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Industrial electrification: an opportunity for Canada

by J.G. Melvin

L'Électrification industrielle: une occasion pour le Canada

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SYNOPSIS

The technical and economic scope for industrial process electrification in Canada is assessed in the light of increasing costs of combustion fuels relative to electricity. It is concluded that electricity is capable of providing an increasing share of industrial energy, eventually approaching 100 percent. The relatively low cost of electricity in Canada offers industry the opportunity of a head start in process electrification, with consequent advantages in world markets both for industrial products and for electrical process equipment and technology. A method is described to promote the necessary innovation by providing access to technology and financing. The potential growth of electricity demand due to industrial electrification is estimated.

RÉSUMÉ

On examine les possibilités techniques et économiques d'électrification industrielle au Canada à la lumière de l'augmentation du coût des combustibles en fonction de l'électricité. On en conclut que l'électricité peut assurer une part d'énergie industrielle de plus en plus grande qui, en fin de compte, sera voisine de 100 pour cent. Le coût relativement faible de l'électricité au Canada doit permettre à l'industrie d'avoir une grande avance dans l'électrification industrielle et donc des avantages sur les marchés mondiaux, non seulement en ce qui concerne les produits industriels mais aussi en ce qui concerne le matériel et la technologie électriques. On décrit un moyen pour encourager l'innovation nécessaire par l'accès à la technologie et aux sources de financement. On évalue l'augmentation possible de la demande d'électricité due à l'électrification industrielle.

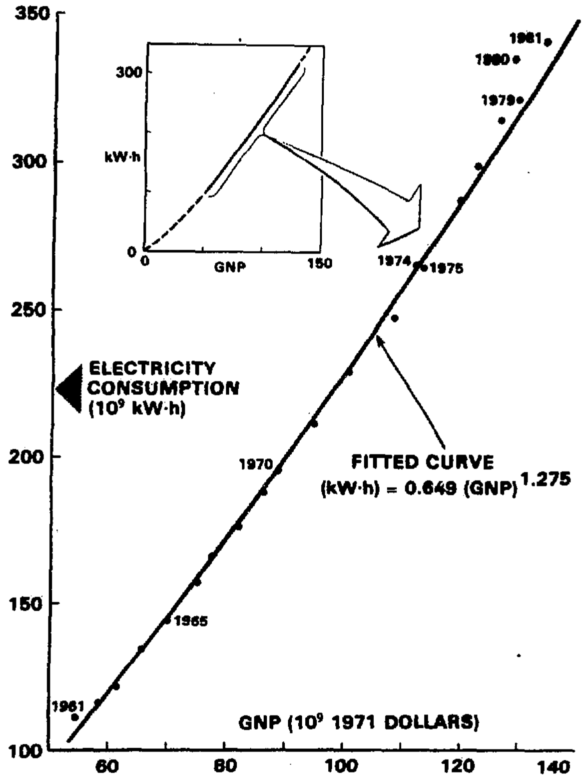
INTRODUCTION

The purpose of this study is to assess the scope for electricity-based processes in Canadian industry, to identify the potential benefits of industrial process electrification and to estimate the likely penetration rate of electricity in competition with other forms of energy in the industrial sector.

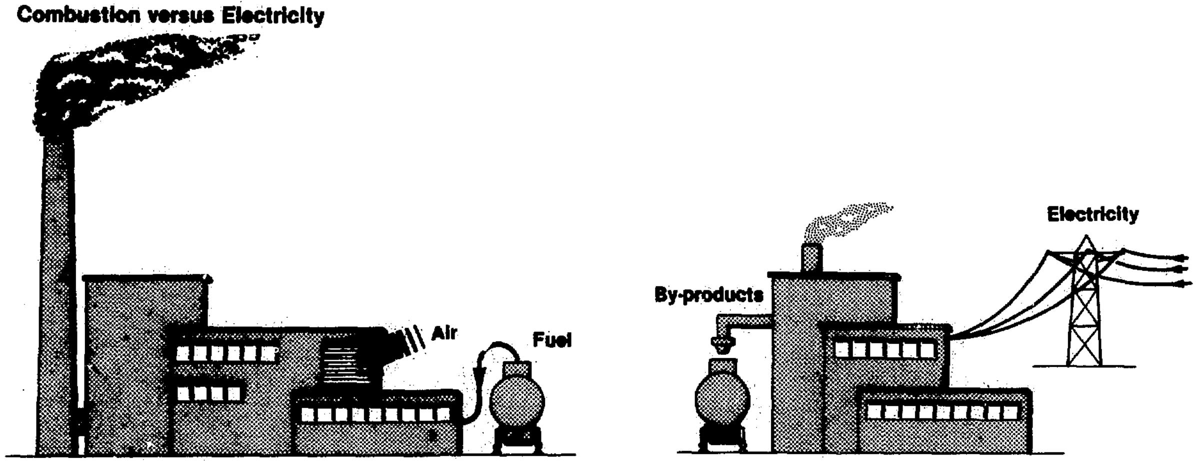
By concentrating on the industrial sector, this work adds depth to an earlier study (Melvin, 1980), which concluded that electricity is a feasible substitute, economically and technologically, for most of Canada's projected oil imports. A second report (Melvin, 1981), which revealed the close linkage between electricity demand and total output of the economy, shown in Figure 1, led to the industrial focus reported here. A similar linkage in other countries has been reported by Starr (1982) and by Colombo (1982).

Most of the industrial plant that now exists was created before the oil crises of the 1970s which brought many-fold increases in the prices of oil and natural gas. Energy cost, previously a minor or even negligible factor in process selection, has now become important. Environmental protection through control of emissions has also become an important and costly factor. As a result of the energy and environmental revolutions, many production processes are operating in an economic environment for which they were not designed and to which they are ill-adapted. The industrial sector therefore faces a period of transition

Figure 1 Electricity Consumption versus Real GNP. Canada



Combustion versus Electricity



Open Cycle
Heat Lost
Wastes to Atmosphere
Large Air Flows for Combustion
Fossil Fuel Input
Coarse Process Control
Dirty Working Environment
Unskilled Work

Closed Cycle
Heat Recycled
Wastes to By-products or Disposal
Small Air Flows
Electricity Input
Fine Control
Clean Working Environment
Skilled Work

during which old processes will be upgraded or replaced by new ones.

Energy is an essential input to any production process. In the past, combustion was the normal source, delivering energy to the process either directly from the burner or indirectly via a heat transport medium such as process steam. Electricity, then a premium form of energy, was reserved for lighting, control, mechanical power and special processes.

In today's world, flame is no longer cheap and, at least in Canada, electricity is competitive. The events of the 1970s have thus reversed the picture so that electricity is becoming the normal energy form and flame the last resort. It is not that electricity has become less costly, but that combustion has become more expensive. The effective use of energy is becoming more important as the option of cheap energy fades. Energy productivity, like labour and capital productivity, now commands attention.

In the new "post-combustion" era the selection of a process to manufacture a given product is heavily influenced by the input energy requirement; it is no longer sufficient to adopt a traditional process and then choose the most convenient fuel. In this new era electricity is a strong competitor not only because of its relative price but also by virtue of its ability to be applied directly to the process material in a variety of ways, thus achieving high efficiency and productivity. A simple illustration of these virtues is the heating of a steel billet, rapidly, cleanly and under precise control by electromagnetic induction, as opposed to flame-heating.

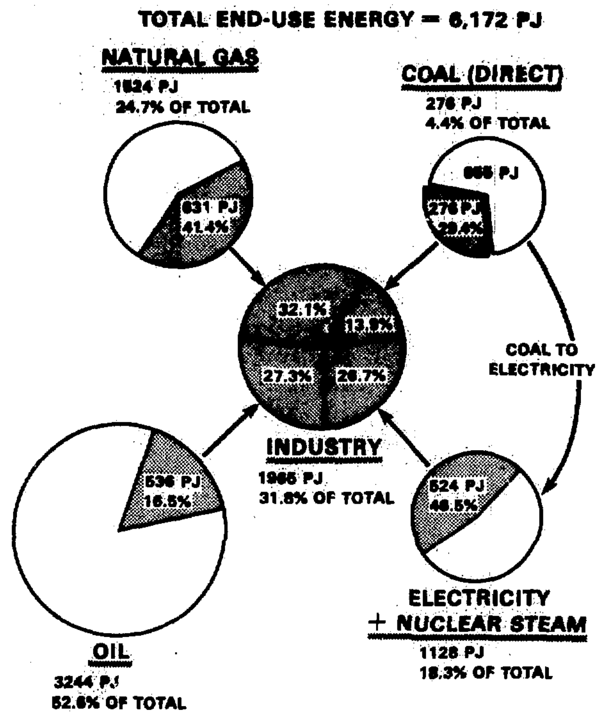
The low cost of electricity, present and projected, relative to most other countries, offers Canada the opportunity to gain a competitive edge through industrial electrification. This advantage can be translated into a technological upgrading of Canadian industry to capture a larger share of domestic and international markets. Industrial electrification would contribute substantially to economic growth.

ENERGY IN THE INDUSTRIAL SECTOR

Electricity Share

Almost one-third of Canada's end-use energy is consumed in the industrial sector. The composition of this energy, by source, is shown in the pie diagrams of Figure 2. The central pie shows the contribution of each form of energy to the total used by industry. Each of the four surrounding pies, one for each form of energy, shows the industrial demand as a fraction of total Canadian demand for that form of energy. Natural gas is the largest component of industrial energy, followed by oil and electricity with approximately equal shares. The bulk of the coal share is used by the iron and steel industry, largely as coke and coke oven gas. An equal or larger amount of coal is used indirectly by industry in

Figure 2 Energy Shares. Canada 1980



the form of electricity (nominally, 46.5% of 655 PJ, or 305 PJ).

