then, a validation of the relevance of the main issues was carried out through a preliminary survey among key Canadian industry players. Their comments and suggestions were integrated into a final selection of the issues to be studied in compiling the roadmap forecast.

The top ten issues selected by the industry officials for study were:

- refurbishment of existing power plants and transmission/distribution networks
- cleaner power generation from fossil fuels
- intelligent, reliable, multipurpose and remote controlled power delivery
- convergence in the delivery of multiple services

- efficient energy use or end-use efficiency
- power quality
- renewable sources of energy
- small-scale distributed generation
- nuclear energy
- vehicles of the future, driven by electric, hybrid and alternative fuels.

From the above list, workshop participants selected four issues (combining some) for development into roadmap forecasts. These were:

- assets optimization
- intelligent power delivery
- end-use efficiency and convergence
- small-scale generation and renewables.

Working groups were established to analyse these four issues. The Assets Optimization working group subsequently split to focus on two aspects of the issue under analysis, namely, generation and transmission/distribution.

1.2 Methodology

A technology roadmap is an attempt to try to understand what the market in the future will demand in terms of products and services, so that the firms making up the industry today can make the appropriate R&D investment decisions necessary for satisfying that future market. It is an industry-led initiative that focusses on market-pull rather than technology-push analysis.

Technology roadmaps provide a long-range view of technologies, product direction and timing. They also allow for the integration of interdependencies between technology, market trends and the characteristics of a competitive environment. Technology roadmaps adopt an all-encompassing, multidisciplinary and structured process, combine business and technology analysis, and represent valuable strategic tools for individual firms/organizations (private or public) as well as for groups of firms and whole industries.

The purpose of a technology roadmap is, among other things, to:

- reduce technology investment risk
- identify and seize future market opportunities
- respond to competitive threats
- strengthen technology infrastructure
- identify the critical technologies, skills and core competencies needed
- bring the supply chain (upstream and downstream) into the planning process.

Each of the working groups analysed their issue in terms of market demand in 2020:

- What products and services will customers demand in 2020?
- Will the customers of 2020 be the same as today’s?
- Will the suppliers in 2020 be the ones we are familiar with today?
- Will the products being delivered in 2020 be recognizable to people of today?

This market-pull analytic focus is the product of this report. It forecasts the technology areas on which the industry will need to focus, given the market demands of 2020.

Each chapter in the present report examines one of the key issues identified by the launch group and analysed by the four working groups, as explained above under Background. Each working group was composed of a different mix of industry representatives, but each approached the issue from the same market-pull analytical perspective. See Appendix B for a list of working group participants.

The particular issue and the mix of working group members have led to some variance in the way these chapters have been presented. For example, the issues identified by the Assets Optimization — Transmission working group are very similar to the ones identified by the Intelligent Power Delivery working group, so there is some duplication. There are some crosscutting technologies such as information technologies, which are critical across a number of issues, so again there may be some duplication. Finally, it was recognized by the launch committee that there are more than just the four issues being discussed in this report. The future of nuclear generation, for example, is very important for this sector. However, for this first roadmap forecast, the launch committee decided that the industry should focus on the four issues described above under Background.

1.3 Market Drivers

Today, electricity is a relatively cheap and reliable energy source. It is supplied by provincially operated monopolies at near cost for the economic growth and social benefit of the provinces. There is no competition among suppliers, and very few purchasing options are offered. Electricity has become “a necessity of modern life” and is supplied automatically with no decision required by the consumer. In addition, it is generally available on demand, whatever the quality and at whatever time. Prices are set by regulators, based on the cost of supply.

However, fundamental changes are impacting the energy market and the companies supplying energy products and services, influenced by three major drivers. These drivers will continue to shape the industry to a greater or lesser extent to the year 2020 and beyond. They are:

- cost/competitiveness
- environmental issues
- customer choice.

Cost Competitiveness

Deregulation and the opening of electricity markets to competition will change the way traditional suppliers do business in 2020. The electricity industry will attract new entrants with new products, services and capabilities. The ability to “wheel” power across jurisdictions and the separation of buyer from seller will open up new markets, and formerly captive markets will have to be defended. This impending competition will force all utilities to understand the costs, revenues and profitability of each segment of their business.

For example, energy suppliers will be under extreme price pressure. Frequent switching by customers to get the lowest price will cause great uncertainty. There will be a need for highly efficient, economical, flexible systems. In addition, the energy supplier will be financially at risk for capital investments associated with capacity additions. This will tend to favour less capital intensive projects and shorter construction schedules. Small-scale generation and renewable systems will be less capital intensive and will require shorter installation times than central systems. This will result in lower risk for the supplier. In addition, there will be a large number of ideal sites where uses will exist for waste heat. Highly efficient use of fuel will result in lower prices. On-site generation will avoid the costs and losses incurred by the transmission and distribution system and may even be used to defer upgrades to the transmission and distribution system (by supplying a new load from an on-site generator rather than building new transmission and distribution to service it).

Equipment and service providers will no longer be able to rely on long-standing relationships with customers that permit joint planning and design of customized products. Price, short lead times, performance guarantees and support services will be critical. Equipment will be able to self-diagnose and perhaps self-fix through software. More money may be made from operating and maintaining equipment than from selling it. The sector will be impacted by strategic alliances, partnerships, and mergers and acquisitions, all aimed at exploiting synergies and reducing risk. This globalization of all aspects of this sector as well as all areas of economic life will drive companies to find low-cost solutions to all areas of their businesses.

Along with deregulation and competition will come the financial discipline expected of every private company. Whether or not former Crown corporations are privatized, all players in the new environment will need to display bottom-line awareness. Instant communication via the Internet will allow investors to move capital quickly and efficiently. Therefore, successful companies will have a very strong focus on shareholder value and the equity markets.

Environmental Issues

Whether the Kyoto Protocol is implemented by the signatories or not, the importance of the environment as a factor in decision making in all areas of economic life will be clear to everyone in 2020. For the electric power industry, this will mean especially greenhouse gas emissions. Government policy may be needed to create market mechanisms to ensure the benefits of “greener” energy sources will be rewarded, for example, by putting costs on a par with “dirtier” sources. There is no question, however, that environmental issues will drive this sector, as it will others.

There will be more government intervention to regulate greenhouse gas emissions and the use of water. Particulates, mercury, heavy metals, various oxides of sulphur (SOx), migratory fish protection, dam safety and watershed management will be subject to stricter regulation and public scrutiny. Land use restrictions, particularly those relating to large hydro reservoirs, will also be an impediment to building new greenfield hydro projects. Environmental standards may also be used as entry barriers in different markets.

Customer Choice

The customer will be king. The customer will increasingly put demands on the electricity provider for services and levels of performance not anticipated by utilities today. Customers will demand total energy solutions that deliver both electricity and heat, with the installation engineering provided by the energy supplier. Unreliability will not be accepted, and customers will switch suppliers with the ease with which telephone customers switch providers today. The Internet will provide customers with the information needed to make the best choices regarding price, quality and preference for specific characteristics such as environmentally friendly energy sourcing.

For example, power quality will be absolutely critical to some industries using sensitive electronic controls, as even small electrical irregularities can cause industries to shut down, costing them large amounts of money and time. Industrial and institutional customers will pay a premium for improved power quality and reliability from locally installed distributed generation projects if bulk transmission and distribution systems fail to perform to expected standards. The customer will not care how the energy is produced or who delivers it, so long as it has the required attributes. Using the current telephone industry as a model, in 2020, there will be products we cannot yet imagine and solutions for which we have yet to define the problems. The entities that understand the customers and their needs will prosper. Those that do not will disappear.

2 ASSETS OPTIMIZATION — GENERATION

2.1 Today's Reality — A Snapshot of the Industry

Today's reality is that all Canadian electric utilities are in various stages of transition. They are moving from an "obligation to serve" role to an open-market, competitive commodity supply role. The future electricity market will be much different from that in the years leading up to the 2000s. Customers are changing. Products and their values are changing. The utilities themselves are changing in response.

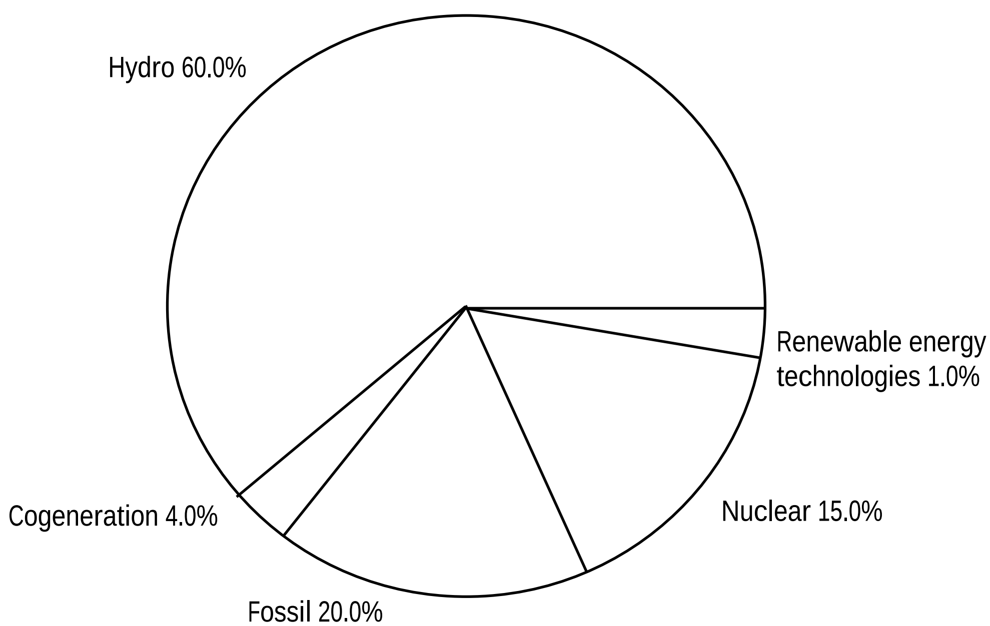
The current distribution of electricity by supply type varies throughout the country (Figure 2-1). Hydro-electric generation predominates, especially in British Columbia, Manitoba and Québec, where it supplies almost 100 percent of needs. Nuclear generation also supplies a large portion, approximately 50 percent of Ontario needs. Fossil fuels, primarily coal, supply about the same share as nuclear generation. Alberta, Saskatchewan, Nova Scotia, New Brunswick and Ontario are major coal users. Renewable energy technologies and cogeneration provide only a small part of the overall supply.

Customers

The customers of the vertically integrated, monopolistic electric utilities are fairly straightforward. They can fit into one of four classes of franchise customers: direct industrial, municipal electric utilities, direct retail, or remote area customers. There are also external utility-to-utility sales.

Direct industrials are very large corporate customers who typically consume large quantities of capacity (measured in megawatts), use large quantities of energy (measured in megawatt-hours) and take their electricity at higher voltage levels. They pay according to a series of fixed-rate schedules, over which they have little if any control or input. While these customers pay lower rates than retail, they frequently feel they are subsidizing the retail sector, and at times consider cogeneration or on-site independent power supply. The ability to pursue these paths, however, often is or is seen to be blocked by utilities and/or regulatory requirements. These customers demand high reliability and in some cases high quality. They are reluctant to spend funds and resources on

Figure 2-1. Today's Canadian Electric Power Sources



secondary businesses such as internal electricity generation facilities.

Municipal electric utilities provide electricity distribution systems to large municipally sited retail and industrial customers. Essentially they take electricity from the vertically integrated generation/transmission utility and lower the voltage to levels suitable for their systems. They may be either government or privately owned and/or operated. They are accustomed to very simple purchase price schemes (capacity and energy rates, peak and off-peak) and selling rate approval systems. They have very little if any control over the costs of their electricity supplies. Their primary focus is the design and operation of their distribution systems for cost-effective, reliable supply locally.

Direct retail customers are generally residential and smaller commercial/industrial customers still served by the main electrical system but located outside a municipal electric utility's boundaries. Essentially these customers have some form of default supplier — often the franchised, vertically integrated electric utility of the province or region. These customers pay significantly higher energy prices than their urban counterparts, but are still usually subsidized by the overall system or through government grants.

Remote area customers are generally served by remote, off-grid local generation and distribution systems. Many are in northern, fly-in communities. Small, high-priced local generators using diesels and diesel oil serve these customers. Generation cost is very high, often two to ten times that for grid-supplied, municipal customers. Prices are also high, but are usually subsidized by grid system customers of the franchised supplier or through government grants. These areas are favourite spots for trials and use of higher capital cost renewable technologies. Customer generation is more favourably looked at, but generally cannot compete with the lower, subsidized rates.

Surplus energy and capacity are often sold and/or traded between utilities. In the past, these trades were strictly between franchised utilities; the two parties shared equally the margin between the marginal cost of the seller and the marginal cost of the buyer. The arrangement was very cooperative between utilities, but gave actual customers no option or choice in the matter.

Products

Today's vertically integrated monopolistic electric utilities in Canada typically have a single focus — electricity generation. As a result, they have only four major products: electrical energy, electrical capacity, thermal energy and by-products.

Energy is sold by the unit based on a small number of "price schedules" to various franchise customers. The franchise customer prices are averaged over some period of time, with minimal variation by day or by season. Some time-of-day pricing is used, but it is not widespread.

Energy is also sold outside franchise areas, but on a negotiated basis between two franchise utilities. The sales result in a sharing of the savings from the sale between the two utilities. Both long-term and short-term supply contracts exist, although in recent years most have been short-term and/or spot market sales.

Electrical capacity is sold primarily to larger wholesale customers — direct industrials and municipal electric utilities. A monthly charge is based on peak use of power by that customer during a month, usually with little regard for time of day or season. Interruptible service customers, who may have their service interrupted with little or no notice, do not generally pay for "capacity."

Capacity is also sold between regionally franchised utilities (utilities that have exclusive rights to service clients in a specific geographical area). The sale is usually custom-tailored and hence either includes a season/time-of-day capacity component or buries that component in the energy price. This is less common as more utilities go to the spot market.

Thermal energy is not a major product for electric utilities. Given its added capital costs and complications to technical and commercial operations, thermal energy is generally the exception. Most often, it is initiated by a local customer or developer.

By-products are bulk materials that utilities produce on an ongoing basis as a result of their normal electricity production operations. They generally sell the by-products either to make a profit or to reduce their disposal costs. Some examples are coal fly ash for concrete manufacture, gypsum from a flue gas desulphurization system, or tritium from heavy water production.

Suppliers

Government or privately owned vertically integrated utilities are by far the dominant suppliers of electricity in Canada. Governments started most as a means to ensure that all their constituents received reliable electricity supply at the lowest practical cost. Most electric utilities in Canada are near sole-supplier monopolies that have been provincial government-owned (except in Alberta) since their inception. Many, however, are in the initial stages of transitioning into something different: public/private partnerships, private sector splits into smaller, more diverse entities, or growth into regional or global energy utilities.

