ELECTROCHEMISTRY IN CANADA: STATUS AND OPPORTUNITIES*

Report of

Committee 13: Electrochemistry

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FOREWORD

The material selected for this report is intended to represent several aspects thought to be important to the objectives of the Survey commissioned by the Science Council of Canada. The extent and the rate of growth of the Canadian electrochemical industry were examined, and an attempt was made to recognize opportunities and relevant topics needing careful thought in any projection of the future of the industry. The depth of the technological base upon which the industry rests was studied, from the points of view not only of physical equipment but also of supply and demand of suitably educated personnel. Topics generally encompassed under the term "new vistas in electrochemistry" were also considered, culled and stated. Throughout the analysis an attempt has been made to arrive at specific recommendations -- recommendations which if substantially based should be equally sound to scientific or engineering people, at the management level, whether they be in industry, in government, in university, or elsewhere -- in other words, recommendations which can enjoy a large measure of support simply because they are based on factual information and well founded projection.

Three main sections -- on Electrolytic Processing, on Electrochemical Energy Storage, and on Electrofinishing -- are followed by statements on Electrothermics, Corrosion, Semiconductor Electrochemistry and Biological Electrochemistry. The final section, intended to be speculative, is on New or Developing Segments of Electrochemistry.

The report concludes with some general conclusions, which indicate, amongst other things, that this report represents a "best effort in the time allotted" by interested individuals working on their own initiative, generally without the comfort of reassignment of time from normal duties.

Dr. W.C. Cooper, Noranda Research Center, nominated by the Ontario-Quebec Section of the Electrochemical Society upon invitation, was able to act as Associate Chairman of Committee 13. Part 1: Electrolytic Processing was due in large part to the careful analysis made by Mr. R. Ellison, Cominco. Part II: Batteries, Capacitors and Fuel Cells was prepared after interviews with and analyses by Mr. K.R. Brands, Mallory Batteries of Canada Ltd., Mr. D.G. Bates, Electric Storage Battery Company, and Dr. P.L. Bourgault, Johnson Matthey and Mallory Ltd. Part III: Electrofinishing was prepared in conjunction with Mr. K.G. Wells, W.W. Wells and Company, and was reviewed by Dr. R.R. Rogers, Dept. of Energy Mines and Resources.

Electrothermics was not studied by Committee 13, but was logically reassigned to Committee 14 on High Temperature Reactions,

by the Chairman of the Study. The section on Corrosion was prepared by the Toronto Section of National Association of Corrosion Engineers, particularly by Mr. J.D. Palmer, Ontario Research Foundation. The section on Semiconductor Electrochemistry was prepared jointly with Mr. R.F. Ferguson, Northern Electric Laboratories. Biological Electrochemistry is discussed from the point of view of biophysics, by the Committee Chairman.

New and Developing Segments reflects contributions by Mr. R. Ellison, and by Dr. I.H.S. Henderson, Defence Research Board, and Dr. B.E. Conway, U. Ottawa.

Inputs by Drs. R.N. O'Brien, U. Victoria, K.R. Johnson, U. Saskatchewan, R.G. Barradas, U. Toronto, M.J.B. Hotz, Dept. of Energy Mines and Resources, A. Hone, L'Ecole Polytechnique de Montréal, L.S. Renzoni, International Nickel Co., B. Cox, Atomic Energy of Canada Ltd., and many others, are gratefully acknowledged -- for this has been a cooperative effort. The Committee Chairman acted as editor, and in this capacity had to select, summarize, and assess priorities in the main report in order to arrive at the distillate which is given in the Summary.

SUMMARY

In this report electrochemistry has been approached from rather practical points of view: What are the strengths and weaknesses of industrial electrochemistry as expressed in production of metals, chemicals, batteries, capacitors and electrolytically finished surfaces? What research and development effort in industrial, governmental and university laboratories supports and feeds the industry? What are the weaknesses? What are the opportunities? What needs to be done to shore up the weaknesses and exploit the opportunities?

The subject itself was considered to comprise any chemical process in which the charge transfer under a controllable electric field is either predominant or essential. Under this definition are included electrolytic processing of metals and chemicals, electrofinishing of surfaces, batteries and capacitors, semiconductor electrochemistry, corrosion: and research and development on these -- as well as investigations of the more basic aspects. Electrodialysis, fuel cells, solid-state electrochemical phenomena, electro-organic syntheses, and several other topics with great potential have been reviewed. Electrothermic reactions have been covered by Committee 14 on high temperature reactions. Biological electrochemistry was mentioned only briefly. Although economics and technical aspects were considered to the depth possible within the limitations of knowledge obtainable by the committee and the effort and time available for the study, the report should be considered only as a best effort. Further analyses are needed, and are recommended. However, certain factors have become clear.

Electrochemistry as defined has a strong industrial backbone in Canada, representing productivity of 1.6 billion dollars a year. Value added by electrochemical methods turns out to be about half this figure. The contribution is truly substantial. However, growth rate currently is only 4.6%/yr. Total research and development, under the same definition, is much less than the 3.5% proposed by development-minded Canadian economists, possibly only about 0.2% as indicated by the incomplete data available. The level of engineering development seems to be sporadic and discontinuous, and much of the published research does not seem to have had clear objectives. There are highlights -- in nickel refining, in electrolytic capacitors, and in the generation of important new knowledge -- in which Canadian versatility, imagination or ingenuity has been prominent and justifiably recognized. Since much of the Canadian electrochemical industry is substantially under non-Canadian ownership, research and/or engineering development tends to be done elsewhere. Most of the published research is done at government labs and at universities under government sponsorship. Patent positions generated by this work are not strong, there being

little coordinated attempt to focus on selected Canadian interests. The net effect of these factors might be described as uncertainty. The weaknesses seem to be in engineering development, in the teaching of the implications and technical importance of electrochemical engineering, and in the amount of objective or supporting research being done. As a result, new opportunities are being recognized and exploited more slowly than in U.S., Europe and Japan.

The opportunities, the needs, and the remedial actions proposed have been given in some detail in the main Report. The reasons behind each recommendation are carefully stated so that the reader can assess the quality of the bases from which it was made. Only the general features of the recommendations follow.

Opportunities for growth exist as follows: in electrofinishing, in electrocoating, in electrolytic processing of metals and chemicals, in fuel cells and in certain other branches of applied electrochemistry. It is recommended that each of these opportunities be now studied jointly by industrial and government specialists from a technico-economic viewpoint: with a view to selection of those for which joint sponsorship of industrial development teams can be organized and the desirable work financed and expedited. When large installations are being considered, the influences of the trends towards public ownership of electrical power, worldwide locations of forthcoming nuclear stations, possible changing availability of raw materials, and new product-consumption patterns must be considered, as well as traditional technico-economic factors.

Seven academic chairs of electrochemistry need to be established: four being supported by (and working on problems relevant to) the electrolytic process industry; three being fully supported by the Federal government -- one oriented to electrofinishing problems, one oriented to electrochemical energy storage problems, and one oriented to theory and techniques of measurement. Appointment of industrial researchers to three of the seven chairs is recommended.

For the development of the broad industrial, governmental and educational base which now exists coast to coast, the several-centers-of-excellence approach is preferred over the central-institute approach. For improved communication among them an "Electrochemical Communication Center" is needed.

The Committee predicts that a full technico-economic study of research, development and manufacturing, would probably show that, to maintain a healthy and growing industry, supported by an improving technology and constant infusion of new knowledge -- the basis of new opportunities for Canada in the World -- a total yearly expenditure in excess of 1% of electrochemistry's contribution to the GNP should be made for scientific, engineering, and economic studies. Under the definition which the Committee used for electrochemistry as it is practiced in Canada, 1% means a total expenditure of $16 million per year. A budgetary breakdown, supported and detailed in the body of the Report, suggests yearly industrial investment in R and D to an amount of $9.6 million, and governmental support to an amount of $6.2 million. Of the total, $10 million should be spent in industry (principally at first on engineering development), $3 million in universities and technical institutes (principally on new scientific, electrochemical engineering, and economic studies), and $2 million divided between selected research institutes and government laboratories, whose personnel must help span the interface.

The advances made in this field in the USSR in the past ten years are astounding. They provide excellent guidelines for renewed Canadian effort.

INTRODUCTION: STRUCTURE of CANADIAN ELECTROCHEMISTRY

Electrolytic Processing, or Electroprocessing, is industrially the most important segment of the electrochemical industry. Its basic operation is electolysis, which represents the most common process for converting electrical into chemical energy. Electrochemically, this is the same as the process which occurs during the recharging of storage batteries, and the reverse of the process principle on which fuel cells are based.

Electrochemical Processing may be divided into two major classifications. These are: (a) Electrowinning and Electrorefining of Metals; and (b) Electrolytic Production of Industrial Chemicals.

Electrowinning, the recovery of metals from solution by electrolysis, consists of 2 major types. In the first, raw or semi-processed material is leached to produce an aqueous electrolyte rich in the ions of the metal to be recovered. The purified solution is then electrolyzed to produce, at the cathode, a relatively pure metal deposit of copper, lead, nickel, silver or zinc. In the other type, the basic material is fused, often after adding salts which lower its melting point, and the resulting melt is electrolyzed to deposit the metal at the cathode. Metals commonly produced by fused-salt electrolysis include aluminum, calcium, lithium, magnesium and sodium. Of these, only aluminum is produced by fused-salt electrolysis in Canada.

In electrorefining processes, which are closely related to electrowinning, anodes of relatively crude or impure metal are immersed in a suitable electrolyte in a refining cell. Thin sheets of refined metal are used for the cathodes. Proper control over voltage and current density results in migration of only the desired metal to the cathode. The unwanted impurities, which are often valuable by-products, either remain at the anode as a slime or stay in solution. Electrorefining yields metals of extremely high purity, notably copper, lead, silver, gold, and bismuth. More than 90 percent of Canada's copper metal production is electrorefined.

In the production of industrial chemicals, electrical energy, although generally more expensive than other forms of energy, is more selective. Oxidation and reduction can be carried to intermediate levels, and some components of a mixture can be caused to react without disturbing other components. Alkali and chlorine industries, which feed into the pulp and paper industry of Canada, are major users of electrolysis. In 1965, the Canadian production of chlorine alone,almost exclusively by electrolytic processes, was 585 thousand tons. (Typical production is 0.6 to 0.8 pounds Cl_2 per k.w.h., and 0.7 to 0.9 pounds NaOH per k.w.h.). Other important industrial chemicals produced via electrolytic techniques in Canada are sodium chlorate, hydrogen peroxide, and electrolytic hydrogen.

Electroorganic Processing, while it has not yet reached the stage of commercial exploitation in Canada, is making significant progress in the United States, Europe and Japan.

Five times smaller than the huge Electrolytic Processing Industry, just introduced, is the Electrofinishing Industry. Under this title we subdivide into four major parts: (a) Automotive Plating (b) Electrotinning and Electrogalvanizing (c) General Job Plating and (d) Architectural Anodizing. Electromachining and electroforming comprise a small, although technically important, fraction of the total. So does decorative anodizing. This part of the industry is broad-based in some 1300 plants from Coast to Coast, although most of the high-volume work is done in central Canada.

Seventeen times smaller in total economic importance than Electrolytic Processing, but still accounting for sales of about $70 millions, is the Electrochemical Storage-Device industry: Batteries, Capacitors and Fuel Cells. Lead-acid storage battery and Leclanché dry battery production accounts for over 85% of the total, the remainder being in specialty batteries and electrolytic capacitors. There are signs of vigor in the more recent specialty field, as certain high quality items are beginning to be exported.

Four other general topics are reviewed in brief form, but not with analytical detail: Electrothermics; Corrosion; Solid State Science; Biological Electrochemistry. First: certain processes, especially in the metallurgical and inorganic chemicals industry, proceed rapidly and quantitatively at elevated temperatures, maintained in furnaces in which heat energy can be localized by current flow. Such processes are called Electrothermic processes, and have been considered traditionally as electrochemical processes and make a major contribution to the Canadian economy. For this Survey, however, they are reviewed and reported by Committee 14: High Temperature Chemistry, not Committee 13: Electrochemistry. No analyses or quantitative estimates on electrothermics are included in this report.