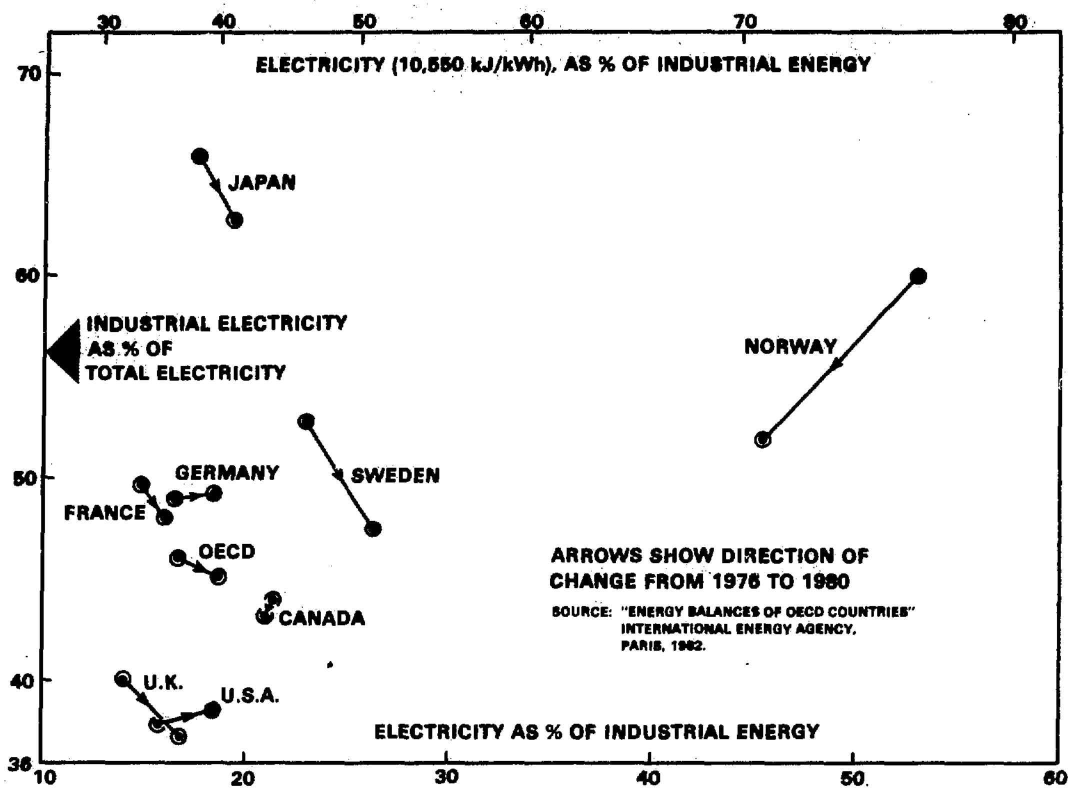
It is significant that electricity represents little more than one-quarter of industrial energy (26.7%), but this accounts for nearly half (46.5%) of all electricity consumption in Canada. This suggests that there is scope for further penetration of electricity into industry and that this penetration will substantially increase total electricity demand.

These two indices, the percentage of industrial energy that is electrical and the percentage of total electricity that is used by industry, are plotted in Figure 3 for Canada and other OECD countries for the years 1976 and 1980 (IEA, 1982). (The percentages for Canada in Figure 3 are not consistent with those in Figure 2 because Figure 3 is based on primary energy while Figure 2 is based on end-use energy.) Five of the eight devote a larger fraction of their electricity to industry than does Canada, but this fraction is decreasing in most cases.

In terms of the share of industrial energy provided by electricity, Norway is in a class by itself. Canada is unique among the other seven in that the electrical share decreased during the period. The decrease was small and may be merely a statistical artifact or the result of a reclassification of end-use categories.

It might be assumed that the relatively small fraction of total electricity used by Canadian industry simply reflects an unusually large fraction consumed by the

Figure 3 Electricity Consumption in Industry. OECD Countries



residential sector. The OECD data show otherwise; the residential share of total electricity is lower in Canada than in OECD countries as a whole and substantially (more than five percentage points) lower than in the United States, the United Kingdom and, in 1980, France. The difference appears to be in the commercial sector, where Canada consumes a larger share of electricity than the OECD average.

The perception that electricity-intensive industries such as aluminum smelting and abrasives production, attracted by hydroelectric resources, play a major role in Canada's industrial economy, is not supported by Figure 3. The Canadian industrial sector as a whole is not electricity-intensive. The overall impression is that Canada is not yet exploiting its resources of low-cost electricity in the most productive sector of the economy. This is not surprising because the figures reflect an industrial structure built in an era of cheap oil and gas when electricity was a premium form of energy, but it does indicate the large scope for industrial electrification in the post-combustion era that has now begun. Furthermore, the figures reflect a world in which all countries were equal, in terms of energy cost, because of universal access to cheap oil. A country in which electricity has become less costly than international oil has gained a competitive advantage. Canada is such a country, almost alone in the industrial world.

Energy in Manufacturing

Manufacturing industries in 1980 consumed 85% of industrial end-use energy; mining used 11% and the balance was split between the forestry and construction industries.

The wide spectrum of manufacturing operations is classified by Statistics Canada under a Standard Industrial Classification (SIC) code and energy consumption is reported by SIC category (SC, 1979). The top groups, ranked by total energy consumption are listed in Table 1; together they consume almost 80% of manufacturing energy. The remaining 20% of manufacturing energy is distributed among approximately 100 three-digit SIC groups. The table also gives the rank of each group in terms of consumption of three kinds of energy: electricity, heavy fuel oil (HFO) and natural gas.

It is evident from the table that energy consumption is dominated by a few industries, 50% of the total being consumed by the top four. Moreover, an industry that is a heavy consumer of one type is generally a heavy consumer of other types as well.

The concentration of energy consumption in relatively few SIC groups is shown graphically in Figure 4, which shows HFO use to be the most concentrated.

The top seven SIC groups, of more than one hundred, use 80% of the HFO consumed by manufacturing industries, while the top seven electricity consumers use 70%. More than three quarters of HFO, electricity, natural gas and total energy is used by the top twenty SIC groups in each case. As indicated in Table 1, the composition of the top twenty is different for each energy source but the same groups occupy five of the top six positions for each.

The total energy consumption of each SIC group divided by the number of establishments in the group gives the mean consumption per establishment. The top five consuming groups are also the largest consumers per establishment. More than half of manufacturing energy is used in 415 plants, representing about 5% of the total number of manufacturing establishments.

Conclusions

Energy in the industrial sector is used mainly in manufacturing and is concentrated in a few major industries led by pulp and paper, chemicals, iron and steel, metal smelting and refining, cement and petroleum refining. Moreover, this dominant share of manufacturing energy is consumed in a small number of plants in large-scale production units. The share of industrial energy provided by electricity will depend to a large extent on its role in major energy-using processes.

Figure 4 Distribution of Energy Consumption Among Manufacturing Industries

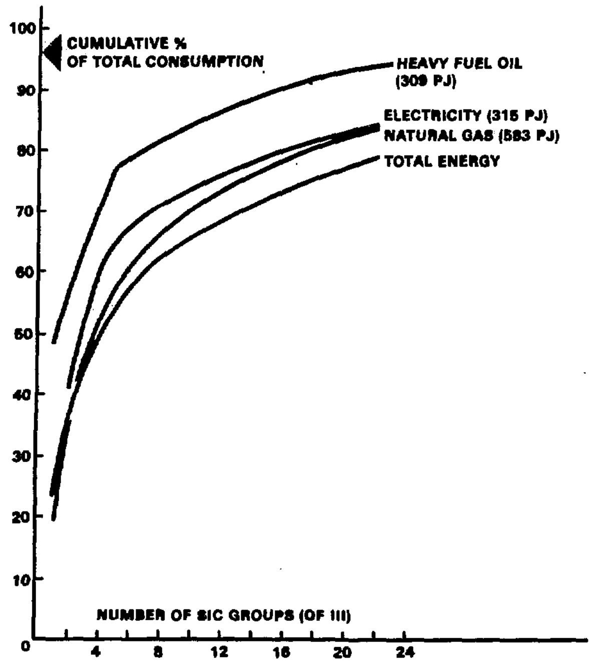


Table 1 Energy Consumption, Manufacturing, Canada, 1979

		Purchased Energy				Rank		
Rank	SIC**	No. of Establishments*	(k$)	%	Cum. %	Elec.	HFO†	Natural Gas
1	2710 Pulp & Paper Mills	146	919 459	23.7	23.7	1	1	2
2	3780 Indus. Chem.	156	490 274	12.6	36.3	2	5	1
3	2910 Iron & Steel Mills	53	332 856	8.6	44.9	4	2	3
4	2950 Smelting & Refining	32	207 354	5.3	50.3	3	3	5
5	3520 Cement	28	143 437	3.7	54.0	7	4	6
6	3650 Petroleum Refining	61	135 821	3.5	57.5	5	—	4
7	2510 Sawmills, etc.	1424	126 254	3.3	60.7	6	—	10
8	1080 Misc. Food Industries	442	73 920	1.9	62.6	12	10	7
9	3250 Motor Vehicle Parts	294	65 118	1.7	64.3	8	21	12
10	1090 Beverage	355	58 461	1.5	65.8	19	12	9
11	1010 Meat & Poultry Products	613	54 202	1.4	67.2	13	18	13
12	1040 Dairy	472	53 949	1.4	68.6	20	13	—
13	3590 Non-metal Minerals	121	52 532	1.4	69.9	15	6	11
14	3560 Glass & Products	113	45 618	1.2	71.1	22	—	8
15	3230 Motor Vehicle Manufacturing	22	44 166	1.1	72.3	17	8	19
16	1830 Synthetic Fibre Mills	92	40 623	1.0	73.3	11	9	17
17	1620 Rubber	133	40 081	1.0	74.3	16	14	—
18	3730 Plastics & Resins	59	39 065	1.0	75.3	10	11	15
19	1650 Plastics Fabrication	866	35 694	0.9	76.3	14	—	—
20	3150 Miscellaneous Machinery	1189	35 223	0.9	77.2	18	—	—
21	3580 Lime	15	31 817	0.8	78.0	—	7	14
22	3040 Met. Stamp, Press, Coat	919	30 608	0.8	78.8	—	—	18

Total — 3 056 532 (of 3 879 624)

* Source: Statistics Canada, Catalogue 31-203, 1979 ** SIC Standard Industrial Classification † HFO Heavy Fuel Oil

ELECTRICAL PROCESS TECHNOLOGY

General

Electricity is able to provide both heat and mechanical work; it is therefore possible to perform any industrial operation with a process having electricity as the only energy input. To say that the exclusive use of electrical energy is possible does not mean that it would be economic in every case, but the economic balance is shifting towards electricity as the preferred input.

