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THE DEVELOPMENT OF METALLURGY IN CANADA SINCE 1900

Erich Weidenhammer

Ingenium
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Canada

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Molten steel from an open hearth furnace is tapped into a ladle at the Stelco steel company. Hamilton, Ontario, November of 1943. (Ronny Jaques/Library and Archives Canada/National Film Board Fonds, e000762027)

Roger LaFrance, foreman in the remelt department at the Aluminum Company, works with crane operator piling ingots for shipment. Arvida, Quebec, January of 1943. (Ronny Jaques/Library and Archives Canada/National Film Board Fonds, e000761296)

Ursula Franklin, research metallurgist and activist, at the University of Toronto circa 1980. (University of Toronto Archives and Records Management System, A2012-0009/009)

Abstract

The history of metallurgy in Canada since 1900 represents a vast historical topic. This report seeks to provide a coherent summary by focussing on three core themes: the histories of major companies involved in the production of base metals, the nature and evolution of metallurgical engineering, and significant Canadian contributions to the international field of metallurgy. Each theme is discussed in a chapter of this report. This broad overview makes it possible to address fundamental questions, particularly whether Canada experienced a "golden age" of metallurgical research and development that spanned the second half of the twentieth century, and, if so, whether this period has come to an end.

This report also seeks to contextualize this overall account by presenting relevant anecdotes and themes in sidebars accompanying the main text. This account has been informed by the writing and guidance of professional engineers familiar with the history of Canadian metallurgy. It represents, above all, the perspective of this community of technical experts, and forms part of an effort to document the history of metallurgy by the Canada Science and Technology Museum (CSTM) and the Metallurgy & Materials Society (MetSoc) of the Canadian Institute of Mining, Metallurgy & Petroleum (CIM). It is hoped that this approach will serve both as an introduction to the progress of metallurgy in Canada, as well as a starting point for research in other important aspects of metallurgy's place within Canada'sian diverse culture and landscape. Suggestions for areas of further research are provided in the report's conclusion.

Keywords: Canada, Metallurgy, Engineering, Technology

Résumé

L'histoire de la métallurgie au Canada depuis 1900 représente un vaste sujet historique. Ce rapport cherche à en fournir un résumé cohérent en se concentrant sur trois thèmes principaux : le passé historique des grandes compagnies qui participaient à la production des métaux communs, la nature et l'évolution de l'ingénierie métallurgique et les importantes contributions canadiennes au domaine international de la métallurgie. Chaque thème est abordé dans un chapitre de ce rapport. Grâce à ce large tour d'horizon, il est possible de traiter de questions fondamentales. On cherche particulièrement à savoir si le Canada a vécu un « âge d'or » de la recherche et du développement métallurgique qui se serait étendu sur la deuxième moitié du 20^e^ siècle et, dans l'affirmative, si cette période est terminée.

Ce rapport cherche aussi à contextualiser ce compte-rendu général en présentant des anecdotes et des thèmes pertinents à l'intérieur d'encadrés accompagnant le texte principal. Ce bilan s'appuie sur les écrits et les conseils d'ingénieurs professionnels qui connaissent l'histoire de la métallurgie canadienne. Il représente surtout la perspective de cette communauté d'experts techniques, et s'inscrit dans la lignée d'une initiative venant du Musée des sciences et de la technologie du Canada (SCMT) et de la Société de la métallurgie et des matériaux (MetSoc) de l'Institut canadien des mines, de la métallurgie et du pétrole (ICM), de recueillir des informations sur l'histoire de la métallurgie. Nous espérons que cette approche servira à la fois d'introduction au progrès de la métallurgie au Canada et de point de départ pour des travaux de recherche sur d'autres aspects importants de la place qu'occupe la métallurgie au sein de la diversité culturelle et des paysages variés canadiens. Des suggestions pour de futures voies de recherches sont fournies dans la conclusion de ce rapport.

Mots-clés : Canada, métallurgie, ingénierie, technologie

Foreword

For almost 40 years, the Metallurgy and Materials Society of The Canadian Institute of Mining, Metallurgy and Petroleum (METSOC of CIM) has been documenting the history of metallurgy, with special emphasis on Canada. Now, with pride and enthusiasm, I am pleased to introduce *The Development of Metallurgy in Canada Since 1900*, a joint endeavour of the Society — through its Historical Metallurgy Section — and the Canada Science and Technology Museum Corporation (CSTMC). The current volume enhances the stature of the Museum and the Society, joining the Society’s other signature publications that document metallurgical history: *All That Glitters* (1989), a compendium of historical metallurgy notes, and *The Canadian Metallurgical & Materials Landscape 1960-2011* (2011), a 500-page volume celebrating the golden anniversary of the Conference of Metallurgists.

Initially, *The Development of Metallurgy in Canada* was intended to provide a road map for guiding Museum efforts to collect meaningful artifacts representative of Canada’s metallurgical culture and enterprise. But through the excellent research and writing of author Erich Weidenhammer, the monograph goes far beyond that narrow role to provide a readable, engaging narrative about this aspect of Canadian history. The role of governments in providing financial and technical support to the fledgling industry is documented; the role of metallurgy during two World Wars is described; environmental issues and conflicts are delineated, and the entrepreneurs and inventors responsible for Canadian innovations such as the steel mini-mill and differential flotation of sulfides are feted.

Of particular interest is the 1950-1990 period, which has been dubbed the “Golden Age” of Canadian metallurgy. At this time, Canada was a global leader: public and private support for research and development created innovative achievements, generated tremendous growth and wealth, and thrust Canada into the international forefront of metallurgical developments. To document this era in greater depth, the Society and the Museum conducted a related project, “From Rock to Reality — the Mining and Metallurgy Legacy Project,” an oral history of mining in which video interviews with leaders in mining and metallurgy are archived and made available through web access. By examining events and conditions leading to and during the “Golden Age,” *The Development of Metallurgy in Canada Since 1900* places these personal interviews in historical context, and enables the student to understand the importance of the interviewees’ comments and contributions.

Avant-propos

Depuis près de 40 ans, la Société de métallurgie et des matériaux de l’Institut canadien des mines, de la métallurgie et du pétrole (METSOC de l’ICM) documente l’histoire de la métallurgie et se concentre particulièrement sur le Canada. Maintenant, c’est avec fierté et enthousiasme que je vous présente *The Development of Metallurgy in Canada Since 1900*, un projet conjoint entre la Société (histoire de la métallurgie) et la Société des musées de sciences et technologies du Canada (SMSTC). Le présent volume rehausse le statut du Musée et de la Société en s’ajoutant aux autres publications phares de la Société qui documentent l’histoire de la métallurgie : *All That Glitters* (1989), un recueil de notes historiques sur la métallurgie; et *The Canadian Metallurgical & Materials Landscape 1960-2011* (2011), un livre de 500 pages qui célèbre le 50e anniversaire de la Conférence des métallurgistes.

Au départ, l’ouvrage *The Development of Metallurgy in Canada* devait fournir une feuille de route pour orienter les efforts du Musée à collectionner d’importants artefacts représentatifs de la culture et de l’esprit d’entreprise métallurgiques du Canada. Mais grâce à l’excellente recherche et à la remarquable rédaction de l’auteur Erich Weidenhammer, la monographie dépasse largement la fonction restreinte de fournir un texte intelligible et engageant sur cet aspect de l’histoire canadienne. Le rôle des gouvernements à procurer du soutien financier et technique à cette industrie naissante y est documenté; le rôle de la métallurgie durant les deux guerres mondiales y est décrit; les questions et les conflits environnementaux y sont définis; et les entrepreneurs et les investisseurs responsables des innovations canadiennes, comme la petite aciérie et la flottation différentielle des sulfures, y sont honorés.