Second: Corrosion has many electrochemical features in its basic mechanisms. Further, although prevention of corrosion is usually by judicious choice of materials or by suitable coatings, the techniques of cathodic protection of metals are largely electrochemical as well. Annual losses in Canada due to corrosion have been estimated at about $400 million, and are climbing. The brief expands these points.

Third: The whole new field of Solid State Science has provided many publications in the electrochemical journals. Discussions of charge-transfer processes involving chemical change do permeate these reports, although the emphasis is usually on the electrical phenomena which can be developed into electronic solid-state devices, particularly for the communications industry. Growing rapidly in Canada, and backed by substantial research and development, at first glance it appears to have a bright economic future. However, certain barriers are outlined in the brief. The Electrochemical Society has become a widely used forum for new work in this field in Canada.

Fourth: Biological Electrochemistry, without any commercial importance but with deep medical significance in the phenomena which occur in nerve and in other living membrane phenomena, is reviewed also in brief form. Buried as it is within electrophysiology and biomedical engineering, of course no numerical analysis was possible on this topic.

A major part of this study is given under the title: New or Developing Segments of Electrochemistry. The approach was to try to recognize opportunities arising from research in progress here and elsewhere. Each of the apparent opportunities needs to be examined in more detail for its commercial possibilities. In each case there is strong Canadian research, but little exploratory development.

All the recommendations are collected, out of context, for convenience of reference, in a separate section of the report at the end.

The overall Summary distilled from the various contributions and analyses of the Committee 13, precedes this Introduction.

During the study a major difficulty persisted: it was seldom possible to correlate numerical data from the formal survey with that obtained from our own net. Two reasons are offered: Firstly, the scope of the subject matter as defined by this Committee possibly did not correspond exactly with that used by the individual as he was preparing his answer to the Chemistry Questionnaire. Secondly, the fine structure or detailed breakdown of the subject matter used by us could not be included in the questionnaire. Doubtless much of what this Committee thought logically to be part of Electrochemistry is reported in part by other Committees. This difficulty could not be avoided. Faced with these problems, the Committee reported a self-consistent picture based on information collected in its own net, and made cross-reference to tabular data from the formal survey where possible.

PART I : ELECTROLYTIC PROCESSING

Background Information

The electroprocessing segment of the electrochemical industry in Canada probably began its significant history in 1901 when the Northern Aluminum Co. first commenced the production of aluminum metal at Shawinigan, Quebec, utilizing power supplied by the Shawinigan Water and Power Co. This event was closely followed in 1902 by the installation of copper refining and lead refining facilities at the Canadian Smelting Works at Trail, B.C. The lead refining operation was the pioneer commercial unit of the Betts electrolytic lead refining process, and continues in operation at the present time. Other significant milestones in electrochemical processing in Canada include:

(a) The first commercial large-scale production of electrolytic chlorine and caustic soda at Windsor by the Canadian Salt Co. (now C.I.L.) in 1911.

(b) Commencement of electrolytic zinc production in Canada by Cominco in 1916 at Trail, B.C. Subsequently, other electrolytic zinc production centres have been established by Hudson Bay Mining and Smelting Co. (Flin Flon, 1930) and Canadian Electrolytic Zinc Co. (Valleyfield, 1963).

(c) Commencement of electrolytic nickel refining at Port Colborne, Ontario, by the International Nickel Co. in 1922.

(d) Establishment of aluminum reduction works on the Saguenay River in Quebec in 1926. Present operations in this area include Isle Maligne and Arvida aluminum reduction works of Aluminium Ltd.

(e) Establishment of Canadian Copper Refiners' massive copper refinery at Montreal East, Quebec, in 1930.

(f) Construction of the large Kitimat aluminum smelter by Aluminium Ltd in British Columbia, with production commencing in 1954.

(g) The nickel refinery of International Nickel Co. at Thompson, Manitoba, commenced production in 1961, utilizing a new process based on the direct electrorefining of nickel sulfide matte.

In 1888 Ernest LeSueur, of Ottawa, patented his chlorine/caustic diaphragm cell while still a young student at MIT. One of the cells whose design and installation he supervised in Rumford, Maine, was dissembled in 1965 after 67 years of useful production. Such are LeSueur's credentials as the father of Canadian electrolytic processing. However, W.H. Aldridge, who guided the construction of the world's first electrolytic plant for lead refining, with the assistance of the inventor A.G. Betts of Troy, N.Y., during the winter of 1901-02, at Trail, B.C., surely must be considered a close competitor.

Economic Analysis

A breakdown of the electroprocessing segment of the electrochemical industry in Canada for 1965 is outlined in Table I.1. It will become evident from the physical and economic data presented that the electroprocessing industry, with a gross annual value of $1.2 billion, and a value added approaching half a billion dollars, is by far the most important segment of the Canadian electrochemical industry.

Dominating the electroprocessing category is the electrowinning and electrorefining of nonferrous metals, principally aluminum, copper, nickel, zinc and lead, which account for some 90% of the total, in terms of both gross value and of value added.

For the purpose of determining the overall growth rate of the electroprocessing industry in Canada in recent years, corresponding data to those in Table I.1, but covering the year 1960, have been assembled in Table I.2. In terms of gross value, the growth rate for the period 1960 to 1965 is 4.7%; in terms of value added, the electroprocessing industry growth rate for the period 1960 to 1965 is 4.6%. per annum.

A comparison of electrochemical industry parameters for Canada and the United States is quite revealing. From the data in Table I.3, it is evident that on an industry-wide basis, per-capita production of electrochemical products in Canada is about double that in the United States. In certain products the disparity is even more pronounced; these include electrolytic zinc, 10 times more important per capita; aluminum, 5 times per capita; and electrorefined copper, at 3 times per capita.

However, this healthy state of affairs does not extend to current growth rates of the respective electrochemical industries. A recent study of the U.S. electrochemical industry by Wenglowski reveals that for the 5-year period 1958 thru 1963 the growth rate, or average annual percent change, was 7.3%. In contrast, the indicated growth rate for the electroprocessing segment of the electrochemical industry in Canada for the period 1960-1965 has been calculated to be 4.6%. Details are collected in Table I.4.

TABLE I.1

Major Areas of Canadian Electrochemical Processing - 1965

RANK	Product	Production, Shipments	Gross Value	Ratio* %	Value Added
		(TONS)	($MM)		($MM)
1.	Aluminum	840,000	437	46	200
2.	Copper	434,000	304	23	70
3.	Nickel	136,000	228	(40)	91
4.	Zinc	359,000	101	36	36
5.	Lead	186,000	56	11	6
6.	Chlorine	(585,000)	38	60	23
7.	Sodium Hydroxide	643,000	40	61	24
8.	Silver	20 M. ozs.	28	53	15
9.	Sodium Chlorate	50,000	7	54	4
10.	Hydrogen Peroxide		3	33	1
		TOTALS	1,242		470

*Value Added by Electrochemical Methods divided by Gross Value. For each product the ratio has been estimated from actual costs of processing costs of alternative processes, alternative marketability of raw material and partially processed intermediates, and other factors. The values used in most cases are those worked out recently from these factors by Wenglowski.

TABLE I.2

Major Areas of Canadian Electrochemical Processing - 1960

RANK	Product	Production, Shipments	Gross Value	Ratio %	Value Added
		(TONS)	($MM)		($MM)
1.	Aluminum	762,000	386	46	176
2.	Copper	417,000	250	23	58
3.	Nickel	128,000	179	(40)	72
4.	Zinc	261,000	68	36	24
5.	Lead	159,000	35	11	4
6.	Chlorine	325,000	22	60	13
7.	Sodium Hydroxide	375,000	23	61	14
8.	Silver	22M. troy ozs.	19	53	10
9.	Sodium Chlorate	40,000	5	54	3
10.	Hydrogen Peroxide		2		1
		TOTALS	989		375

TABLE I.3

Comparisons of the Electrochemical Processing Industry, in Canada and the USA - 1966

A. General US/Canada Ratios

Description	United States	Canada	Ratio*
POPULATION (Millions)	200	20	10
G.N.P. ($ billion)	743	58	13
E.P.I. (a) Shipment basis ($ million)	7,900 (e)	1,650	4.8
(b) Value Added basis ($ million)	3,800 (e)	670	5.5

B. US/Canada Ratios for Selected Products

Product	U.S. Shipments	Canada Shipments	Ratio*
	($ billion)	($ million)	
ALUMINUM	980 (e)	460	2.1
COPPER	1,104 (e)	365	3.0
ZINC	116 (e)	107	1.1
CHLORINE	469	44	10.6
STORAGE BATTERIES	560	46	12
PRIMARY BATTERIES	220	14	16

(e) - Estimated. Based on U.S. 1963 data and a 7% per year growth rate.

*US value/Canada value. Any ratio smaller than 10 -- that for population -- indicates an electrochemical product of relatively more economic importance to Canada than to the USA. See text.

TABLE I.4

Growth Rates of Major Segments of Electrochemical Processing Industry

	Product	Canada Shipments ($ millions) 1960	1965	Ratio*	Growth Rate (%/yr)
1.	Aluminum	386	437	1.13	2.5
2.	Copper	250	304	1.22	4.1
3.	Nickel	179	228	1.27	4.9
4.	Zinc	68	101	1.49	8.3
5.	Lead	35	56	1.60	9.8
6.	Chlorine	22	38	1.73	11.6
7.	Sodium Hydroxide	23	40	1.74	11.7
8.	Silver	19	28	1.47	8.0
9.	Sodium Chlorate	5	7	1.40	7.0
10.	Hydrogen Peroxide	2	3	1.50	8.4
	TOTALS	989	1,242	1.26	4.6

*Shipments 1965/Shipments 1960

Research and Development

Considerable research and development work in electroprocessing has been undertaken in the past in Canada, and some degree of activity exists at the present time -- primarily geared to the support- or process-improvement types of research.

Industrial:- Most of the industrial research presently being carried out in Canada in electroprocessing falls in the in-house category. It is undertaken by major firms in the primary metal production field, such as Alcan, Cominco, Inco, Noranda, and others, and by similar major firms in the industrial chemicals industry, such as C.I.L., Electric Reduction, Shawinigan Chemicals, and others.

In general, basic or fundamental research in electroprocessing in the industrial sphere is primarily confined to, or centered in, the central laboratories or technical research centres maintained by the major industrial organizations, some of which have been mentioned previously. Some domestic firms are also in a position to supplement or replace research activity of this type by access to research programmes maintained by parent or associated firms in other countries.

With respect to applied or development research, this type of activity generally has a more widespread base. In addition to programmes underway in technical research centres or laboratories, considerable development or applied process research is undertaken at industrial plant locations throughout Canada.

A major feature of industrial research in electroprocessing in Canada is its spasmodic nature. Peak levels of activity are generally oriented to: (a) Applied research and development programmes, associated with pilot-plant operation of any new commercially successful electrochemical process; (b) Support applied-research programmes, following the installation of new plant facilities utilizing major electroprocessing techniques.

The level of support of industrial electrochemical research and development could not be estimated with any accuracy. Various estimates have placed it at 1.5% of value added for Canadian industry as a whole. In view of the slow growth rate of the electroprocessing industry, it is probable that the level of support of electrochemical R and D may be much less than half of 1.5% of VA. The large problems to be solved in product- or process-development and which are always very expensive are not usually electrochemical in nature but rather consist of chemical handling. This point is discussed again later in the report.

Government:- Fundamental research, and, to a lesser degree, applied research in the field of electroprocessing are carried out by a number of government agencies. At the Federal level, major contributions have been made by the National Research Council and by the

Mines Branch in Ottawa. Their Laboratories have been consistently productive for at least 30 years. Probably the direct outlay for electrochemical process R and D is approximately 5 professionals at the Mines Branch. Further, the activity is on obtaining basic design data, not on scaling up, although consulting with industrial firms occurs.