Industrial operations and products cover a broad spectrum from the mine to the end product, with a variety of processes at each stage. There is a diversity of processes, from one stage to the next, e.g., mining, ore concentration, smelting, refining, etc., up to a metal part in a product delivered to the user. There is also diversity at each stage, e.g., metal forming by rolling, forging, stamping, casting and extrusion.

Most existing industrial plants have been in place for many years and reflect the relative energy costs and the state of technology that existed when their processes were selected. If these plants were being planned under present circumstances, different choices would be made, including less oil and more electricity. The combination of changing conditions and the longevity of capital plant means that the mix of processes in place at any time is far from optimal.

The gap between what exists and what would be best suited to the times depends largely on the rate of investment in plant expansion and renewal. The rate of investment in turn depends on economic health, as measured by cash flow, and this identifies a feedback mechanism of particular significance to Canada's industrial prospects: loss of market share leads to reduced cash flow, declining reinvestment, impaired competitiveness and further loss of market share. This feedback loop can, however, operate upward rather than downward, if a way can be found to arrest and then reverse the cycle.

The upgrading of industrial processes through electrification is one possible way. Japanese and German industries are said to have gained advantage over their U.S. competitors because they were rebuilt, and thus upgraded, following the war. The opportunity now exists for upgrading Canadian industry through electrification in response to declining productivity and rising energy costs. This approach would be consistent with the most likely future and would be an effective use of Canada's resources of low-cost electricity.

The problem is how to launch such an approach and where to start. The diversity of industrial processes, with respect to both product and scale, defies rigorous assessment or master plans, but at the same time offers manifold opportunities for action.

France has adopted a policy of electrification, spearheaded by the national utility Electricité de France (EDF), to reduce dependence on imported energy. The EDF program includes the identification of electrical technologies appropriate to French industry (Harlow, 1976) and the promotion of electrification through organizations designed to provide technological and financial consultancy (Bouchet, 1982). In the United States, an article in the EPRI Journal observed "an emerging consensus that the U.S. manufacturing sector will respond to lagging productivity and fossil fuel supply uncertainties by a market-driven program of electrification" (EPRI, 1982).

Canadian industry has a greater need for productivity improvement and a greater opportunity for electrification than most countries. The potential is recognized in a discussion paper by the Department of Industry, Trade and Commerce: "Thus, if electricity becomes the dominant energy form of the future, the ability to exploit opportunities for growth will fall disproportionately to those countries which most successfully adapt their industrial systems to the efficient use of electricity and which secure an international comparative advantage in manufacturing electricity consuming products." (ITC, 1980).

Electrical Process Technologies

Electrical processes divide into two classes:

- traditional electrical processes that are standard in industry either because there is no alternative or because they were the preferred choice even when fuels were cheap
- optional processes that are now becoming ripe for application because of the change in relative energy costs or because of technological advances which make the processes more effective or less costly than in the past.

The two classes are discussed in sequence below.

Traditional Electrical Processes

Examples of large-scale processes are:

a) electrolysis, embodied in the Hall process for aluminum smelting, and in chlor-alkali plants for the production of chlorine, caustic soda and by-product hydrogen

b) electric-arc furnaces for the production of certain steels, abrasives and calcium carbide

c) mechanical processes, such as the rolling of paper or metals, the grinding of lime, cement or wood pulp, the movement of large volumes of process fluids, as in petroleum refining, and the sawing and planing of wood.

These processes predominate among the top seven electricity-consuming groups which collectively use 70% of the electricity in manufacturing industries.

Industries that depend on traditional electrical processes are likely to expand preferentially in regions offering low-cost electricity, as indicated by the interest of Alcan and Pechiney in Manitoba and Quebec, respectively, as potential sites for aluminum smelters, and the recent completion of a new calcium carbide furnace by Cyanamid at Niagara Falls.

Such expansions in the traditional uses of electricity are useful additions to the economy, but represent a less advantageous use of electricity than those processes that upgrade other manufacturing industries and thereby increase productivity. The traditional electrical process industries tend to locate their primary operations in low-cost electricity regions, exporting the raw product, such as aluminum ingot or abrasive grain, for the manufacture of products elsewhere. While these primary processes contribute more to the Canadian economy than would direct export of the equivalent electrical energy, they nevertheless represent truncated operations which generate few jobs relative to the capital invested and in which Canada must compete not on the basis of industrial or technological maturity, but simply on the basis of raw electricity price.

Optional Electrical Processes

The electricity-based processes listed in Table 2 are all in commercial application, but at different stages of maturity. The following discussion, based largely on Harlow (1976), Day (1980), and the Conference on Electrotechnologies in Industry (1982), is intended to provide illustrative examples.

1) *Mechanical Processes.* These systems, which use electrically driven compressors to recover heat, have been in use for many years in special applications and are in the realm of conventional engineering. What is new is the increased cost of energy, which broadens their economic range of application.

   Heat pumps are becoming cost effective for space heating and heat recovery from drying operations. There is interest in heat pump working fluids capable of delivering heat at temperatures suitable for process steam generation.

   Vapour recompression systems are becoming increasingly economic to upgrade and thus recover the heat from distillation processes.

   The common characteristic of the two systems – heat pumps and vapour recompression – is the application of a relatively small amount of electricity to make available a much greater amount of heat.

2) *Membrane Processes.* These processes are electricity-based in that the energy input is in the form of pumping power to circulate the liquids and maintain pressure differentials across membranes. The processes are used to purify or concentrate liquid solutions. Some applications are: potable water production, recovery of metals from surface treatment baths, concentration of industrial liquid wastes, and a variety of food, medical and pharmaceutical processes.

   These are not large electricity-consuming processes; their significance lies in their low energy consumption relative to the evaporation process that might otherwise be used.

Table 2 Electrical Processes

Mechanical
Heat pump
Vapour recompression
Membrane
Ultrafiltration
Reverse osmosis
Electrodialysis
Resistance
Induction
Arc
Plasma
Dielectric
Radiofrequency
Microwave
Radiation
Laser
Infra-red
Ultra-violet
Electron beam
Electrochemical
Electrolysis
Synthesis
Deposition

3) *Resistance Heating.* Conducting materials are heated directly by passing a current through them, as for example, in the heating of metal rod or strip in rolling mills, glass in melting furnaces, or water in boilers, and for the production of silicon carbide abrasive in resistance furnaces.

   Indirect resistance heating uses a heating element to convert electricity to heat which is then transferred to the material being heated. The material might be a solid, e.g., a die block, or a process liquid, vapour or gas.

4) *Induction Heating.* Alternating current in a surrounding coil induces current in the object to be heated. The object is, in effect, resistance heated, but without the need for an electrical connection. Induction heating is used in metal melting, forming and heat-treating operations.

5) *Arc Heating.* An arc furnace, in which the arc passes between an electrode and the charge to be melted, is in effect a large, enclosed, arc-welding torch. Steel melting and aluminum oxide production are two common applications.

6) *Plasma Heating.* Ionized gas, called plasma, conducts electricity. In an arc-plasma torch, a stream of gas, ionized by the applied voltage, conducts an electric current between two electrodes and is resistance heated in the process. Large amounts of energy can thus be put into the plasma to achieve very high gas temperatures in a very short time and space (Fey and Harvey, 1976). The application of arc-plasma heaters to blast furnaces is discussed

later. Other possible applications of arc-plasma heaters include iron ore pelletizing, or direct reduction, as well as various kiln processes such as cement making. The substitution of an arc heater for a combustion torch eliminates the need for large flows of air and combustion products, thus allowing more compact design and easier control of pollution. Arc-plasma torches are also being developed as chemical reactors for the production of, among other things, acetylene, ferroalloys (Gauvin et al., 1981) and for the reduction of various metal oxides, including iron, chromium and manganese.

Small scale and flexibility of operation are among the virtues cited for plasma-based metallurgical processes. These characteristics offer the potential for incremental expansion and diversification without the major capital commitments required for world-scale plants based on traditional metallurgical processes.

7) *Dielectric Heating.* Electromagnetic radiation in the radio frequency (RF) and microwave ranges (nominally 2-100 MHz and 300-3000 MHz, respectively) can penetrate non-conducting material and deposit energy as heat, thus offering an efficient means of drying, cooking, or polymerizing. Applications are numerous in the food, paper, wood products and plastic products industries.

8) *Radiation Processing.* Infra-red radiation is useful for applying heat to dry or cure surface coatings on metal, wood and paper. As one example of benefits, an infra-red oven 3 metres long replaced a gas oven 30 metres long, while allowing the strip product speed to be increased (Eeg, 1982).

Ultra-violet radiation can be applied to surface processes in the same manner as infra-red, but appears to be restricted to special purposes, notably the drying of appropriately formulated inks.

The laser offers a method of delivering energy at high density to selected areas of a surface, thus placing it in competition with the electron beam (EB) in welding and surface heat-treatment operations. The EB process, due to its earlier introduction, appears to have pre-empted much of the field, but certain advantages of the laser, such as the possibility of direction by mirror and the lack of need for vacuum, leave scope for some applications.

EB applications, which began with specialized welding systems, are expanding into many of the coating, curing, and heat-treating areas mentioned above, while new possibilities continue to be identified (Morganstern, 1982). In some of these potential applications, such as sewage treatment, food preservation and the sterilization of medical disposables, EB would be in competition with radioisotopes. An EB process for the removal of SO_2 and NO_X from stack gases, and their conversion to marketable fertilizers, is at an advanced stage of development (ED, 1980).