La période de 1950 à 1990, surnommée « l’âge d’or » de la métallurgie canadienne, est particulièrement intéressante. À cette époque, le Canada était un chef de file mondial : du soutien public et privé pour la recherche et le développement a permis de créer des réalisations innovatrices; de générer une croissance et une richesse exceptionnelles; en plus de propulser le Canada à l’avant-scène internationale des développements en matière de métallurgie. Pour documenter cette ère en profondeur, la Société et le Musée ont dirigé un projet connexe, « Du roc à la réalité – Projet historique de la métallurgie et des mines », une histoire orale de l’industrie minière présentant des entrevues vidéo avec des experts du domaine, lesquelles sont accessibles sur Internet. *The Development of Metallurgy in Canada Since 1900,* par l’examen d’événement et de conditions qui ont mené à « l’âge

As the twenty-first century matures, motivations and achievements of twentieth century leaders become part of the accepted way of doing things. Veteran voices of change — with regards to business, the environment, human dignity and health — once strong, slowly fade into murmurs. Together, *The Development of Metallurgy in Canada* and the Legacy Project chronicle these leaders' achievements and preserve their voices. A foundation of understanding is created, an origin from which future directions for development emerge.

This important work was possible due solely to the support of our sponsors: the Canadian Institute of Mining, Metallurgy and Petroleum (CIM), the Metallurgy and Materials Society of CIM (METSOC), the Canadian Mineral Processors of CIM, Hatch Associates, the United Steelworkers (USW), the Museum and individual contributors. The legacy of metallurgy and mining owes much to their benevolence.

Sam Marcuson
Chairman, Historical Metallurgy Section,
METSOC of CIM
May 2017

d'or » et qui se sont déroulés pendant cette période, met en contexte ces entrevues personnelles et permet aux étudiants de comprendre l'importance des commentaires et des contributions des personnes interrogées.

Au fil de l'évolution du 21e siècle, les motivations et les réalisations des leaders du 20e siècle s'intègrent aux pratiques couramment acceptées. Les anciennes voix du changement (par rapport aux affaires, à l'environnement, à la dignité humaine et à la santé) autrefois fortes, s'éteignent lentement. Ensemble, *The Development of Metallurgy in Canada* et le Projet historique relatent les réalisations de ces chefs de file et préservent leur voix. On crée ainsi les fondations de la compréhension, l'origine de l'émergence des orientations de développements futurs.

Cet important travail a été rendu possible seulement grâce à l'appui de nos commanditaires : l'Institut canadien des mines, de la métallurgie et du pétrole (ICM), la Société de la métallurgie et des matériaux de l'ICM (METSOC), la Division de la minéralogie de l'ICM, Hatch Associates, le Syndicat des Métallos, le Musée et des collaborateurs individuels. Le patrimoine de la métallurgie et de l'industrie minière doit beaucoup à leur générosité.

Sam Marcuson
Président, histoire de la métallurgie,
METSOC de ICM
Mai 2017

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It has been a genuine privilege to learn from metallurgists with decades of experience in their fields. I am especially grateful for their patience.

I would also like to thank Anna Adamek and Will McRae at the Canada Science and Technology Museum for their help.

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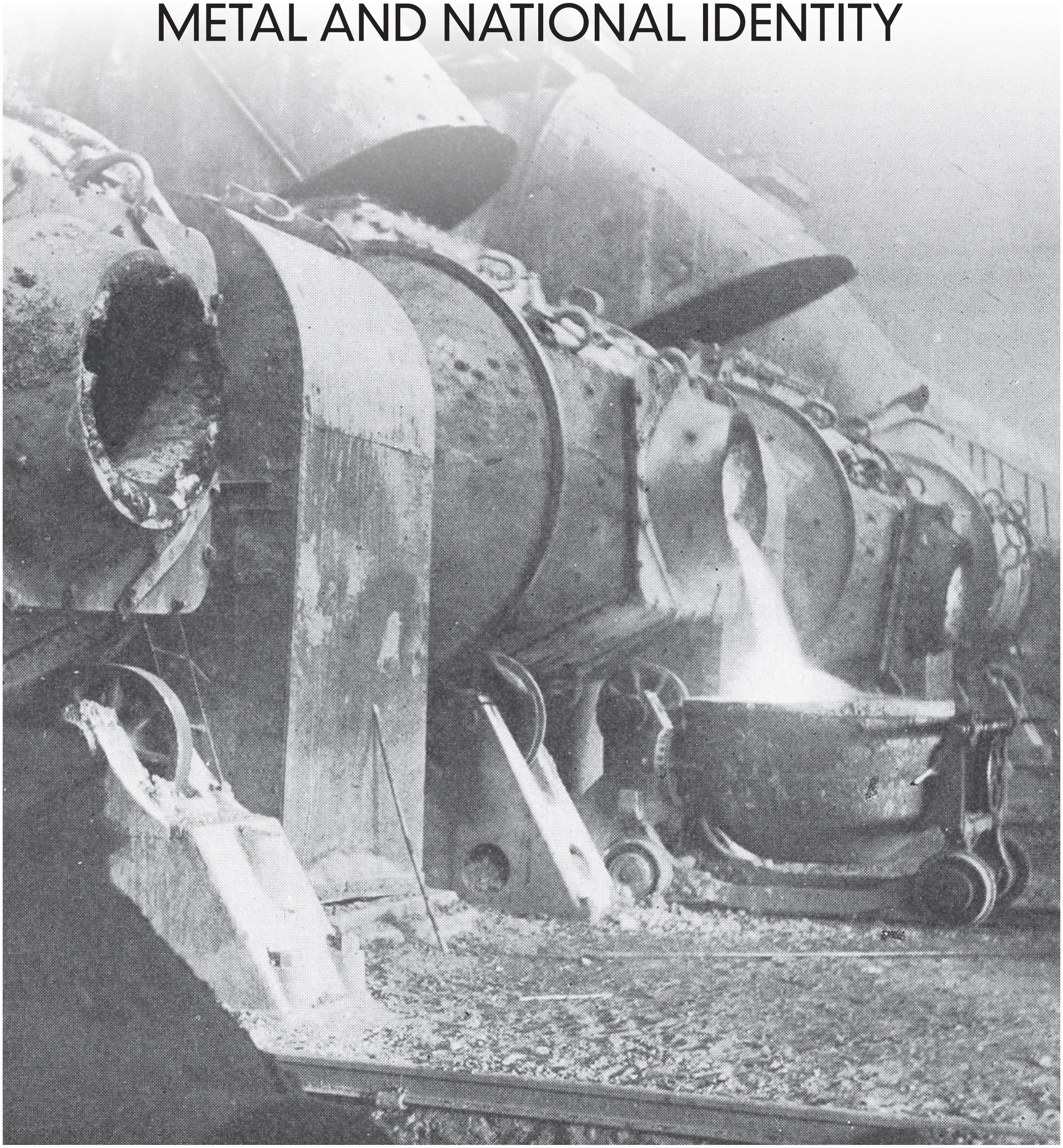
Ce rapport a été écrit avec la précieuse assistance des membres du comité historique de la Société de la métallurgie et des matériaux de l'Institut canadien des mines, de la métallurgie et du pétrole. J'aimerais particulièrement remercier Sam Marcuson, Chris Twigge-Molecey, Alex McLean, Monica Nasmyth, Carlos Diaz et Jim Popowich. John Dutrizac a également fourni de nombreux commentaires utiles et beaucoup d'autres personnes ont gentiment répondu à des questions par courriel.

Ce fut un véritable privilège d'apprendre de métallurgistes comptant des dizaines d'années d'expérience dans leur domaine. Je suis particulièrement reconnaissant de leur patience.

J'aimerais également remercier Anna Adamek et Will McRae du Musée des sciences et de la technologie du Canada pour leur aide.

INTRODUCTION

CANADIAN METALLURGY AROUND 1900: METAL AND NATIONAL IDENTITY



INTRODUCTION CANADIAN METALLURGY AROUND 1900: METAL AND NATIONAL IDENTITY

Canada entered the twentieth century well behind Europe and the United States in the development of its metals industries. Today, over a century later, it is among the world leaders in a spectrum of fields relating to the business and science of mining and metallurgy. This report examines the progress of Canadian metallurgy since 1900 in an attempt to document and explain this remarkable process of development. In doing so, it also presents Canada's contributions to the international field of metallurgy.

This report is part of the Mining and Metallurgy Legacy Project, initiated and co-managed by the Metallurgy and Materials Society (MetSoc) of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM). The Legacy Project is preserving an oral record of important voices within the community of metallurgists. It is a timely project since many of those who entered the field in the 1950s and 60s — an important period in the development of Canadian metallurgical research — have reached an advanced age. Such people also remember an earlier generation that experienced the intense development which took place during the Second World War.