Provincial Government agencies possessing capabilities in the field of electroprocessing include the B.C. Research Council and the Ontario Research Foundation. Support of their work by Industry has been sporadic in the past.

Academic: This is the weakest link in the R and D hierarchy for electrolytic processing. The basic voids are: (a) lack of courses in electrochemical engineering, and (b) lack of graduate studies in electrochemical processing. There are no centers dedicated to research in Electroprocessing, although there is interest, such as at L'Ecole Polytechnique de Montréal. Further, the chemical engineering courses in most of the major universities do not offer courses in electrochemistry which are adequately suited to the man expecting to enter the electrochemical industry, or which consistently use examples from the Canadian electroprocessing industry, although there are isolated examples to the contrary.

Opportunities

Industrial:- In the past, industry or the private sector of the economy recognized an opportunity and pioneered in the area of establishing power-intensive electrochemical industries in those areas of Canada where large blocks of power (most often of hydro-electric origin) were favorably located at attractive prices. In many cases, opportunities for captive ownership of the power source also existed and, in some cases, was probably the significant factor in attracting new industry, e.g. primary aluminum processing. More recently the trend has been towards public ownership of power resources. From the point of view of the industry, public ownership of power resources provides a less attractive climate for the establishment of large power-intensive industries, involving expensive fixed installations, than does captive ownership, because the industry has less control over price of power. However, the development of large new hydro-electric power supplies under provincial government sponsorship such as is taking place at such widespread locations as Peace River and Mica Creek in British Columbia, Nelson River in Manitoba, Manicouagan-Outardes in Quebec, and Churchill Falls in Newfoundland, will undoubtedly provide a favorable environment for medium-scale and small-scale electrochemical enterprises, which will utilize smaller but still significant quantities of electric power.

For the more distant future, prospects are becoming favorable for the establishment of large industrial complexes geared to the utilization of nuclear power, and located adjacent to, rather than isolated from, major market areas.

An intermediate stage in the transition to this latter situation are current developments in Extra High Voltage (ac) transmission and direct current (dc) transmission, which will favor moving the power to favorable processing locations (seacoast, inland waterways, etc.) rather than moving materials to power generation sites as in the past.

Aside from the defensive aspects of the need to recognize now what adjustments must be made if the very large hydroelectric-based industry Canada now has is to continue to be a world leader in say 10-20 years, the opportunity exists now to begin to plan the long-term and slow moving actions which must occur if Canada's Electrochemical Processing industry is to find ways of taking advantage of a changing situation in both domestic and foreign power generation and distribution. Operational research in this area should prove very fruitful. We have the tools, both technical and economic.

There are many, more immediate opportunities. For example, successful tariff negotiations could result in a better climate for export of materials, electrochemically produced, which have been processed "one step more" -- zinc die-castings, as a specific example.

There are opportunities, which appear to be very promising, opening up in the electroorganic synthesis field. Electrochemical reactors to produce tightly controlled polymers, for example, are not yet even on the drawing boards in this Country, as far as we have been able to determine, although pilot lines are already in operation elsewhere.

<u>Government</u>:- Despite Canada's role as one of the leading electrochemical nations in the Free World, both in terms of total and per capita output, there appears to be no federal nor central guiding agency designed to stimulate and maximize the growth of the electrochemical industry in Canada. This role has traditionally been left to private industry and, more recently, to provincial governments interested primarily in support for and use of large hydroelectric power projects. The only exception to this has been Atomic Energy of Canada Ltd., which has been entrusted with the development of nuclear energy in Canada. Does the change in name from Department of Mines and Technical Surveys to Department of Energy, Mines and Resources (EMR) imply a broadening of function which will fill the gap and provide a central guiding agency? Perhaps this role should fall within the Department of Industry, or some joint responsibility of EMR, Industry and Trade and Commerce.

Academic:- In the academic field, there appears to be considerable scope for several types of research programs designed to provide fundamental data and basic principles which might stimulate evolution of the electrochemical industry in Canada. These would include for example:

(a) Research into principles and techniques which will enable designers to maximize electrochemical reaction-decomposition-rates;

(b) Techno-economic studies designed to provide long-range guideposts for industry in choice-of-process decisions and electrochemical-industry trends.

These should be supported by continued work designed to establish fundamental knowledge of electrochemical principles.

Recommendations

1. That a Central Information Centre on Electrochemistry be established in Canada -- possibly in Ottawa -- from which information on electroprocessing, electrofinishing, batteries, technical and economic conferences, research items, etc., can be disseminated rapidly to interested parties in all parts of Canada. Regional offices, associated with existing technical information or research centres, should exist -- for example at Vancouver, B.C. (B.C. Research Council), Edmonton (Alberta Research Council), Saskatoon (Univ. Saskatchewan), Winnipeg (Manitoba Research Council), Toronto (Ontario Research Foundation), Montreal (L'Ecole Polytechnique), Fredericton (N.B. Research and Productivity Council), St. John's Newfoundland (Memorial University for the present).

2. That the Department of Industry and the new Electrical Energy Adviser to Dept. of Energy Mines and Resources jointly compile a directory on the Electrochemical Industry in Canada, including facilities, organization, relevant academic facilities, personnel, possible consultants, etc., and publish it, with amendments to be made to bring it up to date every second year.

3. It is recommended that long-range studies be undertaken by, or supported in the consulting engineering and/or academic fields by, government agencies (including DOI, DEMR and AECL) and industry, concerning the long-range implications and opportunities for the electrochemical industry in Canada in the light of the forthcoming changes in power distribution. Essentially, such studies should determine what steps will be required to maintain for Canada as favorable an environment for large and medium-scale electrochemical industry, as has existed in the past (during what might be termed "the plentiful hydro-electric power era"). The current slow rate of growth is the motivating factor.

4. That four Industrially sponsored Chairs of Electrolytic Processing Studies be established at universities which demonstrate a true interest in the growth of electrochemical engineering as a professional field of research and development. University of New Brunswick, L'Ecole Polytechnique de Montréal, Waterloo University and University of British Columbia should be very seriously considered.

PART II : ELECTROCHEMICAL ENERGY STORAGE

This part of the report contains a review of electrochemistry as it relates to batteries, electrolytic capacitors and fuel cells.

Background Information

The Industry began in the early '20's when several large U.S. firms established subsidiaries in Canada; most of these - ESB (Exide and Willard) and Ray-O-Vac, Union Carbide, Gould-National, Burgess, Prestolite - have remained and have grown with Canada. In more recent years they have been joined by subsidiaries of additional U.S. firms and by subsidiaries of several European manufacturers.

Generally speaking, the Industry's products are heavy in weight for their volume and value and, therefore, distribution costs have played a significant part in the way the Industry has located and grown. There are manufacturing and/or assembly facilities in Springhill, Nova Scotia, and in Vancouver and in most major market areas between. Virtually the entire Industry is owned and controlled by foreign interests, with a total of 20 sizeable factories representing a current investment of 50 million dollars.

Substantially all of the Industry's basic technology flows into Canada from foreign owners, with a noticeable but still small trend toward contributions by the Canadian Industry itself.

The Industry does have higher costs than its foreign counterparts. Mostly this derives from higher material costs, but it is partly because the Canadian Industry must make a wide variety of products in relatively small volumes. Almost without exception it is the policy of the individual Companies to find the major suppliers in Canada. In fact they have succeeded very well, to the point where it is estimated that less than 10% of materials and parts come from outside Canada - largely confined to raw materials not available here and to components which comprise a production volume too small to support Canadian tooling.

This Industry represents an almost classic instance of investment and development by foreign equity of a strong, vigorously competitive Industry of considerable complexity, including technology.

Conventional battery sales -- that is, lead acid secondary and zinc carbon primary -- total about 70 million dollars for 1967 (final DBS data are not yet available), with growth rate at about 5% per year.

The specialty battery and capacitor industry has developed rapidly since 1954. It is still only 1/20 the size of the dry and storage battery industry. Silvercel of Canada Ltd., CIPEL, Electrochemical Products, Exide, Burgess, Alkaline Batteries Ltd., Johnson-Matthey-Mallory, Sprague Electronics, and Mallory Battery Company of Canada, all have facilities, new since 1954, to produce in the specialty battery and electrolytic capacitor field. Three firms -- Canadian Allis Chalmers, Ferranti Electronics Ltd. and Gould-National -- have entered the fuel cell field since 1965.

Economic Analysis

Table II.1 shows an estimate of the value added to the Canadian economy by manufacture and sales of conventional batteries in Canada. The total value added is $33 million. This number represents approximately 50% of factory sales, a value added/shipments ratio equal to that deduced independently by Wenglowski for the situation in the U.S. for the battery industry.

Using the same percentage and an estimated value for factory sales for the specialty battery industry, not included in the, $3.6 million, DBS statistics, a figure for value added for the specialty battery industry of $1.8 million is obtained.

Data for the capacitor industry had to be estimated as a result of personal interviews with the manufacturers. Total Canadian manufacture of electrolytic capacitors in 1966 as factory shipments is estimated to be $3.4 million. Value added/factory sales is 0.66 in electrolytics; this yields a value added of $2.2 million for the Canadian capacitor industry.

The total value added for the battery, capacitor (and fuel cell) industry, then is approximately $37 million.

Data for the period '58-'62 showed that both the dry and storage battery were growing only by 2.2% per year, well below the growth of the Canadian GNP of 5.5%. Fluctuations occurred (DBS data) in the period '62-'66. The full impact of the automotive agreement with the U.S. on the Canadian automobile manufacturing industry is not yet known. High transportation costs may buffer any change in distribution patterns.

The specialty battery industry has been growing at a rate of about 10% per year since '54 and may be approaching a saturation point, except in one or two applications such as cordless appliances or silent power for yachts. In both of these cases the market is just opening up. Specialty electrolytic capacitor production has now had two years of outstanding success, but to state a growth rate would not be meaningful.

Since the total production in both the conventional and specialty industries is small in Canada, and subject to large percentage fluctuations, it is useful to record recent rates in the U.S. (9.5% per year, 1958-1963) as a guideline.

TABLE II.1

Estimate of Value Added to the Canadian Economy by the Electrochemical Energy Storage Industry

Description	Factory Shipments[1] ($ millions)	Value Added[2] ($ millions)	Ratio (%)
Lead Acid Storage Batteries	50	24	48
Leclanché and Mercury Dry Batteries	18	9	50
Special Purpose Batteries[3]	3.6	1.8	50
Electrolytic Capacitors	3.4	2.2	66
Totals :	75	37	

1) 1967 - estimated

2) Factors included in calc.: gross margin of profit, labor, overhead

3) Including nickel-iron, nickel-cadmium, silver-zinc, magnesium-silver chloride, et al.

Research and Development

In this Section we discuss product development, process development, supporting research and development, and exploration.

Industrial:- Process development teams exist in most of the manufacturing concerns. Table II.2 shows an estimate of the scientific or engineering man-years per year assigned to research in the industry. In most cases a technology has been acquired, then modified or developed because of the versatility required for small rates of production. In the smaller companies this work is done by the people who normally act as officers of the company; such people are not included in Table II.2.

The strength of this part of the Electrochemical industry lies in the versatility and ingenuity with respect to the small-job type of production. It is estimated that the total money spent for R and D represents approximately 1% of factory sales, 0.5% of value added. Most of this is concentrated in the two largest manufacturers and in the new research and development facilities co-sponsored by industry and government in smaller firms. The total R and D rate for the Industry is about 32 scientific and engineering man-years per year.

Naturally, under these conditions, each company must narrowly specialize: Union Carbide has a strong engineering development team; Electric Storage Battery Co. seems to be strongest in process development; Mallory Batteries of Canada has strong scientific research; Johnson Matthey and Mallory has a versatile group of top scientists who can range all the way from fundamental research through engineering development, the level of effort in any one area being, of course, low. An unusual versatility is demanded of personnel in the electrochemical energy storage industry.