9) *Electrochemical Processes.* The decomposition of molecules by electrolysis is in large-scale use for the production of, for example, aluminum and chlorine. In addition to these traditional uses, a range of optional applications is now becoming economically attractive.

The electrolysis of water to produce hydrogen is currently limited to small-scale applications, such as hydrogenation of edible oils, while the bulk of industrial hydrogen is produced by the steam reforming of natural gas. As the cost of natural gas increases relative to that of electricity, electrolytic hydrogen will become increasingly attractive. Projections by Hammerli (1982) and by the Ontario Hydrogen Energy Task Force (OHETC, 1981), among others, point to emergence of electrolysis as the most economic route perhaps by the mid-1990s. The resulting indirect substitution of electricity via hydrogen for large-scale uses such as heavy oil upgrading and fertilizer production would have a significant impact on electricity demand, requiring perhaps 80 gigawatts of power by the year 2025 (Hammerli, 1982).

More is involved than the competitive position of electrolytic hydrogen. At about the same time that electrolytic hydrogen becomes competitive with natural gas-derived hydrogen, electrical energy will become competitive with natural gas on the basis of direct heat content. (Electricity will compete with gas much earlier in most applications because of its higher end-use efficiency.)

Other materials produced by electrolysis at present include manganese dioxide, potassium permanganate and several compounds of sodium and potassium. There are, in addition, various organic compounds that can be synthesized by electrolytic processes. Adiponitrile, an intermediate in Nylon production, is produced electrolytically on a large-scale and more than a dozen miscellaneous organic chemicals are in small-scale production by electrolytic processes in various countries (Roberts, 1982).

The literature suggests that, with some obvious exceptions, electrolytic processes are in their infancy and can be expected to evolve rapidly in response to the change in the relative costs of fuels and electricity.

Some Specific Applications

Many of the processes described above are embodied in units which can be added to an existing plant to perform an additional operation, such as polymerization of cable insulation, or which can replace an existing process, such as a paint-baking oven. Each of these unit-operation substitutions represents a tiny increment in total electricity use, but potential applications are numerous and varied; the aggregate can become a significant component of electricity demand.

As noted previously, however, the bulk of industrial energy is consumed by a small number of energy-intensive industries in large-scale processes; if electricity is to become a major component of industrial energy it must penetrate into these industries. The energy-intensive industries tend to involve integrated processes which offer little scope for the introduction of package units. An iron and steel works, for example, entails the coordinated operation of coke ovens, blast furnaces, steel-making furnaces and casting, rolling, or forging mills, each of which is a large, complex and capital-intensive operation. The other major energy users, though less constrained by process integration, are similarly bound by the capital invested in large process units.

While process integration and capital intensity would appear to discourage the penetration of electricity into the major energy-using industries, there are forces which encourage electrification of these processes. Three such forces are:

a) Most of these industries are under increasing pressure to reduce emissions to the atmosphere. Electrical processes, which do not require air for combustion, offer the possibility of closing the cycle so that material previously rejected from the stack can be removed from circulation and, in many cases, marketed as a by-product.

b) Many of the processes burn fuel merely as a means of producing high temperature, as distinct from producing chemical effects. This is true, for example, of glass furnaces, of lime, cement and brick kilns and to some degree, of metal smelting furnaces. In some situations, therefore, it is possible to replace the burner with an electrical device, an arc-plasma torch for example, and thus extend the productive life of the existing unit. The scope for profitably substituting electricity for fire is particularly large in the major energy-using industries.

c) While the traditional processes in the major energy-using industries tend to be large-scale, their electricity-based counterparts are, in many cases, optimal at a smaller size. The smaller scale could be desirable where the product is limited to the domestic market. Smaller unit sizes are attractive in any case because they allow incremental application which avoids the financial risks associated with new-technology mega-projects.

The following examples of electrical technology applications illustrate the foregoing points.

Example 1 — Space and process heat.
Chalk River Nuclear Laboratories (CRNL) comprises almost 100 buildings, located on a fifty hectare site in a severe (5000 Celsius degree day) climate. Unavoidable electricity demand peaks are caused by major experimental facilities, resulting in a load pattern typical of some industrial operations. Steam is supplied from a central boiler plant for space and process heating. Electric boilers have recently been installed, in parallel with the oil-fired units, to use off-peak power. Even at present oil and electricity prices, the new units have a two-year payback time.

The steam needs of individual buildings during summer are being eliminated by the substitution of electric domestic water heaters for the original steam heaters, thus allowing portions of the steam distribution system, with its large losses and its maintenance costs, to be shut down. Two results are reduced costs and increased energy efficiency.

With surplus hydroelectricity available most of the time, Hydro-Quebec is promoting the use of electric boilers in tandem with existing fired boilers in industrial plants. At a Canadian Textile Institute seminar on energy conservation it was reported that three 3 MW and one 13 MW systems currently (1982 October) being installed have payback times of one year or less, while additional projects of 27-44 MW with payback times between twelve and eighteen months are under negotiation (Lambert, 1982).

Example 2 — Blast Furnace.
A major integrated steel producer, having participated in pilot-plant tests, is assessing the application of arc-plasma torches to his blast furnaces (MP, 1981). The expected benefit is largely due to a major reduction in coke consumption, which would save operating costs at the coke ovens and capital investment for their periodic replacement while decreasing air pollution.

Example 3 — Non-ferrous Metals.
The production of metals has traditionally involved the combustion of fuel to provide heat for the drying and smelting of ores. Oil, or natural gas where available, has been economical for these purposes, representing a minor fraction of total operating cost. Escalation of fuel prices since 1974 has made energy a major factor. Some mine/mill/smelter installations, such as the INCO plant in Guatemala, have become uneconomic because of dependence on oil at the world price. Others are becoming vulnerable to competition from new installations based on more energy-efficient processes. Data from a survey of such processes for copper smelting (Carroll, 1980) suggest that higher energy efficiency is associated with an increasing input of electricity relative to hydrocarbon fuel. A nickel smelting process, which uses an electric furnace and recovers most of the sulphur from the ore for conversion to sulphuric acid, has been tested on a commer-

cial scale by INCO (1980). Success of the test could lead to large-scale replacement of existing smelting processes.

A survey of processes for non-ferrous metals production concluded that: "Using copper and lead production from sulphide ores as examples, it was shown that a large reduction in smelting energy is possible by the use of new processes. It is expected that electrical energy will form an increasing portion of the energy requirement of new processes" (Mackey and Parsons, 1982).

ECONOMIC SCOPE

General Approach

It is clear that large scope exists for industrial electrification, but a rigorous quantitative evaluation of the degree of electrification that would be economic now or at some future time is virtually impossible because of the diversity of industrial operations. There is diversity of scale, of process, of product and of location, which affects access to, and cost of, energy.

Nevertheless, the scope for electricity can be estimated and the rate of penetration of electricity into the industrial energy market can be projected on the basis of known technological options and likely energy cost trends. Four general statements can be made with some confidence:

a) The industrial plants that now exist are not optimal.

Most of the capital equipment operating today has been in place for at least a decade. Even those plants that have come into service more recently were, for the most part, committed before the economic slowdown which began in 1974.

The growing significance of energy costs is shown in Table 3, which shows the increase in energy cost as a fraction of value added in selected industries. In every case except metal smelting and refining the fraction increased between 1975 and 1979. It is likely that energy costs have grown even more rapidly since 1979 as Canadian prices for oil and gas have approached the rising world prices.

The decline in the energy cost fraction for smelting and refining might be attributable to process changes, such as oxygen injection in reverberatory furnaces, in response to rising fuel costs. In this process, the electrical energy for oxygen production displaces a larger quantity of combustion fuel energy.

b) In the long run, the share of industrial energy supplied as electricity will approach 100 percent.

Two pressures are acting in this direction and their strength is likely to increase with time. The first is the rising cost of combustion fuels relative to electricity, together with uncertainty of future supply. Even in the absence of a price advantage, electricity would be preferred by most decision makers because it offers price stability, or at least predictability within reasonable limits. Oil is today more costly than electricity for many purposes and will inevitably increase in price as the finite resources are consumed. Superimposed on this long-term trend is the vulnerability of oil supply and price to military

Table 3 Purchased Energy in Manufacturing Industries

SIC	Industry	1975 E (k$)	1975 V (k$)	1975 E/V %	1979 E (k$)	1979 V (k$)	1979 E/V %
100	Food & Beverage	193 841	5 030 036	3.9	357 050	7 663 484	4.7
160	Rubber & Plastics	34 722	964 082	3.6	75 775	1 790 050	4.2
180	Textile	51 515	1 067 877	4.8	94 439	1 772 720	5.3
271	Pulp & Paper Mills	398 692	2 569 050	15.5	919 459	4 539 127	20.3
291	Iron & Steel Mills	139 982	1 348 021	10.4	332 856	2 436 651	13.7
295	Smelting & Refining	141 134	844 537	16.7	207 354	1 333 830	15.5
300	Metal Fabricating	61 289	3 149 631	1.9	120 456	4 838 446	2.5
325	Motor Vehicle Parts/Accessories	29 266	1 008 395	2.9	65 118	2 110 911	3.1
330	Electrical Products	34 312	2 317 885	1.5	61 834	3 491 929	1.8
350	Non-metal Mineral Products	174 274	1 446 135	12.1	361 691	2 147 878	16.8
365	Petroleum Refineries	47 044	818 542	5.7	135 821	1 431 829	9.5
370	Chemical & Chemical Products	216 601	2 422 515	8.9	580 122	4 308 080	13.5
Total — All Industries		**1 805 666**	**36 139 301**	**5.0**	**3 879 624**	**60 823 174**	**6.4**

E = Cost of fuel and electricity
V = Value added in manufacturing

Source: Manufacturing Industries of Canada: national and provincial areas. Statistics Canada. Catalogue 31-203 (1975 and 1979) and political events in the Middle East and elsewhere. An investor contemplating a capital commitment, whether it be a home heating system or a major industrial plant, is not likely to place himself at the mercy of oil supply. Natural gas is a better bet than oil, but is still just that: a gamble that large new discoveries will be made and brought to market at an acceptable price. The price of gas, moreover, is tied to that of oil, if not by national policy, then by the workings of the market.