Until 2000, most Canadian electric utilities faced minimal competition within their home-market franchise. Many were protected from competition by regulation. Competition was primarily limited to who could sell the most to neighbouring utilities (not users) and at what profit. Independent self-generators, cogenerators and independent power producers (IPPs) faced many obstacles in competing.

Reliability of supply is the ultimate focus of the Canadian electric utility monopolies. As the monopoly supplier, lowest cost and reliability sometimes are at odds, with reliability usually the primary criterion. While cost reduction continues to be a major influence on utilities, reliable customer supply remains the first priority.

Fossil fuel generating plants play a variety of roles within different systems in Canada. In Alberta, Saskatchewan, New Brunswick and Nova Scotia, fossil fuel generating systems play a base load role. In Ontario, fossil fuel generation varies from base load to intermediate to even peaking. A common feature of almost all of these plants is that they have been built using proven and reliable pre-1980s technology. Their efficiencies are considered low at 33–38 percent. Efficiency is limited by the theoretical limits of the steam cycle. Efficiency is not as critical as reliability, since coal is cheap. Other alternatives such as natural gas-fueled combined cycles, although more efficient, are considered too unreliable and/or too expensive to operate.

Large, high-efficiency hydro-electric generation is fully proven and largely fully utilized in Canada. British Columbia, Manitoba, Québec, Newfoundland and Labrador, Ontario and New Brunswick all have fully developed commercial systems. The hydro-electric units form the base of these utilities' systems. Most have been built long enough ago that their costs, even including capitalization, are low relative to fossil fuel generation. Significant quantities of larger hydro-electric capacity and small, run-of-river generation remain in some parts of the country. Cost, market limits, environmental issues and transmission requirements have influenced their development to date.

Industrial cogeneration is not common in Canada but is growing. Canadian electricity rates are generally low enough to discourage cogeneration. In addition, there are real and perceived regulatory and commercial barriers that strongly discourage it. Industry itself is reluctant, given the rules, to take the risk of self-generation. The capital needed to develop cogeneration is generally perceived as achieving higher returns when invested in core business.

Nuclear generation was embraced in Canada and in Ontario, in particular, in the 1960s. The dream was realized in 1972 with the start-up of the first nuclear CANDU unit at Pickering, Ontario. Initial operation was very successful. CANDU facilities were added in Ontario, Québec and New Brunswick, and also abroad in Argentina, South Korea and Romania. CANDU reactors were initially world leaders in commercial availability. Equipment reliability problems due to poor management practices and poor maintenance developed in the mid to late 1980s and were exacerbated into the 1990s. These problems led Ontario Hydro in 1997 to initiate its nuclear recovery program. Ontario Hydro took seven units temporarily out of service in order to focus its maintenance resources on the remaining 12. The end of 1999 saw the start of the work on the out-of-service units to return some or all of them to commercial service.

Combined cycle generation began in the late 1980s to take on a more important role with the introduction of the advanced General Electric 7F gas turbine. While initial plans in the early 1990s were expected to see fairly wide adoption of the gas turbine, simple and combined cycle, a major recession delayed implementation in Canada until past 2000. Widespread adoption in the U.S. and the rest of the world makes combined cycle generation the technology of choice for any new additions well into the second decade of the 21st century.

Renewable energy and distributed generation technologies play very small roles in Canada (excluding conventional hydro-electric generation). The up-front costs of renewable technology are a major roadblock to its use, as are its unpredictable or intermittent nature. The high cost is due in part to its development status and, in many cases, to its limited resources and scale. So far, it has not proven either its reliability/life or its efficiency in commercial operation. The unpredictable or intermittent nature of these technologies generally means that additional backup generation facilities or electricity storage facilities are required.

Electricity Generation Equipment and Service Suppliers

The end of the 1990s has seen the near completion of the globalization in the electricity generation technology supplier market. Individual companies have largely completed their internal consolidations. Typically, each one has established individual world product mandate centres. Canada, for instance, has significant facilities in the hydro-electric turbine, industrial boiler, and nuclear steam generator and component areas. Major global mergers have today reduced the numbers of major electricity equipment vendors serving the industry worldwide to only a handful. Canada has retained its significant hydro-electric presence, but has lost many branch production facilities.

The services sector to the electricity generation industry continues to undergo major changes, primarily consolidations. This sector includes areas such as research and development, consulting, maintenance and contract operations, and testing.

Research and development funding has been substantially reduced as utilities in Canada and worldwide move toward more competition and substantial cost-cutting and as governments reduce their R&D support. As a result, the number and scope of Canadian R&D facilities have declined substantially. Their role is to seek a broader market internationally for specific expertise. The role of the universities in Canada in applied R&D is slowly changing to adapt to their growing importance, both on a stand-alone basis and collaboratively with industrial facilities.

Consulting in the 1990s has experienced similar reductions, but with increased growth during the past two years. The emphasis on the environment along with the opening of the electricity market and new load growth have stimulated substantial recent growth in consultant activity. As utilities cut internal staff to reduce embedded costs and as staff ages, consultants are taking on an expanding role in what formerly would have been internal engineering work within utilities. This work is positioning these consultants well to work in partnerships with other consultants in other countries.

Maintenance, contract operations and testing were primarily internal functions within Canadian utilities until the late 1990s. This is expected to be a growing area of work both in Canada and worldwide as utilities subcontract to achieve lower costs. Simultaneously, pressure to achieve maximum performance to maximize profits and reduce costs with aging, older equipment is expected to bring about increased testing and maintenance. Given the number of existing units and the increased numbers of new combined cycles in North America and worldwide, this field is growing. Canadian companies have considerable expertise but face competition from American companies, particularly from the new combined cycle and clean coal technologies.

Environment

Environmental regulations are largely based on issues and technology from no later than the early 1990s. The environmental issues include ground-level pollutant concentrations, acid rain precursors, an initial approach to smog reduction, polychlorinated byphenyls (PCBs) and liquid effluents. The regulations are designed to be reactive — solving a known, well-defined problem that already exists. Electric utilities endeavour to be environmentally responsible. They follow regulatory requirements and at times even champion various environmental causes. Many new issues are on the horizon — greenhouse gases, ground-level ozone, particulate matter <2.5 microns and <10 microns (PM10/2.5), hazardous air pollutants, mercury and electromagnetic fields, to name only a few. In many cases, the exact nature and extent of the issue and the nature of the solution are undefined. In some cases, the cost of implementation can be very significant. The ability of one company or province to move on regulations within a competitive environment can be limited.

2.2 Vision 2020

By 2020, energy providers will replace Canadian electric and gas utilities. There will be a convergence of electric generators, fossil fuel suppliers and service companies. Communication systems and computers will develop into smart systems able to control the production and end use of energy. Large providers of bulk power will sell to direct customers and aggregators. Other energy providers will fill niche markets by taking advantage of unique local conditions such as availability of local fuel sources (landfill gas, hydraulic storage, photovoltaic panels, biomass, wind), remote customers and green power. Thermal energy will become an important by-product of electrical generation. The customer will be able to choose from a wide array of products and energy providers.

Changes in technology, regulations and customer needs will provide a modest range of possibilities by 2010. Looking to 2020, there will be a wider range of possibilities as new options, some not yet even imagined, become a reality. As time passes, some concepts will become obsolete or socially unacceptable, thus narrowing the field of possibilities.

Because utility capital projects are often based on a life cycle of 20 years or longer, without monopoly support, risk will be increased.

Managing risk and maintaining a balanced portfolio will be key business requirements. Correctly gauging customer needs will be key to future success, as customers will be able to choose. The range of customer choices remains to be seen and will be influenced by government regulations and industry offerings.

In creating a vision for 2020 a number of assumptions have been made:

- Electricity will be manufactured using fuel and the price will vary with the price of fuel (availability, security of supply, ease of use).
- Lower-emissions technology used in the conversion of fuel to electricity will affect the price of electricity through life cycle costing, including the mitigation of environmental impacts on health and climate change.
- The markets will be open to all those able to meet governmental regulations regarding safety, emissions and reliability.
- Customers will be able to choose their supplier based on who best satisfies their needs.

Customers

The main classes of customers will be segmented by the priorities they place on the products purchased — price/service packages, or quality/reliability. These types of customers will be found in each of the traditional groups of residential, commercial and industrial sectors.

The cost of energy (electricity or thermal) will be a main driver for customers. The markets will be open to competition, and customers will be able to switch between energy providers. For customers looking for a supplier, the key criterion will shift from reliability of supply to ability to negotiate the best supply terms possible. Energy providers will supply the needs of that market, provided it is profitable to do so, and adapt different technologies to meet their needs.

Customers will also be segmented by how they purchase power and who services them:

- large customers, who negotiate direct purchase contracts with generators
- retail customers, who purchase power from aggregators offering various packages
- sophisticated customers, who purchase energy on the spot market through an independent energy market typical of a futures market.

Direct customers will be the very large corporate customers who typically consume large quantities of capacity, use large quantities of energy and take their electricity at higher voltage levels. These customers will negotiate contracts for capacity, energy and thermal power. Bulk purchases based on a take-or-pay scenario will provide for a cheaper overall price but will require significant planning and production flexibility. The blended rate incorporating all forms of power purchases will result in the lowest overall kilowatt-hour cost.

These large direct-purchase customers will be the most sophisticated users and will blend their power purchases based on firm contracts, spot pricing, off-peak and interruptible pricing. Large industrial customers may purchase thermal energy in the form of steam or hot water. Some generators will locate their generation assets close to these customers to take full advantage of thermal sales.

Aggregators will replace the municipal electric utilities in providing electricity distribution systems to large municipally sited retail and industrial customers. Aggregators will sell their packaged services to a broad range of residential, commercial and industrial customers. The significant difference between aggregators and large customers is that they do not consume the power themselves. They will have numerous retail accounts, which, when totalled, amount to a high capacity. Aggregators will have buying clout and will purchase power from generators.

They typically will buy at a higher transmission voltage and will incorporate energy, transmission and distribution charges. Aggregators will shop for the best prices; the difference between what they pay and sell it for will be their profit.

Remote area and rural customers will be smaller customers in low-density areas. Their costs will be significantly higher due to transmission and distribution costs. All customer costs will be based on the cost of supply. There will be no cross subsidies between markets, but local governments will subsidize some of the power costs to attract new businesses into the area. Some generators will site their assets close to these areas to take advantage of this captive load and to reduce the transmission charges. Transmission primarily will supply emergency backup and stability. A number of smaller generators using biomass and indigenous fuel will fill niche markets. Competition will come from advanced photovoltaic systems and transportable fuels such as coal, liquefied natural gas and propane.

The introduction of fuel cells and advanced photovoltaic systems will allow some customers to generate their own power. New service suppliers will provide packaged units that supply all electrical and thermal needs for the site. These packages can be leased or purchased, with maintenance packages and replacement units available around the clock on short notice. They will be remotely monitored and will have sensors to indicate whether any problems have occurred or are about to occur. Surplus energy and capacity can be sold back to the local aggregator.

Products

Products supplied to customers will meet individual needs. Customers will be able to choose from a wide range of products and will be able to purchase a bundle of one or more of the following:

- time-of-use energy
- capacity (peak and off-peak)
- interruptible power
- power quality
- reliability and security of supply including storage
- ancillaries — VARS (volt–amperes reactive), Reserve, Black Start
- thermal energy
- environmental credits
- fuel tolling and fuel reselling
- by-products created through the generation of electricity
- power monitoring and management services
- risk management, price hedging and futures markets
- green power
- watershed management.

These products may be purchased from aggregators, generators or service suppliers. Generators and power suppliers will provide the infrastructure for many of the products listed.

There will be a greater array of products available to generators to achieve lowest overall cost and to extend the useful life of existing facilities. The options open to generators will be repair, modify and upgrade, repower with new equipment on existing sites, or build new greenfield sites. Many existing facilities will have reached or will be nearing the end of their design life by 2020. Generators may choose to extend the life of plants as long as economically possible or to build new, hoping to grandfather emissions levels to existing standards and regulations.

Energy will be sold on the spot market, and peak power will be much more expensive than off-peak energy. Direct customers and aggregators will negotiate power purchases based on customer demand.

Summer and winter peaks will command the highest price. Power purchasers will use sophisticated weather models to determine future pricing. Spring and fall prices will be lower, when seasonal demand for heat and cooling is lower. Aggregators may average the energy price over the year for their customers and may provide a price guarantee. Intelligent bidirectional meters and the smart house concept will enable loads to be shifted to off-peak periods.

Electrical capacity will also be sold to industrial direct demand customers. This arrangement will primarily be for reliability, as industrial customers will need to be sure that they will get electrical power when needed. Negotiated rates may be daily, weekly or yearly. Generators will carefully balance capacity and energy sales to maximize profit.

Low-cost surplus and interruptible power will be available but may be shut down at any time, for example, because of equipment failure or because the generator has found a new customer at a higher price.

Power quality services will expand for those companies needing cleaner power than that provided through the distribution network. Conditioning will be done at the consumer site rather than over the entire network. Fast-acting controls will reduce the effect of voltage sags and harmonics.

Reliability will be enhanced by supplying generation on-site, including standby generation, and by storing power for short-term outages. The service company may also dispatch these standby generators when not required by the customer.

There will be a market for ancillary services such as VARS (volt–amperes reactive), Reserve and Black Start, especially for local generators that supply to local grids backed up by transmission, although this may account for only a fraction of the total capacity used.

Thermal energy will become an important by-product of generation. Local developers of district energy systems may contract for thermal capacity. Cogeneration will result in higher system efficiency and greater profit. Such generation will be located in areas where thermal energy use can be cost-effective.

Some companies may find it cheaper to purchase environmental credits for their emissions rather than clean up their own facilities. Companies may be required to purchase emissions allowances, and these costs may be rolled into the price of energy generated.

Companies may purchase long-term contracts for fuel and then sell it as prices increase. Generators with the ability to switch fuels may benefit by using the lowest-cost fuel to balance emissions and lower costs.

The aggregators and service providers will rely on intelligent power systems to forecast capacity and energy consumption. Power consumption will be managed locating the lowest-cost power at that moment, switching discretionary loads to off-peak periods or reducing peaks. Monitoring systems will assess reliability of components, self-diagnose problems and dispatch for service when needed.

For many industrial customers and aggregators, the change in power prices may pose a significant financial risk. Insurance products will be common for risk management and price hedging.

Renewable power will gain a greater portion of the market as new technologies become available. Solar power, wind and hydrogen systems will offer great potential for zero-emission generation systems. Emission credits from the use of these systems may offset other higher-emission generation assets or reduce the cost, leading to more widespread use.