Government:- The main government research and development laboratory working in this field is the Defence Chemical Biological and Radiation Establishment in Ottawa, where four scientists and engineers are engaged in the design and development of new devices, and another five are doing supporting and exploratory research -- mainly concerned with batteries and fuel cells, and to a lesser extent with electrodeposition. The interests center on the nickel-cadmium, new non-aqueous, molten salt, and fuel cell systems. About half the work is exploratory in nature. There is no substantial R and D effort in this field in any other Government laboratory.

Through the Defence Industrial Research grants to industry, the Federal Government's commitment to industry is another $150,000 per year, directed toward: product development of the Mg-AgCl system, supporting-research and development on H_2/O_2, hydrazine/air, and molten-carbonate/air fuel cell systems. (In addition to this current support, one industrial firm received support totalling $140,000 during '63-'64 through the Industrial Research Assistance Program for studies on the

TABLE II.2

Estimate of Effort on R and D in
Electrochemical Energy Storage Industry, 1967

	Scientists or Engineers
Production development	10
Product development	6
Process development	6
Product and process design	4
Supporting research	4
Exploratory research	2

TABLE II.3

Estimate of Effort on R and D
Supported by Federal Government, 1967

Product Development and Market Studies	$ 60,000
Process Development	$ 30,000
Supporting Research and Development	$120,000
Exploration	$ 30,000
Direct Government Support of Industrial	$135,000
Direct Government Support of Academic	$ 72,000

nickel-cadmium system, and is now marketing special powders for fueling the cell industry in USA. Two firms and UBC received substantial support for R and D in electrolytic capacitors thru ECRDC in the 1957-1966 period, totalling over $500,000. Rapidly growing shipments of high quality electrolytics are the pleasant results. Support for R and D has now been phased out.)

Other government input is now recorded. The industry generally has benefited since 1965 from the market research studies and economic analyses, being done by the Department of Industry (at the two-man rate): one on batteries and one on fuel cells. No Canadian firm in the Electrochemical Industry has so far taken advantage of the PAIT or CIRD Programs or Program 5 of the Department of Industry. The consulting efforts of scientists and engineers of NRC and the Mines Branch, and occasionally the results of their fundamental studies, have at times aided the industry. Engineers in the Armed Forces and in the Department of Transport have contributed engineering time and effort on product development with industrial firms prior to purchase. Through the NRC/DRB system of Grants-in-Aid of Research $72,000 was made available in 1967 to nine grantees in Canadian universities whose work is clearly identifiable as related to problems in batteries and fuel cells.

An estimated breakdown is given in Table II.3.

Academic:- The academic research of particular interest centers at the University of Ottawa, University of Toronto, University of British Columbia and Loyola College. Studies done are of general interest in the field but are not directed toward the solution of specific problems in the battery or fuel cell or capacitor field. Ph.D. graduates from the field probably number no more than 3 per year, and these are fundamental electrochemists. The field, however, requires metallurgists and mechanical engineers, as well as people trained in plastics, and electrical engineers. There are no interdisciplinary courses to train electrochemical engineers as such in Canada. The interdisciplinary training in systems-engineering required for the increasingly complex fuel cell field especially has prompted one university to open graduate studies in electrochemical systems engineering. Of the students supported by DRB since 1956 at Canadian universities while generally working in this field, only 7% have been working in the field since graduation. Many have gone into teaching, others into other parts of the electrochemical industry, some have emigrated. Conversely, of course, the battery, capacitor and fuel cell field has drawn its scientific and engineering talent from a wide range of disciplines.

Opportunities

Industrial:- Industrial people feel that opportunities lie principally in the areas of:

a) developing free-thinking top Canadian leadership in companies probably destined to remain subsidiaries for many years to come;

b) improving efficiency in production, possibly aided by a subsidy or tax abatement based on increased production;

c) redirecting the supporting staff and production staff to be able to reorient and move fast when required (Learning time in key jobs is too long.);

d) capitalizing on the high skills which exist in production-development within the industry;

e) recognizing new custom-built business which may have a small but substantial market abroad;

f) promoting more effective sales abroad by the government and industrial organizations already in existence.

It will continue to be likely too expensive for small Canadian companies in this field to be able to afford engineering-development teams, to work on projects which could only result in limited production, except in very special cases. Since this conclusion may not be valid for the long term, however, considerable governmental subsidy for development engineering within the industry to enable them to develop men and facilities to the point where the engineering-development teams can become productive, would seem to be necessary.

Government:- The government role would seem to lie in between that of university and industrial research and development: on the one hand, sponsoring long-range and speculative research but at the same time encouraging and finding support for researchers who do become interested in obtaining new fundamental knowledge about materials and about fundamental processes of interest in the battery, capacitor and fuel cell fields; and on the other hand, helping to recognize important technological areas of the future, helping to assess their priority, and helping to provide suitable stimulants. Stimulants which need attention are: (i) better communication; (ii) facilities for computation in data reduction; (iii) market forecasts; (iv) exploratory research and development on speculative and promising topics not yet of interest to academics nor supportable by industrialists.

Of all these stimulants, the greatest opportunity for immediate gain is in communication and market forecasting -- providing a medium for the exchange of views on long-term needs of the country. It is possible that the availability of a computational facility with restricted access could serve the country well, rapidly analyzing financial information for the industries as an alternative to control being more increasingly centered at the corporation's headquarters elsewhere. It seems to be almost axiomatic that if the present trend continues without interruption, influential management of Canadian subsidiaries in Canada will have ceased in 25 years.

Academic:- Stimulated by discoveries in organic and molten salt electrolytes, by the many new physical tools which have become available as spin-off from physical-chemical research, and motivated by new demand for basic information by the engineers in the battery, capacitor and fuel cell industry: academic researchers have opportunities for scientific investigation quite like never before. Research is relatively inexpensive in this field. In the last ten years the number of scientists and engineers doing at least some electrochemistry in Canada in institutions of learning has markedly increased, probably by about 50 or so senior men, as evidenced by recent publications.

In the specialties of electrochemical kinetics and solid state electrochemical processing, Canadian scientists have achieved a worldwide reputation already for their contributions and knowledge, but the translation of this information so that engineering development could proceed has fallen way behind. There is a large opportunity then in electrochemical engineering in academic circles. Relative to scientific electrochemical research, electrochemical engineering is expensive, especially for academic institutions, and is neglected in Canada.

Recommendations

1. That industrial management and governmental management work together to find ways to increase engineering-development teams within the battery, electrochemical capacitor and fuel cell industry. This cooperation would take the form of: (a) joint market prognostications, centered in the Department of Industry; (b) the relaxation of the proscriptions inherent in government assistance programs (PAIT, IRAP, DIR, etc.) so that engineering-development can be strengthened in the Industry; and (c) more careful preparation and assessment of proposals for joint sponsorship of specific engineering development work.

2. That an industrially sponsored Chair of Electrochemical Energy Conversion should be set up at a Canadian university, to maintain continuing objective studies on topics arising in the battery, capacitor and fuel cell field. The University of Ottawa already has interest and proven productivity, and should be considered.

PART III : ELECTROFINISHING

Background Information

There are more than 1300 plants in Canada which do electroplating, electroforming, anodizing and related processes. Of these about 800 are located in Ontario, 350 in Quebec, with British Columbia and Manitoba next in numbers and the balance in the Prairie Provinces and the Maritimes. Some of these establishments have been in operation since the invention of the dynamo in the 1880's.

The recent trend has been to larger and larger installations, with the result that there are probably 45 plants which account for 90% of the total production. These large installations are close to the centres of automobile production in Ontario. With the urgent need for waste-treatment installations in all plating and anodizing processes, this trend to fewer and larger plants will probably be even more pronounced as time goes on. The small operator has neither the space nor the money to comply with regulations necessary to prevent air and water pollution.

The Canadian Electrofinishing industry can conveniently be recognized as existing in four big functional parts: (a) Automotive Electroplating; (b) Electrotinning and Electrogalvanizing; (c) General Job Plating; (d) Architectural Anodizing. In Table III.1 are listed some of the largest firms, in terms of annual production. The figures given are estimated totals, based on the sketchy information available, and are discussed later.

With the exception of the steel companies almost all the large plating companies in Canada are subsidiaries of U.S. companies or are wholly-owned by Canadian zinc producers who have their own die casting plants. It is natural that the research and production-control departments in the U.S. plants pass on to their Canadian affiliates the benefit of their experience to the extent that the same processes with which they are familiar at home are specified for use here.

Economic Analysis

Status:- All fully-automatic plating and polishing equipment installed in Canada is imported from the U.S., as are the proprietary addition agents used in plating baths to improve the crystal structure, the throwing-power, the levelling, and the ductility or the brightness of the plated layer. These addition agents are either imported completely made up, or the basic ingredients are imported for further manufacture by Canadian plating supply companies, all of whom represent U.S. companies. The parent companies have research departments devoted to the development of improved plating processes. The Canadian consumer continues to pay heavily, through

TABLE III.1

Some of the Largest Canadian Electrofinishing Plants

	Estimated 1967 Totals: Gross Value ($ millions)	Estimated 1967 Totals: Value Added ($ millions)
1. Automotive Electroplating	50	35
(a) Bumpers (nickel; chrome)		
(i) Houdaille, Oshawa		
(ii) Ontario Steel Products, Chatham		
(iii) East Side Plating, Windsor		
(iv) Others		
(b) Die-cast Trim (zinc; chrome)		
(i) General Motors, Oshawa		
(ii) Plasticast (Noranda), Windsor		
(iii) Coulter Manufacturing (Noranda), Oshawa		
(iv) Others		
2. Electrotinning and Electrogalvanizing	90	63
(a) Tinplate		
(i) Steel Company of Canada, Hamilton		
(ii) Dominion Foundries and Steel, Hamilton		
(iii) Others		
(b) Galvanized Steel		
(i) Triangle Conduit and Cable, Scarboro		
(ii) Iberville Fittings, Iberville, P.Q.		
(iii) Taylor Electric Co., London		
(iv) Others		
3. General Job Plating	45	31
(i) Hudson Bay Diecasting, Bromelea, Ont.		
(ii) Luster Corp. (COMINCO), Wallaceburg, Ont.		
(iii) Acadian Platers, Rexdale, Ont.		
(iv) Kuntz Electroplating, Kitchener		
(v) Empire Electroplating Works, Montreal		
(vi) Plus some 1200 others, from Grondine's in Saint John to Western Hardchrome in Edmonton		
4. Architectural Anodizing	60	12
(i) Kawneer Co., Scarboro		
(ii) Canadian Pittsburgh Industries, London		
(iii) Raymond Manufacturing Co., Lachine, P.Q.		
(iv) Alcan, Aurora, Ont.		
(v) Reynolds Aluminum (Canadian British Aluminum Co.)		
(vi) Others		
Totals:	$245 million	$141 million

TABLE III.2

Estimate of Value Added to the Canadian Economy by a Nominal Electrofinishing Plant

(Type of Business: (a) Anodizing (b) Electroforming (c) Electroplating (d) Electropolishing)

1.	Net annual sales		$1,000,000
2.	Wages and salaries	$250,000	
3.	Taxes: sales, income and municipal	$ 30,000	
4.	Materials used (a) Anode metals (b) Chemicals including cleaners and brighteners (c) Polishing supplies (i) Buffs and wheels (ii) Coated abrasives (iii) Compositions (buffs) (d) Other materials (including manufacturing jigs and conforming anodes)	$400,000	
5.	Services used in production (a) Electric power (b) Water (c) Process steam (d) Waste disposal	$200,000	
			$ 880,000
	Sales Less Costs		$ 120,000
	Value Added to the Canadian Economy		$ 700,000

Note: Capital Investment (land, buildings, plant and equipment; or annual cost of rented facilities) undepreciated in this calculation royalties, licencing agreements, or in the markup of solutions of unknown composition, for this basic and applied research and for the convenience of using materials which carry a certain amount of guarantee to the small jobber. It is apparently more expeditious at the moment to do this, than it would be for the highly fragmented electrofinishing industry to set up properly staffed research and consulting facilities. Many of the jobbers have been sponsored and supported by the U.S. suppliers, who thereby have introduced this new technology into Canada.