The second pressure is productivity. The productivity of labour is currently of most concern to economists, especially in Canada, but capital and energy productivity, or total factor productivity, are also important. Productivity, by any definition, is generally improved by electrical processes because of their energy efficiency, controllability, and compactness.

c) The actual degree of industrial electrification will always be less than optimal.

The reason is the longevity of capital plant or, in different terms, the low rate of turnover of the stock of capital equipment. This is obvious today, as noted earlier, in that most existing plants were designed for an economy based on cheap oil and gas. It will continue to be true because industrial plants are expected to recover their investment in a period of years, rather than decades, and are designed for present, rather than future, conditions. This is rational, even apart from financial imperatives, because the future is unknown. Once built, however, a successful plant soon pays off its investment and then continues to operate for decades, competing successfully with newer plants carrying capital burdens. It is in the nature of things that capital equipment is obsolete, but profitable.

There is, however, a limit to the technological lag that an economy can afford without becoming uncompetitive. Near-term profits from obsolete plants can obscure, but not prevent, erosion of competitive margins.

d) Canada is in a preferred position.

If the pressures of energy resource depletion and of productivity are forcing a global trend to industrial electrification, Canada is in a position to benefit. Low-cost electricity is a present and future resource which offers a comparative advantage over most other countries in an increasingly electrical world (Melvin, 1981-A). Electrical processes are beginning to compete with their combustion-based counterparts in the world's industries, but due to the relatively low cost of electrical energy in Canada, many of these processes will cross the economic threshold here years, or even decades, before doing so in other countries. The range of electricity costs and the relative advantage of most regions of Canada are evident in Table 4. Low-cost electricity gives Canada the opportunity of a head start towards industrial electrification, which means high-technology, high-productivity manufacturing.

Table 4 Comparative Electricity Rates*

	Cents/kW·h
USA (Consolidated Edison)	14.4
Japan (Chubu Electric)	10.7
Denmark	10.2
Japan (Tokyo Electric)	9.8
Italy	9.2
Japan (Kansai Electric)	9.2
Belgium	9.2
Netherlands	8.9
Germany	8.3
USA (Commonwealth Edison)	7.7
Northern Ireland	7.7
Eire	7.4
England & Wales	7.3
USA (Detroit Edison)	7.3
Scotland	7.0
France	6.7
Spain	6.6
Greece	6.5
Portugal	5.6
Australia (Western)	5.4
Australia (Victoria)	4.7
Sweden	4.7
Canada (Quebec)	3.4
Canada (Ontario)	3.0

* For 500 kW, 60% annual load factor; all taxes included.

Source: British Electricity Council. Based on tariffs as at 1981 August 1

The opportunity offers not only a comparative economic advantage for Canadian products in world markets, but also a leading position in industrial process equipment and technology. Canada has established a reputation of excellence in the generation of hydroelectricity and, to an increasing degree, of nuclear electricity. The opportunity now exists to build a similar reputation for excellence in the productive use of electricity throughout the manufacturing sector, a reputation which can be translated into high-technology export products, the growth of new industries and expanded employment opportunities for Canadians.

The foregoing discussion provides a basis on which to project the penetration of electricity into industry.

Penetration Rate

For the reasons given above, the ultimate share of electricity in the industrial energy market is assumed to be 100 percent; a lower value, say 80 or 90 percent, would not substantially alter the projections for the period of interest because the ultimate level is only approached after many decades. Moreover, no allowance is made for the conversion of existing plants to use electricity in place of oil or gas. The two remaining questions are:

a) At what rate will the electricity share grow from its present value of 26.7 percent?

b) At what rate will total energy demand in the industrial sector grow?

Many factors will influence these rates. Rather than constructing an elaborate model incorporating the many factors involved, a simple approach is adopted here, by assuming that electrical processes will be chosen henceforward for all new plants, both for expansion and for replacement of retired plants. With this assumption, the quantity of combustion energy displaced by electricity at any future time can be projected for any given rates of expansion and replacement.

The quantity of combustion fuel displaced cannot be translated directly into electricity demand because electricity does not replace fuel on a one-to-one basis. Electrical energy is almost invariably used more efficiently than combustion energy. On the basis of experience reported by Felix (1980) and Chaussard (1982), a unit of electrical energy in industrial applications appears to replace between two and five units of fuel energy. This range reflects different mixes of the various processes described earlier, for which individual values can range from a low of about 1.2 for an electric boiler to a high of 10 or more for some radiation or membrane processes.

The total energy demands for the four cases specified in Table 5 are calculated. The two chosen rates of industrial output growth, 2 and 4 percent per year, may be compared with the 5 percent rate of real GNP growth in Canada from 1960 to 1974. The spread in growth rates allows for uncertainty about future economic growth and allows for the possibility that some new production capacity will use oil or gas rather than electricity. For convenience, the retirement rate is made equal to the growth rate in each case. The spread in "effectiveness", defined as the number of units of combustion energy displaced by one unit of electrical energy, allows for the range of possible processes and products involved. The calculations are described in Appendix A.

Table 5 Assumptions for Energy Projections

	Rate of Output Growth and Plant Retirement (% p.a.)	Effectiveness* of Electrical Energy
Case 1	2.0	2.0
Case 2	2.0	5.0
Case 3	4.0	2.0
Case 4	4.0	5.0

* Effectiveness = units of fuel energy displaced by one unit of electrical energy.

The resulting projections of industrial energy demand are shown in Figure 5, in which "total energy" is the sum of combustion fuel and electrical energy. The figure contains two curves in addition to those for the four cases described. The additional curves show the energy that would be required for the two rates of industrial growth in the absence of the efficiency improvement attributed to electricity. These curves thus represent energy growth at the same rate as industrial output growth and are thus equivalent to pre-OPEC energy demand forecasts made by simple trend extrapolation with no technological change.

Figure 6 shows the projected shares of electricity in total industrial energy for the four cases.

Discussion

The conservation, or energy-productivity effect, of electrical processes is evident in the differences between total energy curves for a given rate of industrial expansion. In the high-efficiency cases, where one unit of electricity replaces five units of combustion energy, total energy input actually declines for several years, even in the case of higher output growth rate.

Figure 5 covers a 30-year period; energy projections over a longer period would be neither useful nor credible in the context of this study. Figure 6 however has

Figure 5 Industrial Energy Demand Projections

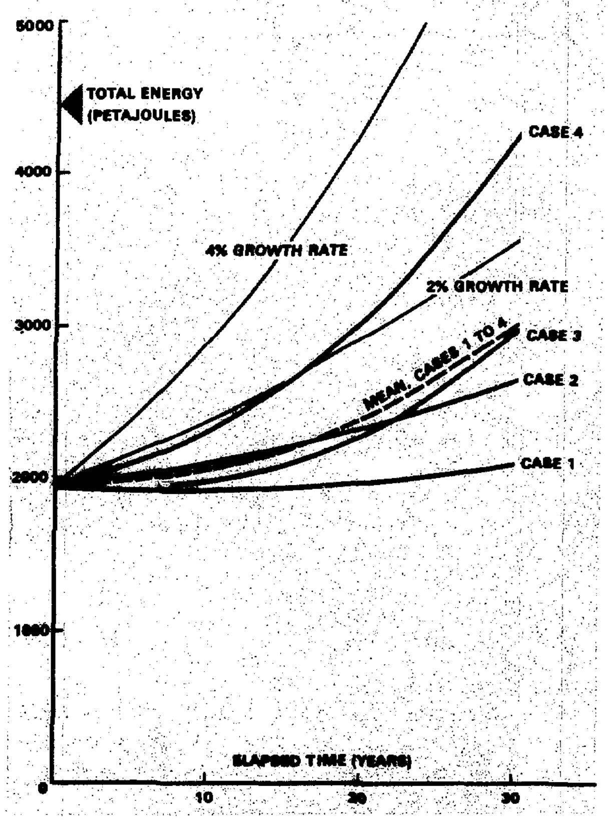


Figure 6 Electricity Share of Industrial Energy

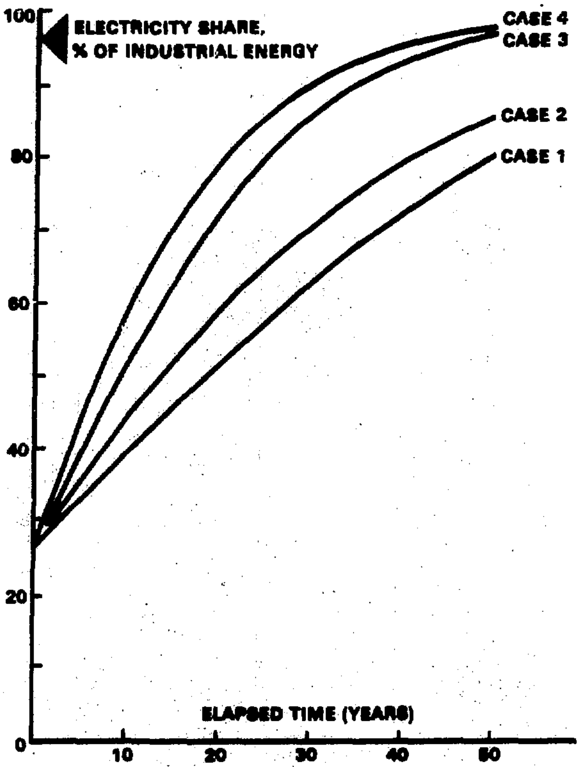
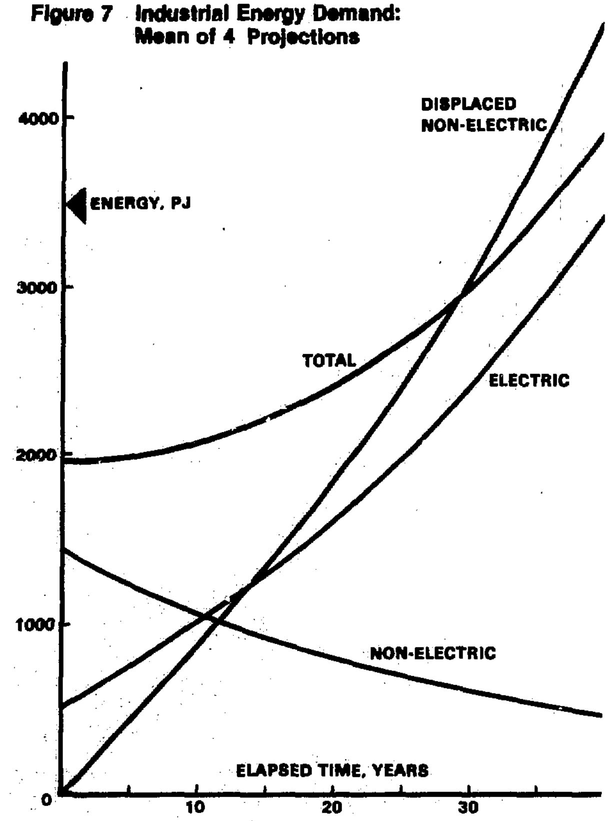


