HSTC Bulletin
Journal of the History of Canadian Science, Technology and Medecine
Revue d'histoire des sciences, des techniques et de la médecine au Canada

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Volume 5, numéro 2 (18), mai 1981

URI : https://id.erudit.org/iderudit/800103ar
DOI : https://doi.org/10.7202/800103ar

Aller au sommaire du numéro

Éditeur(s)

HSTC Publications

ISSN

0228-0086 (imprimé)
1918-7742 (numérique)

Découvrir la revue

Citer cet article

Belfield, R. (1981). Technology Transfer and Turbulence: The Evolution of an International Energy Complex at Niagara Falls, 1896-1906. *HSTC Bulletin*, *5*(2), 69–98. https://doi.org/10.7202/800103ar

TECHNOLOGY TRANSFER AND TURBULENCE: THE EVOLUTION OF AN INTERNATIONAL ENERGY COMPLEX AT NIAGARA FALLS, 1896-1906

Robert Belfield*

(Received 10 October 1980. Revised/Accepted 15 May 1981.)

'(The) American and Canadian systems were regarded as one.'[1] (Harold Buck, 1906)

The Niagara Falls Power Company introduced, in 1895-96, an electric power system which redefined Niagara Falls as one of the world's greatest energy resources. Harnessed to the new technology, the hydroelectric potential of Niagara Falls, Ontario, exceeded by a factor of seven that of Niagara Falls, NY. The company had secured in 1892 from the 'host government' of Ontario an *exclusive* franchise for the development of the Ontario site. With its technology thus protected at Niagara, the firm planned to create an international, interconnected power system -- an international Niagara monopoly. Yet the enterprise failed to appreciate the turbulent impact of its technological innovation in eastern Canada where the scarcity of useful coal and the abundance of water power created an enormous demand for the new technology. Power interests in eastern Canada acted quickly: companies in Québec immediately adopted the Niagara system and even transferred it to Hamilton -- the largest industrial market in the Niagara region of Ontario. These moves forced the government of Ontario to renegotiate, in 1899, the Niagara Co.'s exclusive franchise. With competition possible, the focus of technological activity then shifted from Niagara Falls, NY to Niagara Falls, Ontario. There, both private and public interests formed to plan Niagara projects involving massive generating stations (GS) and high voltage (HV) transmission networks to compete for distant markets. An energy revolution in eastern Canada was in progress.

My purpose here is not to argue political and economic questions such as the merits of the private versus public enterprises but rather to examine the history of the evolution, transfer, and diffusion of this new technological system. The Niagara Co. introduced a seminal technological system or model -- so successful that earlier hydraulic power firms at Niagara became immediately obsolete. Methodically, Niagara Co. engineers decided to improve system designs in association with plans for expansion to meet unexpectedly great demand in its existing local and Buffalo

* Atomic Energy of Canada Ltd.

markets. The Niagara system design evolution culminated in the firm's fully owned, interconnected Canadian subsidiary, the Canadian Niagara Power Company. In the sense that Niagara Co. engineers were primarily responsible for this evolution of an interconnected, international system, the developed Niagara system at Canadian Niagara remained a firm-specific model. Just as Québec firms imitated the original Niagara system of 1895-96, private competitors at the Falls largely imitated the developed Canadian Niagara designs.

It will be argued firstly that the Niagara Co. lost many returns from its work because the firm failed to synchronize its design evolution with the turbulent environment which its technology fostered in eastern Canada. Second, it will be argued that the transfer and diffusion of Niagara Co. designs to eastern Canada -- a complex, subtle and interrelated process mainly involving the movement of designs and individuals -- structured the formation and strategy of Ontario Hydro. Since previous political and economic historians have treated separately the history of the Niagara Co. and that of the origins of Ontario Hydro,[2] this paper hopes to show that, above all, an evolving technological system constituted the historical continuity between the two. Unfortunately, this effort to show the technological continuity among numerous enterprises necessitates a 'company history' approach which makes impossible a strictly chronological overall account.

THE EVOLUTION OF AN INTERNATIONAL SYSTEM

In 1895-96, the Niagara Falls Power Co. introduced its pioneering invention of a universal electric power system. To briefly abstract the invention of the 'Niagara system', which has been analyzed in detail elsewhere,[3] it had centred upon the adoption of a polyphase current system, and the design evolution of an appropriate generator and coupling devices to transform raw power into the current needed by lighting, traction (trolleys) and industrial customers. Once polyphase redefined Westinghouse's 'alternating current' into 'single phase,' polyphase came to refer to a single phase, two phase or three phase alternating current system. A polyphase system offered two main advantages over direct current (dc): first, voltage transformation allowed for transmission beyond dc's five mile practical limit; second, a rotary converter could transform polyphase power into dc. European companies had shown that three phase offered the advantage of inexpensive transmission but that two phase offered the advantage of relatively simply generator design -- and the generator was the most expensive equipment in the Niagara Co.'s high risk, pioneering project.

Guided by Chief Engineer Coleman Sellers, the Niagara Co. aimed for a two phase central station to furnish power for both the local and long distance markets of Buffalo and southern Ontario. Along with a Westinghouse team directed by Lewis B. Stillwell, firm engineers designed a two phase, external revolving field alternator to generate at 2,200 volts/5,000 hp and planned for a ten unit station (50,000 hp). They selected a 25 Herz frequency as a compromise in order to best serve light and power markets since any lower frequency caused flickering in incandescent lamps; in addition, rotary converters, needed to capture the dc motor (including traction) markets, operated well at this frequency. Phase converter transformer connections, which were invented by Charles Scott, allowed for the coupling of two and three phase circuits. The firm decided to transform the two phase generated power into three phase for a 22 mile, 11,000 volt (11 kV) transmission line to Buffalo. Beginning in August 1895, the Niagara system central station supplied all currents needed by lighting, traction and industrial motors, and the new (mainly single phase) electric furnace market. While Niagara engineers dramatically advanced central station technology, Niagara Line Superintendent Paul Lincoln observed that the Niagara - Buffalo line relied upon the existing state of the art of telegraph transmission line technology. The line opened in late 1896 and experienced serious insulation difficulties -- and the severe lightning storms characteristic of the region worsened this problem.[4] Nevertheless, the 'Niagara system' was regarded as a pioneering, exciting and successful invention.

The Niagara Co. viewed the first GS and HV line to Buffalo as the first step in its development of an international system, but Niagara engineers quickly recognized a simple and fundamental dilemma in this strategy. As a synchronous system, the Niagara system demanded voltage stability but the increase of both customers and long distance lines adversely effected voltage stability. Poor line insulators, short circuits in new distribution networks, and imbalances resulting from increasingly complex load (supply) management each caused voltage irregularity which asynchronized, or threw out of step, the whole system from substation cable to Niagara generator. The demand for system expansion was all too clear, especially from the electrochemical and electrometallurgical firms which were rushing to establish huge plants at Niagara Falls, NY in order to take advantage of the inexpensive power rates. But the Niagara Co. also took seriously its plan to capture and develop Buffalo and southern Ontario markets. The firm had secured, in 1892, an exclusive franchise for hydro development at Niagara Falls, Ontario, where power potential was seven times greater than at Niagara Falls, NY; in return, the company promised to develop a mere 10,000 hp at this site by 1898. In terms of existing Niagara technology, this figure signified either two generating units or a transmission line and distributing substation; the former option in fact implied a full GS context while the latter option involved serious insulation problems.

With plans for the eventual establishment of stations and lines on both sides of the Falls, the Niagara Co. envisioned the pleasant prospect of a virtual power monopoly in the international Niagara region. By 1898, the firm committed the full planned capacity of the first GS; by 1901, it was both building a duplicate GS and line project as well as completing design plans for the technological culmination of the Niagara system -- the subsidiary Canadian Niagara Power Co. at Niagara Falls, Ontario. During this period of expansion, Lewis Stillwell was Niagara Co. Electrical Director until 1900 when Harold Buck succeeded him. Both Stillwell and Buck conceived expansion in terms of the evolution of a single system or power pool, and both planned to interconnect the new plants with the old. Not surprisingly, Stillwell and Buck concentrated upon system problem solutions in their efforts to build incrementally an international, interconnected system at Niagara.