It is estimated the Electrofinishing industry in Canada does a total amount of business of $245 million per year. This is composed as follows: Of the total tinplate and galvanizing estimated to have a gross value of $180 million per year, about 80% of the tinplate is produced by electrotinning, and about 20% of the galvanizing is done by electrogalvanizing; so that the contribution of electro-tinplate and electro-galvanizing to the Electrofinishing Industry works out to be about $90 million. At a cost of about $125 to electroplate each vehicle ($110 in USA), the 400,000-odd new Canadian cars, trucks and tractors produced each year account for about $50 million per year. Zinc, brass, decorative nickel, precious-metal plating, and specialty work, account for another -- conservatively estimated -- $45 million per year.

From these gross values, using the ratio of 0.7 for value-added/shipments, as recommended by the U.S. Census of Manufacturers, the total value-added for electroplating industry works out to be about $130 million per year. For anodizing, in which the major cost is electrical energy, a better ratio is 0.3, and the total value added therefore is about $18 million. Total value-added to the Canadian economy by the Electrofinishing industry is therefore about $148 million per year.

Growth Rate:- No reliable estimates of growth rate could be made: the industry is too fragmented and unresponsive to release of data. A similar, also rather tenuous, study of the surface finishing industry in the USA, done in 1965, however, showed that this is a fast growing part of the industry in the USA, growing at a rate of nearly 14.4% per year between '58-'63. Gold plating in the electronics industry in Canada has had a phenomenal growth rate since 1964, as part of the integrated printed circuit production. It is estimated that $500,000 of gold plate will be used in this application in 1967.

There has been considerable work in the aluminum and steel industries on decorative anodizing as a means of surface finishing, some of which has resulted in beautiful and marketable products. The dollar value is still relatively small, however.

A recent innovation, which, although it is still small in scope in Canada, has the potential to grow rapidly from the very broad base of small electroplating firms from Coast to Coast, is the electrodeposition of plastics and paints on metal objects, and the converse, the metallizing of shaped plastic bodies. For instance, electrodeposition of tenacious non-porous deposits of plastics on wire and cable and other parts needing insulation, and on car bodies, shaped ornaments as both protection and color is receiving rapid development. Several Canadian firms are investigating further uses of these techniques, but no information on the extent of effort could be obtained. For example, Ford of Canada recently opened a new plant for electro-painting of cars in St. Thomas, Ontario. However, no estimate of the value of electrodeposition of plastics and paints in Canada was available for this Report.

Research and Development

Industrial:- When it is considered that to deposit one ton of nickel, which costs $1850, there is an expenditure of approximately $450 for addition agents, it seems that a more-than-fair return is being made for the research and development which was necessary before these addition agents were proven. In Canada all suppliers and large platers have analytical and control laboratories, but there is almost no basic research carried on in any of them.

The American Electroplaters' Society has for years been operating a research programme in which there have been projects carried out on 25 different subjects. Up until two years ago, two of these had been at the Ontario Research Foundation with the joint financial support of the American Electroplaters' Society and the Canadian plating industry. This work has stopped. Since a large percentage of the financial support for these projects comes from companies who are themselves interested in promoting the use of their own products, these research projects have been confined to uncontroversial fundamental subjects. (Should anything patentable come out of these projects the Society would apply for the patent and grant licenses to use it without charge). This type of research is essential, and no doubt beneficial to mankind, but it is not the type that would show direct return on the investment either to the Canadian plating industry or to Canada. However, the usefulness of the competence of the agency actually doing such work, in the role of consultants to the supporting firms, is obvious.

Consider nickel, for example. The consumption of nickel for plating purposes in the free world is about 110 million pounds per year, a value in Canadian dollars of $100 million. As almost all of this is plated with addition agents in the plating solutions, there is a world-wide market of nearly $25 million in addition agents for nickel plating alone. Add to this the market for addition agents for electroplating of copper, zinc, cadmium, silver and gold, and there is a potential return in royalties which would seem to warrant a jointly sponsored (industry/government) research programme, provided the research programme is followed completely through to the pay-off point of manufacture and sale of plating solutions and addition agents on a cost-plus basis to the many Canadian electroplaters. Export should be possible as well.

Governmental: A long history of fundamental and applied work in this field is evident by the publications of the Mines Branch in Ottawa, some processes of which have been the subject of patents. The facilities at DRB Halifax and NRC in Ottawa have consistently made contributions to both fundamental and applied knowledge. The Ontario Research Foundation for several years maintained a viable and productive program, industrially sponsored, as was mentioned above, but this work has ceased.

If a suitable governmental R and D effort in this field were estimated as only 25% of the desirable total of 3% of the contribution ($240 million/yr) of this industry to the GNP -- which works out to $2.4 million/yr for government sponsored R and D -- it becomes obvious that present governmental R and D is but token.

Academic:- Academic research on electrodeposition has been sporadic for the last 40 years in Canada, the 1950's being perhaps the most productive decade. However, since '58, academic researchers in at least three locations have begun to study elementary adsorption, in an attempt to understand better how brighteners and levellers work. However, academic workers seem largely unaware of what a true competence in this field could mean to the Electrofinishing segment of the economy of Canada, and of the advantages of protecting the results of their work. Anodic reactions have been studied on many metals but at only two academic locations, and again this work has been sporadic.

Electrodeposition of plastics and of paints both for insulation and color, is under investigation in at least two academic institutions. In one of these, basic information such as chain length and chain branching induced by the electrochemical reaction at the cathode, is being pioneered.

Very few postgraduates enter the Canadian electrofinishing industry, although there are a good number of people with the Bachelor's degree. Of the highly skilled or trained researchers in the electrofinishing industry, most seem to be exploring opportunities in anodizing. With a few exceptions, academic electrochemists have not been interested in electrofinishing per se, although the new techniques for examining thin films and the new theoretical descriptions of the solid state could very advantageously be developed for thin electrodeposits.

Opportunities:

Industrial:- Much remains to be done in neutralization of plating room wastes, and even on electrowinning (i.e. rejuvenation and reclaimation) of plating room wastes. Present processes are effective but they are cumbersome in size and expensive, both in installation and in operation. Improvements in this sector are the most immediate need of the plating industry and would be of the greatest benefit to the country as a whole. Further, they will become essential whenever and wherever laws on industrial waste control are tightened.

A second opportunity for the large volume plater is the production research laboratory mentioned above. His addition agents, bought like patent medicines, are very expensive.

A marked expansion is in progress in the use of non-conventional electrochemical techniques for the application of metals, ceramics and plastics to surfaces, for protection, for beauty, and to make functional devices as well. Cheaper and better finishes can often be offered. Competence and exploration in this area certainly should lead to new products.

Governmental: There is an opportunity for a government agency to assist Canada's very broadly based and widespread electroplating and electrofinishing industry by initiating a systematic research and development effort directed towards proofing-out selected innovations in this field, working out the technological controls which must be applied to Electrofinishing processes, and helping to devise ways to neutralize industrial plating wastes. These tasks could be most simply done within the framework of the industrial/governmental cooperative R and D programs which already exist, such as NRC's Industrial Research Assistance Program, or Dept. of Industry's "GIRD". As has been pointed out, this is a field in which Canadians are paying heavily for undisclosed chemicals, and in which effluents will need further processing, in plant.

This whole field needs a stronger scientific and engineering cadre. The substantial growth rate of the industry (14%/yr in the USA) makes it a good investment, of both industrial and governmental money.

Academic:- The investigation of the elementary processes and initial growth upon which subsequent deposition must occur -- in other words, preparing the interface under controlled and reproducible conditions -- seem to remain the greatest challenge to the academic worker in this field. The problems are unusually difficult and require the development of new techniques for observation and control. New knowledge, new approaches and experience, and the proper education of young scientists in this field would enable us to span the very real and apparently bottomless gap which exists between the few fundamentalists in the country and the 1300 or so operating plants. There are already substantial scientific as well as monetary awards available for educators and researchers truly competent and broadly conversant with this field.

Recommendations

1. That a Chair for Electrofinishing Studies be established in one of the Country's polytechnic institutes, to offer a provocative education in science and engineering relevant to this field, and through research to provide new information on nature and properties of addition agents. The granting agency should reserve the right to assess the captive aspects of the information produced, before publication.

The void, the need and the dispersion of the industry suggest complete subsidy by the Federal Government at a rate of $60,000/yr for 10 years plus an initial capital outlay grant of $50,000 for necessary equipment.

2. That the electroplating industry renew its good faith by re-instituting its former collective support of fundamental electroplating studies in one of the research institutes.

3. That imaginative firms propose to Government cooperative programs; under IRAP, or GIRD, to investigate techniques and processes for electrodeposition of plastics on metal, or metal on plastics, and for electromachining of metallic precision parts.

4. That those government agencies concerned with industrial-waste control designate an area in which sizeable pollution occurs primarily from this source, and initiate a pilot study of methods of control, -- the results to become the property of the 1300 or so Canadian owners of electroplating plants.

PART IV. BRIEF STATEMENTS on FOUR IMPORTANT FURTHER TOPICS

This section of the Report contains briefs on Electrothermics, Corrosion, Semiconductor Electrochemistry and Biological Electrochemistry. Each has a unique importance and stimulating aspects for study. However, each has much wider vistas than purely electrochemical. In corrosion and solid state science much of the knowledge and many of the problems are not electrochemical at all, in the sense defined in the Introduction. These Briefs record some facts and opinions, but are not presented as anything but "other information" which has relevance to electrochemistry.

A. ELECTROTHERMICS [1.]

In this section we refer very briefly to a family of processes which occur at a satisfactory rate at high temperatures, in reactors kept hot by the dissipation of electrical energy. Industrially these processes are very important to the Canadian economy. The following paragraphs illustrate.

Electric Reduction Co. utilizes phosphate rock, coke, and quartzite to produce elemental phosphorus (25,000 tons per year), as well as ferro-phosphorus and slag. The markets for these products are fertilizers, detergents, foods, steel (ferro-phosphorus), and rust-proofed steel. The company is currently building a large smelter in Newfoundland to produce elemental phosphorus starting late in 1968. Quebec Iron and Titanium Corp., Sorel, uses ilmenite ore and coal which are smelted to produce 70-72% TiO_2 slag (470,000 tons per year) and high purity pig iron (330,000 tons per year). The markets for these products are: slag for paint, rubber, plastics and paper industry; and pig iron for the iron and steel industry. Shawinigan Chemicals at Shawinigan, P.Q., uses limestone as their principal raw material to produce calcium carbide. This is used as the basis for the manufacture of acetelyne and various organic chemicals derived therefrom. The company markets industrial chemicals and petrochemicals for a wide variety of uses. A new Research Laboratory was recently built west of Montreal.

Union Carbide Canada operates two major plants, one at Beauharnois, P.Q., and the other at Welland, Ont. The smelter at Beauharnois utilizes quartzite, ferrous scrap, carbonaceous reducing agents to produce ferrosilicon and silicon metal. The markets for these products are the steel industry, iron foundries and the aluminum industry. At Welland the raw material for ferro-alloy production include manganese ores, chromium ores, ferrous scrap, and carbonaceous reducing agents.

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1. Refer to Report on High Temperature Chemistry for full discussion of this topic.

Principal products are ferromanganese, silicomanganese, and ferrochrome, which are marketed to the steel and iron-foundry industry. There is also a carbon products plant at the same location where various products made of carbon and graphite are produced for the metallurgical, electrical, and chemical industries. Principal raw materials used are high grade anthracite, metallurgical coke, petroleum coke and coal tar pitch. The principal products include arc-furnace electrodes, carbon refractories, and graphite anodes. Great Lakes Carbon Corp. operates a graphite plant at Berthierville, P.Q., where they import raw forms which are graphatized and machined. The principal products produced are arc furnace electrodes and graphite anodes.

Chromium Mining and Smelting Corp. operates a smelter located at Beauharnois, Quebec; principal raw materials used are quartzite, manganese ore, ferrous scrap, and carbonaceous reducing agents. Products produced are ferrosilicon, silicomanganese, and ferromanganese, which are marketed to the steel and iron-foundry industries. Norton Co., Chippewa, Ont., produce high-grade magnesia and related refractory materials by the electrothermic route.