This report is considered a Historical Assessment Update, a short summary report commissioned by Ingenium: Canada's Museums of Science and Innovation (formerly Canada Science and Technology Museums Corporation). It is one of several such documents which, taken together, will cover the history of Canadian mining and metallurgy in a comprehensive and inclusive way. This report will, by necessity, cover only part of this story. In doing so, it should serve as an introduction to other aspects of the field. Its scope, and its connection to existing and planned Historical Assessments, is discussed below.

This report is divided into three interrelated chapters. The first gives an overview of major Canadian metal companies along with their situation in the Canadian landscape and their growth over time. Its purpose is to explain the circumstances under which new technologies were developed. The second chapter provides the institutional context of metallurgical research, focusing especially on the government, university, and private research labs, their histories, and their interrelationships. These are the places at which metallurgists have worked and in which their professional identity has developed. The third chapter discusses notable Canadian contributions to the field of metallurgy. The report concludes by discussing possibilities for further historical research in this area.

METHODOLOGY

Certain topics are so vast that they can be thought of as a wide angle lens through which nearly all aspects of society and culture may be studied. This is certainly true of metallurgy. Metals are inextricably, often invisibly, woven into the material culture of modern society. The economic and social shadow of Canada's metals industry, both nationally and internationally, is enormous. In an industrial society continually expanding through a vast landscape (frequently occupied, one hastens to add, by existing cultures with their own complex relationships to metal), the story of metallurgy follows the overall contours of our national story like molten metal poured into a mould.

The terms "metal" and "metallurgy" together encompass a huge range of materials and practices. Metals, according to the scientific definition, are chemical elements with physical properties such as ductility and electrical conductivity. They occupy a significant portion of the periodic table. The business of mining and metallurgy imposes a more functional definition, separating major industrial metals such as iron, copper, aluminum, lead, and zinc, from other economic minerals and compounds which are, according to their scientific definition, metals. The term "metallurgy" encompasses both the processing of mineral bearing ores — an older understanding of the term — as well as the scientific study of the material properties of metals.[1]

This short report must, of necessity, employ a narrow focus if it is to provide a coherent introduction to the topic. It examines a handful of base metals that have had a particularly important social and economic importance: iron/steel, nickel, copper, aluminum, as well as lead and zinc. This report deals primarily with several sizeable and long-lived companies that have left a significant imprint on the economic and social landscape of Canada. These companies are sufficiently large and integrated to have developed facilities for smelting and refining ore as well as to have undertaken metallurgical research to advance these operations. Finally, it omits certain aspects of metal production, especially mining. This topic has previously been addressed in a CSTM Historical Assessment of metal mining in Canada from 1840 to 1950 written by Jeremy Mouat in 2000. Mouat's report also covers the topic of precious metals in some detail.

This report cannot examine the production of semi-finished products such as castings, rolled sheet, slab, wire, powder, or pipe, or more recent materials such as metal matrix composites and structural foams, in any sort of detail. Such products are an important part of the metallurgical story and have seen significant advances over the twentieth century. Processes such as hot rolling, casting, pickling, tinning, and welding have been as much the subject of research and development in the field of metallurgy as beneficiation, smelting, refining, and alloying. In the case of integrated operations, value-added products are often produced at the same facilities as other primary metallurgical operations. Molten metal is now frequently transformed into a finished product in an increasingly continuous, automated operation, further blurring the distinction between producing metal and producing value-added product. In other cases, the final product is a refined powder, ingot, or simply a relatively unrefined concentrate destined for further processing.

Most importantly, this report represents one community: that of the professional metallurgists and the institutions that they inhabit. For reasons of clarity, and to avoid tokenism in what is already a short document, it does not discuss the labour community, nor does it discuss those communities of land owners, notably Indigenous communities, who are involved in many mining endeavours. Finally, it does not cover the complicated story of Canadian overseas mining operations, a topic shaped by the changing circumstances of international politics and evolving legal norms relating to land use and social justice. Plans are underway at Ingenium: Canada's Museums of Science and Innovation (formerly Canada Science and Technology Museums Corporation) to ensure that these perspectives are properly represented in future reports similar to this one.

Even this narrow focus presents methodological challenges. Most obviously, it is difficult to speak about several different metals in general terms. The chemical properties of individual metals vary greatly. A single metal may appear in various natural chemical forms and concentrations in numerous kinds of ores, all requiring different processing. The technologies employed by a single smelter or refinery may change significantly over the period of its existence, especially if it operates for several decades. Frequently, several metals may be economically recovered from a single mine, all requiring different processes, sometimes different facilities, for extraction and refining. The flowsheet representing the beneficiation, smelting, and refining of a particular metal at a single company at a given moment in time will reveal a complicated array of interconnected technologies that will be utterly bewildering to an outsider.

To summarize, the approach taken by this report is necessarily anecdotal rather than comprehensive; it cannot thoroughly explain the metallurgical processes that it describes. Rather it aims to provide a coherent and well documented narrative which can help orient those readers seeking to further explore a particular aspect of the topic. While this map may lack detail, it will, hopefully, prove accurate and useful.

SOURCES

As with most topics relating to contemporary science and technology, recent Canadian metallurgy is very well covered in both the primary and secondary literature. As to the former, one could ask for no richer source than the publications of the Canadian Institute of Mining, Metallurgy, and Petroleum (CIM), namely *The Transactions of the Canadian Institute of Mining and Metallurgy,* first published in 1895, the *Canadian Mining and Metallurgical Bulletin*, first published in 1908, and the *Canadian Metallurgical Quarterly,* first published in 1962. The journal *Canadian Metals and Metallurgical Industries*, which began publishing in 1938 with a broad focus on the metals business, is an excellent source of industry news and advertising. This publication gradually narrowed its focus towards metalworking before ceasing publication in 1969. Together these journals provide a detailed chronological record which includes technical illustrations, photographs, and maps.

This report relies mainly on secondary monographs and journal articles. This notably includes several company histories published from the 1950s through to the 1980s. Two edited volumes, both commissioned by CIM, are particularly valuable: *All That Glitters* (1989), edited by Michael L. Wayman, contains numerous useful essays on various facets of the history of Canadian metallurgy. Likewise, *The Canadian Metallurgical & Materials Landscape, 1960–2011* (2011), edited by Joël Kapusta, Phillip Mackey, and Nathan Stubina, provides an absolute wealth of information on recent developments. This report can, in certain respects, be considered a gloss on these existing volumes, albeit one with a single narrative that is more accessible to the general reader.

Existing experts in the field of Canadian mining and economic history deserve special acknowledgement as this report relies substantially on their published analyses. Jeremy Mouat, professor of history at the University of Alberta, is especially notable as an authority on Canadian mining and economic development. Finally, much of the technological discussion in this report has been guided by conversations with the members of the MetSoc Historical Committee, all of whom are distinguished members of the Canadian metallurgical community.

FOUNDING A DISCIPLINE

During the early settlement of Canada, metal production was done on a relatively small scale in order to supply forged implements for farming and small industry.[2] As larger operations emerged, such as the mining of iron ore in Nova Scotia or copper-nickel ore in Sudbury, it typically proved economical to ship intermediate products such as concentrate or pig iron to refineries in Britain or the United States.[3] New infrastructure such as railways, steamships, and the electrical grid drove demand for metal. Growing transportation networks in turn permitted the metals industries to bring together raw materials and to ship finished product to market.

The Dominion government played a leading role in this process by funding the Intercolonial Railroad, the longest railway in the world when it was completed in 1885. The growth of iron production in Canada was encouraged by national and provincial tariffs on iron manufactured goods from the United States, and through financial incentives ("bounties") for local products such as steel rail and bridging material. It was hoped that a flourishing metals industry would supply domestic needs while reducing a substantial balance of trade issues with the United States. However, not all Canadian industrialists were pleased to have their access to cheap metal limited in favour of the railway interests.[4]

Metal production was interwoven with Canadian sovereignty in other ways as well. Beginning in the 1850s, an influx of American prospectors into the Colony of British Columbia provoked concerns that this region might fall victim to the manifest destiny of the Dominion's southern neighbour. A major conflict between Britain and the United States had ended only decades earlier, while boundary disputes, such as the 1859 "Pig War" over the possession of islands in the Strait of Juan de Fuca, continued to flare. A railway link to the eastern colonies was the main condition for British Columbia's entry into Confederation.