Suppliers

Various forces such as government regulations, technology choices and environmental concerns will shape suppliers and their products. Customers will have a greater influence in a deregulated competitive market and suppliers will try to differentiate themselves by providing customers with viable alternatives. Green power such as solar and wind will be more costly but its price will be competitive, since total life cycle environmental impact costs will be included. Technology choices will become increasingly important, as generators purchase permits allowing the production of greenhouse gas, thus raising the cost of generation by specific fuels.

Electric utilities in Canada will no longer have any monopoly support. Provincial governments will have sold all assets to private companies and the market will become competitive. Many companies will amalgamate and grow into regional and global energy utilities. There will be no geographic restrictions, and many companies will grow into national suppliers. A convergence of utility industries supplying water, sewer, electricity, fuel and telecommunications will evolve. Retail outlets will become the customer point of contact and lead to cross branding of products.

Independent power producers, self-generators and cogenerators will compete in an open market. Regulations will be set by government bodies, and anyone meeting these minimum requirements will be allowed to sell power.

Generators will make great strides to maintain reliability of their assets, pushed by the transmission and distribution systems, since higher utilization ratios may result in higher revenues. For a competitive supplier, the primary criterion will be the lowest cost able to meet the minimum reliability standard.

Fossil fuel generating plants will play a variety of roles within different systems in Canada. In Alberta, Saskatchewan, New Brunswick and Nova Scotia, fossil fuel generation systems will play a base load role. In Ontario, fossil fuel generating plants will vary from base load to intermediate even to peaking. Coal will still be an important fuel. Sequestration technologies will allow central plants to remain competitive.

Large, high-efficiency hydro-electric generation will be fully proven and fully utilized in Canada, playing a significant role in British Columbia, Manitoba, Québec, Newfoundland and Labrador, Ontario and New Brunswick. Across Canada, the total amount of power generated by hydro-electricity will remain constant. New capacity will be supplied by other technologies.

Industrial cogeneration will grow. Many of the perceived regulatory and commercial barriers that strongly discourage it will have been eliminated. A service industry will grow to supply cogeneration power, because many industries will prefer to invest their funds in their core businesses. As total electric power consumption increases, the percentage of power from renewable and cogeneration plants will increase. Combined-cycle natural gas turbines will see increased popularity as improvements in efficiency and cost reductions occur. Boilers may become fuel-flexible, being able to cofire natural gas, coal and biomass depending on the fuel price, availability and ability to meet emissions regulations. Suppliers will provide various technologies to reduce emissions.

The widespread use of combined-cycle natural gas will continue to generate a major share of the power generated. Its small footprint and flexible fuel source will make it the generation technology of choice for any new additions. Combined cycle turbines will become an alternative to repower some nuclear sites.

Environment

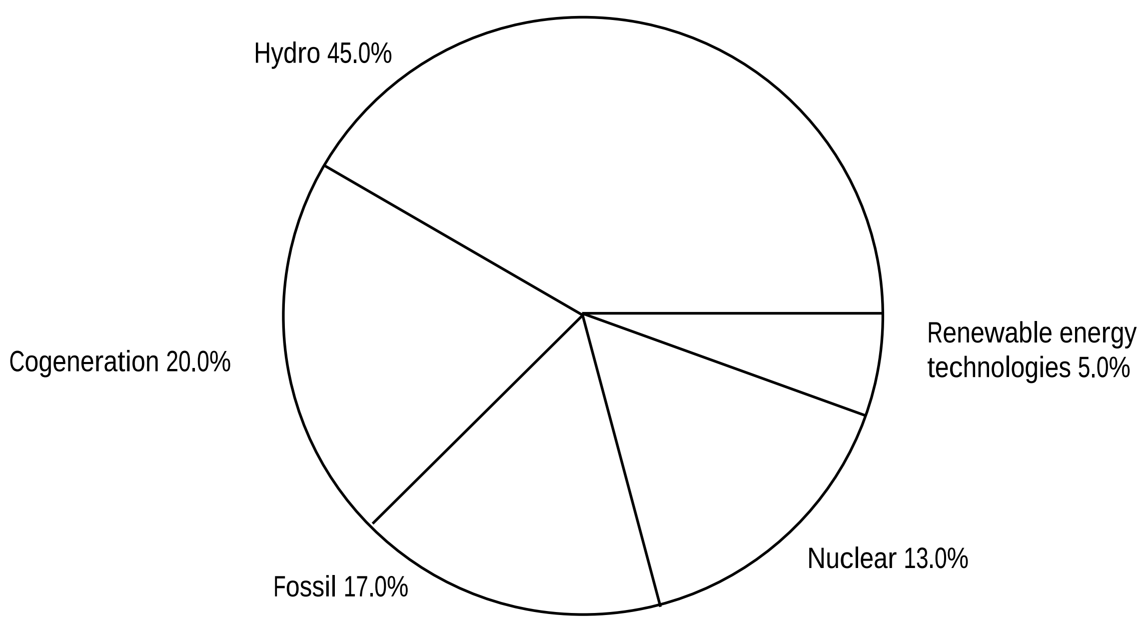
Environmental regulations will become increasingly stringent, with restrictions on all contaminants that impact on the ground, water and air. There will be quantitative limits for all types of ground-level pollutant concentrations, greenhouse gases, ground-level ozone, particulates (PM10/2.5), hazardous air pollutants, mercury, electromagnetic fields, acid rain precursors, PCBs and liquid effluents. Given the emphasis on climate change and groundwater quality, the regulations will increasingly try to be proactive to forestall greater environmental degredation. With an open market, environmental legislation will become international in scope, sanctioned by restrictions on trade for non-compliance.

Supply Characteristics

The distribution of electricity supply type will vary throughout the country (Figure 2-2). Hydro-electric generation will still predominate, but with a lower share, because the overall supply mix will increase while hydro generation will remain relatively constant. Hydro-electric generation in British Columbia, Manitoba and Québec will continue to meet almost 100 percent of needs. Nuclear generation will continue to supply a significant though smaller portion compared with the 1990s, since many older units will have been decommissioned and no new units built. Fossil fuels, primarily coal, will continue to be an important fuel, especially in Ontario, Alberta and Saskatchewan. Renewable energy technologies including solar, hydrogen, wind and biomass will provide a relatively small percentage of the total supply mix. Cogeneration/distributed generation will grow as a result of the use of natural gas combined-cycle plants.

Renewable energy and distributed generation technologies will play a growing role in Canada's generation mix. New technologies will reduce the initial costs of photovoltaic and hydrogen systems. Large-scale fuel cell plants will use hydrogen to produce green power. Hydraulic storage technologies will enable power to be saved for use in high-demand and high-revenue periods. Distributed generation will be cost-competitive, especially with deferred distribution and transmission costs.

Figure 2-2. Canadian Electric Power Sources Forecast for 2020



2.3 Critical Technology Areas

Tables 2-1 to 2-4 outline the technologies and drivers impacting generation according to major fuel sources. Generation companies will also need to focus on other technology areas if they are to ensure reliability in 2020 (Table 2-5).

Table 2-1. Hydro Generation

	Drivers	
Critical technology area	**Cost**	**Regulation**
Equipment and environment monitoring systems	• reduce maintenance cost • extend life of equipment	reservoir greenhouse gas monitoring
Turbine	• economical design for low head generation	
Hydraulic computational fluid dynamics (CFD) modelling	• increase efficiencies of water passages	
Dam materials	• reduce construction costs	
Risk management tools and modelling		dam safety
Dam maintenance	• repair techniques	
Fuel cell	• advanced materials required	
Hydrogen storage and distribution	• lower cost	safety
Batteries	• reduced cost of materials • long cycle life	

Table 2-2. Energy Storage Generation

Critical technology area	Drivers: Cost	Drivers: Regulation
Pumped hydro	• reduce capital costs and find suitable sites	environmental regulation
Batteries	• develop batteries with lower materials and manufacturing costs and with long cycle life	none
Hydrogen: electrolyzer/fuel cell combination	• reduce materials and manufacturing costs	new regulations for wide hydrogen infrastructure and safety
Superconducting magnetic energy storage	• lower capital and operating costs	regulations to handle very low temperatures
Compressed air energy storage	• economical if naturally occurring aquifers are available	none
Flywheel storage	• emerging flywheels using superconducting bearings, though expensive, are of interest for small energy storage	nothing special
Capacitors and super capacitors	• ideal units for utility power control applications and in electrical vehicles • new materials and lower cost needed	none
Dams as large hydraulic batteries	• cheapest way of storing electricity bought at cheap rates at off-peak hours on spot market	none
Storage for dispersed power production units not connected to grid	• energy production from wind or solar farms, in regions not connected to grid, can be stored either in batteries or in electrolyzer/fuel cell combination	none

Table 2-3. Gas Generation

Drivers	Critical technology area
Improved efficiency	• combustion modelling • flow models for turbine and boilers • flame analysis
Material development	• high-temperature materials • high-efficiency, high-speed bearings • wear-resistant materials • low oxides of nitrogen (NOx) catalytic materials • high-speed, high-temperature lubrication • high-efficiency and lower-cost heat transfer components
Maintenance and automation	• real-time sensors for combustion and control • real-time condition analysis measurement techniques
Retrofit and by-product	• higher-intensity, low-volume burners • additives introduced into combustion zone to reduce oxides of nitrogen (NOx) and other pollutants • use of combustion cycle as exothermic reaction to produce new by-products
Sequestration and capture	• production of hydrogen and sequestration of carbon prior to combustion • absorption • adsorption • membrane
Environmental issues	• control of oxides of nitrogen (NOx) • particulates (PM10, PM2.5)

Table 2-4. Coal Generation

	Drivers		
Critical technology area	**Cost**	**Environment**	**Other**
Pulverized coal			
Pressurized fluid bed	less than $45/megawatt-hour		
Integrated coal gasification combined cycle (ICGCC)		carbon dioxide capture/sequestration removal and disposal at <$20/tonne carbon monoxide	flexible for different market conditions
Zero emissions	less than $20/megawatt-hour thermal energy		
Eco industrial park		zero net oxides of sulphur (SOx) and of nitrogen (NOx)	
Integrated coal gasification fuel cell combined cycle (ICGFCC)			

Table 2-5. Other Critical Technology Areas

Critical technology area	Requirements
Generation technologies	• ultra supercritical pulverized coal (USCPC) • supercritical pressurized fluidized-bed combustor (SCPFBC) • simple • new cycles • flexible systems • high-efficiency fuel cells • oxygen/carbon dioxide systems • high-efficiency combustion turbine unit (CTU) • high-efficiency, top/bottom cycle
Controls	• high-temperature gas analysis • high-temperature flame characterization • artificial intelligence • full automation • instantaneous coal carbon monoxide • low-cost continuous emission monitoring (CEM)
Environmental controls	• oxides of sulphur (SOx) • oxides of nitrogen (NOx) • particulates (PM10, PM2.5) • mercury • volatile organic compounds • heavy metals • fly ash • bottom ash • liquid effluents
Asset management	• remaining life calculation • life trending versus potential • artificial intelligence
Materials	• high-temperature strength • high-temperature corrosion • high-temperature flexible • high-catalyst concentrations
Maintenance	• output assessment

3 ASSETS OPTIMIZATION — TRANSMISSION

3.1 Today's Reality — A Snapshot of the Industry

Transmission has been undervalued and forgotten, but now is the enabler of deregulation. It has been severed from its traditional role in the vertically integrated electric utility structure of the past and now is designed and continually extended to meet the needs of captive customers. Transmission has become a service provider in an era of continuous change, liability and new, diverse customer relationships.

The electricity supply industry is restructuring to focus on competition and customer choice. The impact on transmission is enormous. Network capacity is limited. Wheeling transactions are increasing significantly. Congestion and price volatility are increasing. Customers are demanding improved power quality and reliability. Customers require new products and services such as ancillary services and differentiated reliability. New facilities face severe siting constraints, particularly in urban areas. The risk of unreliability is already evident as seen in public backlash (and lawsuits) stemming from the power line cable failures in Auckland and brownouts in the United States. Consumer concerns may influence distributed sources, thus stranding transmission assets and lowering their value.

There is a critical need to evaluate transmission system vulnerabilities and to develop market and technological solutions to demand and reliability issues. There is an urgent need to control delivery costs while improving reliability, availability and maintainability to achieve sustainability and ensure that the assets and necessary additions are there when needed, to manage risks and uncertainties for customers and shareholders, and to meet increasingly stringent environmental and societal requirements.

Customers

For the present, customers are unchanged but they are no longer captive. Customers now have choices through open access. The service provider must meet their needs and expectations in terms of delivery cost, dependability and sustainability. The goal of the transmission service provider is to retain customers and maximize the value of the asset while managing risks and uncertainties and meeting environmental regulations.

Products and Services

As already noted, transmission is a service provider. The products (or really the technologies) of interest are those that support and enable the service (Table 3-1).

Suppliers

Products today are acquired from discrete vendors specializing in particular product areas. Major equipment comes from one supplier, protection and control equipment from another, and telecommunications equipment from yet another. Convergence will change all of this. Suppliers too will tend toward becoming service providers themselves and even partners with their customers.

3.2 Vision 2020

Customers

Customers in 2020 will still be the generating companies and the consumers. The generating companies will probably be much larger than today as a result of consolidation. Whether independent power producers will play a significant role is a good question but is difficult to answer at this time. Consumers will be the major industrial accounts, commercial accounts, distribution companies, and others such as cities, municipalities and co-ops formed by residential consumers.