There are others, but this list indicates that the contribution of Electrothermics to the Canadian economy is substantial.

No attempt was made to assess the extent of research and development in the Industry. This is reviewed elsewhere.

The long history of published work by the laboratories of the Mines Branch attests a sustained attempt by the Federal authorities to contribute to this part of the ceonomy through research and development.

B. CORROSION [2.]

"In Canada, Corrosion as an engineering science is rather young. Its economic significance has yet to be fully appraised, and its importance to the technological community has been insufficiently emphasized. Research has been scanty, and has occurred because of the interest of individual organizations, rather than as a result of any broad general interest or appreciation. Expenditures on corrosion-resistant materials, and in mitigation action, represent several percent of the gross national product, but much of this cost is wasted because of a general unawareness of the technologies involved.

Economic Factors

Two aspects of corrosion control are reflected in economic estimates. The capital expenditures on corrosion resistant materials

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2. Quotations are taken from a brief submitted for this Survey by the National Association of Corrosion Engineers, Toronto Section. Two substantial recent reviews are available: Can. Chem. Processing, March, 1967, p. 37 and p. 43.

and processes probably represents a large but minor portion of the expenditure, while loss as a result of deterioration represents a major proportion.

Using data from a study carried out by Stanford Research Institute in 1964 as a guide, the following expenditures for materials and systems for 1962 are presented ($ millions), with the projected 1975 figures in parentheses: Surface Coatings 115 (150); Metals and Alloys 75 (140); Plastics 10 (33); Inhibitors 10 (20); Anodic and Cathodic Protection 3 (8). Totals are, for 1962: $213 million, and for 1975 projected: $351 million.

It is estimated that the economic loss through abnormal deterioration is at least as great as the capital expenditure, and probably somewhat more. The total bill for corrosion in Canada is presently therefore, somewhat greater than $400 million, and is projected to rise over $700 million by 1975.

These figures are of necessity approximate, since no surveys have been made of corrosion costs in Canada, to our knowledge. Even in the U.S.A. deterioration of economic loss as a result of corrosion has only been of an approximate nature.

Education

Education in corrosion science in Canadian Universities and Technical Schools at the undergraduate level is minimal or non-existent. The subject is touched on by some courses in metallurgy and electrochemistry, and may be referred to in general courses on engineering materials. However, little is done to make undergraduates aware that corrosion may represent their greatest single operating problem when they begin to practice. This is certainly true for those entering the petroleum or chemical processing fields, or the automotive industry.

At least one technical school (Ryerson Institute) specifically includes corrosion as a subject in its Gas Technology course, but this is an exception rather than a rule. Attendance at the few "short courses" offered through N.A.C.E. and other technical societies indicates that interest is high among practicing engineers, and that expanded opportunities for post-graduate education are needed as well as undergraduate training. In central Canada, Queen's and McMaster Universities offer both undergraduate and post graduate corrosion courses -- to metallurgical engineers at Queen's, and to materials science students at McMaster.

Research and Development

Previous published Canadian studies have shown that, except for work carried out under Government agencies, corrosion research and development work is limited to the efforts of a few uniquely Canadian companies, and a few individuals who have been able to assemble the facilities. Conversely, INCO a Canadian company specializing in corrosion resistant materials, does little or no corrosion research work in Canada. A major problem exists in the translation of the results of fundamental research carried out by N.R.C. into terms with which the practicing engineer can deal.

Recommendations

A three fold programme would be necessary to bring the level of corrosion activity in Canada to a noteworthy level.

1. Define Problems

A survey of expenditures and losses, by industry and by process would serve to better define the extent and concentration of economic losses. The results of the survey, properly published, would do much to remove the largely negative aspects of corrosion, and emphasize the need for acceptance of corrosion as a distinct technology.

2. Improve Education

All undergraduate courses concerned with the metal industries, and process industries, should include at least one term of corrosion lectures and laboratory examination of sample material. Implementation of this would be difficult, but University faculties must be made aware of the need for courses of this type in industry. Post-graduate options in corrosion could be introduced both by the farming out of Government-sponsored projects, and by the active solicitation of industrial funds by Universities.

3. Increase Research and Development

An increased availability of trained corrosion scientists would stimulate an increased awareness of remedial actions which could be investigated. For example, product development is one of the major avenues to a demand for more corrosion resistant-materials or other means of control for longer life of reactors.

In industries where corrosion is a relatively severe problem, the present depreciation allowance and maintenance-cost tax-provisions tend to foster a replace-in-kind philosophy, rather than to stimulate an intensive search for better materials and equipment. Changes in this part of the taxation structure could be made to increase the incentive to preserve and improve, rather than to ignore and replace."

C. SEMICONDUCTOR ELECTROCHEMISTRY

Two viewpoints are presented in this brief on semiconductor electrochemistry: First, the perhaps narrow and traditional one, in which charge-transfer at the electrode is a prerequisite for inclusion; and second, the broadened viewpoint which has evolved within the Electrochemical Society, which goes even so far as to list as one of its topics the whole field entitled: "Solid State Science".

In the former, narrow sense most of solid state science is not electrochemistry at all : no chemical change occurs during the operation of the device; and the electrochemical part consists only of those electrochemical operations or effects used in the preparation. In the latter, broad sense the subject includes the investigation of electrical phenomena of materials in the solid state, a subject which leads into the manufacture of practical devices in which these phenomena are utilized. From the broad point of view of solid state science, the traditional phenomena of charge-transfer reactions might be essential, important, minimal, incidental, or even non-existent, depending upon the application in view and the technology required to reach the defined goal.

The common fundamental, both in concept and in fact, is the existence and behavior of what have become known as "surface states".

Background Information

There are two general practical fields in which semiconductor electrochemistry plays a role : solid state electronic devices, and flotation of suspended particles in metallurgical and chemical processing. In processing, the effects of compositions of the slags and electrolytes which promote stability of the suspension has been utilized for many years. However, basic detailed knowledge of the semiconductor/electrolyte interface is only now being elucidated. By contrast, the solid-state device industry is very new in Canada, and the substantial R and D to support it is newer still, since about 1961, following antitrust legislation in the USA.

Neither the metallurgical industry and the general chemical industry on the one hand, nor the solid state device industry on the other, considers itself primarily electrochemically based. In this paper we point out that (a) there are certain key steps in each of the process industries which could be better understood, and perhaps better controlled, if a better understanding of the electrochemical interfacial phenomena existed; and that (b) the intense concentration of R and D directed towards electronic devices can make serious contributions to better control in the conventional industries, if translation of the information from the language of the device man to the language of the process man can be accomplished. The electrochemist, because of his varied training and experience, should be best prepared to do the translation. The Ontario-Quebec Section of the Electrochemical Society recognizes this, and has been promoting interdisciplinary scientific meetings for this purpose.

That part of the device industry which has relevant R and D in progress is represented by Northern Electric Co., with by far the largest program, Canadian Westinghouse, RCA, Fairchild, Sprague, and Noranda. Relevant university work is located at Waterloo, McMaster, Simon Fraser and Carleton. ("Relevant" here means "electrochemical", in the broad sense defined above.)

Economic Analysis

No way could be found to do a useful economic analysis. In the metallurgical and general chemical industry the isolation and identification of the importance of interfacial phenomena in processing could not be completed in the time available. In the electronic device industry two problems occur: (a) Much of the market is a directed one -- Northern Electric for the telephone system, for example -- and production data are not readily isolated from data available; (b) The fraction of production which could be classified as electrochemical in the narrow sense described above is not only small, but also is changing rapidly as the items which are produced change. The amount of electroplating, for example, shifts sporadically. It is interesting to note, though, that the amount of plated gold which will be used in the device industry this year is quite substantial: approximately $0.5 million.

Rate of Growth

The established process industry has doubtless enjoyed the growth rate suitably reflected in the GNP. However, no analysis could be made which led to any better estimate of this figure.

The device industry has been growing since the mid-'50's, with the maximum rate of growth achieved between 1964-1966. For example, during that period the payroll for R and D and production of solid state devices doubled for one large company, and a certain amount of expert was achieved for the first time.

Research and Development

Industrial:- Growing much more slowly than in other countries following the invention of the transistor, through the '50's, Canadian industrial research and development, directed as it is towards electronic devices, has expanded rapidly in the '60's, especially since 1962. In the narrow sense of the definition of electrochemistry, electrochemical etching, metal deposition, polishing, or metalliding has played a minor economic, although technically important, role. Indeed some of the electrochemical techniques which have been developed have been found to be indispensable.

In this field of solid state science many government/industry, shared-cost R and D programs exist, with a total value of about $3.2 million in 1967. (The Defence Industrial Research program spent $1,525,000 on 50/50 cost sharing programs in this field in 1967.) Only one or two of these projects are electrochemical in the narrow sense; perhaps as much as 70% are electrochemical in the broad sense used by the Electrochemical Society. From the Industry's point of view, these projects are simply: "R and D in support of the electronic device industry".

The important conclusion drawn from the difficulty with definition is that, whatever it is called, there exists a blossoming area of interface science and solid state science which has a practical and important association with two big sectors of industry; and that this area must be properly assessed somewhere in the Science Council's surveys. This present assessment must be considered to be only an introduction.

Government:- Besides its direct support of about 50% of the cost of 3.2 million dollars' worth of this kind of work, several government agencies -- AECL, NRC, Mines Branch, DRTE, for example -- do a substantial amount of broadly based investigations not so specifically oriented towards electronic devices, for example: NRC's investigation of new materials with semiconducting properties; Chalk River's ion implantation and solid-state channeling investigations. Practically none of this work is "electrochemical" in the narrow sense; probably all of it is in the broad sense accepted by the Electrochemical Society and its publications!

Academic:- University work in solid state science has had its greatest productivity in studies done from about 1956 on, on anodic oxidations, leading to new understanding of the behavior of thin oxide films under high electric fields, and to electrolytic capacitors (See Part II), for example. Lack of facilities to produce and handle materials with the necessary purity probably represent the greatest obstacle to academic researchers who wish to study the electrical or structural properties of thin solid-state films, or similar problems. The academic leadership presently seems to rest in metallurgy or "materials science" departments: at UBC, Queens, Waterloo, McMaster, and U. de Montréal, for example.

Even the routine tools in this field are very expensive and difficult to maintain -- controlled, dust-free atmosphere, for example. It would seem that the academic approach might logically be to try to collaborate closely with industrial laboratories for instructions. The Committee found one case in which this is being done, apparently without inconvenience which one might think might be attached to arranging instruction for students in the industrial R and D facilities which already exist, and certainly at much less expense to the university.

The university weaknesses are lack of ability to produce R and D people with a broad background in both solid state theory and practice so as to require minimum instruction upon entering industry. On the technological level, the courses now offered do not prepare the student for assisting in R and D in this field : for example, the electronics graduate seems to be strictly electrical, with little background in chemistry and physics; the chemical graduate is oriented towards organics, heavy chemical or analytical chemistry, with little appreciation of the high purities required in the solid state field. A wealth of opportunity for research on surface states awaits the academic researcher who has learned how to examine them experimentally under ultrapure experimental conditions.

Recommendations

1. That Universities and Technological Colleges respond soon to a real need in the Industry for people suitably educated in solid state or materials science, and with the basic background in electronics, physics and physical chemistry, and the techniques of making and handling ultra high purity materials.

2. That the Federal Government (thru NRC, or Energy Mines and Resources, or possibly through an ancillary program to DRB's well established industrial contractual system in this field), make available substantial support for one University and one Institute of Technology, provided they are prepared to work out with the solid-state-device Industry the part-time use of high-overhead Industrial facilities for instructional purposes, as well as a suitable curriculum.

3. That a special committee, composed of Industrial, Governmental and University representatives*, now be formed by the Science Council, to make a review of Solid State Science, from the point of view of recognizing opportunities for Canada and recommending specific actions.