The gold rushes in British Columbia and the Yukon also developed expertise and infrastructure needed to support more sophisticated mining efforts. As easy sources of bog iron and placer gold were exhausted, Canadian miners and engineers turned to more complicated ores such as the hard gold-bearing quartz in the Cariboo, and the extremely challenging copper-nickel sulphide ores of the Sudbury basin.[5] These new, more ambitious, mining projects demanded new institutions to organize research and cultivate expertise. The earliest of these were the provincial land surveys and the federal Geological Survey of Canada, whose origins preceded Confederation. The survey projects provided the basis for later federal efforts aimed more directly at assisting the mining industry.

In Europe, traditional mining and smelting centres had existed for centuries, developing specialized mining schools and fostering generations of skilled workers. In North America, this knowledge required deliberate cultivation; it was slower to develop in Canada than in the United States. In the nineteenth century, developing a mine, or building a blast furnace, invariably meant inducing a European engineer to lead the project. Early efforts were hampered by poor materials, limited understanding of local ores, and unskilled workers.[6] As the American industry grew, Americans increasingly provided investment capital and expertise to projects in Canada. The provincial and Dominion governments also had ambitions to advance domestic expertise by integrating mining and metallurgy into the university curriculum.

Over the latter half of the nineteenth century, several existing Canadian universities established "practical" programs related to surveying, mining, and engineering while expanding teaching in existing areas such as chemistry, geology, engineering, and physics. This greatly improved the prospects for aspiring Canadian surveyors, mining engineers, and metallurgists. In 1873, the recently founded Department of Mining Engineering at McGill University graduated the first university-trained mining engineer in Canada. Other engineering programs explicitly related to metallurgy emerged elsewhere in Canada beginning in the early twentieth century.[7]

Canadian professional mining organizations began to form in the 1870s at the provincial level. Their purpose was to gather people in the mining industry together into a coherent lobby.[8] By 1896, most provincial bodies had decided to establish a Federated Canadian Mining Institute that would be based in the industrial centre of Montreal. A notable landmark in the development of this community was the appearance of journals dedicated to sharing ideas and information from across Canada. The *Canadian Mining Review*, published in Ottawa, was launched in 1879.[9] Meanwhile, the failed *Journal of the Federated Canadian Mining Institute* was replaced in 1898 by the *Journal of the Canadian Mining Institute*.

By the dawn of the twentieth century, Canada had developed institutional and commercial foundations for a successful mining and metals sector. Nevertheless, the nineteenth century had seen major advances in metallurgical technology which were just starting to be assimilated by Canadian engineers. The following chapter traces the commercial aspects of this process — the larger mining companies, their development in time and space, and how that process set them along particular technological paths that drove Canadian research in the twentieth century.

NOTES

1 “metallurgy, n.” OED Online. Oxford University Press. http://www.oed.com.myaccess.library.utoronto.ca/view/Entry/117276?redirectedFrom=metallurgy (accessed March 14, 2017)

2 For an early history of Canadian blacksmithing, see: Robert Tremblay and David-Thiery Ruddel, By *Hammer and Hand all Arts Do Stand: Blacksmithing in Canada before 1950* (Ottawa: Canada Science and Technology Museums Corporation, 2010). For the early history of Canadian iron and copper production, see several essays in Michael L. Wayman, ed., *All That Glitters: Readings in Historical Metallurgy*, (Montreal: Canadian Institute of Mining and Metallurgy, 1989).

3 Christopher Andreae, “Nineteenth-Century Nova Scotia Iron Works,” in Wayman, ed., *All That Glitters*, 117.

4 For a near-contemporary source analyzing the Canadian tariff and bounty system, see William John Alexander Donald, *The Canadian Iron and Steel Industry: A Study in the Economic History of a Protected Industry* (Boston: Houghton Mifflin, 1915), especially Chapter 5, “The Tarriff and Bounty System.”

5 Jeremy Mouat, “‘The Assistance of Science and Capital’: The Role of Technology in Establishing B.C.’s Hard Rock Mining Industry, 1876-1906,” *Scientia Canadensis: Canadian Journal of the History of Science, Technology and Medicine/Scientia Canadensis* : revue *canadienne d›histoire des sciences, des techniques et de la médecine* 16, no. 2 (1992): 166-168.

6 Donald, *Canadian Iron*, 72.

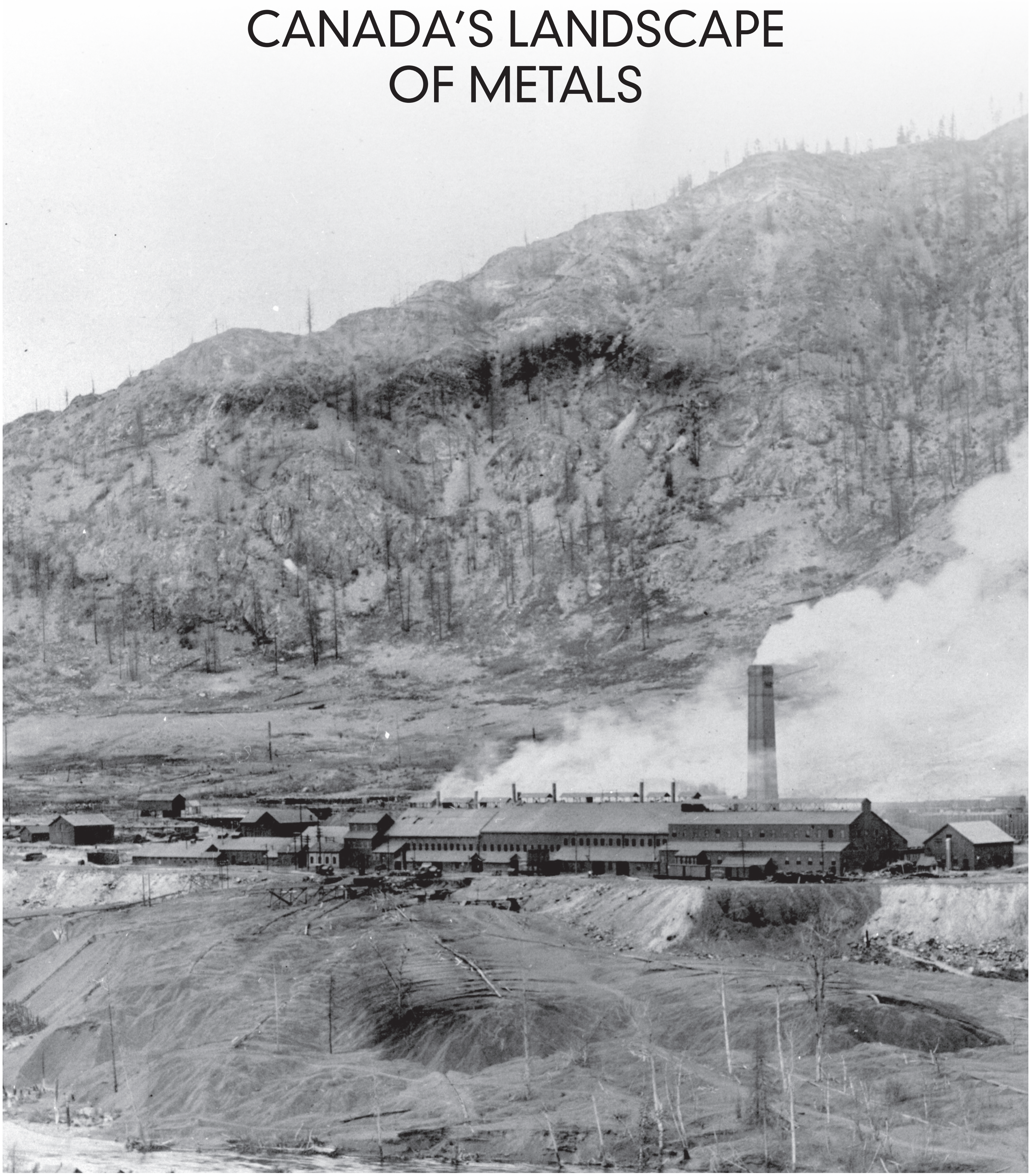
7 Fathi Habashi, “The Beginning of Mining and Metallurgical Education in Canada — Part 1,” *CIM Bulletin* 97, no. 1077 (2004): 75.