Table 3-1. Existing Technologies and Incremental Improvements Required

Driver	Existing technology (2000)	Incremental improvement to existing technology (2005)
Management processes/ work force skills	• high level of human input to decision making • individualistic • inconsistent • reluctance to adopt new technologies and take risks	• process-based organization • empowered delivery teams working within defined processes • risk management techniques supported by increasing levels of information technology
Planning	• reactive • deterministic	• proactive • probabilistic
Operation	• reactive • advanced supervisory control and data acquisition systems (SCADA)-based, limited analytical tools	• proactive • use of on-line knowledge and management systems (e.g., dynamic security assessment) • automatic scheduling, billing, settlement
Maintenance schedules	• time-based • corrective • off-line condition monitoring	• reliability centred • on-line condition monitoring
Equipment utilization	• nameplate • manufacturer's recommendations • conservative	• dynamic circuit/equipment ratings based on real-time monitoring • increased real-time loading of transmission assets
Specific technologies	• traditional monitoring and protection • multiple sensors • limited integration	• network monitor • incipient fault detection • enhanced modelling • life extension techniques for insulation systems • life extension techniques for tower steel and woodpoles • communications protocols for high-speed integrated information exchange

Table 3-2. Converging Technologies in 2020

Driver	Converging technologies
Management processes/ work force skills	• asset decisions based on real-time knowledge acquisition, delivered to the right people at the right time, supported by sophisticated risk management models and artificial intelligence methods to determine level and timing of investments • highly automated quality and performance management systems
Planning	• predictive, based on on-line monitoring and data mining technologies • automatic generation of electric system plan
Operation	• highly automated operation based on: – knowledge systems – sophisticated dynamic and thermal security models and analysis – delivery of premium reliability and power quality
Maintenance	• determined by knowledge systems, data mining, continuous monitoring and modelling, integrated with work management systems for optimal scheduling of resources • residual and end-of-life equipment assessment
Equipment utilization	• automated (e.g., load system on basis of value calculation, revenue versus cost of reduced life) • significantly greater real-time loading of transmission assets with minimal investment
Specific technologies	• high-temperature superconducting cables and transformers • advanced polymer cable systems • low-cost flexible alternating current transmission systems (FACTS) devices for directed power flow/power quality enhancement • wide-area real-time analysis and optimized power flow • advanced sensors • advanced energy storage devices • advanced meters

Products and Services

The technology used by transmission providers in 2020 will be the convergence of information technology, electronics and communications (Table 3-2).

The transmission system of the future will be a virtually automated, intelligent system incorporating the following visionary technologies and more:

- single-point data acquisition and delivery utilizing advanced sensors and IEDs
- overlaid high-speed fibre-optic data network
- self-addressing of components and customers
- advanced on-line analysis including triggered data mining, for example, to predict faults and outages.

Suppliers

Suppliers in 2020 will provide systems representing the convergence of the traditional power products and the concept of information technology, electronics and communications. The suppliers may operate and maintain the systems on a merchant type basis but will at least be responsible for maintenance.

3.3 Critical Technology Areas

Similar to those affecting intelligent power delivery, the four main critical technology areas will be dictated by the concept of information technology, electronics and communications (Table 3-3 below).

Sensing/Monitoring

New technologies will be required to monitor the status and condition of assets.

Telecommunications

Higher-speed digital transmission will become more important as control and monitoring systems require the reliability currently enjoyed by protection systems. New solutions will be needed to support the addition of real-time asset-condition monitoring. The transmission and distribution system itself may be used as a low-speed, telecommunications transmission medium. Like the Internet model, power system elements may have intrinsic addressing, and the system may become aware of the elements attached to it.

Processing and Decision Making

Requirements will include more and faster processing, and knowledge systems to make decisions that currently require human operators. These will involve the development of expert systems and off-line and on-line data mining technologies.

Command/Control

The need for more data and faster decision making will reduce the role of the human operator. The operator functions will be taken over by automated processing and decision making systems. The command/control function will simply become the output of the decision-making process.

The control centre will be replaced by a distributed system management system. Human intervention will be required more on a management-by-exception basis. With increasing levels of sophistication in management systems, the nature of the decisions will approach that of business decisions, and become much more separated from system technical decisions.

Table 3-3. Critical Technology Areas and Requirements

Critical technology area	Requirements	
	Extrinsic technologies	**Intrinsic technologies**
Sensing/monitoring	• robotic sensors that sense changes in physical condition of assets (e.g., robotic infrared cameras) • fixed sensors that sense changes in physical condition of assets • distributed, synchronized intelligent devices and remote terminal units for integrated protection and control, condition monitoring, metering and so on	• embedded optical fibres that sense changes in physical condition of assets • assets made from smart materials that sense changes in themselves • assets with IP-type (Internet Protocol) addressing capability
Telecommunications	• Internet-based monitoring and analysis technologies • distributed micro transmitter systems • ultra high-speed, reliable wide area networking • highly reliable network security systems • highly secure network and system management systems • low-speed IP networking over transmission and distribution system • standardized protocols • interoperable intelligent devices (e.g., low environmental orbit satellite)	• embedded optical fibres that facilitate communication of asset condition data • smart materials that facilitate communication of asset condition data
Processing and decision making	• ultra high-speed digital protective relaying systems • ultra high-speed, neural network-based control systems • integrated protection and control systems • data mining systems • knowledge systems • simulation systems • prediction systems • expert systems with inputs from all of above • advanced risk/technical/financial decision-making tools	

4 INTELLIGENT POWER DELIVERY

4.1 Today's Reality — A Snapshot of the Industry

Electric power systems around the world are moving from regulated monopolies toward a deregulated environment consisting of competing power producers and power marketers. Transmission and distribution networks, however, remain as regulated monopolies. The ability to operate competitively in this environment while maintaining an acceptable level of system security and reliability is a major challenge in electric energy delivery.

Customers

Current electricity rate structures and conditions of electricity supply offer residential and commercial customers few choices. There are neither financial incentives to shift their daily consumption patterns to off-peak periods, nor are there financial incentives to accept lower power reliability. Such incentives are available only to large industrial consumers. Consequently, large quantities of electricity are consumed during peak periods for activities such as water heating, clothes washing and clothes drying, some of which can conceivably be shifted to off-peak hours.

Products and Services

Until recently, large regional electricity monopolies in Canada provided integrated electricity generation, transmission and distribution. While demand was growing rapidly, their focus was primarily on large projects that offered economies of scale in the production and delivery of electricity.

Distribution of electricity at the local level has been the responsibility of large utilities or of publicly owned municipal entities. The latter purchase their power from the large utilities, and may generate some of their own. Both have had a monopoly in selling directly to their customers at regulated rates that do not vary with time of day. Moreover, the quality of the electricity is the same for all customers.

The existing distribution systems are a mixture of overhead and underground wires to the consumer. Electricity consumption is measured by analog meters at the consumer site, which are manually read on a regular basis. Connection and disconnection of service is also manual, and is done at the consumer site. Utilities rely on customers to report power failures and the location of these failures before repair crews are dispatched. Customers must contact the utilities by telephone to learn the status of power restoration in their area.

Suppliers

The transmission of electricity from generator to customer is managed by control centres. In these control centres, human operators make dispatch control decisions based on:

- transaction requests from utilities, energy providers and power marketers
- network outage requests for maintenance and construction
- off-line load forecasts
- pre-established system security limits.

Their objectives are to operate the system as economically as possible while still maintaining system security and safety.

As the complexity of these systems grows, the role of the operator is becoming more difficult and stressful. This is resulting in lower system security and reliability as well as higher electricity wastage.

4.2 Vision 2020

To develop a focus for its discussions on intelligent power delivery, the working group looked into the future and developed the following outcome statement:

> *It is 2020. Canadian utilities are operating very successfully as net exporters of electricity in a deregulated North American electricity market by overcoming system and environmental constraints. Much of its success is due to extensive automation of the purchase, generation and delivery of power. This automation has been fostered by the development of intelligent equipment and systems by Canadian suppliers, who themselves have become world leaders in the supply of some of these products. Customers are satisfied with both the choices and reliability of electricity supply.*

Customers

In 2020, industrial, commercial and residential customers will be able to select the electricity service provider that best meets their needs and expectations. Customers will be able to change energy service providers as more attractive products and services, from their perspectives, appear on the market.

Some of the choices that customers may have to consider in selecting their electricity supplier of choice include:

- price versus reliability of supply
- cost/benefit of allowing the utility to control the time-of-day during which certain appliances can operate (demand-side management)
- price they are willing to pay for level of customer service and response to trouble calls
- choice of generation source (e.g., green power)
- price they are willing to pay for different grades of power quality.

Products and Services

The products and services offered will reflect the consumer choices listed above. In return, customers will face the following implications of their choices.

- The reliability of electricity supply will be a trade-off between profit maximization and the contractual obligations of the service provider with its customers. Customers who opt for the cheapest rates can expect to be the first to lose their service during power shortages.
- Demand-side management will require a spectrum of controls that require significant development and implementation investments combining different telecommunication technologies with power delivery technologies. For residential customers, this can be seen as home automation that includes the remote control of certain electricity loads, automatic meter reading, remote disconnect/reconnect of service and monitoring the health of major appliances. Ultimately, the customers will pay for these investments; therefore, the convenience and savings from demand-side management will have to justify the cost.
- Electricity service providers will weigh the expense of providing more sophisticated customer call-taking facilities against the level of service required to attract and retain customers.
- Green power (solar, wind, biomass, etc.) may be available from certain service providers, probably at a premium.
- The highest levels of power quality will come at a premium, requiring the installation of suitable hardware for custom power, as well as uninterruptible power.

Suppliers

The quality of the electricity provided to customers will be highly dependent on the transmission and distribution sector. This sector will be faced with the following related challenges:

- asset condition monitoring, such as line temperature and sag and tower rusting
- system condition monitoring, including function, limits and performance of the interconnected transmission and distribution system
- supply and demand monitoring, including translation of market information into system-useful information
- fault condition monitoring, including enhancement of existing devices to monitor condition of equipment such as breakers, transformers, insulators, etc.
- fault condition prediction, which will use asset condition monitoring to predict possible faults and take anticipatory corrective actions
- problem condition monitoring, which will diagnose undesirable system conditions resulting from unusual supply/demand conditions that may lead to generation/load rejection
- problem condition prediction, including the ability to predict undesirable system conditions and to take anticipatory corrective actions
- information and knowledge sources, including enhancement of current databases for real-time/near real-time knowledge provision
- command/control, including further automation that changes the role of the operator
- processing and decision making, using automated, high-speed, wide-area control and protection when needed, or slower speed where there is sufficient time and a need to use advanced techniques for decision making.

Market Drivers

Understanding the growing challenges faced by transmission and distribution requires a look at the emerging market drivers, namely:

- deregulation and competition in electricity generation and supply
- re-regulation of transmission and distribution based on profit incentives
- distributed generation
- demanding customers
- environmental constraints
- advances in information technology.

Economic and Environmental Impact

These drivers are expected to have the following impacts on the electricity sector as a whole:

- As utilities carry minimal power reserves, the transmission and distribution systems will become more susceptible to power outages over the short term.
- Whereas deregulation will attract an increasing number of power marketers and electricity providers, it will place more demands on the operations of transmission and distribution.
- As the inadequacies of existing transmission and distribution systems for cost-effective operation become more evident, information needs for load forecasting, system security assessment and current status will increase.

- Because of economics and environmental constraints, the addition of transmission line capacity will be more challenging, thus putting the owners of transmission and distribution systems under pressure to take greater risks by pushing assets harder.

Customers

Customers believe that a move away from large, regulated monopolies to a more privatized and competitive environment will provide them with the benefits they are looking for. These include:

- improved reliability of supply and fast restoration after an outage
- option of different grades of power quality at different costs
- option of different levels of reliability of supply at different costs.

Customers see the electricity sector as one that should be able to offer them choices, such as:

- ability to shop around for best deals
- customer load management to optimize costs
- freedom to choose the energy source (e.g., green power) and exercise environmental responsibility
- better information during power outages
- power conditioning
- combined buy/sell arrangements.

System

At the distribution level, the demand is growing to provide easy market access to smaller-scale generators that are often located near the users. These autonomous or independent power producers, some of whom are operating cogeneration facilities, are demanding the right to sell their electricity to consumers as well as to purchase electricity when they need it. The impact of local electricity generation on the transmission and distribution networks will be significant.

4.3 Critical Technology Areas

Similar to those affecting transmission (see section 3.3 above), the four main critical technology areas will be dictated by the concept of information technology, electronics and communications (Table 4-1).

Sensing/Monitoring

New technologies will be required to monitor the status and condition of assets, including lines, towers, poles, transformers, breakers and buswork. Also, new approaches to protection and control will be driven by market pressures to make more intelligent decisions based on wider system information. As well, new information collection systems will be required for supply and demand.

Telecommunications

Internet-based and higher-speed digital transmission will become more important as control and monitoring systems require the reliability currently enjoyed by protection systems. New telecommunications solutions will be needed to support asset condition monitoring.

The transmission and distribution system itself may be used as a low-speed telecommunications transmission medium. Like the Internet model, power system elements may have intrinsic addressing and the system may become aware of the elements attached to it. Such a system may also make distribution automation more cost-effective for load and outage management, power quality control and lower electricity losses. The barriers to distributed automation will be its high cost, lack of a functional system architecture and the lack of industry standards.

Process and Decision Making

Intelligent power delivery will require more processing, faster processing and knowledge

Table 4-1. Critical Technology Areas and Requirements

<table>
<tr><th rowspan="2">Critical technology area</th><th colspan="2">Requirements</th></tr>
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<tr><td>Sensing/monitoring</td><td>• robotic sensors that sense changes in physical condition of assets (e.g., robotic infrared cameras)
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• highly secure network and system management systems
• low-speed IP networking over transmission and distribution system
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• integrated protection and control systems
• data mining systems
• knowledge systems
• simulation systems
• prediction systems
• expert systems with inputs from all of above
• advanced risk/technical/financial decision-making tools</td></tr>
</table>

systems able to make decisions that currently require human operators. It will also require tools to address the increasing amount of uncertainty and potential for upsets, created by the open market and much more distributed generation. This will involve the development of advanced knowledge-based technologies such as neural nets, fuzzy logic and data mining required to develop expert systems.

Command/Control

The need for more data and faster decision making will change the role of the human operator. Many operator functions will be taken over by automated processing and decision making systems, and the operator will have access to better advisory tools. The command/control function will simply become the output of the decision making process.

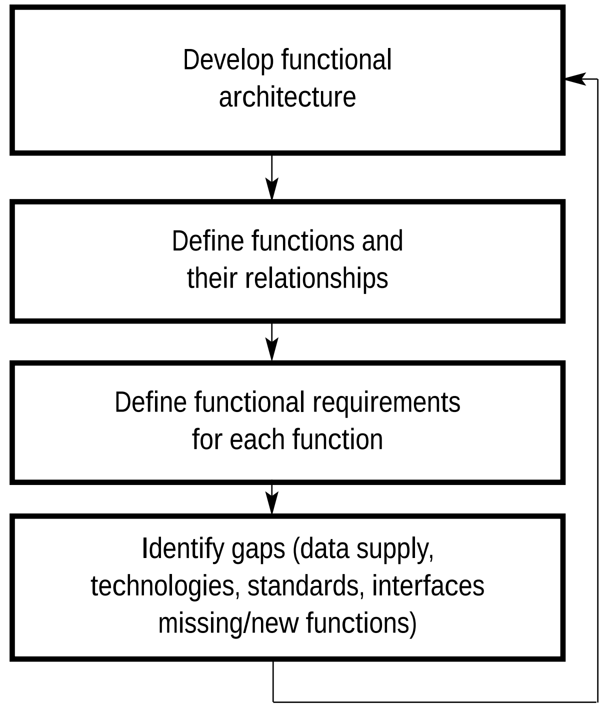
The control centre will be replaced by a distributed system management system. Human intervention will be required more on a management-by-exception basis. With increasing levels of sophistication in management systems, the nature of the decisions will approach that of business decisions, and will become much more separated from system technical decisions.