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*Suggested personnel: J. Goldak (Carleton), K. Smeltzer (McMaster), R. Ferguson (Northern Electric), R. McIntyre (RCA), J. Davis (AECL, Chalk River), P.A. Redhead (NRC). Committee to have its secretariat within Dept. of Industry, who would provide the overview.

TABLE IV.C.1

Rate at Which Solid State Science*
is Being Done in Canada - 1967

Type of Work	Industry	Federal Gov't incl. AECL	University
Development of Devices	80	10	5
Process R and D	30	15	15
Applied Research	20	30	25
Basic Research	20	15	15

*In the broad sense defined by the Electrochem. Soc.
Units: Scientific and Engineering Man Years during 1967

N.B. These numbers are rough estimates based only on the opinions of three people active in the field, and should be considered only as roughly made first approximations. However, they are the only numbers available to date.

D. BIOLOGICAL ELECTROCHEMISTRY

Many control mechanisms in living organisms are largely electrochemical in nature. In this Brief four examples of electrochemical control in biological systems are outlined, and a recommendation is made that they be reviewed further.

Nerve Transmission

Along the nerve axon, information is transmitted by a depolarization (chemical and structural changes which can be observed as a voltage change) which can pass rapidly down the tubular membrane of which the axon is constructed. Recovery behind the wave is rapid. The process essentially seems to be due to a transient change in the permeability of sodium and potassium ions. The topic has had extensive investigation from the points of view of electrophysiology, and more recently of biophysics; but it is still pretty much a virgin territory for the fundamental electrochemist. Transient-state models which have been proposed to describe measured events need development directed towards prediction. The electronic pulse techniques and reference electrode techniques of the electrophysiologist are very advanced. The experimental material shows electrical properties which could be semiconducting as well as ionic, a fact which adds to the intrinsic interest of the subject, offers new principles to be unravelled, but which suggests how very complicated these highly refined control processes really are!

There is research activity on this topic in most of the medical schools and in some university departments of biology in Canada. The electrophysiology published by certain researchers at Montreal Neurological Institute contains some purely electrochemical content, but the approach is basically different from the electrochemist's.

Living Cell Walls

The general cell membrane is highly specialized, in another way. For example , that of the red blood cell encloses a small but fully operational chemical factory; and it controls the passage of raw materials into, and of products out of, the cell. The structures and the ionic and molecular mechanisms which provide this control are of importance in studies of growth rate, ageing and cancer.

It seems that the new tools of thin-film solid state science for examining structure could be applied, and that modern theories of electrochemical rate processes in membrane phenomena should be developed for living cell walls.

Blood Flow

In a typical physical process such as blood flow through capillaries, the molecular/surface structure and electrical properties of the inner wall of the capillary will doubtless affect the physical drag (i.e., resistance to flow) which is experienced by the blood plasma and suspended erythrocytes. Further, the cells themselves will experience forces during flow which will depend, amongst other factors, on the surface charges they carry.

New principles are being worked out in model studies at McGill University and at University of Western Ontario, but in general the subject of electrochemical hydrodynamics has been badly neglected in Canada, with reference to biological processes as well as more generally in flotation phenomena.

Polyelectrolytes and Colloids

Basic knowledge on this topic is well grounded in Canada, including the more recent advances made by electrophoretic techniques. However, although there exists in the huge pulp and paper industry some of the world's finest accumulated knowledge on the electrochemistry of colloidal and polyelectrolyte phenomena, it is suggested that this knowledge has not been fully translated into practice in biological practice. For instance, there seems to be a good opportunity to develop more refined techniques for measuring sedimentation rate in plasma sampled from arthritic victims, in hospital laboratories. An applied electric field would assess the normality of the composition and behavior of the polyelectrolytes in the sampled plasma, and provide clues which might suggest remedial action. Electrochemical relaxation phenomena would provide another tool for examining the two critical quantities simultaneously: structure and charge distribution.

Recommendations:

1. That the Medical Research Council and the National Research Council study how best the few and conceptually isolated Canadian electrophysiologists, membrane biophysicists and biological electrochemists can assess cooperatively the need for some planned effort directed towards (a) developing improved diagnostic and therapy procedures and equipment, such as pacemakers and prosthetics, (b) improving our understanding and control of psychologically active electrochemical noise in the nerve and brain, and (c) promoting truly fundamental research on the nature of biological electrochemical processes.

PART V. SOME NEW OR DEVELOPING SEGMENTS OF ELECTROCHEMISTRY

Water Desalination and Membrane Electrochemistry

Of a number of processes or phenomena which may prove to have considerable technological importance in the future, membrane electrochemistry offers exciting promise for almost immediate large scale application. Because of its potential significance in the fields of pollution control and desalination, substantial sums have already been spent in other countries, with the result that a number of techniques are in or approaching pilot scale development.

The two principal techniques, which seem of most importance because they are essentially complementary, and because neither involves a change of state, are Reverse Osmosis and Electrodialysis. The first affords a means for removal, or substantial reduction in, concentration of all solutes in an aqueous solution (or conversely, an enrichment of solute in the input solution); whereas the second provides a means of recovering industrially valuable reactants or by-products by separating the solute constituents into ionic and non-ionic fractions. There is the promise that ionic separations may be possible when appropriate ion-exchange membranes are produced.

Canada (at NRC) is well advanced, at present, in the development of Reverse Osmosis for commercial exploitation. The process depends upon establishing a moderate (10 atm) pressure differential across a membrane whose surface preferentially absorbs one of the constituents of the solution, with the result that the solution passing through the membrane is enriched substantially in the "wetting" component. For example, in desalination of sea water, reduction of salt concentration to potable levels (200 - 300 ppm) is achieved in a single pass at a rate of 10 - 20 gal/ft^2/day. In pollution control it has been shown that the technique is effective also in the removal of organic constituents (e.g. detergents). Appropriate selection of membranes may also prove valuable in the separation of constituents (e.g. polar from non-polar organics) of solutions resulting from industrial synthesis, eliminating in some instances the necessity for fractional distillation. The degree of separation achievable in practice may limit its direct analytical application on a large scale, but its use to provide preliminary separation in conjunction with the more selective electrodialysis technique, makes reverse osmosis a potentially valuable tool for the analyst.

Electrodialysis provides a means for the removal of ionic constituents from a solution. Because of inherent cost of power, its application will tend to prove much more specialized than reverse osmosis. For example, it has already been demonstrated that electrodialysis can cheaply and effectively "sweeten" citrus juices (particularly some types of grapefruit juice) by selective removal of citrate ion, leaving the remaining solid content, including the pulp, entirely unchanged.

In general, electrodialysis is carried out in a multi-compartment cell, the compartments of which are permeable to anions or cations or solvent. Application of an electric field produces a net drift of positive ions toward the cathode and negative ions to the anode. Imposition of ion-selective membranes (ion-exchange membranes) results in the depletion in alternate compartments of ionic constituents, and an enrichment in pure solvent. (The slower process which occurs in the absence of a field in the same type of cell is simply "dialysis".) Since removal of ionic constituents results in a substantial increase of resistance, the voltage across the cell must rise if constant current is to be maintained, thus greatly increasing the power level if very complete separation is to be achieved. However, if the initial concentration of solute were to be increased by reverse osmosis, subsequent separation and recovery of valuable intermediates (e.g. in pulp mill effluent) could be achieved quite economically.

It may be assumed that in the future, membranes will be available to permit both analytical and large scale separation of ions. Divalent ions may even now be separated from monovalent ions, and isotope enrichment in Li^+ solutions has been observed. Natural membranes are responsible for maintaining Na^+/K^+ separation in cells, so it is not unreasonable to presume that synthetic membranes to achieve such separations are possible. If so, the analytical possibilities are obvious.

Gases can also be separated by the use of membranes. Commercial application is already being made of H_2 purification through Pd and Pd-Ag alloy, and small scale application of O_2 enrichment (to say 30%) for hospital use has been demonstrated. Furthermore, CO_2 can be effectively removed through membranes, a process which has obvious application where men are to work in confined spaces such as in submarines or space capsules.

The last membrane technique to be mentioned is that which has recently been applied to the well-established process of electrophoresis. This is Forced Flow Electrophoresis, in which the input solution enters the top of the anode compartment and enriched solution is removed from the bottom of the same compartment. Pure solvent passes through a membrane separating anode from cathode compartment and is removed from the latter. Application is seen as a non-clogging "filtering device to separate coarsely suspended materials such as algae, bacteria, clay and other gelatinous precipitates", and also oil-in-water emulsions. Selective removal of colloid components could probably be carried out more effectively than with conventional electrophoresis.

Electro-organic Synthesis

Electro-organic synthesis has been investigated for many decades because of the promise it holds for carrying out controlled-potential, and hence selective, oxidation or reduction of a number of organic molecules. The principal limitations are the lack of suitable solvent/supporting-electrolyte systems in which to carry out synthesis. Ideally, one would have a reactant fed to the appropriate electrode comparment defined by a barrier membrane, together with a product which is either insoluble in the electrolyte or readily separable from it and from the reactant flow system. There is no known theoretical limitation.

In several places in the world it has been announced that investigations of the problems arising in the scaling-up of recently disclosed and patented processes for producing literally hundreds of organic chemicals are in progress. For example, one U.S. company has announced it has on-stream a large pilot-plant facility for making adiponitrile from acetonitrile in an electrolytic reactor. More recently, work at the University of Manitoba has shown it to be possible to produce polymers of controlled branching, in suitable electrochemical cells. One gains the impression from the press releases and rapid rise in the rate of patent disclosures, that the exploitation of electro-organic synthesis is about to explode.

Canadian research in this field has been sparse. R and D directed toward commercial exploitation has been non-existent, as far as the Committee could determine. The opportunities would seem to be enormous.

Electroanalytical Devices

Further refinements in electrochemical techniques applied to analysis may occur in instrumented routine analyses of samples having approximately the same composition -- in the quality control of a product, or in analysis of blood specimens, for example. The development of selective electrodes, specific for one or a class of oxidants or reductants, has application in chronopotentiometry and high-speed polarographic analyses.

Of special significance is the development of gas coulometry, based on new fuel-cell electrode technology. The principle is simple: at some fixed value of cell overpotential the rate of reaction at the gas electrode (i.e. the current through the electrode) is directly proportional to the concentration adsorbed on the surface; and this in turn is related to the rate of supply from the sample gas stream. From a source, then, the rate of supply of gas is measured continuously as a current. Hydrogen and oxygen coulometers, a NO_2 coulometer to monitor air pollution, and the recent Mines Branch development of a high-temperature O_2 coulometer to monitor O_2 in molten steels, are examples. There is some work in progress at the Universities of Saskatchewan, New Brunswick and Alberta, and at AECL and Stelco, but it is not extensive.

Photopotential and Electrochemiluminescent Devices

Generally, photo effects at electrodes are much less pronounced, and hence more difficult to observe, than the photo-voltaic effects that occur in semiconductors. The immediate application of such effects at electrodes in contact with electrolyte solutions is as an effective research tool in the study of the behaviour of the solvated electron. In principle, use could be made of the phenomenon in solar energy conversion, or in actinometry, but at the present state of the art this looks unpromising.

Of somewhat more promise is the converse effect, namely electrochemiluminescence, which may provide a means of producing "cold", substantially monochromatic light in the visible range, and possibly at higher electrical efficiency than from other sources. Several low-intensity sources have been demonstrated. Light emission occurs on the return of an excited product molecule to its ground state, and the molecule itself must either fluoresce or transfer its energy to an intermediate which can fluoresce. To achieve a high intensity, the excited product must be produced at high concentration,and self-quenching must be minimal.

Relevant research is in progress at NRC, Department of Agriculture laboratories in Ottawa, and at both U.B.C. and the University of Western Ontario.

Electrocoating

The electrodeposition of plastics on metallic surfaces for their protection against corrosion is an exciting field just opening up. Two large companies, International Harvester Co. and Ford of Canada, have new facilities, the former to coat disc harrows, and the latter to coat car bodies. The paint is a water-thinned system of low solids content, and the suspension is of charged macromolecules. Electrophoretic migration occurs under the influence of the applied electric field. The field strength is so large at the interface that absorbed water is squeezed off as polymer deposits. The deposited layer can be very tight and thin. So far, however, it can be used to apply only the primer coat, usually discolored.