Figure 7 Industrial Energy Demand: Mean of 4 Projections



been extended over a half-century in order to show the hypothetical effect on electricity shares of the assumptions made. The electricity share increases with time in an almost linear manner initially, though at a different rate for each case. One salient feature is the sensitivity to growth/replacement rate. This is expected and reasonable because expansion of output provides both the funds and the opportunity for technological change.

A second feature of Figure 6 is the gradual slowdown in the increase of electricity shares with time, which is a direct result of the assumptions, but which is also reasonable in practice because of the longevity of some major plants, the insensitivity of some processes to energy cost and the difficulty of converting some processes entirely to electricity.

ELECTRICITY DEMAND

Annual Consumption

In the previous sections of the study, four cases were evaluated in order to assess the effects of various assumptions and to estimate the range of uncertainty of the projected energy requirements.

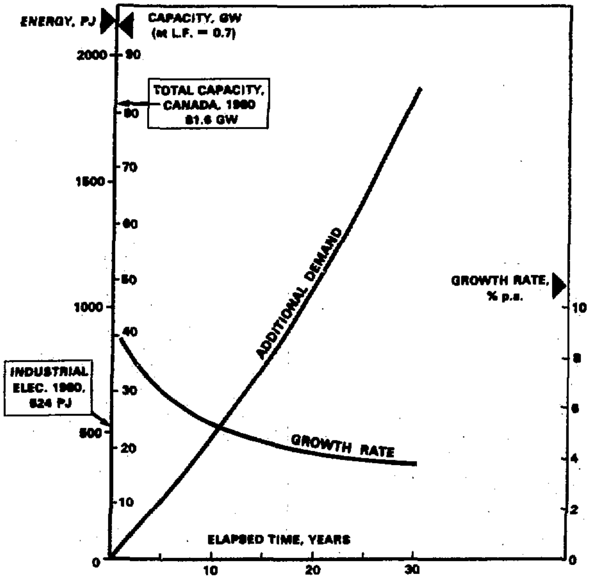
For the balance of this study, the complication resulting from multiple cases is avoided by choosing a single representative projection. This projection is simply the mean of the previous four; it is represented by the broken line on Figure 5 and its components are shown in Figure 7.

The increase in demand from time zero (nominally 1980) is shown in Figure 8. This figure also shows the generating capacity that would be required to produce this energy, assuming an annual load factor of 0.7, and the annual growth rate of industrial electricity demand implied in the projection. The additional generating capacity actually required to meet the projected demand would be less than that estimated in Figure 8 because the growing industrial load would increase the overall system load factor.

System Growth

The significance of the additional load created by the electrification of industrial processes is illustrated in Figure 9. Up to 1980, the curve shows actual electricity consumption in Canada in all sectors, residential, commercial and industrial. The projection beyond 1980 was constructed by adding the new industrial

Figure 8 Additional Electricity Demand, Industrial Sector



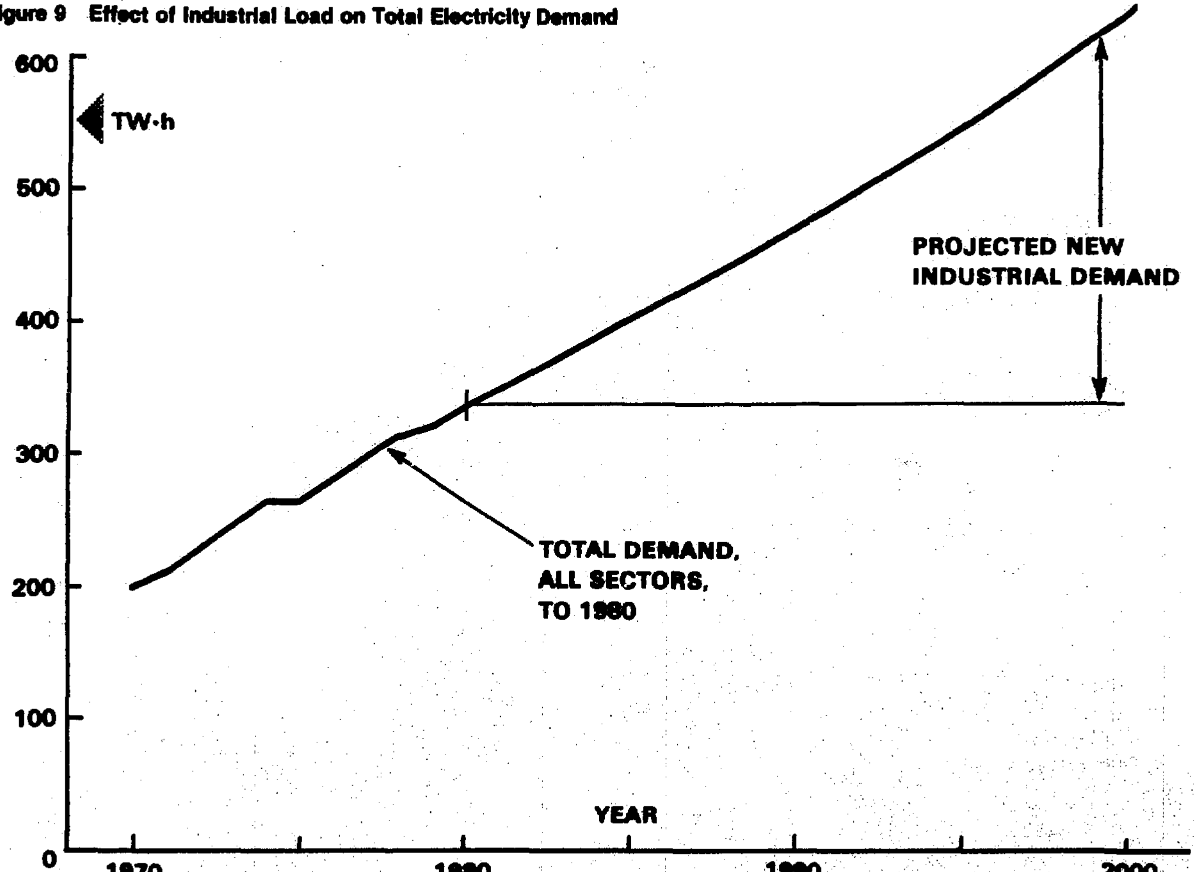
load, as estimated in this study, to the total 1980 load. The projection therefore represents the electricity demand that would occur if industrial electricity consumption were to grow as estimated while consumption in the residential and commercial sectors remained constant at the 1980 level.

The average annual growth rate, from 1980 to 2000, is 3.2 percent. Any growth in the residential and commercial sectors, such as increased use of electricity for space heating, would increase this growth rate. Major structural changes, such as a shift to electrolytic hydrogen for chemical uses, or the emergence of electric vehicles, would further accelerate demand growth.

Discussion

The penetration rate of electrical energy into the industrial sector has been estimated on the basis of plausible rates of industrial output growth and plant retirement. This penetration was first calculated in *terms of combustion energy displaced by electricity;* the displaced energy was then translated into electrical energy demand on the basis that one unit of

Figure 9 Effect of Industrial Load on Total Electricity Demand



electrical energy displaces several units of combustion energy.

The assumption that all new plants will be electricity-based is not entirely valid, at least for the near term, during which natural gas will be price-competitive in a few particular cases. While it is thus possible that the electricity share of industrial energy has been overestimated, the estimated demand for electricity is probably on the low side because of the low rate of growth, about three percent per year, assumed for industrial output. On balance, the projected demand for industrial electricity is believed to be conservative, given Canada's mineral, technological and electrical resources, and the perceived need for productivity improvement by the upgrading of industrial technology.

The potential for electrical energy use by the industrial sector alone is therefore likely to result in a growth rate in excess of three percent per year in electrical energy. Any growth in electricity consumption by the residential or commercial sectors will add to this demand growth. This reinforces the conclusion reached in earlier studies by Melvin (1980, 1981), that a doubling of electricity demand in about 15 years is desirable for displacement of oil imports and likely unless the economy remains stagnant. At this rate of demand growth the existing and planned capacity of Canadian electric utilities would be fully absorbed in ten years or less, which means that a new generating unit committed today would barely be ready when needed.

These, or any other projections, are subject to uncertainty with respect to economic growth. Energy in any form, and electricity in particular, are used mainly to produce goods and services. An earlier study (Melvin, 1981) examined the close linkage between electricity consumption and economic output, reaching a conclusion that is just as valid here: to produce more goods and services for more people requires more electricity and, conversely, by producing less it is possible to reduce the growth of electricity demand.