Conclusions

Canadian electric utilities will be faced with significant challenges in deciding on the levels of automation required to remain competitive. They will have to decide not only what functions to automate, but also in what order. In this context, the electric utilities that come out ahead will be those that develop a comprehensive and integrated vision, and acquire the best tools to achieve this vision. Canadian utilities and Canadian industry have an opportunity for collaboration in the development of a vision as part of the next phase of the Industry Canada Technology Roadmap initiative. The steps in the process that may be followed to achieve this vision are shown in Figure 4-1.

Once the vision has jointly been established, Canadian suppliers will face significant challenges in deciding on which technologies to pursue in anticipation of new market demands. In developing these new technologies, Canadian companies as much as possible should take advantage of existing government-supported R&D capabilities such as the universities, Centres of Excellence and industry-focussed collaborations such as PRECARN.

Figure 4-1. Development Process for Transmission and Distribution



Technology areas that should be considered by Canadian companies for development include:

- simulation algorithms for load flow, stability and dynamic security
- Internet-based communications for both monitoring and analysis
- transmission and distribution data management systems that can utilize advanced knowledge-based technologies as they become available
- intelligent operations and maintenance systems for monitoring asset/system conditions for analysing the state of the system and for providing decision support
- participation in international initiatives to develop international standards.

5 END-USE EFFICIENCY AND CONVERGENCE

5.1 Today's Reality — A Snapshot of the Industry

Electricity use is synonymous with industrial growth. For decades in industrial countries, electricity growth in demand has closely tracked economic growth. Today, an advanced information society, computer-aided design and manufacturing techniques and lifestyle changes all require greater, high-quality electricity supply. The energy needed for these activities cannot be met from sources other than electricity.

Electricity use in general promises less energy use, less pollution, better indoor air quality, less material waste, better-quality products, greater process intensification, remote operation of manufacturing, healthier work environments, and greater compatibility with advanced sensors and controls, neural networks, computer controls, robotics and decentralized manufacturing operations.

The ***residential sector*** uses electricity to operate appliances (ranges, refrigerators, etc.), lights, entertainment systems and air-conditioning in some locations. Some residential dwellings also heat the domestic water with electricity, although the majority use natural gas where available. In Canada, a small percentage of residences are heated with electricity, most with electric resistance and a few with heat pumps. The penetration of electric heating varies widely by region, being high in Québec and low in the Prairies. In the highrise residential market, electric resistance heating dominates in some regions (e.g., British Columbia, Québec), but is a minor player in others (e.g., Ontario at 20 percent). When purchasing electricity, the residential user has no options whatsoever. There is only one supplier offering only one purchase plan.

The ***commercial sector*** includes a number of diverse operations — offices, schools, restaurants, stores, etc. These customers use electricity primarily for light and some aspect of space conditioning (cooling, ventilation and sometimes heating). Some commercial operations also require hot water but usually this is supplied using natural gas. Commercial and institutional users must buy electricity from the local monopoly and there are very few or no purchasing options offered. Power quality has not been an issue in the commercial sector.

The ***industrial sector*** includes primary industry and manufacturing. While a lot of electricity is used by industry, it is a minor expense in most operations relative to the cost of production, capital expenditure, etc. (except certain electricity-intensive processes like the production of aluminum). Generally, industrial processes use heat generated from other fuel sources, although as industries modernize, more electrotechnologies (e.g., microwave) are being used to increase their productivity and competitive position.

The bulk of industrial electricity use is to power electric motors to drive machines, conveyers, compressors and ventilation systems. Of course, lighting systems are also electric powered.

While industry must also deal with only one electricity supplier, it is able to negotiate special rates. This is possible because industries are large users and how they use electricity can have an impact on the supplier's system. Special rates like interruptible power and time-of-day usage are offered to this sector. Industry also has the ability to select where to locate its plants and thus is able to negotiate special rates. Generally speaking, electricity supply to industry is reliable and inexpensive, and its purchase does not require a lot of effort from industry. Power quality is starting to become an issue in recent years in some computer-dependent industries.

In all three sectors, the purchase of electricity requires very little thought. There are very few choices to be made because electricity is cheap. There is little incentive to increase energy efficiency. Although a number of utilities offer programs for energy efficiency, these programs have been scaled back in recent years, and few offer rebates or incentives for energy efficiency.

At present, electricity plays a very limited role in the transportation sector (mainly in mass transit systems) although battery, fuel cell and hybrid (fuel/electric) vehicles are beginning to appear. While battery and fuel cell vehicles are a long way from economic viability, hybrids are starting to appear in the marketplace. Hybrids do not need to be charged from the power grid. However, the on-board electrical storage can be used to manage the electrical demand of a residential building. Very little “green” technology (solar, windmills, etc.) is currently used. This is expected to change as consumers demand and regulators mandate environmentally friendly electricity supply. Both green and natural gas generation are driven in part by climate change considerations and the effort to reduce the emission of greenhouse gases. The growth of green electricity in the near term is limited by cost considerations.

There are a number of emerging issues that have a strong influence on the future electricity market. The deregulation of telecom and the growth of the Internet is increasing the availability of information, allowing new approaches to be taken. For example, a company may be able to consolidate its energy operations from far-flung locations and act as a single customer.

The emergence of a world economy is resulting in the merger of companies with strong economic control and the ability to move operations around the globe to wherever it is most advantageous (e.g., airlines, manufacturers, service companies). It is likely that we are at the beginning of the globalization of the electric production industry. Globalization is creating a shifting world balance that will result in many changes to the status quo (e.g., today, 30 percent of the world is without electricity).

The 1990s saw the opening of the electricity market to competition, while the natural gas market was deregulated in the 1980s. Many jurisdictions started to move toward an open market and a few completed this in the 1990s. However, the bulk of competition will occur in the period 2000 to 2010. Consequently, the user will have to know a lot more about how to use electricity and all forms of energy including heat in order to evaluate different “deals” being offered by different suppliers. Cogeneration of heat and electric power will offer an advantage for some users. A new group of agents may arise to help users understand and negotiate the best deal. The incentive to use energy efficiently and to optimize the time of use will be high. Pricing will be based on a spot market, which may be very volatile, with large fluctuations in short-term pricing. The user will be looking for arrangements to provide the lowest price and at the same time protect against price swings.

5.2 Vision 2020

Electricity will continue to be the energy source of choice. There will be greater “electrification of economies,” with a concomitant demand for a wide range of all electric end-use technologies, hybrid electricity/fossil fuel technologies, and associated information processing, communication and control technologies.

The nature of these technologies will be influenced significantly by continuing advances in information processing and communication technologies and by the convergence in the delivery of energy services. Another major influence will be the ongoing deregulation of electricity generation, which may result in volatile energy pricing and raise questions about reliability.

A number of information sources confirm that the key factors operating up to 2020 and even further will be:

- globalization, driven by the overall electrification and telecommunication connections throughout the world, which already have had a profound effect on all aspects of economic life, manufacturing and customer service and which may accelerate in the coming decades
- the enormous possibilities offered by fast communication such as the Internet, which are making the financial market ever more volatile, with investors putting their money wherever they want at the touch of a button and with very strong focusses on shareholder value and on the equity market
- rules and regulations regarding risk and liabilities related to environmental impact, health and safety issues, and protection of shareholder value.

Sectoral Visions

Over the next two to five decades, buildings will have integrated intelligent management systems that will be responsive to approaching meteorological conditions, maximize the use of natural heat and light sources, and minimize emissions. They will likely have some combination of in-building cogeneration, energy storage and/or feedback to the grid, central alternating current/direct current (AC/DC) conversion for feedback to the grid, conversion of grid power to direct current for power quality improvement, capability to correct for low power quality from the grid, in-building waste processing and recycling, in-home virtual reality entertainment systems, and high-efficiency integrated systems for space conditioning, hot water, lighting and power needs, and high-efficiency direct current appliances.

Industry will feature highly computerized manufacturing, manufacturing for recycling and reuse, and flexible manufacturing for many small, specialized products. Companies will have low-discharge/closed-cycle plants and highly integrated, intensified process/plant facilities utilizing all waste streams, greater use of bioprocesses and advanced biomaterials, greater in-plant generation of electricity, greater intensity of end-use electrotechnologies and natural gas end-use technologies, with greater capacity to improve power quality in a low power quality grid scenario and to feed excess power back to the grid.

Transportation will see technologies such as intelligent vehicle highway systems, hybrid electric/gasoline vehicles, fuel cell-powered vehicles with hydrogen from reforming of natural gas or electrolysis or from reforming of gasoline specially made for fuel cells and considerably cleaner gasoline and diesel-powered vehicles. From a systems perspective, there will be greater integration of transportation systems through urban design and redesign, allowing easier and less energy and time to travel to work, electrified multimodal public transportation systems and less use of private automobiles. There will also be a reduction of transportation during peak hours, with more people working at home (including operating manufacturing facilities from the home).

For the buildings, industrial and transportation sectors, a variety of power systems will include “mini-grids,” no grid connection at all for some buildings and industries, “energyplexes” that provide heat, power, chemicals and materials, “eco-industrial parks” that integrate industry and buildings by providing heat and power from cogeneration plants and processing wastes, and “sustainable communities” that integrate buildings, industry, transportation, municipal services and land use and that provide their own electricity and heat.

These systems are predicated on highly sophisticated sensors, controls and electronic management systems. A unified, digitally controlled transmission grid will move large amounts of power precisely and reliably throughout North America while managing a rapidly growing number of commercial electricity transactions.

Market Drivers

Globalization, market saturation and a strong focus on shareholder value in a large number of industries will force low-cost manufacturing. From an energy standpoint, this means a strong focus on reductions in energy costs. Maintaining low energy costs will be very important and will be possible in a deregulated market. A supporting factor will be immediate access through information systems to energy cost information on the spot market regarding, for example, low-cost energy producers, those providing real-time customer services such as pricing flexibility, customer energy profiles, rapid power failure diagnostics and reporting, and energy management systems.

Low-cost products, environmental and demographic pressures will also favour energy efficiency in the long run. Providers of services and technologies will then be favoured in the following areas: advanced energy analysis, process integration, and hybrid energy systems and technologies. This last item embodies the concept of multiple energy sources — for example, gas and electricity combined — whereby the overall energy efficiency of systems will be higher than the one based on a single source of energy.

These market drivers will rank differently according to the market segment chosen (Table 5-1). Despite investigating several different ways of segmenting the market, the working group finally settled on the traditional way based on residential, commercial/institutional and industrial segments.

5.3 Critical Technology Areas

This section is designed to help the Canadian electric power industry better prepare itself for impending competition during the period to 2020 by identifying the critical technologies associated with end-use efficiency and convergence, based on market demand. These technologies are expected to be required either to meet new customers' demands or to match the competition during the period concerned.

The chain of activities is as follows:

Customer Needs → Functional Needs → Supporting Technologies

For each customer need, the functional needs and supporting technologies are outlined below in Tables 5-2, 5-3 and 5-4 for each of residential, commercial/institutional and industrial market sectors. Functional need translates the customer needs in terms of general technical requirements, without limiting the technology to our present knowledge. Supporting technologies define more precisely the functional need and identify some technologies that appear to be

Table 5-1. Customer Needs for Three Market Sectors, in Order of Decreasing Priority

Residential sector	Commercial/institutional sector	Industrial sector
• reliable energy • low energy cost • indoor air quality and health • reliable telecommunications • reduced environmental impact • compact energy systems	• low energy cost • reliable energy • indoor air quality • integrated systems including telecommunications • intelligent energy management • reduced environmental impact	• reliable energy • reduced production cost • increased productivity • observance of environmental regulations

Table 5-2. Residential Sector Supporting Technologies

Customer needs	Functional needs	Supporting technologies
Reliable energy	• heating and cooling using: – bi- or multi-energy systems (electricity, oil, gas) – thermal storage (hot and cold) • on-premise electricity production and storage using combined heat and power	• new design/packaging for: – furnace using electricity and oil or gas – thermal storage using solid materials (chemical reaction or adsorption) or phase change materials (water/ice or others) • small-scale generation: cogeneration, micro turbine, fuel cells, battery, photovoltaic, use neighbourhood electric vehicle as backup power
Low energy cost	• energy management: – auto-load control delaying non-essential appliances – multi- (bi) energy system: auto-select electricity or fossil fuel according to price (time of day) – data acquisition on usage (kilowatt-hour or fuel) by main appliances	• flexible and user friendly control devices (electricity, fuel and rate choice), capable of communication system for price signal and data acquisition options • energy (electric and thermal) storage
Indoor air quality and health	• adequate indoor air quality using advanced heating ventilation and air conditioning systems, depending on occupation, number of occupants and time of day • reduce particles in suspension in indoor air: no combustion inside house • reduce allergy-caused pollution: better housing material and furnishing • reduce ozone production • better regulations	• heating ventilation and air conditioning system with advanced control (adaptive or neuronic) and advanced filters to meet IAQ requirements • develop new furnace design • develop new housing and furnishing material to reduce allergy problems
Reliable tele-communications	• reliable telecommunication • adequate quality of electricity supply (continuity, power quality and EMC) to assure remote control, automated housing, banking, security, remote meter reading, necklace alarm for elderly and infirm	• reliable telecommunication systems with backup • power electronics with electric energy storage • power supply for individual applications and/or integrated to house wiring
Lower environmental impact	• low energy requirement with minimum emissions • option to select green power	• heat recovery systems (heat pumps) from appliances and water usage to assist water and space heating • on-premises green power generation using photovoltaic panels, thermal, solar • new material for compact thermal insulation
Compact energy systems	• development of miniaturization systems for water heating, and space heating and cooling	• development of compact units using new materials