Immediately after 1896, Niagara engineers responded to exploding power demand by installing all ten units in GS 1 and by planning a duplicate project: a new, separate transmission line and a second GS at the Falls. The new line consisted of three 10,000 hp circuits and was built parallel to the original line: henceforth, the failure of one line could not sever power transmission to Buffalo. Stillwell and Paul Lincoln, the Line Superintendent, adopted a new insulator which offered greater mechanical strength by a more secure fixture of pin and insulator,[6] but the new insulators succeeded only marginally. Given the inverse relation between copper costs and transmission voltage, Stillwell doubled to 22 kV the line voltage. The higher voltage helped offset the costs of needing to build a separate line to help ensure service continuity. The Cataract Power and Conduit Co., the Niagara Co. subsidiary for power distribution in Buffalo, stepped down the power to 11 kV for underground distribution to seven substations. Stillwell described the overall load of the system:

> The local load varies between 14,200 kw. and 15,700 kw. This remarkable uniformity of output is explained by the fact that nearly all of the power used locally is delivered to manufacturing companies whose processes are continuous and whose use of power is practically constant. The long distance load varies from a minimum of 3,300 to a maximum of 15,600 kw. Of this maximum, probably 90% is used for railway and lighting purposes.[7]

When the lights blacked out and the trolleys stopped, the Buffalo public was aware of technical problems in the Niagara system.

The interconnection of the entire system from substation cables to Niagara generators made critical the need to protect the system from excessive voltage variation. As new distribution feeder cables were laid to new customers, accidental short circuits increased. Similarly, an increasing number of large customers at Niagara entailed increasingly complex load management: like short circuits, sudden substantial load changes resulted in voltage variations with their dangerous asynchronizing effects on the system. Although insulators remained inadequate, the overall problem was reduced by a successful attack on short circuits in distribution cables. Niagara and General Electric (GE) engineers devised an automatic time-limit relay circuit breaker which isolated short circuits to the feeder (cable) alone 'without opening the main transmission circuits at the Niagara end and so interrupting the entire long distance service.'[8] The breaker needed to function quickly because short circuits involved voltage drops which, if prolonged, would 'cause all of the synchronous apparatus to drop out of step.'[9] The new device worked within a three second period: the breaker isolated within a fraction of a second the troubled feeder, opened within one second the terminal line, and opened within three seconds the 22 kV transmission line. Then, the process reversed automatically for restart. The new invention thus allowed for an incremental shutdown and an automatic incremental restart within a matter of seconds.

The new GS was the setting for another system improvement. Whereas most utilities served numerous small power consumers, the Niagara Co. served a small number of large power consumers in the local market -- and, similarly, sold bloc power to its Buffalo subsidiary distributing station. Single phase electric furnaces posed especially serious voltage problems:

> Since it is impossible to control these furnaces, so that at all times the same number shall be in operation from each of the two phases, inequality of load on the phase results and the voltages are unbalanced. This unbalancing is disastrous to polyphase synchronous and induction motors on the system, for the high voltage phase tends to carry all the load, and windings on this phase are overloaded. These results can be rendered inappreciable only by the use of generators of close regulation.[10]

The new GS contained eleven generating units manufactured by GE -- the last five following an internal revolving field design[11] -- whose voltage regulation exceeded by a factor of three that of the original units. Otherwise, the new units bore the same electrical design standards as the first Niagara generator, i.e. 25 Hz frequency, 5,000 hp, two phase, 250 rpm, and 2,200/2,300 v. In order to ascertain closer regulation, Paul Lincoln invented a frequency indicator which measured a generator's speed independent of voltage.[12] Lincoln based the new meter upon his synchroscope which he had invented in 1895 to help synchronize the generators for the purpose of paralleling -- or power pooling. The third improvement of the 'GS 2 - line 2' project over the original Niagara system was a centralized switchboard which simplified the task of paralleling the units in both GS -- made possible by the common 25 Hz frequency. Two GS buildings supplied a single interconnected system.

Harold Buck, Niagara Electrical Director as of 1900, identified the automatic circuit breaker, closer generator regulation, and the new switchboard as the three major advances of this second project. Since these advances were directed towards system-wide problems and power management, the Niagara system was evolving on a system basis. Niagara Co. engineers, rather than the electrical manufacturers, were primarily responsible for designing and directing this evolution. While Westinghouse had equipped GS 1, GE equipped GS 2; in both cases, the apparatus was supplied according to design specifications issued by Niagara Co. engineers.[13] Admittedly, these specifications sometimes rested upon joint utility-manufacturer design and testing work -- as was the case with the circuit breaker. Overall, then, the Niagara system remained a firm-specific system. A certain momentum towards standardization had, however, set in. Interconnection necessitated some standardization of generation equipment and both major electrical manufacturers, Westinghouse and GE, had participated in Niagara Co. projects; consequently, each manufacturer could offer its own version of Niagara designs. Only the Niagara Co.'s exclusive franchise prevented the immediate formation of competing projects at the Falls. When the exclusive franchise collapsed in 1899 (to be discussed later), two separate groups planned their own projects at Niagara Falls, Ontario -- the Ontario Power Company based in Buffalo and the Electrical Development Company based in Toronto.

Worried by this competitive threat to its dream of a Niagara monopoly, the Niagara Co. quickly planned a third GS, the Canadian Niagara Power Co., which was the firm's fully owned subsidiary at Niagara Falls, Ontario. Electrical Director Harold Buck presided over the design of Canadian Niagara as the most advanced of the firm's projects, and intended to allot its power to both Toronto and to existing markets. Buck explained his design policies in a presentation to the American Institute of Electrical Engineers. Aside from a doubling in capacity, the hydraulic features of the earlier plants were retained. Buck adopted his engineers' recommendation to double unit capacity from 5,000 hp to 10,000 hp in order to cut in half construction costs per horsepower -- since either unit would occupy the same physical wheelpit space.[14] Niagara engineers retained the 250 rpm turbo-generator speed and internal revolving field design features but proceeded to design an advanced generator for Canadian Niagara: they issued to GE design specifications for a unit to generate at 12 kV/10,000 hp of three phase current. Buck explained that 'after a radius of about one mile is exceeded, it becomes cheaper to transform to 12,000 volts three phase and distribute at this voltage than to supply power directly at 2,200 volts.'[15]

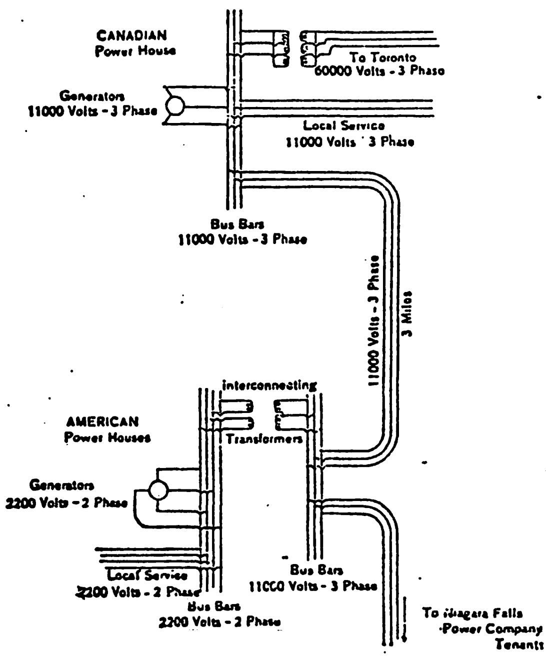
These design advances rested upon the continuing use of a 25 Hz frequency -- perhaps the heart of the evolving system. A uniform frequency, along with phase converters to couple the two phase and three phase units, allowed for interconnection into one system. Buck announced:

> The frequency will be retained at 25 cycles for the sake of uniformity with the American plants so as to permit of parallel operation. In selecting a unit of this large size, the American and Canadian systems were regarded as one.[16]

To ease interconnection, the engineers allotted one switchboard per five units[17] and thus simulated the capacity of GS 1 and GS 2 (50,000 hp); ten units were planned for Canadian Niagara (120,000 hp).[18] The company also advanced to 60 kV its high voltage insulation standard for the firm hoped to transmit economically to Toronto. The line insulators were designed to be constructed of 'electrose', a new material with greater resistance to a popular (somewhat dangerous) habit of using insulators for target practice. It was not until 1907, however, that Buck managed to introduce the truly effective Buck-Hewlett suspended insulator which revolutionized HV transmission.

Contrary to the arrangement shown in Buck's diagram (see Diagram #1), Canadian Niagara did not transmit to Toronto when the plant opened in 1906. Instead, the company sold some of its power at Niagara Falls, NY, and transmitted the bulk of it to Buffalo on a new 24 kV line -- although Canadian Niagara was insulated at 60 kV. The new line crossed the border at Fort Erie, Ontario, and interconnected with the earlier lines at the Buffalo terminal station. As Buck pointed out, this arrangement virtually guaranteed continuity of service since 'it is exceedingly improbable

Diagram #1



The Niagara Co. International System Interconnection[19]

that a storm would ever extend over a sufficient area to cause simultaneous interruptions on both the Canadian and American transmission systems.'[20] This contribution to system reliability resulted less from technological rationality than from the Niagara Co.'s effective loss of the Ontario market. Technologically, Canadian Niagara represented the advanced culmination of one system which had evolved, as we have seen, in an incremental, technologically rational manner. By the time that the enterprise realized its plan for a reliable, interconnected, international system, competing enterprises had undermined the firm's grip on Ontario markets. The Mackenzie Syndicate's success in securing a Niagara franchise was especially effective in aborting the Niagara Co.'s plan for a Toronto transmission. The Niagara enterprise therefore retreated to the rich and secure markets of Niagara Falls, NY and Buffalo.