The analysis presented here illuminates the connection between GNP and electricity demand by showing the sensitivity of projected electricity demand to the rate of growth of industrial output and the recent shift in the relative costs of fuels and electricity.

The worldwide economic recession has not only slowed the increase in total energy demand, but has also impaired the ability of industrial firms to invest in new plant. The impact of the energy revolution on electricity demand has therefore not yet been felt and has not entered into the plans of electricity producers or consumers. Economic recovery can produce both the need for industrial expansion and the cash flow with which to build, thus accelerating the electrification of industrial processes.

BENEFITS OF ELECTRIFICATION

Economic Impact

This study did not include a conventional econometric analysis of the effects of industrial electrification. The validity of such an analysis would be questionable in any case because it is outside the range of experience represented by historical data. Some crude estimates can, however, be made and they indicate that the impacts would be favourable and substantial. Three such indicators are: the historical impact of electricity production, the market for electrical equipment and the relationship between electricity demand and GNP.

Electricity Production Impact

An economic impact study by EEMAC (1979) using the Statistics Canada interprovincial model, estimated that the production of one million dollars' worth of electricity generates about $1.2 million of economic activity and about 44 person-years of employment in Canada. On this basis, the increase in electricity demand of some 15 TW·h each year (Figure 9), assuming a price of two cents per kilowatt-hour, represents an additional $300 million, or about 0.1% of GNP, with a corresponding increase of 13 200 jobs. These figures reflect only the production of the electrical energy, not its use, and thus measure just a fraction of the total impact.

Electrical Equipment Purchases

Two methods offer rough estimates of the investment in equipment to use electricity.

First, available data indicate that the cost of electricity-consuming equipment ranges from about $50 per kilowatt of capacity for boilers to several thousand dollars per kilowatt of industrial process equipment. At a cost of, say, $500 per kilowatt of electricity-consuming equipment, and a load factor of 0.7, the annual demand growth of 15 TW·h implies an investment of $5 billion each year in electrical equipment.

A second estimate can be made from the relationship between electrical equipment purchases and electricity demand. During the period 1971 to 1981, electricity consumption increased by an average of 13 000 GW·h each year, while annual purchases of industrial electrical and electronic equipment amounted to an average of (1971) $4.5 billion. This indicates an electrical equipment investment of approximately $350 000 per GW·h of additional energy consumed. For the projected 15 TW·h increment, this would amount to purchases of $5.25 billion each year. This amount, about 4% of GNP, overestimates the volume of business for the Canadian electrical and electronics equipment industry because a substantial fraction would be imported, but it underestimates the total volume of Canadian business because electrical equipment is only one component of the business generated.

Gross National Product

The relationship between electricity consumption and GNP shown in Figure 1 provides the basis for estimating the total economic effect of the projected increase in electricity demand. The electricity intensity of incremental GNP, as reported by Melvin (1981) is about 3 kW·h per $(1971). The additional annual consumption of 15 TW·h would thus be associated with $5 billion of incremental GNP, or approximately 4% growth.

Conclusion: Economic Impact

The total impact is estimated to be about 4% of GNP each year for the projected rate of industrial electrification.

Industrial electrification thus constitutes an ongoing "mega-project", but with the additional benefits stemming from dispersal, both geographic and sectoral. Industrial electrification is not focused on a particular region or concentrated in a particular industry, but is distributed throughout the industrial economy. Moreover, it does not have the boom-and-bust character of a conventional mega-project.

National Benefit

The benefit to Canada as a whole, or to an individual province, is the economic growth due to an expanding share of domestic and foreign markets. Electrical technology offers an economic advantage over foreign competitors because of the relatively low cost of electricity in Canada. The advantage can be amplified by the increased productivity associated with electricity-based processes. In effect, electrical production processes can be classified as "high-technology"; electrification thus entails technological upgrading, with improved productivity and quality of employment, along with smaller environmental impact.

In exploiting the opportunity for leadership in industrial electrification, Canadian industry would be forced to depend heavily on domestic technology, thus stimulating R&D and the development of the technological infrastructure. The resulting know-how could itself become a valuable export product.

The scope of the electrical opportunity thus stems basically from low-cost electricity, but is amplified by the high-technology characteristics of electrical processes. Among the most significant of these characteristics is controllability and this has many ramifications because it allows, even encourages, the application of microelectronics, robotics, telecommunications and related technologies to basic production processes.

Electrification of industrial processes on a large scale would reduce the future demand for oil and natural gas in Canada. Lower oil demand would reduce vulnerability to interruption of supply from foreign sources while also improving the balance of trade. In effect, dollars invested in the production and application of electrical energy would otherwise have been spent abroad to purchase oil. An earlier study (Melvin, 1980) estimated that the investment in electrical generating capacity required to eliminate oil imports would approximately equal the cost of the avoided imports.

Under present circumstances there is little to be gained by substituting electricity for natural gas because Canada is able to produce more gas than domestic and export markets can absorb. The current situation is, however, abnormal and not tolerable for many years because it represents worldwide economic stagnation in the face of large and growing human needs. Stagnation is not an acceptable basis for planning. In an expanding world economy, natural gas would soon become a valuable commodity in international trade, at a price set by that of oil. Petroleum economists disagree on the likely trend of international oil prices in the near term, not just with respect to the rate of change, but even regarding the direction of change. The major uncertainties relate to demand, not supply, and future demand will be determined mainly by economic conditions. The present surplus of oil is attributed partly to economic recession and partly to structural change, meaning conservation and substitution. There is little consensus on the relative magnitudes of the two, but if even half of the reduction in demand is due to economic slowdown, the glut would rapidly disappear in the wake of economic recovery.

While the future cannot be known, the spectrum of possibilities lies between two bounds: strong economic growth leading to recurrence of the "energy crisis", or continuing economic stagnation leading to social crisis. The former would be manageable by economic and technological means and is inherently self-limiting; the latter is neither manageable nor stable.

The conclusion is that the national interest requires global economic growth which in turn will place energy supply under stress, raising the cost of oil imports and the value of natural gas exports.

The Canadian industrial sector is heavily dependent on oil and even more so on gas, as shown in Figure 2. The projections made in this study do not assume the conversion of existing plants from oil or gas to electricity although that might well happen. Instead, for the reasons given above, it is assumed that new plants will be electricity-based, so that dependence on oil and gas will decline at a rate which depends on the rate of economic expansion. Thus the economic growth that leads to energy crisis would be used to attenuate the severity of the crisis.

Benefits to Industry

Combustion is an increasingly expensive process not just in Canada, but worldwide; within narrow limits, industries everywhere face the same fuel prices and, increasingly, the same pollution controls. Energy, which is an essential input, has become a significant element of cost in many operations, so that the effect of energy cost on profitability is increasing.

Electrical energy is the alternative to combustion and, in most parts of Canada, is price-competitive on an energy-content basis with oil at the present world price, e.g., electricity at 2¢/kW·h has the same cost per unit of contained energy as oil at $36 per barrel. At least, therefore, electricity places a ceiling on the cost of energy, but this grossly underestimates its significance.

As discussed earlier, electricity is not normally substituted on a one-to-one basis for combustion fuel; the substitution is usually indirect, involving a process change which results not only in lower energy input per unit of product, but also other benefits such as higher productivity of labour, greater operating flexibility, finer control and reduced emission of pollutants.

If the various countries competing for world markets were on an equal footing in terms of energy supply, electrification of Canadian industry would have to keep pace with the rest of the world and would confer no particular advantage. In fact, Canadian industry would probably be at a disadvantage because of the characteristic lag in the application of new processes which, typically, have been developed elsewhere.

The low cost of electricity in Canada relative to other industrial countries, however, presents the opportunity to lead rather than lag, and thus to gain an initial advantage. The opportunity exists because, due to lower-cost electricity, many electrical processes will become economic in Canada years, or even decades, earlier than elsewhere.

The opportunity is two-fold. By taking early advantage of electrical technologies, the Canadian producer can compete more effectively and thus expand his share of world markets. In addition, the opportunity would thereby be created for Canadian suppliers of electrical process equipment and technology to gain a position of international leadership based on their early experience at home.

As an illustration, arc-plasma devices appear to be at the threshold of economic application to various metallurgical processes, but the economic feasibility of these high-energy systems is sensitive to the local cost of electricity. The result is that an arc-plasma application has been rejected after early enthusiasm by a steel company in the United States just when the same application was becoming attractive in Canada (MP, 1981).

Benefits to Electric Utilities

The most obvious benefit to the electric utility from electrification of industrial processes is increased volume of electricity sales. Increased volume would have a direct and favourable impact on unit costs for those utilities which have excess capacity in being or under construction. Many Canadian utilities are in this position due to the combination of long construction periods, especially for hydraulic or nuclear stations, and the slowdown in demand growth. Generating capacity which was committed during the 1970s in the expectation of continuing annual load growth at the traditional rate of six or seven percent, will be coming into service in the 1980s when the expected loads have failed to materialize. Under the accounting regime applied by most electric utilities, the operating and amortization costs of a unit appear as an expense only when the unit begins to produce. Thus, when a new generating plant comes into service, one result is a step increase in the revenue requirement of the utility. If there is not a corresponding increase in the amount of energy sold, the additional revenue requirement results in a higher average cost per kilowatt-hour. The average cost, which is simply the revenue requirement divided by the total energy sold, is therefore sensitive to the relationship between capacity growth and load growth. Under present conditions in most parts of Canada, unit costs would be lower with load growth than without it.

A less obvious benefit relates to load factor. Electricity is becoming the preferred source of space-heating energy, for new premises and for off-oil conversion of existing buildings. Since inception of the National Energy Program in 1980 October, 68 000 Canadian residences have been converted from oil to electric heat (EMR, 1982) and the trend is expected to continue. Space heat demand, however, is dictated by climate; it is most needed in winter. More important, it is dictated by weather, in the form of "cold snaps" of relatively short duration, but of great severity, as discussed by Clayton et al. (1980). To illustrate, a residence might consume in total 20 000 kilowatt-hours of electricity for heating during a full year. This is an average load of 2.3 kilowatts, but on the coldest night of the winter, the home might require 15 kilowatts. The annual load factor, defined as the ratio of average load to peak load, would thus be 15 percent.