Table 5-3. Commercial/Institutional Sector Supporting Technologies

Customer needs	Functional needs	Supporting technologies
Low energy cost	• energy management • auto load control delaying non-essential equipment • multi- (bi) energy system: auto select electricity or fossil fuel according to price (time of day) • data acquisition on usage (kilowatt-hours or fuel) by main equipment or usage • develop more energy-efficient equipment and appliances	• flexible and usage-friendly control devices (electricity, fuel and rate choice), capable of communication system for price signal and data acquisition options • energy (electric and thermal) storage
Reliable energy	• heating and cooling using: – bi- or multi-energy systems (electricity, oil, gas) – thermal storage (hot and cold) – cogeneration (electricity and heat) • on-premises electricity production and storage: combined heat and power	• new design/packaging for: – furnace using electricity, oil, gas – thermal storage using solid materials (chemical reaction or adsorption) or phase change materials (water/ice or others) • small-scale generation (cogeneration): micro turbine, fuel cells, battery, use neighbourhood electric vehicle as backup power
Indoor air quality	• adequate indoor air quality using advanced HVAC systems depending on equipment used, number of occupants and time of day • reduce allergy-caused pollution • better building material and furnishings	• heating ventilation and air conditioning (HVAC) system with advanced control (adaptive or neuronic) and advanced filters to meet IAQ requirements • develop new building and furnishing materials to reduce allergy problems
Integrated systems including telecommunications	• reliable telecommunications • adequate quality of electricity supply (continuity, power quality and electromagnetic compatibility (EMC)) to assure reliable communication	• reliable telecommunications systems with independent backup • power electronics with electric energy storage • power supply for individual applications and/or integrated to building wiring
Intelligent energy management	• advanced information and communication systems • intelligent interface between demand (customer) and production	• information system coupling customer with commerce/institution
Reduced environmental impact	• control pollution from hazardous waste • recycle, wastes treatment • option to select green power	• variety of electrotechnologies • green power: thermal, solar, photovoltaic panels

Table 5-4. Industrial Sector Supporting Technologies

Customer needs	Functional needs	Supporting technologies
Reliable energy	• device to assure continuity of electricity supply of adequate quality (power quality and electromagnetic compatibility) • reduce effect of power failure and disturbance • uninterruptible power supply for critical process: battery, fuel cells • on-premises electricity production and storage: combined heat and power	• electric energy storage technologies (short disturbance): series compensators, ultra capacitors, flywheels • emergency power supply for individual applications (power electronics with electric energy storage) and/or integrated to building wiring • direct current applications • adapt fuel cells design • cogeneration
Reduced production cost	• development of new materials: ceramics, composite materials, new compact thermal insulation material, surface treatment • energy management: – multi- (bi) energy system: auto-select electricity or fossil fuel according to price (time of day) – auto-load control delaying non-essential process (on/off option) – energy consumption profile (kilowatt-hours or fuel) by process • more energy-efficient process • better heat recovery	• intelligent and adaptive control devices to select different type of energies (energy storage and load shifting), and to provide appropriate data acquisition • efficient motors and drives (variable-speed drive) for pumps, compressors and blowers • data acquisition options • heat pumps to recover heat from various processes to assist heating requirements
Increased productivity	• customized manufacturing • intelligent interface between customer and manufacturing plant • use of electrotechnologies to facilitate process control, product quality (Table 5-7)	• adaptation of breakthrough process technology • flexible manufacturing process • information system coupling customer with manufacturing plant • efficient motors and drives (variable-speed drive) for pumps, compressors and blowers • appropriate electrotechnologies by industry sectors (Table 5-7)
Meet environmental regulations	• recycle effluents and waste • change processes to produce less waste • real-time sampling and analysing of contaminants • replace processes by lower greenhouse gas emitters	• appropriate electrotechnologies by industrial sectors (Table 5-7)

required to respond to the need. This prediction is based on the present knowledge and our extrapolation into the future. Breakthrough technologies may go beyond the extrapolation, and cannot be predicted. The term “supporting technologies” is preferred to “critical technologies” because working group members have not evaluated the degree of development or maturity of each technology. The repetition among the tables is intentional to present a complete picture for each sector.

Now that the supporting technologies have been identified for each of the three market sectors, the various required technologies needed (called critical technologies) are then regrouped by major applications. Critical technologies are expected to be essential for the end users or equipment manufacturers to meet customer needs as restated by the supporting technologies. A critical technology can be either developed or purchased, or a new breakthrough technology may come on the market.

In summary, the chain of activities to identify the critical technologies is as shown schematically below:

Customer Needs → Functional Needs → Supporting Technologies → Critical Technologies

Since there are some similarities in the required technologies for the residential and commercial/ institutional sectors, they are combined. Moreover to ease the consultation, they are listed by major application or customer need in Table 5-5; consequently, there are a few duplications in the list of critical technologies.

For the industrial sector (Table 5-6), no attempt is made to identify each specific critical technology at this time, because of the very wide diversity of industrial processes and technologies. Functional needs and supporting technologies are identified as shown in Table 5-7. To identify a critical technology for a given industrial subsector with some precision, the input (or consultation) from end users themselves, equipment manufacturers or their associations is required. This more in-depth exercise is expected to be carried out in the next phase of the technology roadmap exercise.

The approach used by the working group in this study appears to be a reasonable method for identifying a list of critical technologies that are expected to be required, based on customers’ perceived needs. At this stage, there is no strong attempt to restrict the list, since it is felt that a proper assessment of the required technologies should involve the concerned players themselves; that is, end users, equipment manufacturers and/or their respective associations. These findings should therefore be validated by a survey or additional consultations among these players.

In the meantime, this list of technologies is a good tool to start the consultations with a view to validating which technologies are really critical, then to decide which ones should be developed in Canada rather than purchased elsewhere. For these consultations, grouping of industrials with similar technological concerns may be a good approach, since the results will be focussed on their specific problems.

Although convergence has not been specifically addressed, the impact of convergence has been considered in the evaluation of customer needs and in the identification of the required technologies.

Table 5-5. Residential and Commercial/Institutional Sector Critical Technologies

Customer needs	Critical technologies
Reliable energy	• multi- or bi-energy furnaces with self-contained backup power source (e.g., advanced batteries, redox flow battery, micro turbines, fuel cells or electric vehicle) • flexible combined heat and power systems (cogeneration) of appropriate capacities • compact and efficient thermal storage (hot and cold) using solid or phase change materials • internal combustion engines, micro turbines, Sterling engines and fuel cells to meet lighting, heating and cooling simultaneously • for short power disturbances: power quality control devices and electric energy storage (e.g., low-cost series compensators, ultra capacitors, flywheel) • real-time power failure diagnostics
Low energy cost	• intelligent and adaptive (user friendly) control devices to select different types of energy based on rates (including energy storage and load shifting) • higher-efficiency appliances such as combined water/space heater/heat recovery ventilator: (e.g., heat pumps and ground source heat pump for space heating and cooling, and water heating) • communication systems to get price signal and data acquisition • district heating and cooling • on-premises combined heat and power systems (internal combustion engines, micro turbines, Sterling engines and fuel cells)
Indoor air quality	• heating ventilation and air conditioning systems with advanced control (adaptive and neuronic) • new furnace designs to eliminate combustion emissions • active filters to remove volatile organic compounds: carbon monoxide and other contaminants • new housing and furnishing materials less susceptible to allergy problems
Reliable tele-communications	• information systems to couple customer demands with residences, businesses or manufacturing plants • low-cost communication systems to monitor and control appliances, process equipment, lighting, heating and cooling systems
Reduced environmental impact	• higher-efficiency end-use equipment and systems such as combined appliances, combined heat and power systems, and heat pumps • intelligent and adaptive control devices to optimize efficiency and reduce greenhouse gas emissions • use of heat pumps and new techniques for waste heat recovery • use of green power: photovoltaic, thermal, solar • new material for thermal insulation • use of electrotechnologies when applicable in commercial sector (Table 5-7)

Table 5-6. Industrial Sector Critical Technologies

Customer needs	Critical technologies
Reliable energy	• emergency power supplies meeting power quality and electromagnetic compatibility requirements • combined heat and power systems (cogeneration) integrated with adjacent industrial plants or communities • for short power disturbances: power quality control devices and electric energy storage (low-cost series compensators, ultra capacitors, flywheels) • real-time power failure diagnostic
Reduced production costs	• intelligent and adaptive control devices to select different types of energy, energy storage and load shifting, based on rates • communication systems to get price signal and data acquisition • heat recovery from various processes to assist heating requirements (heat pumps, mechanical vapour recompression) • on-premises combined heat and power systems • extra power to supply electricity, heating and cooling to adjacent community
Increased productivity	• adopt breakthrough technology • use of electrotechnologies as suggested for various industrial sectors (Table 5-7) • flexible manufacturing processes to respond to information systems • efficient motors and drives for pumps, compressors and blowers
Meeting environmental regulations	• higher-efficiency end-use equipment • intelligent and adaptive control devices to optimize efficiency and reduce greenhouse gas emissions • use of electrotechnologies, as suggested in Table 5-7 • new materials for better performance and ease of manufacturing • process integration to reduce water and energy consumption (heat recovery) • use green power: wind, thermal, solar, photovoltaic
Industrial applications	• use technologies as suggested in Table 5-7 for customer needs shared in common with residential, commercial and institutional sectors • use of electrotechnologies as suggested for various industrial sectors (Table 5-7)

Table 5-7. Functional Needs and Supporting Technologies by Industrial Subsector

Industrial sectors	Functional needs	Supporting technologies technology-process	Status
Aluminum	• more energy-efficient electrolysis • electrode less consumable • reduce perfluorocarbon from anode effects	• improve Hall-Héroult cell efficiency • new electrolysis process • wettable cathodes, graphite electrodes	R&D R&D R&D
	• replace fossil fuel by electric technology to dry electrodes	• electrotechnologies available (require process redesign)	R&D
	• better aluminum recovery from scrap (containing other metals, vanish, dross, etc.) using less or no flux	• melting furnace in inert atmosphere: Droscar and Alcan using EA or plasma is available	commercial
	• melting/remelting with less greenhouse gas	• replace fossil fuel furnaces by electric furnace: EA, plasma, induction • improve actual furnace efficiency	commercial
Steel	• stirring	• electromagnetic stirring	commercial
	• increase recycling		
	• replace pelletizing by sintering		
	• production of steel with less greenhouse gas in replacement of some blast furnaces	• electric arc furnace (EAF) • direct smelting reduction • improve process control and sensors • electrolysis (new process) • natural gas injection instead of coal	commercial R&D R&D development R&D
	• use of direct current instead of alternating current in EAF	• power electronics	development, commercial
	• improve total energy efficiency	• assisted by heat pumps, high-temperature heat pumps	development, commercial
	• melting/holding/remelting with less greenhouse gas	• electric arc furnace, induction	commercial
	• thin slab casting	• thin slab casting technology	commercial
	• heat treatment with less greenhouse gas	• resistance, induction, infrared	commercial
	• finishing operation (surface treatment) with less greenhouse gas	• electrochemical deposition • thermal deposition	commercial commercial
	• motor power: more energy-efficient	• efficient electric motors plus variable-speed drive	commercial
	• produce more efficiently heat and power	• cogeneration	commercial

Chemicals	• new synthesis processes	• electrochemical process	R&D
	• new nanoscale catalysts		R&D
	• new electrochemical reactors		R&D, development
	• electrodialysis for production/ separation of certain chemicals		R&D, development
	• new material for electrodes		R&D, development
	• new electrocatalyst process		R&D, development
	• separation/concentration to replace distillation	• hybrid membranes/distillation • mechanical vapour recompression	R&D, development
	• recycling chemicals and particular solid wastes		development
	• more efficient membranes for caustic/chlorine		development
	• more stable electrodes for electrolysis		development
	• heat recovery	• heat pumps, mechanical vapour recompression • high-temperature heat pumps	commercial R&D
	• motive power	• efficient electric motors plus variable-speed drive	commercial
Pulp and paper	• real-time monitoring of paper	• control and sensors	
	• real-time control of chips feedstock	• control and sensors	
	• paper softness	• ultrasonic sensors	
	• drying of hog fuel	• flue gas recovery, mechanical vapour recompression	
	• recycling chemicals	• membranes, electrochemical processes	R&D, development
	• improved quality of waste water	• filtration, ozone	R&D, development
	• paper drying • paper thickness	• induction (impulse drying) • induction, resistance	development development
	• less polluting bleaching process	• use of ozone	R&D, development
	• pulp production with less green-house gas (to replace Kraft process)	• thermo-mechanical pulping/ chemical-thermo-mechanical pulping	commercial
	• motive power	• energy-efficient motors plus variable-speed drive	commercial
	• biomass and black liquor gasification	• cogeneration	commercial, development
	• drying of sludge	• impulse drying, mechanical vapour recompression	development

Mining	• more efficient grinding process	• on-line size separation • ultrasonic techniques	
	• alternative to using dynamite	• high electric discharge, laser, high-pressure water	R&D, development
	• motive power	• energy-efficient motors plus variable-speed drive	commercial
	• heat recovery	• heat pumps, mechanical vapour recompression	commercial
	• heat optimization	• heat pumps • high-temperature heat pumps • cogeneration	commercial development commercial
	• electric vehicle in mines	• efficient motors and battery	commercial, development
	• combine heat and power	• cogeneration	commercial
Petroleum refining	• improve distillation and separation processes	• integrate membranes to process	R&D, development
	• process equipment modifications		
	• improved catalysts		R&D
Non-metallic minerals-glass	• thermal boost	• electric boost devices	
	• recycling glass		
Cement	• new process using fluidized bed reactors		
	• new additives from waste material		
Food	• low-fat cooking		
	• sterilization	• radiation, infrared, microwave, radio frequency	
	• fast cooking		
Wood	• sterile material		
	• improve lumber drying		
	• improve wood handling		
	• engineered wood products		
Fabrication	• improve productivity	• adoption of advanced electrotechnologies	R&D
Crosscutting technology	• process optimization and control with artificial intelligence systems	• sensors and software	development
	• heat recovery	• heat pumps, high-temperature heat pumps, mechanical vapour recompression	commercial, development
	• combine heat and power	• cogeneration	commercial
		• biotechnologies	
	• motors and drives systems	• efficient motors and variable-speed drive	commercial

6 SMALL-SCALE GENERATION AND RENEWABLES

6.1 Today's Reality — A Snapshot of the Industry

To date, small-scale generation and renewables have not made much of an impact. Electric power supply is dominated by large, central generation stations operated in Canada as monopolies by provincial governments. Under the existing climate, small-scale generation and renewables have not been able to compete. But the landscape is changing rapidly as the electric supply industry moves into a new era of open competition. This, coupled with increasingly stringent environmental concerns and issues surrounding the risk of capital, is creating great interest in distributed generation that utilizes small-scale generation and renewables.

Customers

There is increasing concern about the environmental impacts of existing generation and distribution methods. For example, the following methods give rise to specific concerns:

- nuclear generation — concerns about spent fuel storage/disposal
- fossil fuel generation — concerns about air pollution, greenhouse gas and acid rain
- hydraulic generation — concerns about dams and flooded valleys
- transmission systems — concerns about visual impact and possible harmful effects of electromagnetic radiation.

Customers see small-scale generation and renewables as a possible solution to these problems. There is growing interest in green, clean and small. However, industrial cogeneration is not common in Canada. Electricity rates are low. Customer generation is often perceived to be opposed by the monopoly supplier utility (who may offer a better contract in order to stop the cogeneration installation) or by onerous regulation. In addition, investors have concerns about high cost and poor reliability for continuous operations. Small-scale generation is often viewed as risky, with a more profitable use of capital through increased investment in their core business.