8 For a discussion of these early provincial mining associations and university departments, see E. Tina Crossfield, *Pride and vision: The Canadian Institute of Mining, Metallurgy and Petroleum, 1898-1998* (Montreal: Canadian Institute of Mining, Metallurgy and Petroleum, 1998): 10-24.

9 Crossfield, *Pride and Vision*, 8.

CHAPTER ONE

CANADA'S LANDSCAPE OF METALS



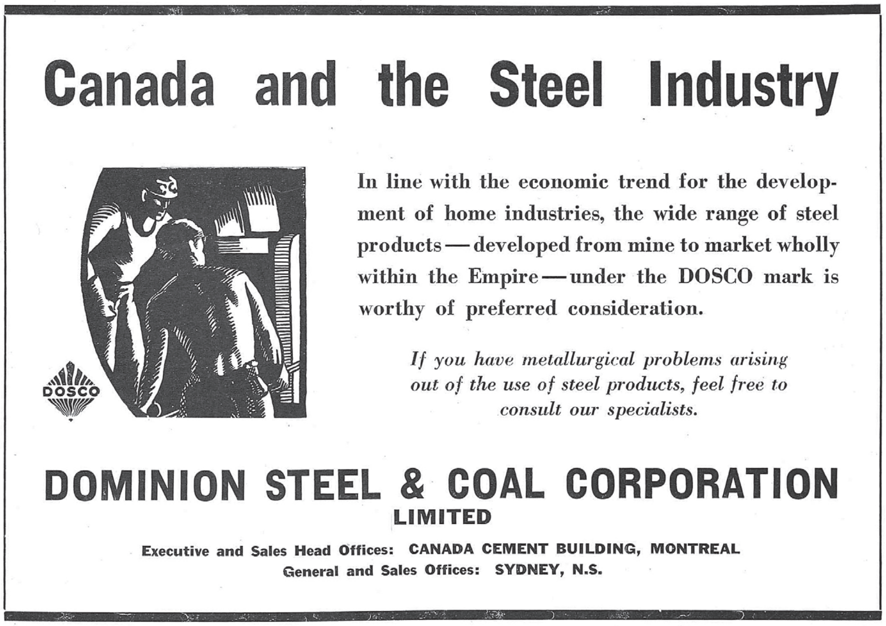
CHAPTER 1 CANADA'S LANDSCAPE OF METALS

If we could conjure a dynamic and detailed map of all activity with the Canadian metals industry since the beginning of the twentieth century, it might appear as a shifting, web-like pattern of thousands of interconnected points. Large facilities (integrated mills, smelters, and refineries) would be connected to their inputs (coal, ore, and other raw materials, as well as sources of energy) by networks of road, rail, ports, and transmission lines. We would notice brief periods of frenzied activity and expansion — war years, commodity booms — followed by periods of stagnation and contraction, during which marginal and inefficient mines and mills would disappear. During these periods we might notice nodes vanish intermittently, sometimes for weeks or months, due to labour disputes and temporary closures brought on by hard times.

These networks would expand and shift as mines were exhausted and new ore bodies developed in increasingly isolated regions of the country. New facilities would appear, and new suppliers and service providers would evolve into an ever more complicated technological network. These networks would root themselves increasingly in urban centers of manufacturing and research, as higher quality materials, value added products, and advances in mineral processing became increasingly essential to the survival in a global industry.

We might notice how particular metals industries develop in characteristic geographical locations. Aluminum smelters, governed by their massive energy needs, emerge alongside hydroelectric projects in the wilderness of Quebec and British Columbia. Smelters for processing copper and nickel appear next to major ore bodies. In these cases, new communities — company towns — take hold in the wilderness, sometimes providing a seed from which new industrial centres grow over time. Located on the Great Lakes and the Atlantic coast, the integrated steel mills are bound to foreign exports and to imports of high-quality American ore and coal.[1] They appear as important nodal points, bringing together fuel, flux, and concentrated ore, and distributing finished goods in forms such as cast slab, wire, sheet, rail, and tube.

To be properly representative, such a map would need to be global in scale, in order to depict the international scope of knowledge exchange and trade. In the early years of the twentieth century, these international connections would lead mainly southward to the United States and, to a lesser extent, eastward across the Atlantic to the UK. A few incongruous strands would appear at this early stage, for instance connecting a nickel smelter in Sudbury to a refinery in Norway.



Canada and the Steel Industry

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Figure 1: The protected trade arrangements of the British colonial sphere were essential to the early development and identity of the Canadian metals industry. This ad from 1938 boasts a steel production chain "… wholly within the Empire." (Dominion 1938, 35).

A wider view would reveal that Canada's infant metals sector emerged, in part, from the broad periphery of a larger existing network focussed on American industrial centres. New operations would develop as experienced American business people, engineers, and venture capitalists were lured northward by land, business incentives, and access to the British market. Over time, Canadian refineries would persist and develop after the mines for which they were built were exhausted. As connections were established to new mines in other countries, Canadian industries would, in turn, become the centres of international networks.

In the period following the Second World War, a few connections to overseas mining projects would be joined by numerous others. Likewise, new points would appear in Canada's north. With time, such projects would emerge more slowly, as the empowerment of local communities and an increasing focus on environmental responsibility began to prolong the gestation of new projects.[2] With the expansion of global trade, mining would become increasingly globalized, with mergers and takeovers occurring across international boundaries. Towards the end of the twentieth century, the complicated patterns of Canada's largest mining companies, shaped by decades of growth, would tend to vanish into the much larger networks of giant foreign multinationals.

How can we begin to give a sense of the activity depicted in our imaginary map? This chapter seeks to trace the patterns formed by the biggest, most persistent nodes, Canada's largest metals companies. We begin with steel because it is, in many respects, the most closely associated with national infrastructure and sovereignty. The emergence of this "protected industry" in the first decades of the twentieth century neatly reflects Canadian ambitions during a period of institutional development.[3]

BIG STEEL IN CANADA

Steelmaking entered the twentieth century as a relatively mature set of technologies. Producers were able to make industrial quantities of steel from blast furnace-smelted iron, known as hot metal, using methods developed in the nineteenth century: the Bessemer converter, then giving way to the open hearth furnace. Over this period, large "integrated" facilities, incorporating both iron making and steel making, became the norm. This was, in part, due to the energy saved by converting molten iron directly into steel rather than first remelting cast iron "pigs" produced elsewhere. Integrated plants typically combined several operations, processing coal to coke, ore to hot metal, hot metal and scrap to steel, and then into semi-finished products by means of various mills. The level of infrastructure and expertise required to run this system economically explains why Canada's industry was, at the opening of the twentieth century, only beginning to establish itself amidst already flourishing industries in Britain, Germany, and the United States.[4]

Steelmaking has evolved from a highly labour-intensive process towards efficiency and automation. Notably, the oxygen-top-blown Linz Donawitz converter (LD), which was developed in Austria and first adopted within North America by Dofasco in the 1950s, produced steel much more quickly and efficiently than the open hearth furnace method it supplanted. This technology, with various modifications, was subsequently implemented throughout the world and became known as the basic oxygen process (BOP). Likewise, the continuous casting process made it possible to bring steel from molten metal to a finished state without the intermediate steps of reheating cast ingots and hot rolling.[5] Stelco's Hot Strip Mill Coilbox was an important Canadian contribution this process of streamlining and automating the steelmaking process.