The effect of electric space heat on the load factor of a small municipal utility has been documented by Phillips (1981).

The electric space-heating load is growing. If this growth is not balanced by some other load, it will reduce the load factor served by the utility, with the result that generating capacity will be under-utilized for most hours of the year and the unit cost of electricity will rise.

Industrial loads offer a counterbalance. These loads reflect production rates, rather than climate or weather, and thus tend to be more uniform throughout the year. Data from AMPCO (Lounsbury, 1982), for example, indicate a load factor of about 70 percent for major industrial customers. Moreover, industrial operations offer scope for load management. Many operations can be rescheduled to avoid periods of peak electricity demand and some can be cut off, at the discretion of the utility, at times of peak demand. For example, glass-melting furnaces or cement kilns can be restricted at peak demand hours, or during cold snaps, with little effect on annual production.

In summary, the space-heating demand on electric utilities is growing and the negative impacts of this load can be offset by corresponding growth of industrial loads.

AN ELECTRIFICATION STRATEGY

Need and Opportunity

Given the Canadian capability to provide low-cost electrical energy, it can be assumed that industrial electrification would proceed without policy intervention. Progress might, however, be too slow to take advantage of the opportunity.

Canadian industry is not innovative, but depends heavily on process technology which has been developed and put into practice abroad before being applied here. This technological lag and the reasons for it have been amply documented by the Science Council of Canada (Britton and Gilmour, 1978). The fundamental change that has occurred during the past decade of "energy crisis" has altered the position of Canadian industry relative to competitors and has removed, or even reversed, some of the factors which contributed to the technological lag. This revolution is summed up in two statements:

- the relative costs of electricity and oil have been inverted; electrical energy is now less expensive than oil energy, and
- this inversion has occurred only in Canada, among the industrial countries.

The significance of this is that the countries upon which Canada has depended for industrial technology lack the immediate incentive for electrification of industrial processes and therefore can no longer be regarded as suppliers of technology appropriate to Canada. If industry in this country is to exploit the opportunities presented by the energy revolution, domestic process innovation is required; by waiting for others to lead the way, Canadian industry will forego a clear advantage. Ultimately, process electrification seems to be inevitable everywhere, but Canada is in position to lead and to profit by doing so.

There are, however, barriers to be overcome. Three of these are awareness, access and cash flow.

Awareness. Many industrial decision makers have not yet realized that combustion is becoming more costly than electricity. Others, having accepted this fact, remain unaware of the electrical process options that exist.

Access. Electrical technologies are not yet being disseminated through the usual channels, which are parent firms and process equipment suppliers. Both channels have traditionally delivered technology to Canadian industry from abroad, but neither is yet in a position to benefit greatly from electrical technology, so neither channel is likely to deliver what is appropriate to Canadian circumstances.

Cash flow. Some firms, particularly the large, energy-intensive ones, are fully aware of the process options, the available technologies and the potential benefits of electrification, but are without the financial means to act. For many the current problem is not one of expansion or upgrading, but survival.

Components of a Strategy

Given the barriers identified above, two of which are structural and the third a transient economic condition, it is unlikely that Canadian industry will take full advantage of the electrical opportunity in the absence of government initiatives. Economic recovery is a necessary but insufficient condition because the two structural barriers, awareness and access, would remain and even the cash-flow impediment might persist if alternative uses of available funds were perceived to be more desirable.

Provincial or Federal government policy aimed at capturing the benefits of low-cost electricity would thus require three components: promotion, delivery and financing. The relative importance of each would vary from case to case. For example, the needs of a major integrated steel producer would be different in type and magnitude from those of a small manufacturer.

A Possible Approach

The three components of an industrial electrification strategy would require contributions from various organizations including government agencies, electric utilities, engineering and technology development firms, manufacturers, contractors and financial institutions. Each group stands to benefit and collectively they could provide the necessary elements, viz.,

Promotion: to create awareness of the need, the benefits and the availability of electrical processes.

Delivery: to provide access to relevant engineering data, performance assessment, equipment selection and project engineering.

Financing: to provide advice on options for financing, assistance in assembling an appropriate package and access to incentive programs sponsored by governments or utilities.

An umbrella organization with participation by each of the relevant branches of expertise could focus the electrification strategy and offer one-stop shopping to prospective clients by affording access to a diverse mix of skills and knowledge.

Such an organization might take the form of a joint enterprise, owned and staffed by its shareholding member firms and agencies. Such an organization could draw on the knowledge and experience of its members to provide technical and financial consultancy over the range from initial feasibility assessment to eventual project management. A key strength would be the ability to tailor the financing of a project to the expected savings or revenues; this would be particularly attractive to small and medium businesses lacking the in-house capabilities of a large firm, but the service could also be of value to large firms facing major decisions involving technological and financial risks.

By acting as a technological clearing-house for a broad range of clients and members, the organization could develop world-class scale and competence in the development and application of industrial technology, eventually becoming a vehicle for the exploitation of Canadian expertise in international markets.

CONCLUSIONS

There is large scope for increasing the share of industrial sector energy provided by electricity. This scope exists because the present share is small, about one-quarter, but electrical processes are capable of performing almost any industrial operation. The share can eventually approach 100 percent.

The share of electrical energy in industry is expected to grow rapidly, once economic recovery begins, because of the increasing advantage of electricity over combustion. The advantage is in part a direct energy cost saving and in part a mixture of indirect benefits including greater productivity and smaller environmental impacts. Process electrification generally represents technological upgrading.

The incentive for electrification is stronger in Canada than elsewhere because of the lower cost of electricity, present and projected. As the costs of combustion fuels rise relative to that of electricity throughout the world, any given electrical process will tend to become economic in Canada sooner than in other countries. In other words, electricity places a ceiling on production costs which is lower in Canada than elsewhere.

The electricity-cost advantage offers to Canadian industry the opportunity of leadership in the world-wide transition from combustion to electricity as the prime form of process energy. The opportunity is two-fold. Lower production costs can provide a competitive edge for export products, while leadership in industrial electrification can give Canadian suppliers access to world markets for electrical process technology and equipment.

Exploitation of the opportunity to upgrade industrial processes and to develop leadership in electrical process technology will require new initiatives by industry and government. Traditionally, much of Canada's industrial technology has been imported at a mature stage of development. To achieve leadership in electrical processes, however, it will be necessary to develop the technology at home, gaining a head start on the basis of low-cost electricity. A concerted effort by producers, designers, developers, suppliers, utilities and financial houses seems necessary to stimulate and support the innovation process. An appropriate vehicle would be a joint enterprise, chartered for the purpose of industrial electrification, constituted by shareholding firms and agencies with relevant capabilities.

A moderate rate of industrial electrification would double the total demand for electricity in Canada in about 25 years. Demand growth in other sectors would be additional. In view of the opportunities, and barring an extended economic depression, electricity demand is likely to grow at an annual rate not less than five percent.

The economic activity associated with industrial electrification at the projected rate is estimated to add several percent to GNP each year.

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APPENDIX A

Electrical Energy in Industry Penetration Rate Projections

Assumptions

Electricity demand by the industrial sector is projected using two basic assumptions:

a) future additions to industrial capacity are powered entirely by electricity.
b) existing non-electric industrial plants are replaced, upon retirement, by all-electric units.

Time zero is 1980, the latest year for which industrial energy data were available.

In addition to these general assumptions, two specific assumptions are necessary:

a) the annual growth and retirement rates. The growth rate is the year-to-year increase in total industrial production. The retirement rate is the fraction of surviving non-electric industrial plant that is retired each year. The two rates are taken to be equal, both for convenience of calculation and because of the logical association between the two. Two annual rates, 2% and 4%, are chosen.
b) the quantity of fuel energy, i.e., heat value, equivalent to one unit of electrical energy. This ratio is called effectiveness; two values, 2 and 5, are chosen to represent the likely range.

Calculation Method

Q_O = total energy consumed by industry in year zero
E_O = electrical energy consumed by industry in year zero
N_O = non-electrical energy = $Q_O - E_O$
g = annual growth rate of industrial output
r = annual retirement rate of non-electric plant
e = effectiveness, as defined above
D_n = non-electric energy displaced in year 'n'
E_n = electrical energy consumed in year 'n'
N_n = non-electrical energy consumed in year 'n'
Q_n = total energy consumed by industry in year 'n'
S = electricity share of total energy
T = total energy that would be consumed to produce the expanded output in year 'n' in the absence of technological change.

Then:

$$D_n = \left[N_o(1+g)^n - N_o\right] + \left[N_o - N_o(1-r)^n\right]$$

$$= N_o\left[(1+g)^n - (1-r)^n\right]$$

$$E_n = E_o(1+g)^n + \frac{D_n}{e}$$

$$N_n = N_o(1-r)^n$$

$$Q_n = E_n + N_n$$

$$S = E_n / Q_n$$

$$T = Q_o(1+g)^n$$

Data for Four Projections

Four projections were made, using the calculation method described above.

Case	1	2	3	4
Q_O (PJ)	1965			
E_O (PJ)	524			
g,r	0.02	0.02	0.04	0.04
e	2	5	2	5

Conversion to electrical units

$$\text{Energy: } 1\ \text{GW·h} = \frac{(\text{PJ}) \times 10^{15}}{3600 \times 10^{9}} = 277.8\ \text{PJ}$$

Peak capacity, with load factor = 0.7:

$$\text{Peak GW} = \frac{(\text{GW·h})}{0.7 \times 8760} = 0.045 \times (\text{PJ})$$

i.e., 1 PJ of annual energy requires 0.045 GW of capacity or 1 GW of capacity provides 22.1 PJ of annual energy.

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