INTER-COMPANY TECHNOLOGICAL DIFFUSION AND STANDARDIZATION

Upon its introduction in 1895-96, the Niagara system immediately ignited an unforeseen degree of enthusiasm in both Québec and Ontario due to the shortage of useful coal and abundance of water power in eastern Canada. Because the exclusive franchise precluded diffusion at the Falls, the Niagara system was adopted first in Québec; the Westinghouse Co. functioned as the central source of personnel and technology in the transfer of various aspects of the Niagara system to that province. There, the Royal Electric Co. of Montréal (1890) and the Shawinigan Water and Power Co. (1899) imitated the Niagara Co.'s technological designs and soon advanced HV technology in order to transmit over longer distances. Because these firms directly influenced hydroelectric development in the Niagara region of Ontario, we cannot neglect this unexpected route of transfer and diffusion. Specifically, the Cataract Power Co. was formed in 1896 to devise a hydro project on the Niagara escarpment for transmission to Hamilton; this firm turned for technical guidance and supply to Royal Electric. The Shawinigan Co. was incorporated in 1899 to undertake a transmission to Montréal -- over 90 miles distant; if that was possible, so was a transmission over the shorter distance between Niagara and Toronto. Once the Niagara Co.'s exclusive franchise ended, the Ontario Power Co. and the Electrical Development Co. formed to exploit the enormous potential of Niagara Falls, Ontario. Although Québec's experience was not lost upon them, both companies turned to the Niagara Co. as their model. Since the Niagara Co. had captured the Niagara Falls, NY market, Ontario Power and Electrical Development especially sought long distance markets in Ontario and upstate New York. Compared to the Niagara Co.'s relatively controlled transfer of its designs to its Canadian subsidiary project, the free and uncontrolled adoption of Niagara Co. designs by numerous companies was a disjointed and chaotic process ordered only by the movement of individuals and by approximate design standardization by electrical manufacturers.

The Royal Electric Co. of Montréal was a corporate descendant of the Thomson-Houston Co. of Canada (1883), and the firm remained technologically linked with American electrical manufacturers. Indeed, Royal Electric's chief electrician was Fred Thomson who was the brother of Elihu Thomson -- the co-founder of Thomson-Houston. In 1894, Royal Electric purchased the exclusive Canadian franchise for the manufacture of equipment designed by the Stanley Electrical Manufacturing Co. of Great Barrington, Ma.[21] -- a 'spin off' of William Stanley's early pioneering design work at Westinghouse. The Stanley, Kelley, Chesney system, popularly referred to as the 'SKC' line, was an alternating current (single phase) system which supplied arc lights, incandescent lights, and motors.[22] In 1895, Royal Electric appointed William H. Browne to the post of General Manager. Browne had helped Frank Sprague pioneer his electric traction system in Richmond, Va., until 1891 when Browne joined Westinghouse. Browne worked at Westinghouse when that firm concentrated its talents upon the Niagara project. At Royal Electric, Browne suggested and presided over that firm's adoption of the Niagara two phase universal system. The new switchboard indicated the new 'universal combination' plan, by means of which there is an interchangeability of circuits, dynamo and exciter connections'[23] -- that is, generator paralleling and centralized supply management. J.A. Kammerer, a Royal Electric engineer, proceeded to recommend to the Canadian Electrical Association[24] the two phase system as the best means of increasing the load factor -- the percentage of power sales over full capacity. Kammerer pointed out the universal market advantage of Royal Electric's new system and advised the selection of diverse customers whose power needs overlapped minimally during a 24 hour period as a means of increasing the load factor. Kammerer thus articulated what Samuel Insull later termed and developed as the 'diversity factor.'[25] Of course, the Niagara Co. had the highest load factor on the continent, largely due to tis electrochemical and electrometallurgical clients who needed large blocs of continuous (24 hour) power. Royal Electric needed to adapt the system to diversified urban markets.

As of 1897, Royal Electric began to diffuse its new system. In Québec, the firm engaged in projects at Trois-Rivières[26] and Chambly. The Chambly plant transmitted at 12 kV over 25 miles to Royal Electric's Montréal lighting station.[27] Royal Electric also agreed to supply the Cataract Power Co. in Hamilton -- to be discussed below. In 1901, Browne divested the company, selling its manufacturing business to Canadian GE and merging its Montréal plant with the Chambly Manufacturing Co. and the Montreal Gas Co. to form the Montreal Light, Heat, and Power Co. This consolidation, which formed 'the largest industrial organization in the Dominion,'[28] became one of the main clients of the Shawinigan Water and Power Co.

Incorporated in 1899, the Shawinigan Co. boldly imported the Niagara system to develop hydro power at Shawinigan Falls for local supply and for transmission to both Trois-Rivières and Montréal.[29] Chief Engineer Wallace C. Johnson had been employed at the Niagara Falls Hyraulic and Manufacturing Co. until the Niagara system made obsolete hydraulic power supply at Niagara. Johnson adopted the Niagara system for Shawinigan: the turbo-generator units imitated almost exactly the Niagara designs and were acquired from the same manufacturers, I.P. Morris and Westinghouse. The Shawinigan generator was external revolving field, two phase, 2,200 V, and 3,750 kw (5,000 hp) but it generated 30 Hz power. Shawinigan's 30 Hz power frequency was close enough to Niagara's 25 Hz frequency to indicate that it aimed at the same market spectrum as the Niagara project.[31] Indeed, Niagara and Shawinigan even shared the same first customer: the Northern Aluminum Co. was the Canadian subsidiary of the Pittsburgh Reduction Co. which had been the Niagara Co.'s first customer.[32] Shawinigan thus provided a striking example of just the sort of competition through technological imitation which the Niagara Co. feared at Niagara Falls, Ontario. But competition involved more than the Niagara location: by the time Canadian Niagara started power service in 1906, important aluminum and carbide customers had already contracted to locate their subsidiary plants at Shawinigan Falls.[33]

Shawinigan's long distance transmission involved a major advance in that the firm planned to transmit over 90 miles at 50 kV. Unfortunately, all that we know about this line design is that the engineer in charge was Ralph D. Mershon.[34] Mershon's involvement helps to explain the advance: he had participated with Charles F. Scott and V.G. Converse in the pioneering Telluride High Voltage experiments of 1894.[35] Mershon applied this advanced High Voltage design knowledge in Québec. The site of advanced HV work then returned to Niagara Falls, Ontario, where Canadian Niagara was first to plan 60 kV insulation (and Harold Buck introduced in 1907 the suspended insulator). Mershon and V.G. Converse soon reunited at Niagara in work on behalf of the Ontario Power Co.

The first Niagara-based hydro project in Ontario drew upon Québec's work to supply power to Hamilton, the most industrialized market in the Niagara region. The Cataract Power Co. was incorporated in 1896 by local businessmen for the hydro development of DeCew Falls, on the Niagara escarpment, in order to transmit power over a 32-mile distance to Hamilton. Although J.M. Gibson, Cataract President, also participated in the incorporation of Canadian Westinghouse (Hamilton, 1896),[36] the power company turned to Royal Electric for technical equipment and management: Cataract appointed H.R. Leyden of Royal Electric as Manager and J.A. Kammerer of Royal Electric as Electrical Adviser. They installed two phase-redesigned SKC equipment for the 22.5 kV transmission[37] to the Hamilton Electric Light and Power Co. Cataract soon centralized in one substation distribution service to Hamilton Electric Light, the Hamilton Street Railway Co., and the Hamilton Radial Railway Co. As at Niagara, this specific system of electric power sparked industrial growth: 'The growth of manufacturing establishments in Hamilton in late years has been due in large part to the adoption of electricity as a motive power ... today the factory not using electric motors is an exception,'[38] reported *Canadian Electrical News* in 1904. By then, Browne had divested Royal Electric and Hamilton turned to Westinghouse equipment supply for a full-scale conversion to the universal polyphase system.[39] Technological continuity with the Niagara model underlay this vivid example of desirable and clean urban growth. To sum up, the Niagara Co.'s lack of control over the transfer and diffusion of its designs to Québec resulted in the loss of the Hamilton market to a local enterprise and the loss of preferred customers to the imitative Shawinigan project. Clearly, the associated impact upon urban and economic organization is worthy of further, detailed investigation.