Historically, Canadian iron ore has been leaner and less abundant than the rich hematite ore of the Lake Superior region that drove Pittsburgh steel production in the United States.[6] Canada was initially dependant on imports of American ore, except in Nova Scotia, which had access to ore from Bell Island, Newfoundland.[7] This situation began to change following the end of the Second World War. In 1948, foreign ore supplied 93 percent of Canadian consumption. By 1970, this had declined to 18 percent while Canada had become the world's fourth-largest producer of iron ore. Over this same period, Canadian ore consumption climbed from 3.63 million tonnes to 10.4 million tonnes.[8] In 2016, Canada was the world's seventeenth-largest steel producer at 12.6 million tonnes of crude steel. China was by far the largest at 808.4 million tonnes.[9]

Canada's steel industry was fostered by bounties, as well as by tariffs on American imports.[10] Government intervention increased during times of war, since steel production was considered a strategic industry. Especially notable is steel's place within the War Industry Control Board devised by C. D. Howe (1886–1960), the minister of munitions and supply. Under Steel Controller Hugh Scully, prices were fixed, ambitious production targets set, and new infrastructure built.[11] Direct government involvement in the steel industry reached its climax when the provincial governments of Quebec and Nova Scotia transformed facilities on the verge of closure into government-run entities. Neither effort proved economically sustainable.

Gerry Heffernan and the Lake Ontario Steel Company (LASCO): Origins of the Minimill

The development of the minimill concept created a competitive challenge to many of the operations performed by the integrated steel mill. Whereas integrated plants process iron ore to generate steel products, minimills, with few exceptions, process mainly recycled steel scrap. They produce steel products, such as concrete reinforcing bar, flat bar, pipe, thin slab, strip, and plate, to meet the demands of nearby markets.[12] Consequently the mills are commonly known as "market mills." The name is, perhaps, more appropriate as the production of modern minimill operations now often exceeds one million tonnes per year.

A minimill consists essentially of several primary components: an electric arc furnace (EAF) for melting steel, a continuous caster, and other equipment for producing finished products. More recent additions include a ladle furnace between the EAF and the continuous caster to regulate steel chemistry and to provide a buffer between the two operations.[13] Because they operate on a smaller scale than traditional integrated steel plants, minimills can more easily be made to operate at levels in line with market demand. Unlike integrated mills, which, under ideal circumstances, are located close to energy supplies and transportation corridors, minimills are built closer to urban supplies of labour and of secondary steel — used cars for instance — that also provide markets for its products.[14]

The minimill concept was pioneered by Canadian metallurgist, Gerald (Gerry) Heffernan. Born in Edmonton, Alberta in 1919, Heffernan studied metallurgy at the University of Toronto. Following his service in the Second World War, he studied briefly at the University of British Columbia under the famous Canadian metallurgist Frank Forward (1902–1972). Between 1948 and 1954, Heffernan worked in the Western Canadian steel industry. In 1955, he founded an electric steel mill company called Premier Steel Mills Ltd. in Edmonton, Alberta. There, he installed an innovative continuous casting system to supplement the ingot casting then in use with electric furnaces. This produced square billets used to make the sucker rods for the Alberta oil industry. This took place shortly after the first commercially successful continuous casting machine in North America was developed by Atlas Steels of Welland, Ontario in 1954. In 1962, Premier Steel was sold to Stelco, becoming Stelco's Edmonton Works, and later a stand-alone company called AltaSteel.[15]

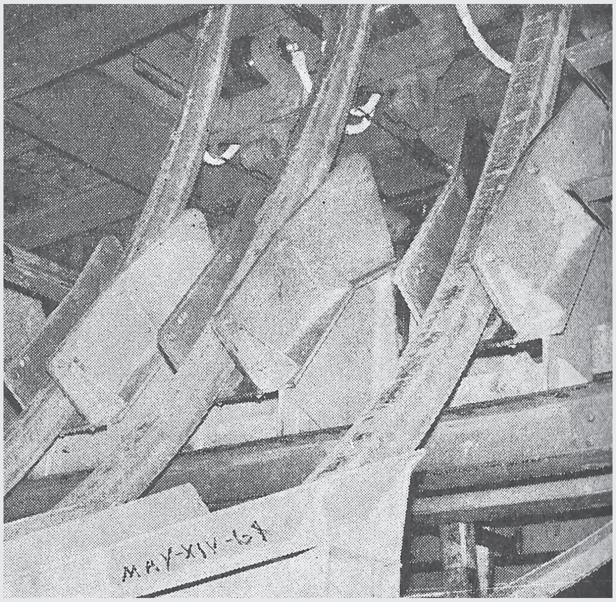


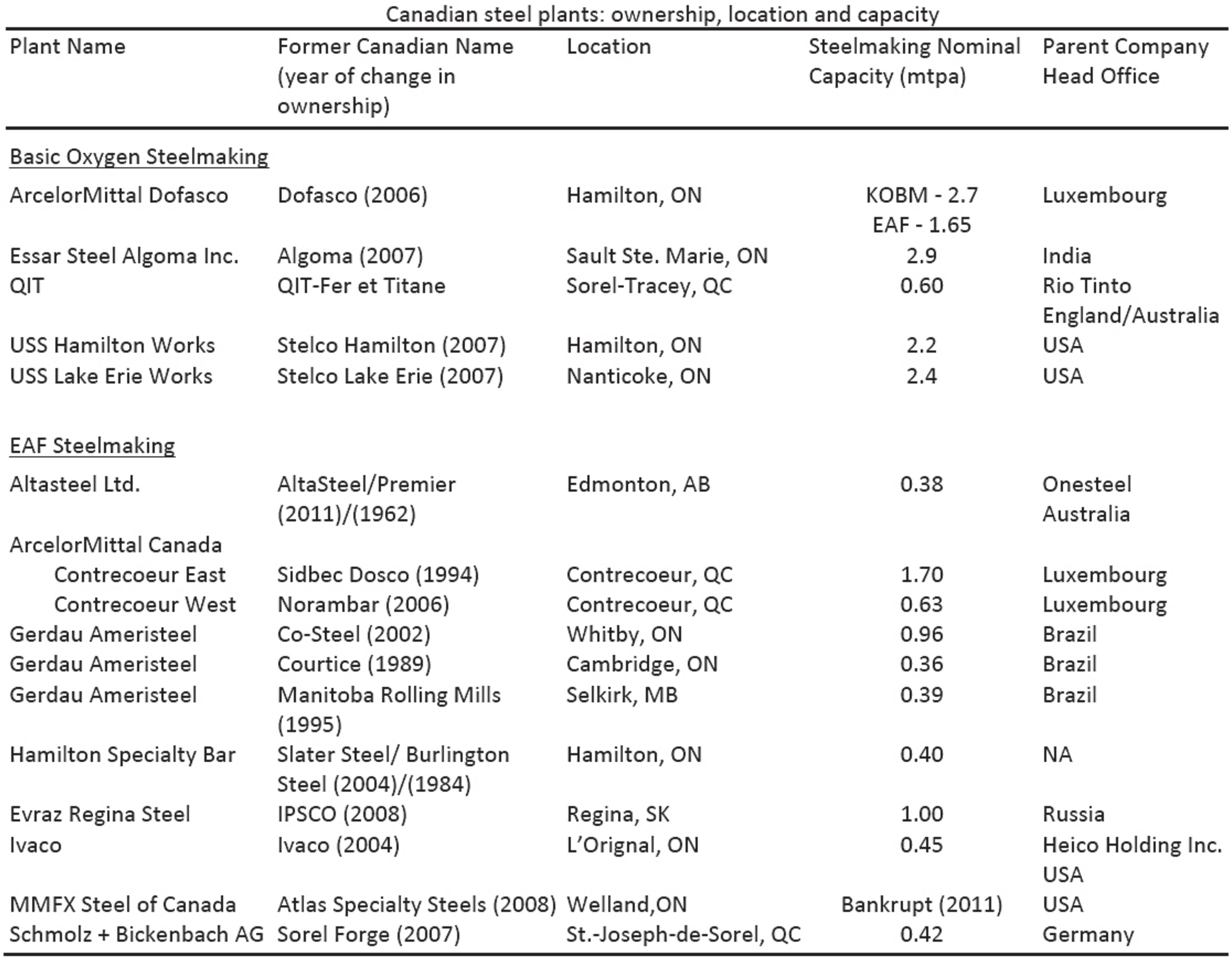
Figure 2: Strands of billet steel emerge from the LASCO continuous casting machine. (Anon 1964, 24)

Between 1963 and 1964, using money from the sale of Premier Steel Mills, Heffernan founded the Lake Ontario Steel Company (LASCO) in Whitby, Ontario. This was the world's first electric arc furnace steel producer to continuously cast 100 percent of its output — the first operational minimill. In 1970, Heffernan founded Co-Steel International to develop a network of minimill operations. This company acquired subsidiary steel mills in Perth Amboy, New Jersey (Co-Steel Raritan), and in Sheerness, Kent (Co-Steel Sheerness). It also co-owned a mill in Midlothian, Texas (Chaparral Steel).[16] In 2002, Canadian Co-Steel Inc. was purchased by the Brazilian company Gerdau S.A. to form a new company, Gerdau AmeriSteel.