There are virtually no small-scale generation and renewables operations in the commercial and residential sectors except for seldom-used backup diesel generators in critical situations like hospitals. For example, in 1998, Ontario Hydro offered a special contract to small self-generators (residential photovoltaic, etc.) to buy back excess power (net billing). Very few were interested in pursuing the offer.

There are a number of reasons for this lack of interest:

- Electricity rates are low.
- Small-scale generation and renewables equipment is expensive and at present requires the customer to do the system engineering.
- Grid interconnect equipment is not readily available and the interconnect rules are still under development.

Present-day applications of small generation are located in remote areas, which are for the most part off-grid. These areas generally use reciprocating diesel generators and the fuel is brought in by air. The resulting cost of electricity is very high but is subsidized by other customers of the provincial utility. Some of these sites are being used to experiment or demonstrate renewable technologies such as wind turbines. These are obvious locations for customer-owned, renewable generation or combined heat and power applications.

However, such systems often have difficulty competing with subsidized electricity from the utility. This may soon change under the rules of a competitive marketplace.

Customers have the expectation that the soon-to-come electrical supply competition will lead to a better product that is cheaper, more reliable and less environmentally harmful.

Products

Small-scale generation products traditionally focus on reciprocating diesel engines for use as emergency backup power for critical applications (e.g., hospitals, electronic microchip manufacturers) and for use in remote, off-grid locations as the main electrical supply.

Recently, there has been the introduction of advanced gas turbine systems, which offer higher performance and efficiency. Advanced gas turbine systems offer the advantage of low-capital, low-risk generation that can be installed quickly (relative to central generation) in order to respond to market forces. By operating on natural gas at higher efficiencies than traditional generators, they produce electricity with less environmental impact.

Another product that is emerging is the micro gas turbine. It is available in capacities as small as 20 kilowatts and, when combined with heat recovery, can also supply hot water. Micro turbines hold much promise for commercial and larger residential applications. Fuel cell technology is another product that offers to increase the efficiency and reduce the environmental impact of electricity generated by natural gas.

Competition is strong among the developers of fuel cells to be first to market with reliable, economical systems. There are four types of fuel cells, designated by their chemical makeup: phosphoric acid, proton exchange membrane, molten carbonate and solid oxide. Of these, proton exchange membrane seems to be the leading contender in the small end of the power scale (5–250 kilowatts capacity) while molten carbonate and solid oxide appear to be better suited to larger sizes (1–10 megawatts capacity). Fuel cells are being designed to be fuelled by natural gas, with the conversion to the actual hydrogen fuel needed taking place inside the fuel cell. Emission levels are 50 percent of those of current engine and turbine technology. Fuel cells are suitable for location within buildings, since they operate quietly. At the same time, proton exchange membrane-type fuel cells are being developed as power systems for the next generation of vehicles. The larger scales of manufacturing for automotive products will result in electric power system costs that are substantially lower than conventional power generators with comparable or even higher efficiency when generated heat can be used.

The emerging global market for renewable energy products and services is creating business opportunities worldwide. For example, global sales of wind energy systems are worth over $3 billion a year, solar photovoltaic systems bring in over $1.5 billion a year, and small hydro projects represent sales of about $3–4 billion a year. The growth potential for these energy sectors is expected to exceed 15 percent annually (current world annual growth rates are closer to 34 percent for photovoltaic systems and over 25 percent for wind).

Renewable energy technologies such as wind turbines are already in operation in some utilities. While wind turbines are distributed generation systems, typically they are located in discrete locations away from high-density areas (because of noise and aesthetics) and with good wind patterns. In Québec, the “le Nordais” 100-megawatt wind farm in Gaspé meets both environmental and regional industrial benefits objectives. The electricity is sold to Hydro-Québec under a long-term contract at $0.058 per kilowatt-hour. With further technological development, supported by market access to transmission and distribution networks, further reduction in the cost of wind energy to $0.04 per kilowatt-hour is predicted.

Photovoltaic panels convert sunlight directly to electricity and provide a simple method to distribute energy on-site. Photovoltaic panels can be integrated into the building fabric (saving money) and supply electricity to the building. With no moving parts, the panels are silent and are suitable for high-density areas. Worldwide installed capacity of photovoltaic panels is 1000 megawatts. The main problem to date is the high cost. However, based on the remarkable cost reductions seen in the electronics industry, it is expected that costs for photovoltaic panels can be reduced. In Canada, Automated Tooling Systems is at the forefront of photovoltaic panel technology development. Its investments in the purchase and automation of its subsidiary Photowatt (France) allowed this manufacturer to capture 7 percent of the world photovoltaic panel market.

A perceived drawback of both wind and solar power is the intermittent nature of the power supply. This means that an alternate energy supply has to be found for those times when the wind is not blowing or the sun is not shining. The user must either draw power from the electrical supply grid (perhaps at some cost penalty because of the intermittent nature) or invest in a storage system of some kind. At present, electricity is difficult and expensive to store, although new developments (e.g., ultra capacitors, high-speed flywheels, batteries for short-term energy storage and hydrogen fuel for larger-scale energy storage) are expected shortly. Renewable energy technologies in Canada currently face barriers such as limited market access, little consumer choice of energy supply or failure to account for environmental impacts and implementation barriers.

Hydro-electricity contributes 62 percent of Canada's electricity supply and additional large hydro sites are available (currently 66 823 megawatts of hydro capacity). These require the erection of dams, which result in the flooding of large land masses. In contrast, small and micro hydro technologies can be sited and adapted to minimize their impact on the environment. Systems with capacity less than 30 megawatts are considered under this category; Canada's remaining small hydro potential capacity is estimated at 20 000 megawatts. Although they are not new, the development of low head turbines and run-of-river turbines, which do not require dams and reservoir controls, are required to realize the full potential of small hydro technologies. There is some experimentation/ demonstration taking place with mini-hydraulic and run-of-river hydraulic generation in an attempt to lessen the environmental impact of dam hydraulic generation. The engineering for this is understood and it is a matter of finding the correct economics/environmental situation.

Canada is a world leader in the development of biomass fast pyrolysis and related technologies. Our systems are leading-edge since they are currently the only ones being developed at the industrial demonstration and commercial scale. Companies involved in this field are aggressively marketing their technologies in the U.S. and Europe to address energy and environmentally sustainable development issues. A major strategy of a biomass-to-electricity program is the continued development of these technologies with government and industrial partnerships in joint research programs. As a result of recent successes, many industrial players such as forest companies and engine manufacturers have become involved in the development of these electricity generation systems.

Canada is also a world leader in the development of fuel cells and in electrolytic hydrogen production technologies. Initially targeting the automotive market, the fuel cell using electrolytic hydrogen may have a profound impact on the electricity infrastructure, providing a huge new market for electricity, and through fuel production, large-scale "virtual" storage for less-flexible generation capacity such as nuclear and renewable power.

Suppliers

Electricity in Canada is supplied by provincial monopolies operating large, central generating facilities and extensive transmission and distribution systems. All planning for future needs is done centrally by the monopoly. The customer has no choice of supplier and little room to negotiate price. Generally speaking, there are no limitations on the customer, who can use any amount of power at any time (with some exceptions for very large users).

Each type of today's central method of electricity generation (nuclear, hydro-electric and fossil fuel) has its own distinct operating characteristics, costs and impact on the environment.

For example, nuclear plants are best suited to steady operation. They have low fuel costs, but are relatively expensive and time-consuming to throttle up and down. For this reason, nuclear plants are used to provide traditional base electricity load. The drawbacks to nuclear power plants are the need to manage the waste disposal and the high costs of decommissioning plants after they have reached the end of their operating lifetime.

Hydro-electric plants are versatile, and the cost of power they produce is inexpensive. The drawbacks to hydro-electric stations are that variations in water supply can significantly affect the amount of electricity they produce. The environmental impact of dams (reservoir flooding and water level fluctuations) is becoming an issue.

Thermal generating stations fired with coal, oil or natural gas take longer to bring to full capacity than hydro-electric stations. Thermal stations are very flexible in meeting variations in demand but have emission limits imposed on their operation.

The electricity produced by the central generating stations is carried to the user over the wires of the transmission and distribution system. Some power is lost due to electrical resistance and other factors (inductive loads, transformer efficiencies, etc.).

With the advent of a competitive electrical supply marketplace, a new group of non-traditional suppliers is starting to emerge to compete with the existing central systems. They are expected to make use of the emerging technologies of natural gas-powered advanced turbines (immediately) and fuel cells (as they become available). In many instances, they install new generation close to the loads and gain increased efficiency through the use of combined cycle (gas turbine plus steam turbine) or combined heat and power (for district heating) or cogeneration (electricity and steam) systems. Suppliers of small-scale generation are able to react quickly to market needs, as installation time is short and capital investments are small relative to those for central systems. In the fast-moving, non-centrally planned competitive marketplace, small-scale generation may be the only new-generation technology coming on-line.

Suppliers using renewable resources are beginning to appear. There are independent power producers that generate electricity from the combustion of wood waste usually obtained from sawmills eager to dispose of it. About 10 such plants in Canada produce electricity to sell to electric utilities, with an installed capacity of approximately 200 megawatts.

Electricity is also generated from methane at six municipal landfill sites. The current capacity in Canada is 82.5 megawatts. About 1.2 megatonnes of methane is generated by over 10 000 landfill sites in Canada. Only 25 percent of this gas is captured in 33 of the largest sites. More than half simply flare the methane gas.

Gasification of processed municipal refuse and industrial wood waste is now being seriously examined, as are projects to demonstrate these technologies in industrial applications.

6.2 Vision 2020

By 2020, the competitive electrical marketplace is expected to be fully developed and highly competitive with wholesale and retail wheeling. Electricity will be a commodity sold in conjunction with value-added products and services.

According to the U.S. Department of Energy, the United States is projected to require 366 000 megawatts of new capacity including replacements over 1996–2020. A large amount of new/replacement capacity will be required in Canada. Because of environmental and capital risk considerations, much of this will be supplied in 2020 by small-scale generation and renewable technologies, mostly as distributed generation, although there is a possibility that 3000 megawatts of capacity will be on-line at Churchill Falls by 2010. Technical and regulatory barriers will have to be overcome to allow fully integrated, dispersed electricity supply. Distributed generation will be widely used because it will:

- provide relatively low capital cost and quick response to incremental increases in power demand
- avoid transmission and distribution capacity upgrades and power losses by locating power close to where it is most needed
- have the flexibility to put power back into the grid at user sites
- allow waste heat from generation to be used
- operate with high efficiency and/or low environmental impact.

Environmental issues will have a priority. Consequently, fuel use efficiencies will be maximized and green power will be economically competitive. Natural gas will be the fuel of choice, as it is cheaper to transport molecules than electrons and then use the new technologies (micro turbines/fuel cells) to convert to electricity and heat. It is also a relatively clean fuel.

Hydrogen will be widely used as a transportation fuel in zero-emission fuel cell-powered urban transit systems, commercial fleets and commuter vehicles. Its use will improve the air quality of urban centres and reduce the greenhouse gas emissions from the transportation sector. Hydrogen will be produced from steam reformation of natural gas and electrolysis of water using renewable energy. Electrolytic hydrogen will provide new markets for large-scale penetration of renewable power. The hydrogen fuel supply infrastructure will be highly distributed, using hydrogen fuel appliances, low-cost, mass-manufactured, on-site hydrogen generators that connect to the existing electricity and natural gas infrastructure.

Worldwatch Institute, in a press release dated July 16, 1998, predicts that renewables technologies will play a major role by 2020 and will supply 50 percent of the world's energy by 2050.

Customers

Customers in 2020 will demand and expect low prices, high quality, personal control and value-added services. They will be much more environmentally demanding, and some will pay a premium for special green offerings. Customers will have on-site generators such as fuel cells, micro turbines and photovoltaic systems. Rural customers will have switched to distributed generation, which is cheaper than central power (because there are no transmission and distribution costs). Often, a local fuel source will be available (e.g., biomass, landfill gas, wind).

Customers will manage their own systems and will demand and receive a high level of personal service. For example, commercial customers with facilities across the country will deal with one energy supplier (and receive one bill) for all the facilities. They will negotiate a better deal because of the increased size of the aggregated load.

Customers will purchase value-added products and services designed to improve their lifestyle or increase the efficiency of their businesses. For example, customers will buy the end product (lighting, heating, cooling ventilation, etc.) that they need rather than the energy to do it themselves. This will allow them to save on capital and maintenance so they can focus on items of higher importance (e.g., core business, lifestyle).

Products

By 2020, significant technological advances will have yielded major improvements in modular power generation systems. Most of these systems will be used as distributed generation and will operate on a broad range of fuels to provide clean, reliable, efficient and flexible on-site power. Carbon dioxide emissions will have been reduced to half that of traditional central generation stations. Products will include gas turbines, diesel generating sets, wind, photovoltaic systems, fuel cells, energy from waste and micro hydro installations. Fuel cells, wind turbines and photovoltaic systems will be fully developed and competitive. Advanced renewable energy technologies such as building integrated photovoltaic panels and mass-produced, low-cost wind turbines will be in widespread use. The cost of photovoltaic electricity will be 25 percent of its present-day cost. Small stationary fuel cells will have benefited from the advances made in advanced, low-pollution transportation based on proton exchange membrane fuel cells. The supply of hydrogen for transportation fuels will be integrated into the electricity supply infrastructure, with electrolysis providing large-scale energy storage for renewable energy, and with reformation of natural gas providing hydrogen for stationary and mobile power generation.

Advanced, high-efficiency gas turbines, micro turbines and fuel cells will be used in combination with various heat recovery systems to produce high efficiency. Systems such as combined cycle (combined gas and steam turbines) and fuel cell/gas turbine combinations will be in use, often combined with district energy systems (heating and cooling). District energy systems will be common in high-density areas, and products such as heat extraction systems (equivalent to furnaces) and energy metering will be readily available at economical prices.

Advanced communication and control technologies will be available to optimize the operations of the distributed generation equipment. They will provide remote dispatch on price signals (time-of-day use, peak management, spot market, etc.) and will produce virtual energy storage in industrial processes. They will also monitor the performance and condition of the distributed equipment and of renewable resources to predict the availability of wind and solar energy. Power electronics equipment will have been developed and will be in use to allow safe and efficient grid connection of distributed generation, permit advanced storage of electricity (e.g., ultra capacitors and high-speed flywheels), control and correct power quality and facilitate the use of direct current micro grids.