A similar process began in 1899 at Niagara Falls, Ontario. The Niagara Co. failed to develop by 1 November 1898 10,000 hp at Niagara Falls, Ontario, and therefore did not fulfill the condition of its exclusive franchise. That is not so surprising. During 1897, the firm was still completing GS 1, was beginning excavations for GS 2, and was trying to solve system problems. While the Ontario reaction will be noted later, its result was the renegotiated contract of August 1899 by which the Niagara Co. lost its exclusive rights. The technological centre of gravity then began to shift from Niagara Falls, NY to Niagara Falls, Ontario in terms of both the number of projects and the degree of technological advancement utilized. The Niagara Co. was first to plan a project for the Ontario site, and I have discussed the subsidiary Canadian Niagara plant. Two other companies, the Ontario Power Co. and the Electrical Development Co., soon planned to develop power at the Ontario site.

Financed from Buffalo, the Ontario Power Co. received in 1899 a franchise to divert water at Niagara Falls, Ontario, for the ultimate development of 180,000 hp -- the largest project at the international site. Ontario Power President P.L. Nunn had owned the Telluride Power Co. where he had presided over the early pioneering HV experiments of Charles F. Scott, V.G. Converse, and Ralph Mershon -- mentioned earlier. Nunn now appointed V.G. Converse to the post of Chief Electrical Engineer, and hired Mershon from Shawinigan as a transmission consultant. That these engineers chose to imitate largely the turbo-generator designs of Canadian Niagara indicated the respect held by the profession for the continuing pioneering status of the Niagara enterprise. Arranged horizontally, the 12,000 hp Francis turbines were direct connected to Westinghouse generators which delivered three phase, 25 Hz current at 12 kV and 187.5 rpm. Though slightly larger, Ontario Power generators thus borrowed essentially the Canadian Niagara electrical design. Ontario Power advanced switching by adopting a 'unit value' design in which each unit could be operated as an isolated power plant or paralleled in any combination with other units; later large stations tended to adopt this relatively safe unit switching plan.[40]

Ontario Power's first major customer was an HV transmission company formed to transmit Niagara power between Buffalo and Syracuse -- the Niagara, Lockport and Ontario Power Co. Niagara Lockport became, in 1904, a subsidiary of Ontario Power, with which it contracted for power supply.[41] Ralph Mershon designed a 154-mile trunk line between the border tie line and Syracuse to operate at 60 kV.[42] Ontario Power thus advanced beyond the Canadian Niagara model in terms of HV long distance transmission. Since Canadian Niagara had been insulated for 60 kV as well, the Ontario Power advance was more a marketing than a technological development. Deprived of the Niagara and Buffalo markets, Ontario Power extended over greater distances in search of regional markets.

The third firm to receive a franchise at Niagara Falls, Ontario was the Electrical Development Co. and its subsidiary HV transmission organization, the Toronto Niagara Power Co. Three powerful men in Toronto organized this enterprise in 1902; by then, the Shawinigan, Canadian Niagara, and Ontario Power projects provided sufficient precedents to limit the risk. William Mackenzie was President of the Toronto Street Railway Co., and, perhaps, the leading financier of traction in Canada. Frederic Nicholls was General Manager of Canadian General Electric. Lt. Col. Henry H.M. Pellatt was President of the Toronto Electric Light Co. Popularly known as the 'Mackenzie Syndicate', these three men controlled most electric utilities in Toronto -- that is, they owned the Toronto market for Niagara power. Not too surprisingly, Canadian Niagara tried to block the Syndicate's franchise application,[43] but the Syndicate managed to secure in January 1903 a franchise for an ultimate development of 125,000 hp. The Syndicate hired F.O. Blackwell as Chief Electrical Engineer and Hugh L. Cooper of New York City as Chief Hydraulic Engineer. Cooper, who was relatively unknown at this time but later became a world leader in hydro projects, introduced some novel hydraulic plans but the turbo-generators displayed very little novelty except for their size: these were the largest units at Niagara but by a factor of only 500 hp. Following Canadian Niagara's model, Electrical Development adopted the I.P. Morris Co. Francis turbines (12,500 hp) direct connected to GE internal revolving field, three phase, 25 Hz, 12 kV, 250 rpm generators. Indeed, these 12,500 hp generators followed Canadian Niagara designs to the extent that slides to illustrate them in public addresses were actually pictures of the Canadian Niagara unit: '"These machines will be very similar to the generators being built for the Canadian Niagara Power Co., and I am, therefore, showing a section of one of these."'[45] On the other hand, Electrical Development did risk the total centralization of switching;[46] that design was not, however, adopted by later plants who turned instead to the Ontario Power unit value plan. The Toronto transmission incorporated the three phase, 60 kV standards introduced by Canadian

Niagara and Ontario Power.[47]

Aside from differences in switching arrangements, the generating unit and related electrical equipment became standardized approximately for the three firms based at Niagara Falls, Ontario, and that standardization resulted in marketing competition. Niagara Co. engineers had developed internally their generator design and located their most advanced work in the subsidiary Canadian Niagara GS. Both Westinghouse and GE had manufactured Niagara Co. designs, and performed the standardizing role whereby these designs diffused to competitors. Firm-specific know-how thus became approximately standardized at Niagara Falls, Ontario. Competitors failed to shake the Niagara Co.'s hold on the local market -- despite a serious effort by the Mackenzie Syndicate.[48] Consequently, the Syndicate decided to supplement its Toronto market. In 1906, the Syndicate announced the formation of the Niagara Falls Electrical Transmission Co. which would compete with Niagara Lockport in the safe, established markets of upstate New York. Inter-company technological standardization had sparked the search for long distance markets which, in turn, fostered an interest in exporting power. Canadian Niagara, Ontario Power, and Electrical Development each declared by 1906 their intention of engaging significantly in the export of power from Niagara Falls, Ontario -- plans which upset development enthusiasts in Ontario.

NIAGARA TECHNOLOGY AND THE ORIGINS OF ONTARIO HYDRO

The introduction and evolution of Niagara Co. technology also ignited the formation of a public movement whose demands for public Niagara power resulted in 1906 in the establishment of a public enterprise, Ontario Hydro. This movement evolved from the articulation of a general development philosophy based upon hydroelectricity (and HV transmission) through a voluntary association stage to the final phase of formal political organization; the state of the art of Niagara-based technology played a leading role in each stage. Generally, contemporary development enthusiasts caught the public imagination by pointing to the long distance transmission of water power, or 'white coal,' as the golden key to Ontario's industrialization. H.V. Nelles, in his *Politics of Development*, has correctly placed this movement in the political context of contemporary development issues in Ontario -- but the technological context must also be considered. Indeed, the evolution and diffusion of Niagara Co. technology accounted for the timing and structure of Ontario Hydro's plans. Ontario Hydro found its niche in the advancing HV transmission front of this international technology.

Nelles has explained that Ontario entered in the 1890's a period of particular concern with resource development and primary manufacturing. The Canadian tradition of crown lands and public participation in development contrasted sharply with American traditions of private ownership and development. In 1898, a legal decision firmly placed under provincial jurisdiction provincial resource ownership. Ontario then tried to duplicate on a province-wide scope the national government's National Policy which had included the public development of a national railroad -- a powerful precedent for public power.[49] Indeed, popular enthusiasm for Niagara technology resembled the prior generation's fascination with the railroad.

In May of 1899, Thomas Keefer, one of Canada's best known railroad engineers, presented to the Royal Society of Canada the end-of-the-century Presidential address on the topic of 'Canadian Water Power and its Electrical Product in Relation to the Undeveloped Resources of the Dominion.'[50] Keefer pointed out that Canada possessed key resources which could be developed into primary manufacturing industries only with the transmission of cheap electric power, and mentioned specifically electrochemistry, electrometallurgy, and pulp and paper. Electric power transmission offered Canadians an alternative to the traditional export of raw resources. Keefer thus identified hydroelectricity (and its transmission) as Canada's most important undeveloped resource. Keefer was not alone. At about the same time, Prof. R.B. Owens, Chariman of McGill's Electrical Department, delivered a McGill University Lecture on the same theme.[51] Both men especially had in mind the Niagara precedent for the development of each province's rich water power resources. Their philosophy represented the enormous unforeseen impact which a new technology may have in a foreign environment. Not surprisingly, Niagara Falls, Ontario became the primary target of development enthusiasts who wished to use electric power to restructure fundamentally the economy, just as the Niagara Co. failed to recognize that these attitudes formed a condition of corporate success in the Ontario market -- as much as attitudes and legislation related to aesthetics had influenced its early work before 1895. Aesthetic concerns about the spoiliation of the Falls had resulted in legislation which created public parklands and therefore forced a Niagara enterprise to design a technological solution to the problem of siting a GS outside of the parklands. Now, development concerns raised questions about the timing of Niagara Co. plans -- and soon about private ownership of Niagara development enterprises.