The success of Heffernan's company over the last decades of the twentieth century reflects a period in which the minimill flourished largely at the expense of the less flexible integrated mills. In the United States, minimills now produce more steel than integrated mills, and their production is likely to increase.[17] Dr. Gerry Heffernan, 97 years old as of this writing and the recipient of numerous honours and awards, has remained an active and widely respected figure within the international engineering community.[18]

Once established, Canada's integrated steelmakers faced competition, first from other integrated steelmakers worldwide, and, more recently, from smaller secondary producers making steel cheaply from scrap using electric arc furnaces (EAFs). These are referred to in the industry as "minimills". A list of Canadian EAF steelmakers, compiled in 2011, is provided below.

Canada's integrated steel companies have undergone a number of alterations to their business arrangements, generating, in the process, a bewildering quantity of acronyms. When speaking generally about the history of a particular company, this paper will refer to it by its well-known historical name: Sysco for the company that ended as Sydney Steel; Algoma for what is (as of this writing) Essar Steel Algoma; Stelco for what has been, until recently, U.S. Steel Canada; Dofasco for what is currently ArcelorMittal Dofasco; and Sidbec-Dosco for what is currently ArcelorMittal Montreal. As of 2010, all Canadian steel production was foreign owned.[19] At the beginning of the twenty-first century, job losses and shuttered mills may seem a more tangible legacy of recent decades than the research capacity built over those same decades by Canadian engineers and scientists working to keep their industry competitive.



Canadian steel plants: ownership, location and capacity

Plant Name	Former Canadian Name (year of change in ownership)	Location	Steelmaking Nominal Capacity (mtpa)	Parent Company Head Office
Basic Oxygen Steelmaking				
ArcelorMittal Dofasco	Dofasco (2006)	Hamilton, ON	KOBM - 2.7 EAF - 1.65	Luxembourg
Essar Steel Algoma Inc.	Algoma (2007)	Sault Ste. Marie, ON	2.9	India
QIT	QIT-Fer et Titane	Sorel-Tracey, QC	0.60	Rio Tinto England/Australia
USS Hamilton Works	Stelco Hamilton (2007)	Hamilton, ON	2.2	USA
USS Lake Erie Works	Stelco Lake Erie (2007)	Nanticoke, ON	2.4	USA
EAF Steelmaking				
Altasteel Ltd.	AltaSteel/Premier (2011)/(1962)	Edmonton, AB	0.38	Onesteel Australia
ArcelorMittal Canada				
Contrecoeur East	Sidbec Dosco (1994)	Contrecoeur, QC	1.70	Luxembourg
Contrecoeur West	Norambar (2006)	Contrecoeur, QC	0.63	Luxembourg
Gerdau Ameristeel	Co-Steel (2002)	Whitby, ON	0.96	Brazil
Gerdau Ameristeel	Courtice (1989)	Cambridge, ON	0.36	Brazil
Gerdau Ameristeel	Manitoba Rolling Mills (1995)	Selkirk, MB	0.39	Brazil
Hamilton Specialty Bar	Slater Steel/ Burlington Steel (2004)/(1984)	Hamilton, ON	0.40	NA
Evraz Regina Steel	IPSCO (2008)	Regina, SK	1.00	Russia
Ivaco	Ivaco (2004)	L'Orignal, ON	0.45	Heico Holding Inc. USA
MMFX Steel of Canada	Atlas Specialty Steels (2008)	Welland,ON	Bankrupt (2011)	USA
Schmolz + Bickenbach AG	Sorel Forge (2007)	St.-Joseph-de-Sorel, QC	0.42	Germany

Figure 3 Table: Canadian EAF Steelmakers. (Brown et al. 2011, 91. Courtesy of Rick Brown).

STEEL PRODUCTION AT SYDNEY, NOVA SCOTIA (SYSCO)

Iron production in Nova Scotia began in the middle of the nineteenth century when the first successful attempts were made to smelt Londonderry ore for shipment to Sheffield, England, where it was processed into steel. This early history includes a notable attempt, in the 1870s, to produce local steel directly from ore. The method, devised by the German-born engineer Charles William Siemens (1823–1883), produced only a few tonnes of substandard steel before it was abandoned.[20]

Integrated steel production began in Canada in 1901 when the Dominion Iron and Steel Company (DISCO) opened a steel works in Sydney. DISCO was the result of a merger, facilitated by the Liberal government's minister of finance, of several smaller companies operating in Sydney coal fields.[21] Its tilting-type open hearth furnaces were designed by H. H. Campbell of Steelton, Pennsylvania, the foremost North American furnace designer of the period. The furnace operators were likewise recruited from Pennsylvania.[22] Located near the coal deposits of Cape Breton and limestone deposits for flux, the mill processed ore from the Wabana ore deposit on Bell Island in Newfoundland, discovered in 1892.[23] Situated at the mouth of the Gulf of St. Lawrence, Sydney was well placed to supply the Canadian interior as well as international ports along the Atlantic.

Rail production at the Sydney Works began in 1905. Rail remained its primary product over much of its history—a notable lack of diversity compared to its counterparts. The early works had a machine shop and foundry, a billet mill feeding a rod mill, and a rail mill.[24] Between 1901 and 1911, the first decade of production at the Sydney Steel works, Canadian steel production rose from roughly 29,000 to 882,000 tons (26,300 to 800,000 tonnes) per year. Most of the steel was made in Sydney.[25]

The Bell Island Ore was abundant, but of relatively low quality due to a high silica and phosphorus content. In combination with the high-sulphur coal of Cape Breton, it produced viscous slag and rapidly ruined furnace linings. These circumstances posed "undoubtedly one of the most difficult problems in the whole industry" and presented an ongoing challenge to metallurgists of the day: the process of removing phosphorus and controlling sulphur using the open hearth process was not well understood. This led to decades of experimentation at the Sydney plant. The eventual success of this effort is indicated by the gradually increasing proportion of Wabana ore relative to imported ores used in the furnace feed over several decades. It culminated, in the mid-1920s, with the development of an innovative slag removal process and resulted in a rapid jump in output. This method was subsequently adopted across North America.[26]

The Sydney steel works was subject to a number of business mergers, reorganizations, and name changes. Between 1921 and 1928, a conglomerate named British Empire Steel Corporation (BESCO) became one of the country's largest employers before being dissolved into the holding company Dominion Steel and Coal Corporation (DOSCO). In 1957, these assets were purchased by A. V. Roe Canada, which was by then a major corporation that owned, among other