No research and development in this field could be located in Canada.

Technically apparently well behind the electrodeposition of plastics on metal is the electrodeposition of metal on plastics -- on plastic parts which have been cast, blown, machined, etc. Significant advances have been made in electroless deposition. Bonding is the big problem, in the first molecular layer in which metal is attached to plastic. Trade literature predicts phenomenal future for metal-coated plastic parts.

Electrochemical Timing Devices and Charge Integrators

Faraday's law has been applied in the form of silver-silver coulometers in small timing devices and other charge integrators. Other metals such as copper and indium have worked as well. Recently the cadmium-cadmium coulometer has been applied to the charge-control system of the nickel-cadmium battery. Always in series with the battery, it integrates the charge taken out, and during recharge it displays sudden voltage when the charge has been replaced. The principle is applicable to many signalling and warning devices, and could be more widely exploited.

The solid/electrolyte interface has peculiar electrical properties not easily amenable to description in terms of equivalent circuitry. Specialized amplifiers and other "electronic" devices are therefore possible, for example in analogue computation, solions, and electrode-potential-controlled proportional-fluid-flow amplifiers or mixers.

The recent rather vigorous investigations of the leaky-memory (i.e., loss of stored charge) properties of certain electrochemically formed anodic oxide films has led to their incorporation into leaky-memory circuits on an experimental basis. Further development of the electret (separated charge stored permanently in a dielectric) has led to its incorporation on a commercial scale in electrometers, detection devices, and telephone head sets. Northern Electric have published on the last item.

Fuel Cell Batteries

This subject was introduced into Part II of this report because of the completed demonstrations of the feasibility and practicability (in certain applications where high energy density or continuous feed or quiet operation is truly important) of the conversion of chemical energy directly into electrical energy as low voltage dc. Canadian research and development effort is growing, with three companies and one governmental agency active.

It is re-introduced here in this part of the report because the possible influence of this development is so enormous: the all-gas home, silent power for yachts, local generation of power for apartment houses, and even power for small remote villages, of this as well as emerging nations.

In principle able to supply electrical power from a few watts to many tens of kilowatts, Canadian efforts are presently concentrated on the 5 watt buoy and the 300 watt field generator.

A recent U.S. publication, Wenglowski's technico-economic study, referred to heavily in Parts I, II and III of this Report, lists the fuel battery as the new and emerging electrochemical device likely to have the most impact on mankind in the foreseeable future.

Recommendations

The rather general and perhaps tenuous nature of possible opportunities under the several headings of this part of the Report on new and developing areas of electrochemistry prompts the following recommendations:

1. That a full technico-economic study of each of these areas be conducted by either the Department of Industry or the Department of Trade and Commerce, or their consultants (possibly as University theses); and their report(s) published. Timing may be critical.

2. That the Technical Information Center of NRC, or other suitable and interested agency such as the Ontario-Quebec Section of the Electrochemical Society, be asked to distribute to all conceivably interested manufacturer, and consumer, R and D agencies, quarterly, for a period of two years as a trial, a synopsis of recent scientific and technico-economic developments on the topics covered in this part of the Report.

PART VI. GENERAL CONCLUSIONS

From the attempt to define problems, recognize opportunities and arrive at useful recommendations, certain general themes can be developed.

The biggest part, Electrolytic Processing, means about five times more per capita to the Canadian economy than to that of USA; it has a special importance.

(1) Effective steps must be taken to increase the growth rate of this industry; it is now just over half the growth rate in USA, for example.

(2) It will take unusual cooperation by government and industrial leaders to determine how big, power-intensive industries such as this one can best grow along with the Country in the new medium created by increased public ownership of hydroelectric power.

(3) The construction of nuclear power stations near the traditional foreign sources of some of the raw materials for the electrochemical industry will make it necessary that Canada specialize in responsible and experienced electrochemical engineering -- both at home for the "one-step-more" of processing, and to developing countries in their quest to purify and process their own raw materials now that power is becoming available to them.

The long-term effects of (2) and (3) need to be considered in more detail in a further review, perhaps as a joint effort by specialists in industry and government, but perhaps also by selected and commissioned theses by the fresh, young minds of graduate students in economics and electrochemical engineering.

The widely distributed base of Electrofinishing in Canada -- many small plants from Coast to Coast -- provides a wonderful opportunity for wide dissemination of corrosion-control information and technology, and new techniques for the deposition of plastics on metals, or metals on plastics. The people and basic equipment are already locally in operation.

Great opportunities for rapid growth seem to exist in electrocoatings, electroorganics, and in solid state devices. Already Canadian technical competence has fallen behind the leaders in these fields.

In every section of this Report the theme is advanced that opportunities for a young person to obtain an education in science, in engineering or in technology specifically oriented towards objective electrochemistry or the electrochemical industry, are lacking.

Courses in electrochemical engineering are weak, or non-existent. Physicists and physical chemists bridge the gap only via expensive reorientation in the industry. Technologists are either electronically or heavy-chemical minded, not electrochemical. The suggestion is that the academic institutions have not responded to the needs of a large number of students and of the economy which will absorb them. Many of the industries which contributed to this Report perhaps have not been as clear as they might be in stating their need.

In the field of electrochemistry the translation of scientific problems and the publication of research results by industry has been only sporadic; while translation of the interests and explanation of importance or relevance of university research has been likewise not too effective. A channel for scientific and technical communication in electrochemistry seems badly needed. In one part of this report a central information agency was proposed; in another it was a journal; in another it was a staff for analysis and translation of information from fundamental to applied terms, or from applied to fundamental; in another it was translation from one part of the field and terminology into another. The first and simplest steps would seem to be logically a news letter, and an increase in interdisciplinary exchanges of information at technical meetings. These require modest support. The technico-economic reports prepared by government departments can be truly effective only if published. Thesis studies by graduate students with the technico-economic approach, focused on Canadian topics, could prove very effective. The establishment of chairs of electrochemistry -- whether industrially sponsored, governmentally sponsored, or jointly sponsored -- was recommended, and the recommendation seems to be strongly supportable.

In this Report an attempt has been made to generate data from which Canadian research and development activity could be expressed as a fraction or percentage of the value added to the economy by electrochemistry. Value added (VA) as used herein includes costs of the electrochemical step and whatever fractions of the preparatory and subsequent steps seem to be largely dependent upon the electrochemical step for their existence. The "fraction", highly developed in large and mature economics, is useful but less reliable in the emerging Canadian technico-economic context, where a decision to exploit often has more positive impact on productivity than even a very successful effort in research and development. In the Canadian situation, then, R and D, expressed as a percentage of either gross value or of value-added, must always seem low.

In Electrochemical Processing we find a growth rate of 4.5% per year, and expenditures on R and D estimated at well below 0.4% of gross value (0.8 of value-added). In Electrochemical Energy Storage the growth rate is about 8% per year, and R and D is about 1% of VA. In Electrofinishing topics the growth rate was estimated at between 10 and 15% per year, higher since the automotive agreement with USA was signed, but recognizable R and D remains much less than 1% of VA. In the New and Developing Segments, no growth is yet recognizable; however, a broad and strong, but scattered base of research exists on which to build. Academic research is excellent in quality in this field, much of it being electrochemical kinetics. Engineering development generally is the weakest part of electrochemistry in Canada.

In Electrothermics no analysis was done, although Canadian capability was outlined. Semiconductor Electrochemistry in its broad sense was shown to have a substantial base in R and D, essentially new since 1962, directed towards the electronics and communications fields. Corrosion losses were estimated at $400 million per year for 1965, and growing; research is scattered. Research in Biological Electrochemistry is scattered also. In all these four fields electrochemistry plays a minor, though important, role.

From the analyses done it was possible to arrive at the facts that although the industry contributes a value-added to the Canadian economy of about $700 million, the amount spent on research and development is less than 0.25% of gross value -- that is, less than $4 millions per year. The weaknesses seem to be in the amount of effort (especially on engineering development) in the specified new and developing segments as well as in the conventional part of the industry, and in the fragmented mutual help between academic and industrial researchers resulting from lack of stimulation for both groups. For reference to the specific Recommendations made, see Table VI.1.

Based upon analyses of what the needs seem to be, where the competence presently lies, and upon an assumed desirable figure of at least 1% of gross value to be assigned for research and development in the field as it has been defined, a proposed work plan, Table VI.2, was generated. It shows the proposed sources and distribution of $16 million annually in R and D: by type of work, by field of electrochemistry, and by institution known to be capable of doing the work. The work plan would be financed jointly by Industry and Federal Government, and would be phased in over a five-year period 1968-1973, if acceptable. It would be coordinated by an Electrochemical Communications Center.

Such a program would probably solve our major problems in this field and assure growth, innovation and discovery in this field, which already contributes so much to the culture and the economy of Canada and the free world. As we broaden our vision and begin to open up the resources of the North for the greater general good of mankind, the proposed plan to develop further our scientific-engineering-economic competence in the field reviewed, would be able to contribute to planning the sociological development of the Country as well, for this particular field of chemistry has a strong scientific-technico-economic backbone.

TABLE VI.1

References to General Conclusions and Specific Recommendations Made in this Report

TABLE VI.2

A Possible Disbursement of Technico-Economic Research and Development Effort Totalling 1% of the Contribution of Electrochemistry to the GNP -- Recommended to be Phased In Gradually Between 1968 and 1973

	R and D to be Done by(*):	Yearly Investment on R and D by: Industry	Government
I. ELECTROLYTIC PROCESSING			
(a) Metals [Al, Zn, Pb, Cu, Ni, etc.]	Industrial Firms	$3,000,000	$1,000,000
	Fed. Govt. (EMR)		500,000
	Contracts with Foundations	250,000	100,000
	Universities	160,000	130,000
(b) Chemicals [chlorate, Cl_2, organics]	Industrial Firms	2,000,000	1,000,000
	Contracts with R and D Institutes	490,000	100,000
	Universities	290,000	120,000
	Sub Total:	6,190,000	2,950,000
II. ELECTROCHEMICAL ENERGY STORAGE [batteries, capacitors, fuel cells]	Industrial Firms	200,000	200,000
	Government Labs	100,000	300,000
	University	60,000	
	Sub Total:	360,000	500,000
III. ELECTROFINISHING [metals and plastics]	Industrial Firms	800,000	200,000
	Government Labs	50,000	200,000
	Universities	110,000	160,000
	Sub Total:	960,000	560,000
IV. FOUR FURTHER TOPICS			
A. Electrothermics	(not included)		
B. Corrosion	Industrial Firms	250,000	100,000
	Contracts with R and D Institutes	60,000	
	Universities	30,000	20,000
C. Semiconductor Electrochemistry [interface phenomena]	Industrial Firms	50,000	50,000
	Universities	40,000	60,000
D. Biological Electrochemistry [nerve; polyelectrolytes]	Industrial Firms	30,000	30,000
	Govt. and R and D Institutes		50,000
	Universities		70,000
	Sub Total:	460,000	380,000
V. NEW or DEVELOPING SEGMENTS			
(a) Pilot Feasibility Studies [water desal., electro-coatings, timers, etc.]	Industrial Firms	500,000	500,000
	Government Labs		200,000
	U.Toronto/Ryerson/ORF	220,000	120,000
	U.Montréal/L'Ecole Polytech.	120,000	120,000
	UBC/BC Res. Council	100,000	200,000
	UNB/NB Res. + Prod. Coun.	100,000	200,000
(b) Supporting Investigations [membranes, electrode reactions, market studies]	Government		200,000
	Universities	110,000	140,000
	Sub Total:	1,150,000	1,680,000
VI. PUBLICATIONS and CONFERENCES	via Electrochem. Communications Center	20,000	35,000
	TOTALS :	$9,630,000	$6,196,000

*See "On the People and Practice of Electrochemistry in Canada", Chemistry in Canada, October, 1967, for specific topics and locations of proven competence.

Report of Committee 14

High Pressure and High Temperature Chemistry, etc.

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