During 1899, the Government of Ontario attacked the exclusive franchise of the Niagara Co. Pointing out the firm's failure to develop by 1 November 1898 10,000 hp at the Ontario site, a franchise condition, the Government asked the High Court of Justice to void at least the exclusive clause of the franchise. The Niagara Co. defended itself with two arguments: long distance transmission problems remained unsolved; and, the company had supplied the local existing demand of 1,000 hp. In January 1899, the High Court of Justice sustained the arguments of the power company! Even the conservative *Canadian Electrical News* expressed skepticism about this legal decision: an editorial pointed to both Niagara Falls, NY and Hamilton as cases in support of the argument that Niagara power supply created demand, and that the purpose of the franchise was not to supply existing demand but to create more demand.[52] The Ontario Government then negotiated an out-of-court settlement with the Niagara Co. and announced in August 1899 the new agreement. The Niagara Co. relinquished its exclusive rights in return for reduced rental rates and a long term franchise. Competition at Niagara Falls, Ontario was now possible and was expected to accelerate the planning and construction of Canadian plants.[53] Niagara engineers then turned to Canadian Niagara design plans and the Ontario Power Co. formed immediately to plan a competitive project.

Politicians, publishers, and even the conservative Toronto Board of Trade were calling by 1899 for a public Niagara development. Alderman F.S. Spence, a leader in the Toronto group, urged the Board of Trade to investigate seriously the public option.[54] As it became clearer that Niagara companies might not include regional transmission in southwestern Ontario as part of a Niagara-Toronto project, E.W.B. Snider of St. Jacobs and Daniel B. Detweiler of Berlin (now Kitchener) began to organize various municipalities which allied during 1902 with the Toronto movement. The Pennsylvania coal strikes of 1902 produced an energy crisis in Ontario which helped to catalyse these observers into a coherent voluntary association. Snider and Detweiler organized a meeting for 19 June 1902 in Berlin where Ald. F.S. Spence and Ontario Power Co. engineer Charles H. Mitchell addressed an audience of manufacturers and business men from Toronto and four municipalities (Berlin, Guelph, Preston, and Waterloo).[55] Warning against the perils of private monopoly -- like the Mackenzie Syndicate -- Spence proposed a government commission to transmit power to all interested municipalities. Charles Mitchell familiarized the audience with the latest state of the art of Niagara technology and outlined Ontario Power's ideas for long distance transmission,[56] a plan which suggested the technological feasibility of Spence's proposals. The meeting then formed a twenty-one-member investigatory committee headed by Snider and Detweiler 'to prepare a co-operation plan for the securing of a supply of electrical power for manufacturing interests on the most favorable terms possible'[57] and to present its findings at a convention scheduled for February 1903.

In January 1903, the Mackenzie Syndicate secured its Niagara development franchise. Alarmed by the prospect of a private monopoly in Toronto in the midst of an energy crisis, the Syndicate's Niagara plans immediately alienated the province's financial and manufacturing communities. The Canadian Manufacturers Association announced to Premier George Ross a lack of confidence in the pricing policies of private Niagara companies and formally threw its support behind the municipal movement. Gaining momentum, sixty-seven representatives of municipalities, boards of trade, and manufacturing associations attended on 17 February 1903 the Berlin Convention where the Snider and Detweiler committee urged legislation permitting collective municipal action 'to develop and transmit such power; or to buy power delivered.'[58] Pointing out the promise of abundant power supply at Niagara, Snider personally favoured the priority of transmission. The report won the support of Mayor Urquhart of Toronto, Mayor Adam Beck of London, many manufacturers, and most of the Ontario press.

Premier George Ross, who favoured private enterprise, could no longer ignore the political weight of the public Niagara power movement. He appointed the Ontario Power Commission to launch a three-year study of the Niagara situation. Chaired by Snider, the Commission included Adam Beck and Canadian Manufacturers Association President P.W. Ellis. The Commission employed Ross and Holgate, a consulting hydroelectric firm in Montréal, and Reginald Fessenden of Washington, DC as a special consultant; Fessenden, a Canadian, was a well-known electrical expert who specialized in communications. Ross and his Liberal Party lost the January 1905 provincial election to James Whitney's Conservative Party. Premier Whitney appointed Adam Beck to the Cabinet post of Minister without Portfolio -- the de-facto position being Minister of Power.[59] Assuming leadership of the movement, Beck established in July 1905 by Order-in-Council (Cabinet action not requiring Legislative approval) the separate Hydro-Electric Power Commission of Inquiry which he chaired. Beck pulled Cecil B. Smith from his post as Resident Engineer of the Canadian Niagara project and appointed him Chief Engineer for the new Commission.

The Ontario Power Commission published its report on 28 March 1906, and Beck's Commission published its findings one week later. Both reports referred to the 'supply push' development philosophy expressed by Keefer and others but offered different means to this end. Snider has asked Ross and Holgate to limit their investigation to seven municipalities which were 'pre-eminently manufacturing communities,'[60] and to estimate the costs of Niagara-based generation, transmission and distribution. Accordingly, Ross and Holgate designed a 60,000 hp project but also initiated a more cost-competitive option of extending the transmission to include eighteen localities whose combined needs amounted to 100,000 hp -- approximating the scale of a standard Niagara GS. Ross and Holgate thus shaped the project according to Niagara dynamics: Niagara project costs demanded a large production capacity which, in turn, demanded a large market.

Reginald Fessenden approved the Ross and Holgate report and focussed his own report on the relationship between a technological state of the art and the feasibility of a public project. Essentially, Fessenden argued that municipal cooperation was feasible *only if the technology was standardized* since obsolescence and public bankruptcy could result from technological advances. Accordingly, he compared the Ross and Holgate plans to the state of the art of Niagara technology:

> The engineering work proposed is of a comparatively simple character. The hydraulic and electrical apparatus has been standardized. The character of the rock to be excavated for the tunnels and wheelpits is known and advantage can be taken of the experience obtained in constructing similar works in the neighborhood... The transmission lines are also of a type which is now standard, and there is nothing experimental about any part of the engineering work.[61]

Fessenden predicted that there would be no new important advances in the state of the art and that, therefore, the Commission faced low risks of obsolescence. This principle articulated by Fessenden also formed a cornerstone idea of the report by Beck's Commission.

Beck's report consisted essentially of the Chief Engineer's report prefaced and summarized by the Commissioners. Chief Engineer Cecil B. Smith was personally familiar with the state of the art of the pioneering Canadian Niagara project. Detailing cost estimates based on the Canadian Niagara and Electrical Development plants,[62] and pointing out that no truly viable plant sites remained at the Falls, Smith recommended that the Hydro Commission avoid the high costs of Niagara GS construction and equipment by purchasing power from existing plants. Allotting that saving to transmission costs, Smith devised a 'transmission formula' based upon standard Niagara technology (25 Hz current at 60 kV transmission) and upon 'knowledge of recent sales of large blocs of power at Niagara'[63] (proprietary sales information). Smith conceived of this transmission cooperative as similar to an electrochemical customer of 24 hour bloc power: since such customers most improved load factor, the power company favoured them with the lowest power rates. Based on these conditions and estimates, Smith calculated that Niagara power could compete with local energy sources (notably steam-electric sources) in thirty-nine municipalities.

Smith termed this territory as the 'Niagara District'; using the same methods, he identified four other Districts and reported on them within a year. Absorbing fully the Keefer philosophy, Smith included in each report the developmental impact of hydro in each District. Within a few weeks of Beck's Niagara District report, the Legislature established the Hydro-Electric Power Commission of Ontario (popularly termed Ontario Hydro) as a quasi-autonomous organization with authority to regulate and develop water power in the province. Ontario Hydro was established as both a Niagara-based transmission organization and a provincial development and regulation agency. Niagara technology thus merged with indigenous traditions and values, and resulted in a uniquely Canadian institution. Opting to form his own private consulting firm, Smith recommended that Hydro hire as permanent Chief Engineer an expert in HV transmission technology. Hydro was, after all, just one more enterprise in the advancing front of Niagara-based HV technology -- like Niagara Lockport or Toronto Niagara. To sum up, both the technological feasibility of the public power movement and Hydro's detailed strategies were structured by the technological state of the art based at Niagara -- including *both* the evolution of Niagara Co. designs and their transfer and diffusion to competing, private firms. Smith's detailed project plans rested entirely upon Niagara standards.