Suppliers

The electricity market of 2020 will be highly competitive, with convergence of gas, electricity, communications and other services. The proliferation of players/energy providers (both traditional and non-traditional) that occur when the marketplace opened will be over, and the subsequent amalgamation into larger multinational companies will be essentially complete by 2020.

Environmental issues will be of the highest importance and will change the playing field by 2020, because previously uneconomical but environmentally sound systems will now be economical. Renewable energy systems (e.g., photovoltaic, wind turbines) will be economically attractive because of their low environmental impact and value for emission trading. Some forms of fossil fuel-powered generation will have become expensive because of emission penalties or the cost of cleaning up the emissions.

Suppliers will be involved in distributed generation, which is suited to fast-moving, market-responsive, competitive electrical systems. Installation times will be short and investments will be small, thereby reducing capital risk. Distributed generation will allow suppliers to achieve high efficiencies and also will give them the ability to sell waste heat. Electricity will be regarded as a commodity. Price competition will result in a very small or non-existent profit margin. Suppliers will develop brand identities based on factors such as environmental responsibility (green power) to generate customer loyalty. Suppliers will provide value-added services, as this will be where the profits lie. One area of value-added services will be providing customers with the amenities they desire rather than just the energy. Energy suppliers will supply heat, cooling, light, ventilation, cooking, etc., and will own and maintain the necessary end-use equipment. For example, for a restaurant business, the energy supplier will own and maintain the cooking, lighting and space conditioning equipment, while the restauranteur will supply the building and staff. Energy suppliers will also provide transportation fuels in the form of hydrogen from steam reformation of natural gas and electrolysis of water through hydrogen fuel appliances.

Market Drivers — Customers

Price

The competitive marketplace will put considerable pressure on prices. Customers will expect price reductions. Control of energy budgets will continue to be a key driver for industrial/institutional customers. However, a number of factors will work against price reduction: the volatility of the spot market prices, the need for suppliers to make a profit and the fact that suppliers have taxes to pay. This will push suppliers to be as efficient as possible in providing lower prices than the competition. In certain cases, distributed generation with waste heat recovery will be the most efficient solution.

With distributed generation systems connected to the grid, a number of issues concerning the cost of electricity will arise. Suppliers may charge a higher rate for electricity supplied as backup, since it will be used only intermittently. Regulators may place a transmission and distribution charge on the distributed generator’s output, even though it will not use the grid, arguing a “stranded asset” charge. Suppliers may wish to supply electricity at one price but to buy back from the distributed generator at a lower price similar to their own cost of generation. The resolution of these issues will have a major impact on the future role of small-scale generation and renewables.

Power Quality/Reliability

At the same time as demanding lower prices, customers will develop a high reliance on electrical devices for comfort, convenience and computer applications, thereby creating a demand for high power quality and reliability.

Power quality/reliability will be absolutely critical to some industries that use sensitive electronic controls. Even small electrical irregularities can cause process failures, which can cost large amounts of money and time.

Studies indicate that power fluctuations in North America currently cause annual losses of $12–26 billion. In 2020, industrial and institutional customers will continue to pay a premium for improved power quality and reliability from locally installed distributed generation projects if the bulk transmission and distribution system fails to perform to expected standards. On-site generation can provide a solution to many power quality/reliability problems.

Environment

As the competitive power market matures, the pressure for enhanced environmental performance will increase. Public policy, reflecting concerns over greenhouse gas emissions, will provide incentives for capacity additions that offer high efficiencies and also use renewables. Some customers will be responsive to green power offerings, even at price premiums. Most if not all industrial and institutional customers will not decide on their energy provider based on the environmental benefits without being rewarded financially. It will be necessary to have government policy create market mechanisms to ensure that the environmental benefits of “greener” energy sources are rewarded such that the costs are on a par with “dirtier” sources. Urban air quality concerns will force introduction of zero-emission vehicles in the larger urban centres, creating an opportunity for battery, electric and hydrogen fuel cell vehicles.

Green power offerings will be utility-based (e.g., windmill farms) or customer-based (e.g., fuel cell plus heating/hot water supply or a roof-mounted photovoltaic system).

Service

Customers will be responsive to total energy solutions that provide both electricity and heat, with the energy supplier engineering the installation. Customers will wish to contract for the end products they desire (light, heat, cooling, transportation fuel) and provide space on-site for the supplier to install small-scale generation or renewable technology. Institutional and industrial customers will continue to focus on their core businesses. The trend toward outsourcing non-core businesses and investments will continue. The distributed generation sector will have to respond with a willingness to invest in smaller energy facilities dedicated to specific host loads.

Customers will regularly face capital replacements for traditional energy infrastructure such as boilers, transformers and emergency generators. Energy supplied from a distributed energy facility that also allows the customer to avoid these capital replacements will be a catalyst for the project. In addition to capital budgets, an important element of outsourcing will be the reduced operating budget. The trend toward outsourcing operations will support district energy schemes, whereby a small energy facility will serve a number of thermal and electrical hosts, with shared costs of operations.

Market Drivers — Products

High Efficiency

Technical improvements in gas turbines and fuel cells will raise primary efficiency. New hybrid systems will combine gas turbines and fuel cells or gas turbines and steam turbines for even higher efficiencies. Applications that can make use of the rejected heat for steam supply in industry, or district heating and cooling or for hot water production, will raise efficiency even higher. Distributed generation will also eliminate the transmission and distribution losses inherent in a central generating system. The system efficiencies achievable with distributed generation will be a major market driver.

Power Quality/Reliability

Power quality/reliability will be an important issue for many customers. Small-scale generation and renewable equipment installed at the customer’s premises under local control and isolated from grid generated problems will be used to provide high-quality, reliable power.

Environment

Because of high efficiency, small-scale generation will produce less pollution for a given amount of output. Renewable technologies will produce no pollution. Oftentimes, waste streams will be available from a manufacturing process (e.g., flare gas, volatile organic compound emissions, steel mill process gas) or from a landfill site that can be used as fuel for local, small-scale generation. These environmental opportunities will create a demand for distributed generation products.

Green energy technologies such as wind and solar power will generate electricity intermittently. For grid-connected systems, it is expected that there will be new market regulations to deal with intermittent supply. Some suppliers may decide to eliminate the intermittence by storing electricity to use when the wind or solar system is not generating. This will be a driver for new storage technologies.

Service

The need to provide a customer with a full-service package to provide all energy needs (electricity, heating, cooling, transportation fuel, etc.) will be a driver of small-scale generation systems and hydrogen fuel appliances. A full-service package installed at the consumer site will be operated and serviced by the energy supplier. Two-way communication systems will be required to operate the system and to track its performance and operational health. High-reliability generation equipment will be a necessity. Important items to producers of distributed generation equipment will be product distribution, service and support. Equipment will be able to self-diagnose and perhaps self-fix through software. More money will be made from operating and maintaining equipment than from selling equipment.

Market Drivers — Suppliers

Price

Under competition, the energy suppliers will be under extreme price pressure. Frequent switching by customers to get the lowest price will cause great uncertainty. There will be a need for highly efficient, economical, flexible systems. In addition, the energy supplier will be financially at risk for capital investments associated with capacity additions. This will tend to favour less capital intensive projects and shorter construction schedules. Small-scale generation and renewable systems will be less capital intensive and will require a shorter installation time than central systems. This will result in lower risk for the supplier. In addition, there will be a large number of ideal sites where uses will exist for the waste heat. Highly efficient use of the fuel will result in lower prices. On-site generation will avoid the costs and losses incurred by the transmission and distribution system and will be used to defer upgrades to the transmission and distribution system (by supplying a new load from an on-site generator rather than building new transmission and distribution to service it). Suppliers will focus on bigger customers. The cost of servicing small residential customers will be high and the exposure to certain legal risks will be greater. Aggregators will be able to develop multi-site/multi-residential loads and add other value-added services (e.g., gas, power and water). In addition, energy suppliers and industry will be able to exploit on-site generation for profitable wholesale wheeling or dispatch of power following marketplace signals. Generation will be attractive, since it will be less risky than transmission and distribution. However, margins will be small, and it will be a problem to achieve enough return to maintain assets. Generation will tend to go through boom/bust periods as the supply/demand situation changes.

Power Quality/Reliability

Energy suppliers will offer different levels of power quality/reliability at different prices. Since all suppliers will share the use of the same transmission and distribution system, the only way a supplier can guarantee the quality will be involvement in the electrical supply on the consumer site — either to clean it up or to install distributed generation to produce clean electricity on-site. Distributed generation will provide an attractive solution when combined with its other advantages.

Environment

Environmental concerns will increase and regulations will become more onerous as society moves to protect the biosphere. The low emissions of high-efficiency, small-scale generation and the zero emissions of renewable technologies will be major objectives. Suppliers will be able to profit from emission trading as well.

Service

Energy suppliers will be able to offer a differentiated service/product based on small-scale generation and renewables — an on-site combined heat and power system owned and operated by the supplier. Aggregators will sell packages of energy services to attract new customers and to promote retention of existing customers. The customer will contract for the heat and power outputs. In more traditional situations, the systems will be leased rather than owned by the user. In addition, small-scale generation will be installed in special applications for peak shaving and standby/emergency power. This flexibility will make small-scale generation and renewable systems very attractive to energy suppliers.

6.3 Critical Technology Areas

Table 6-1. Critical Technology Areas

Critical technology area	Requirements
Small engine generators	• advanced gas turbines with high efficiency (greater than 40 percent) in small capacities (under 5 megawatts) and with exhaust gas heat recovery for combined cycle or combined heat and power operation (key technology areas are: high-efficiency, high-speed bearings; wear-resistant materials; combustion modelling; high-temperature materials; predictive time between failure models; real-time sensors for combustion and control; high-efficiency and lower-cost heat transfer components; high-speed, high-temperature lubrication) • micro turbines (25–500 kilowatts) needed with higher efficiencies and lower costs will be obtained by mass production • external combustion engines (e.g., Stirling) to make use of fuel available from biomass • internal combustion engines (including diesel ignition natural gas engines) with higher efficiencies, heat recovery and higher reliability/lower maintenance
Fuel cells	• advanced fuel cells operating at high temperature combined with gas turbines and heat recovery to provide electrical efficiencies approaching 65 percent • small-scale, high-reliability, simple fuel cells for residential/commercial customer use • advanced fuel cells for stationary power developed from new fuel cell transportation technology
Wind	• improved blade and turbine design • self-erecting wind turbines • variable-speed generators • larger rotors/higher hub heights • advanced controls • hybrid systems
Solar photovoltaic panels	• low-cost photovoltaic panel module technology • automated module assembly • products for architectural integration into buildings to reduce cost
Small hydro systems	• innovative low head and water current turbines • fish-protection engineering designs
Power system components	• interconnection devices to provide automatic switching, safety and high reliability • development of direct current micro grids for reduced costs and improved power quality

Table 6-1. Critical Technology Areas (continued)

Critical technology area	Requirements
Enabling technology	• communication systems/telecom for flow of market information (price/availability) and control of generation devices as well as monitoring "health" of remote generators • software development to allow establishment of virtual utility, which operates by using distributed generation, owned by others • real-time sensors for combustion control and condition analysis measurement techniques • wind and solar forecast tools • advanced supervisory control and data acquisition systems (SCADA) • satellite-derived tools to measure, analyse and predict wind and solar patterns • demand-side management tools to manage combinations of dispatchable and intermittent power sources
Energy storage technology	• ultra capacitors • high-speed flywheels • superconducting magnetic energy storage • flow batteries • advanced batteries • distributed energy storage through provision of hydrogen transportation fuels • hydro generation storage (behind dam) • virtual energy storage in customers' electrical processes
Stand-alone power technology	• high-reliability generators and storage systems: – engines – fuel cells – renewable energy technologies (including hybrid) – storage systems (flywheel, pumped hydro, etc.)
Environmental technology	• cleaner, higher-efficiency generating systems including combined cycle, combined heat and power, with systems to reduce oxides of nitrogren (NOx), for example, reburn of combustion gas, low NOx catalytic materials • renewable technologies (solar, wind, micro hydro) • storage systems to avoid peaking system pollution
Biomass	• advanced gasification and fast pyrolysis processes to convert heterogeneous biomass feedstocks into fuels • development of systems, including boilers, turbines, engines, and fuel cells, capable of efficiently converting biomass fuels into electricity • feedstock assessment, improvement of quality of pyrolysis oil and gas clean-up

7 CONCLUSIONS

This forecast is the first attempt by the Canadian electric power industry to develop a technology roadmap. A diverse group of industry and government officials, working in teams, analysed four issues critical to the industry: assets optimization, intelligent power delivery, end-use efficiency and convergence, and small-scale generation and renewables. Their objective was to develop an industry consensus on what products and services the marketplace will be demanding in the year 2020 and what technologies the industry will need to deliver those products and services.

As with all first endeavours, a number of lessons were learned during the process. The most important lesson, and indeed one of the basic principles of technology roadmapping, is that the initiative must be industry-led. The most successful examples of roadmaps in the United States all exhibit this characteristic. The Electric Power Technology Roadmap forecast did not benefit from such leadership. This first phase of the roadmap relied on the participation of a mixed group of industry and government officials, weighted toward the utility segment of the industry. Consequently, some perspectives were not represented in the analysis.

Industry leadership is crucial because the initiative requires the time and dedication of industry officials, who are essential to this kind of work. However, ensuring that industry officials are able to give a roadmap the attention it deserves requires the interest and support of senior corporate management. Only if the roadmap is seen as a valuable planning tool by and for management will they then release resources toward that effort. This is difficult to do in times of fundamental change, uncertainty and restructuring. When there are so many seemingly more important things for officials to do, a belief that technology planning is critical is a must. The working group members frequently worked on the roadmap forecast after having spent full days on their “day” jobs.

What, then, lies on the road ahead? Road-mapping methodology, as witnessed in the U.S. experience, suggests a need for further analysis of the technologies identified in this forecast document to create the roadmaps leading to the discrete technologies vital for future industry progress. This analysis would ask questions such as the following:

- What are the goals of specific technologies?
- What will be the consequences for a company that does not have a particular technology?
- Why is the technology critical?
- What alternatives will be available?
- What will be the cost/benefit, risk, maturity, etc., of the technology?

As noted above, for this work to be relevant, it must be created by industry, and the effort needs to be led by industry. For a stronger product in subsequent phases of the work, participants from unrepresented or underrepresented segments of the industry need to be involved. These include equipment suppliers, independent power producers, municipal utilities, smaller suppliers, engineering consultants and others.

This forecast document outlines many technologies and technology areas that can be further developed. Not all of these issues need to be developed in the next round, nor do all of the technologies need a roadmap. Where interest warrants, however, this report provides a solid foundation upon which working groups can be assembled around opportunities to take the next step in an effective roadmapping process.

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