Two events thoroughly shocked every enterprise based at Niagara. During 1903, the American Civic Association and the Governor-General of Canada rekindled the old concern with Niagara aesthetics by expressing alarm about the aesthetic impact of the new projects. They issued a joint resolution which urged 'immediate measures for the preservation of the cataract.'[64] President Theodore Roosevelt ordered investigatory reports and recommendations. On 29 June 1906, President Roosevelt signed into law the Burton Act which placed limits upon Niagara water diversions and power export from Niagara Falls, Ontario. The measure was a temporary expedient supported by the Canadian Government; after negotiations, the Boundary Waters Treaty adopted the Burton Acts provisions as international law. For our present purposes, the gap between export plans and limits is relevant (see Table #1). Of course, the Ontario Power and Electrical Development subsidiary transmission organizations had planned larger import supplies over the longer term. U.S. Secretary of War William H. Taft, empowered to enforce the measures, refused to adjust these export limits. Consequently, the strategies of all three projects were ruptured seriously. Competition for Ontario markets inevitably became cut-throat -- especially between the Mackenzie Syndicate and Ontario Hydro.

Table #1

Plant (GS)	Export Limit	Import Applicant	Import Request
Canadian Niagara	52,000 hp	Niagara Falls Power Co.	121,000 hp
Ontario Power	60,000 hp	Niagara, Lockport and Ontario Power Co.	90,000 hp
Electrical Development	46,000 hp	Niagara Falls Electrical Transmission Co.	62,500 hp

Export Limits, 1906[65]

The second event compounded the confusion. After years of design efforts, Harold Buck co-introduced in 1907 a suspended insulator which promised safe HV transmission insulation far beyond the existing 60 kV standard at Niagara.[66] Given the competition and the Burton Act, the new design was useless to the Niagara Co. Only Ontario Hydro had not yet begun to construct transmission lines. On the other hand, Hydro's adoption of the new insulator would make obsolete all of Smith's designs, surveys, and cost estimates based on 60 kV! A higher voltage transmission would, however, yield cheaper rates and thus help Hydro to compete with the Mackenzie Syndicate for Toronto markets. In order to opt for the new insulator, Hydro would need to ignore Fessenden's warning against public involvement in advanced, non-standard technology. Adopting the new insulator meant insulator tests, experimental transforming and protective electrical equipment, experimental transmission tower designs, and new surveys if the suspended insulator was to be used properly in an HV line far beyond the Niagara 60 kV standard. Ontario Hydro scrapped Smith's plans and decided to pioneer.[67] Once again, a new technological design based upon years of work by Harold Buck and others at the Niagara Co. would spark considerable turbulence.

CONCLUSION

If the Niagara Co.'s design work sparked within ten years an energy revolution in Ontario (and Québec), how did this occur? The Niagara Co.'s efforts to improve and expand on a system basis resulted in its loss of potential customers to those power companies in Québec and Hamilton which adopted the Niagara Co. model as well as its loss of an exclusive development franchise at Niagara Falls, Ontario. Quickly, the firm then transferred its most evolved designs to its Canadian Niagara interconnected subsidiary and thus accomplished the form of its technological dream. But when the Ontario Power Co. and the Electrical Development Co. largely imitated the Canadian Niagara designs, these competing enterprises acknowledged the Niagara Co.'s grip on the local markets and implemented high voltage transmission plans to compete for distant markets. Inevitably, the Niagara Co. lost the Toronto market to Electrical Development whose owners, the Mackenzie Syndicate, also controlled Toronto's utilities. Finally, the Niagara Co. had sparked a movement for public power in Ontario and lost to that group its Residence Engineer of Canadian Niagara: Cecil B. Smith became Chief Engineer of Ontario Hydro. Clearly, the Niagara Co.'s technological design accomplishments constituted the central force in each of these stages of technology transfer and diffusion.

I have argued that the Niagara Co. approached with impressive technological rationality its internal design evolution but that the firm's (perhaps inevitable) failure to synchronize this design evolution with private and public demands in the host environment of Ontario resulted in the collapse of its international Niagara monopoly dream. The firm's system design rationality contrasted sharply with the relatively chaotic or turbulent stages of transfer and diffusion marked by the Niagara Co.'s progressive loss of control over its technology. Between the franchise renegotiation of 1899 and the Burton Act of 1906, the 'free market' period, the flurry of activity was more technologically imitative than creative: both the private and public enterprises evolved according to the dynamics of Niagara Co. designs. Indeed, Cecil B. Smith's plans for Ontario Hydro followed from his 'transmission formula' which rested entirely on the basis of Niagara Co. design standards and their diffusion at the Falls.

Yet Ontario Hydro was more than a public Niagara development agency. As a regulation agency, Hydro could ensure some order in hydroelectric development in the host environment of Ontario. The Burton Act of 1906 simultaneously imposed international order by appointing diversion and export (or trade) ceilings. The extent to which this international legislation ignored -- indeed undermined -- the strategies of Niagara-based private enterprises is truly astonishing! By reducing hydroelectric exports from Ontario, the Burton Act, perhaps unintentionally, presented to Ontario a comparative advantage in subsequent Niagara-based developments. Consequently, this international regulation only strengthened the effective authority of Ontario Hydro. After 1906, Niagara-based hydroelectric evolution would proceed in this politically-structured context. Is it surprising that, as of 1907, Ontario Hydro took up the torch of technological design creativity?

NOTES

This article draws from Chapters II and III of my dissertation, 'The Niagara Frontier: The Evolution of Electric Power Systems in New York and Ontario, 1880-1935' (University of Pennsylvania, 1981). The dissertation was based archivally upon the Niagara Archives in the George Arents Research Library at Syracuse University, documents files in the Niagara Mohawk Power Corporation History Office in Syracuse, and Ontario Hydro archives in Toronto. Unfortunately, company records related to this critical period of technology transfer appear to have been lost or destroyed (especially in the post World War II era, the systematic destruction of such technology transfer records is apparently the norm, not the exception). I therefore drew heavily upon technical articles in engineering journals for this turn-of-the-century period: the *Canadian Electrical News* (*CEN*) and the *Transactions of the American Institute of Electrical Engineers* (*Trans AIEE*). *CEN*, the Canadian equivalent of *Electrical World*, is an excellent source of historical information although it tends to lack biographical data. At present, standard biographical dictionaries rarely include sketches of electrical engineers which leaves electrical historians with no simple means of collecting such information. One would like to know, for instance, where J.A. Kammerer received his training and experience before his work at Royal Electric. Certainly, one cannot write the full history of the evolution, transfer and diffusion of any technological system without biographical or professional sketches of the engineers involved.

1. Harold Buck, 'The Electrical Plant of the Canadian Niagara Power Company,' An address to the Canadian Electrical Association published in *CEN* (August 1906), 226.

2. The earlier histories of the Niagara Falls Power Co. are: Edward Dean Adams, *Niagara Power*, 2 vols. (Privately published by the Niagara Falls Power Co., 1927); Harold Passer's section on Niagara in *The Electrical Manufacturers, 1875-1900* (Cambridge, 1953), 282-95; Harold Sharlin, 'Electrical Generation and Transmission' in Melvin Kranzberg and Carroll Pursell, eds., *Technology in Western Civilization*, vol. 1 (New York, 1967), 578-92; John G. Benack, *The Niagara Mohawk Story (1823-1973)* (Niagara Mohawk History Office, unpublished, 1974). The major histories written by non-Hydro individuals who were not involved in an active debate are: W.R. Plewman, *Adam Beck and the Ontario Hydro* (Toronto, 1960); H.V. Nelles, *The Politics of Development: Forests, Mines and Hydro-electric Power*

in Ontario, 1849-1941 (Toronto, 1974); and Nelles' article, 'Public Ownership of Electrical Utilities in Manitoba and Ontario,' *Canadian Historical Review*, 57 (December 1976), 461-84. None of these histories of the Niagara Co. and Ontario Hydro relate their topic to technological developments on the other side of Niagara Falls.

3. Robert Belfield, 'The Niagara System: The evolution of an Electric Power Complex at Niagara Falls, 1883-1896,' *Proceedings I.E.E.E.*, 64 (September 1976), 1344-50. This early article is modified and elaborated in Chapter I of the author's dissertation. Two complementary studies are: Carroll David Kepner, 'Niagara's Water Power: Hydro-Mechanical Power at Niagara Falls, New York, 1758-1925,' (M.A. Thesis, Bowling Green State University, 1967); and, Martha Moore Trescott, 'The Rise of the American Electrochemical Industry: Studies in the American Technological Environment,' (Ph.D. Dissertation, Southern Methodist University, 1980). Kepner shows statistically that, at Niagara, 'The success of electric power ... signaled the astoundingly swift demise of hydromechanical power development', (138). Trescott argues rightly that the successes of the Niagara Co. and electrochemical firms at the New York site were 'symbiotic'. Yet the success of competing firms based at Niagara Falls, Ontario suggest that the Niagara Co. would have succeeded in an international regional market even without the electrochemical market. Indeed, the power company's efforts to supply the local electrochemical market were one major reason why it lost its exclusive franchise at Niagara Falls, Ontario -- and hence lost its international monopoly.

4. Lincoln stated, 'In the construction of the Niagara-Buffalo transmission line, such precedents as then existed were followed. These precedents in turn had followed the practise of telegraph construction -- the only precedent there was to follow in that day.' Adams, *Niagara Power*, II, 277.

5. Lewis B. Stillwell directed the Westinghouse lab's involvement in the Niagara project until 1896 when he became Niagara Co. Electrical Director. Harold Buck succeeded him in 1900 and remained until 1907. Part of Buck's work consisted of his efforts to design and test an insulator appropriate for the Niagara transmission lines and, in 1907, he introduced the Buck-Hewlett suspended insulator which revolutionized electric power transmission. See Adams, II, 281, 283. That both Stillwell and Buck (and Lincoln) were later elected President of the American Institute of Electrical Engineers (Stillwell: 1909-10; Lincoln: 1914-15; Buck: 1916-17) testifies to the perceived significance of their work.

6. Lewis B. Stillwell, 'The Electric Transmission of Power from Niagara Falls,' *Trans AIEE* (1901), 518.

7. *Ibid.*, 522.

8. Harold W. Buck, 'The Buffalo High-Tension Cable Distribution System,' *Trans AIEE* (1901), 837.

9. Harold W. Buck, 'The New Generating Plants of the Niagara Falls Power Company,' *Trans AIEE* (1902), 776. Such articles were, of course, abstracted in *CEN*. Indeed, such engineers as Buck, Paul Lincoln, and Charles Scott were involved actively in the Canadian Electrical Association.

10. *Ibid.*, 768. That many electrical furnaces operated on single phase rather than direct current again illuminates the universal market at Niagara.

11. *Ibid.*, 769ff. The company's return to C.E.L. Brown's original internal revolving field design (Lauffen dynamo, 1891) involved dropping the nickel steel ring which Westinghouse claimed as one of its major contributions to the original Niagara generator design. General Electric worked on the internal revolving field design in the second half of the 1890's, and C.E.L. Brown consulted with GE on this work. Regarding Brown's crucial contributions during the pre-1895 period, see Belfield, 'The Niagara System.'

12. Paul Lincoln, 'Synchronous and Frequency Indication,' *Trans AIEE* (1901), 270. Lincoln's method consisted of measuring over a 24-hour period unit speed which related to both voltage and frequency. Frequency equals speed multiplied by ½ the number of poles. Of course, Lincoln's work assisted in the interconnection of GS 1 and GS 2: synchronism demands uniform speed.

13. S. Dana Greene, 'The Relations Between the Customer, Consulting Engineer and the Electrical Manufacturer,' *CEN* (February 1898), 32-3. Greene pointed to the poor economic conditions of the decade as one major reason why electrical manufacturers attempted to introduce standardized equipment. Manufacture according to design specifications issued by the customer was still the rule, not the exception. Although the Niagara Co. relied upon internal design evolution, the equipment needs of the competing enterprises which soon appeared at Niagara Falls, Ontario provided the electrical manufacturers with an opportunity for some standardization.

14. Buck, 'New Generating Plants,' 779. Here again, the manufacturer (GE) did not originate the increase in capacity or voltage design. Buck stated: 'This size of unit was suggested by the engineers of the Niagara

Falls Power Company and was adopted upon their recommendation.'

15. *Ibid.*, 780.

16. *Ibid.*, 778.

17. Buck, *CEN* (1906), 222f.

18. The size of Canadian Niagara's units varied over time from 10,250 hp to 12,750 hp; and, the last five units were supplied by Canadian Westinghouse. See Adams, *Niagara Power*, II, 442-3.

19. Diagram from Buck, *CEN* (1906), 226. By the time Buck presented this address to the Canadian audience, however, he and the Niagara Co. knew that the Toronto market was lost to competitors. This diagram was also used in Buck's 1902 paper.

20. 'The Hydro-Electric Plant of the Canadian Niagara Power Company,' *Ibid.* (September 1907), 296. Detailed information on the electrical featrues of this and the competing plants is also available in *The Niagara Falls Electrical Handbook* (*Trans AIEE* publication, 1904).

21. 'Editorial,' *CEN* (December 1894), 101.

22. 'The Royal Electric Company,' *Ibid.* (March 1897), 43f.

23. P.G. Gossler, 'Reconstruction of the Alternating Current System of the Royal Electric Company,' *Ibid.* (April 1897), 62.

24. J.A. Kammerer, 'Day Loads of Central Stations and How to Increase Them,' *Ibid.* (June 1897), 124-5. See also the article by J.R. Robertson who was also a Royal Electric engineer, 'The Influence of the Load Factor on the Design and Operation of a Lighting and Power System,' *Ibid.* (July 1901), 136-42. Unfortunately, the author could locate no background information on Kammerer. A separate historical project on Kammerer and Royal Electric's contributions seems worthwhile.

25. Samuel Insull has often been given credit for devising these principles at Commonwealth Edison of Chicago. See, Samuel Insull, *Central Station Electric Service: Addresses of Samuel Insull*, ed. William Keily (Chicago, 1915); Samuel Insull, *Public Utilities in Modern Life: Selected Speeches, 1914-1923*, ed. William Keily (Chicago, 1962); and, Thomas Parke Hughes, 'The Electrification of America: The System Builders,' *Technology & Culture*, 20 (January 1979), 124-61. Yet Kammerer and Royal Electric were practicing the load factor and diversity factor ideas as of 1897. Furthermore, the

article 'The Montreal Light, Heat and Power Company,' *CEN* (June 1905), 108-12 indicates (112) that this firm's load factor on 26 April 1903 was 81% which indicates that Kammerer's ideas were applied successfully. It is probably the case that such practice was common before Insull articulated and elaborated these ideas. Insull's experiences and successes should especially be compared with those based at Niagara Falls, Ontario in terms of both the Parsons steam burtine versus Niagara generators and the two rural electrification programs.

26. H.R. Leyden, 'Electrical Power Transmission Plant at Three Rivers, Quebec,' *Ibid.* (October 1897), 189-94.

27. 'The Chambly Electrical Power Transmission Plant,' *Ibid.* (December 1897), 229-31.

28. 'Mr. Wm. H. Browne,' *Ibid.* (February 1902), 20.

29. The authoritative study on the history of the Shawinigan enterprise is John H. Dales, *Hydroelectricity and Industrial Development in Quebec, 1898-1940* (Cambridge, Mass., 1957). Dales' work is extremely good as an economic approach to the topic. He does not, however, deal with the role of technology. Nevertheless, Dales' survey chapter on Central Station development is among the best in print; this chapter is probably relatively unknown to American historians due to Dales' specialized interest in Shawinigan Falls.

30. 'Proposed Water Power Development at Shawinigan Falls,' *CEN* (March 1899), 47-8. See also the Kepner thesis on the Niagara Falls Hydraulic and Manufacturing Company.

31. 'The Shawinigan Transmission Line,' *CEN* (January 1903), 9; and, 'The Transmission Line and Terminal Station of the Shawinigan Water and Power Company,' *Ibid.* (April 1903), 49-51.

32. 'Shawinigan Water Power Development,' *Ibid.* (December 1901), 215-16.

33. 'The Shawinigan Water and Power Company,' *Ibid.* (June 1905, 114.

34. 'The Shawinigan Transmission Plant,' *Ibid.* (February 1903), 29. Ralph D. Mershon deserves a separate study based upon the 200 boxes of his papers located in the Mershon Room at Ohio State University.

35. Thomas Parke Hughes, 'The Science-Technology Interaction: The Case of High-Voltage Power Transmission Systems,' *Technology & Culture*, 17 (October 1976), 648f.

36. 'Electrical Power Transmission to Hamilton,' *CEN*

(August 1896), 161; and, 'The Canadian Westinghouse Company,' *CEN* (November 1896), 221. For a good survey of electrification in Hamilton, see Ian Vincent, 'Hamilton: The Electric City of Canada,' (M.A. Thesis, University of Toronto, 1974).

37. Different articles in *CEN* cite different electrical specifications concerning the transmission voltage from DeCew Falls and the length of the line. The range cited is 22.5 kV to 24 kV, and 32 miles to 40 miles. I adopt the lower limit of this range.

38. 'The Electrical Features of Hamilton,' *Ibid.* (June 1904), 111.

39. 'The Hamilton Cataract Power, Light & Traction Company,' *Ibid.* (June 1904), 113. See also, 'New Equipment for the Cataract Power Company,' *Ibid.* (August 1903), 175.

40. *The Niagara Falls Electrical Handbook* provides detailed information on each of the three projects based at Niagara Falls, Ontario. This information on the Ontario Power Co. is also drawn from: P.L. Nunn, 'The Development of the Ontario Power Company,' *CEN* (June 1906), 141-8; and, 'Niagara Power in South-Western Ontario,' *Ibid.* (November 1910), special issue.

41. 'The Ontario Power Company of Niagara Falls and Associated Companies' Pamphlet, 1913. Niagara Mohawk History Office. On Niagara Lockport, see also, John G. Benack, *The Niagara Mohawk Story (1823-1973)* (Niagara Mohawk, unpublished), 105ff. Niagara Mohawk History Office.

42. John G. Parker, 'Niagara Power at the Lackawanna Steel Plant,' *CEN* (August 1907), 226. The full statement reads, 'The 60,000 volt transmission line supplying the plant is a part of the system of the Niagara, Lockport & Ontario Power Company, designed under the engineering direction of Mr. R.D. Mershon.'

43. 'The Toronto-Niagara Power Company, *Ibid.* (February 1903), 29.

44. 'Electrical Power Development at Niagara Falls,' *Ibid.* (February 1904), 25. I could locate no biographical sketch of Blackwell. That no full length biography of Hugh Cooper has appeared is remarkable but, for a survey of Cooper's contributions, see Harold Dorn, 'Hugh Lincoln Cooper and the First Detente,' *Technology & Culture*, 20 (April 1979), 322-47.

45. K.L. Aitken, 'The Toronto and Niagara Power Development,' *CEN* (August 1904), 167. See also, Frederic Nicholls, 'Niagara Power: Past, Present, Prospective, An Address to the Empire Club,' *Ibid.*(February 1905),

22-4. On the Empire Club, see Carl Berger, *The Sense of Power: Studies in the Ideas of Canadian Imperialism, 1867-1914* (Toronto, 1970). Numerous articles in *CEN* indicate that the Mackenzie Syndicate was active in the international transfer of electric traction technology -- though not to the Empire.

46. 'The Electrical Development Company of Ontario,' *CEN* (June 1906), 135.

47. 'Toronto Terminal Station of the Toronto & Niagara Power Company,' *Ibid.* (June 1906), 136-40. It is not clear why Toronto Niagara converted the current to 60 Hz at the Niagara station rather than at the Toronto station (137) -- the coupling device being motor generators.

48. Aitken, 'Toronto and Niagara Power Development,' 168.

49. H.V. Nelles, *The Politics of Development: Forests, Mines and Hydro-electric Power in Ontario, 1849-1941* (Toronto, 1974), see especially Chapters VI and VII, notably 215ff. See also Nelles' article with Christopher Armstrong, 'Private Property in Peril: Ontario Businessmen and the Federal System, 1898-1911,' in Glenn Porter and Robert Cuff, eds., *Enterprise and National Development* (Toronto, 1973), 20-38. See also Nelles' interesting comparative provincial histories in 'Public Ownership of Electrical Utilities in Manitoba and Ontario,' *Canadian Historical Review*, 57 (December 1976), 461-84.

50. Thomas C. Keefer, 'Canadian Water Power and Its Electrical Product in Relation to the Undeveloped Resources of the Dominion -- Presidential Address to the Royal Society of Canada,' *Transactions of the Royal Society of Canada*, 2 (1899), 1-11. A summary appeared in *CEN* (August 1899), 183-4. An edited version is available in Bruce Sinclair, N.R. Ball, and J.O. Petersen, eds., *Let Us Be Honest and Modest: Technology and Society in Canadian History* (Toronto, 1974), 213-15.

51. R.B. Owens, 'Electricity as a Factor in Modern Development,' *CEN* (March 1899), 50-52. Prof. Owens considered the option of using all of Niagara's water power; though his comment below may sound somewhat odd, it was part of the ongoing natural versus technological aesthetics debate which centred upon Niagara: 'should the whole be utilized, leaving the rocky river bed dry and bare, we should but be substituting a wonderful cataract of etheric energy for the splendid flow of gravitational matter so justly famed. Which spectacle would present greater beauty would depend upon the individual.' (51). The McGill Electrical Department, which Owens chaired, was the most advanced electrical school in Canada at

this time. It is worth noting that *CEN* is an excellent source of detailed information on the establishment and development of electrical engineering education at McGill and at the School of Practical Science in the University of Toronto. Such training is, of course, a form of import substitution for technological skills developed abroad. Ontario Hydro soon drew many of its engineers from the School of Practical Science.

52. 'The Niagara Falls Power Franchise,' *Ibid.* (January 1899), 11. See also,' Niagara Power,' *Ibid.* (February 1899), 29.

53. 'Niagara Falls Power Development,' *Ibid.* (August 1899), 173.

54. 'Electric Power for Toronto,' *Ibid.* (September 1903), 183f. Alex Dow, of Detroit Edison, was a consultant in this investigation and advised that a project for transmission to Toronto was feasible. Why the investigators chose to consult Alex Dow is not clear: Dow was not an expert in this field. Detroit Edison was adopting a 'beltway' lineeplan for Detroit service but the plan was not very advanced compared to other power projects. In 1902, however, an engineer from the Ontario Power Co. addressed the formative organization meeting of the municipal movement.

55. Nelles is a good source for a more detailed account of the political origins of Ontario Hydro. See also: W.R. Plewman, *Adam Beck and the Ontario Hydro* (Toronto, 1947), and Merrill Denison, *The People's Power: The History of Ontario Hydro* (Toronto, 1960). All three works have in common a strong focus upon Adam Beck and an equally strong neglect of the projects at both Niagara Falls, NY and Niagara Falls, Ontario.

56. Minutes of Meeting at Berlin, dated 9 June 1902. Beck Papers, Detweiler Collection, Ontario Hydro Archives.

57. *Ibid.*

58. Report dated 17 February 1903. Beck Papers, Detweiler Collection, Ontario Hydro Archives.

59. Denison, *People's Power*, 46.

60. *Official Report of the Ontario Power Commission*, dated 28 March 1906, 16. Ontario Hydro Archives.

61. *Ibid.*, Special Report by Reginald Fessenden, 47.

62. Hydro-Electric Power Commission of the Province of Ontario, *First Report: The Niagara District* (Engineering Report), 14. Ontario Hydro Archives. The first

report consisted of 12 pages of Commissioners' comments and 39 pages of the Engineering Report by Cecil B. Smith. In fact, the first 12 pages functioned to summarize and highlight the Engineering Report.

63. 'First Report of the Hydro-Electric Power Commission,' *CEN* (May 1906), 98. It is worth noting that *CEN* provided exhaustive and detailed coverage of these reports and subsequent Hydro activities.

64. Letter, Attorney General William H. Moody to President Theodore Roosevelt, 14 October 1905. Reprinted in *The Niagara Falls Power Company: Hydraulic Rights and Federal Restrictions*, 95-7. Niagara Mohawk History Office. This invaluable volume, compiled for legal purposes, reproduces all documents (letters, reports, legislation) which were relevant to the company's rights, *ca.* 1878-*ca.* 1930.

65. This information was compiled by the author from two sources: 'An Act for the control and regulation of the waters of the Niagara River, for the preservation of Niagara Falls, and for other purposes,' (Burton Act), 59th Congress, session 1, Chap. 3621, 34 Stat., L 626; Approved 29 June 1906. Reprinted in *Federal Restrictions*, 129-32; and, 'Memorandum by Secretary of War William H. Taft,' 14 July 1906, reprinted in *Federal Restrictions*, 152-60, especially 157. The impact of this international intervention upon the technological development and strategy of each Niagara-based enterprise is discussed in other chapters of the author's dissertation.

66. E.M. Hewlett, 'A New Type of Insulator for High-Tension Transmission Lines,' (1259-62), and Harold Buck, 'Some New Methods in High-Tension Line Construction,' (1263-9) in *Trans AIEE*, 26 (1907).

67. Ontario Hydro's decision to adopt the Buck-Hewlett suspended insulator, and the remarkably far reaching consequences of that decision, are discussed in detail in Chapter IV of my dissertation. The point here is simply to complete the account of pioneering design work based upon Niagara Co. efforts and to underline again the technological linkage between Hydro and Niagara Co.-based designs.