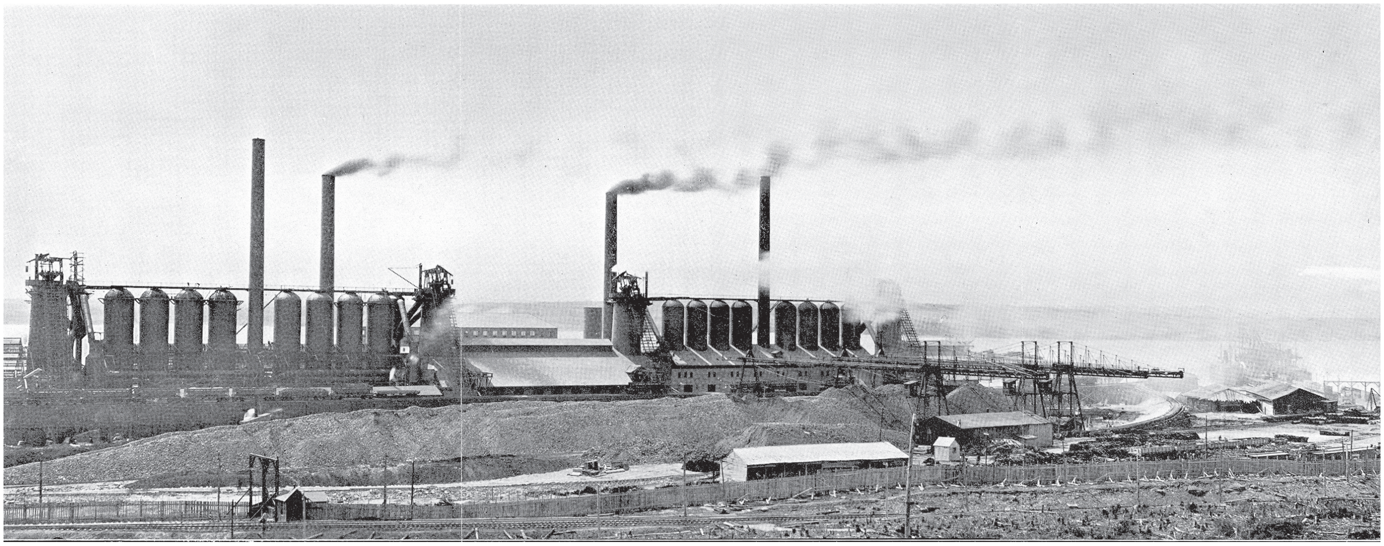
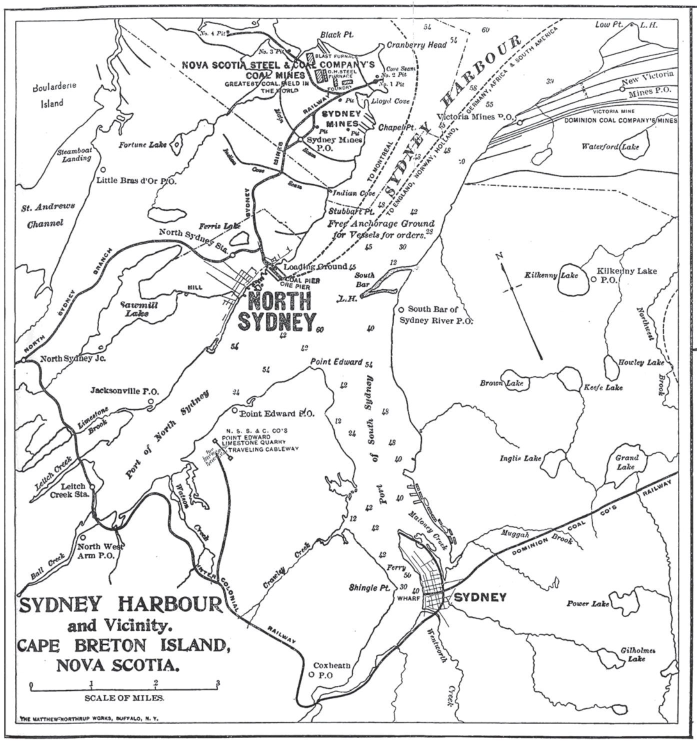


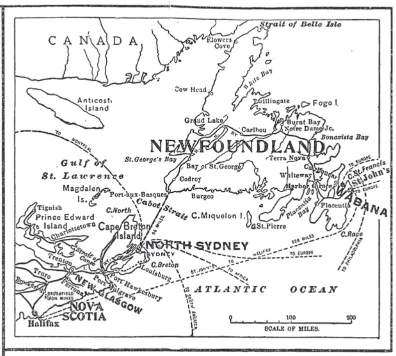
Figure 4: Blast furnaces of the Dominion Iron and Steel Company in Sydney, Nova Scotia circa 1907. (Mines Branch 1908, 626)

entities, the aerospace companies Avro Canada and Orenda Engines. The assets of A. V. Roe Canada were taken over by the Canadian division of the Hawker Sidley Group in 1962.

In 1967, the Nova Scotia government created the Sydney Steel Corporation (SYSCO) as a means to preserve the coal mining industry in an economically depressed region. Meant to last one year, Sysco remained in operation for thirty-three. Over this period, no significant metallurgical research was done, though major changes were made in operations including closing the coke ovens and blast furnace, replacing the open hearth furnaces with an electric arc furnace, and installation of continuous casting facilities. In 1999, provincial funding ended. The plant was finally closed in May of 2000. In 2001, SYSCO was sold to an Indian company, which acquired it for its equipment.[27]

One notable consequence of steel production in Sydney has been the Sydney tar ponds, pools of coke oven waste laden with PCB contaminants polluting a freshwater stream that empties into Sydney harbour. The result of decades of careless dumping of effluent from the coke-making process, the tar ponds were once considered one of the most polluted industrial sites in Canada.[28] After much controversy, the site has been remediated at significant public expense. Former employees of Sydney Steel have worked to set up a museum celebrating 100 years of steel production. Plans are currently on hiatus.[29]





Sketch Maps showing situations of respectively Wabana, Newfoundland, the source of the iron supply and North Sydney, where the iron and steel works of the Nova Scotia Steel and Coal Co. are established.

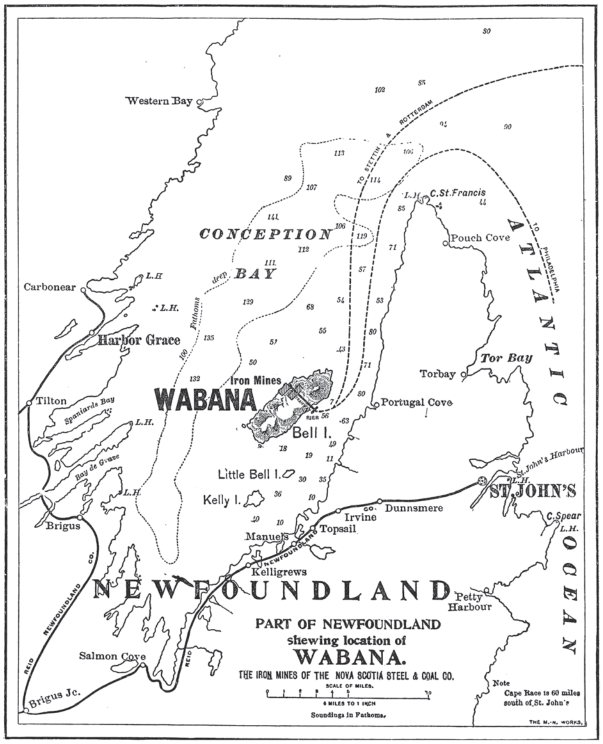


Figure 5: Maps of steel production at Sydney, Nova Scotia (Cantley 1911, 56)

STEEL PRODUCTION IN NORTHERN ONTARIO (ALGOMA)[30]

The first steel producer in Ontario was Algoma Steel of Sault Ste. Marie, Ontario. The company was established by Francis Hector Clergue (1856-1939), a Philadelphia promoter who had become interested in the Sault region because of its potential for hydroelectric power. Following the discovery of hematite ore by gold prospectors in 1897, Clergue sought to develop the area for iron production. Located in the Wawa township (formerly the Michipicoten), this became the Helen mine, named after Clergue's sister. Production began here in 1900.[31]

Clergue's ambitions extended to local steel production, a questionable strategy given the site's distance from coal supplies.[32] Having persuaded the Dominion and Ontario governments to provide heavy subsidies for a railway, the Algoma Steel Company began production in 1902 with a Bessemer converter and a rolling mill to produce rails.[33] The first rails produced in Canada, they earned the company a considerable windfall in federal bounties for fulfilling a large contract with the Dominion government. Its early focus on rail production brought short term rewards, but bound the company to a boom and bust cycle of railway building.[34]

The First World War led the federal government to seek improvements in Canadian production. Algoma's Bessemer converters were replaced by open hearth furnaces. However, attempts to diversify its products were impeded by the company's financial structure and its inability to reach an accord with the federal government over financing new mills. By the end of the war, supplies of Helen hematite ores were exhausted and Algoma turned to local, lower-quality siderite ores.

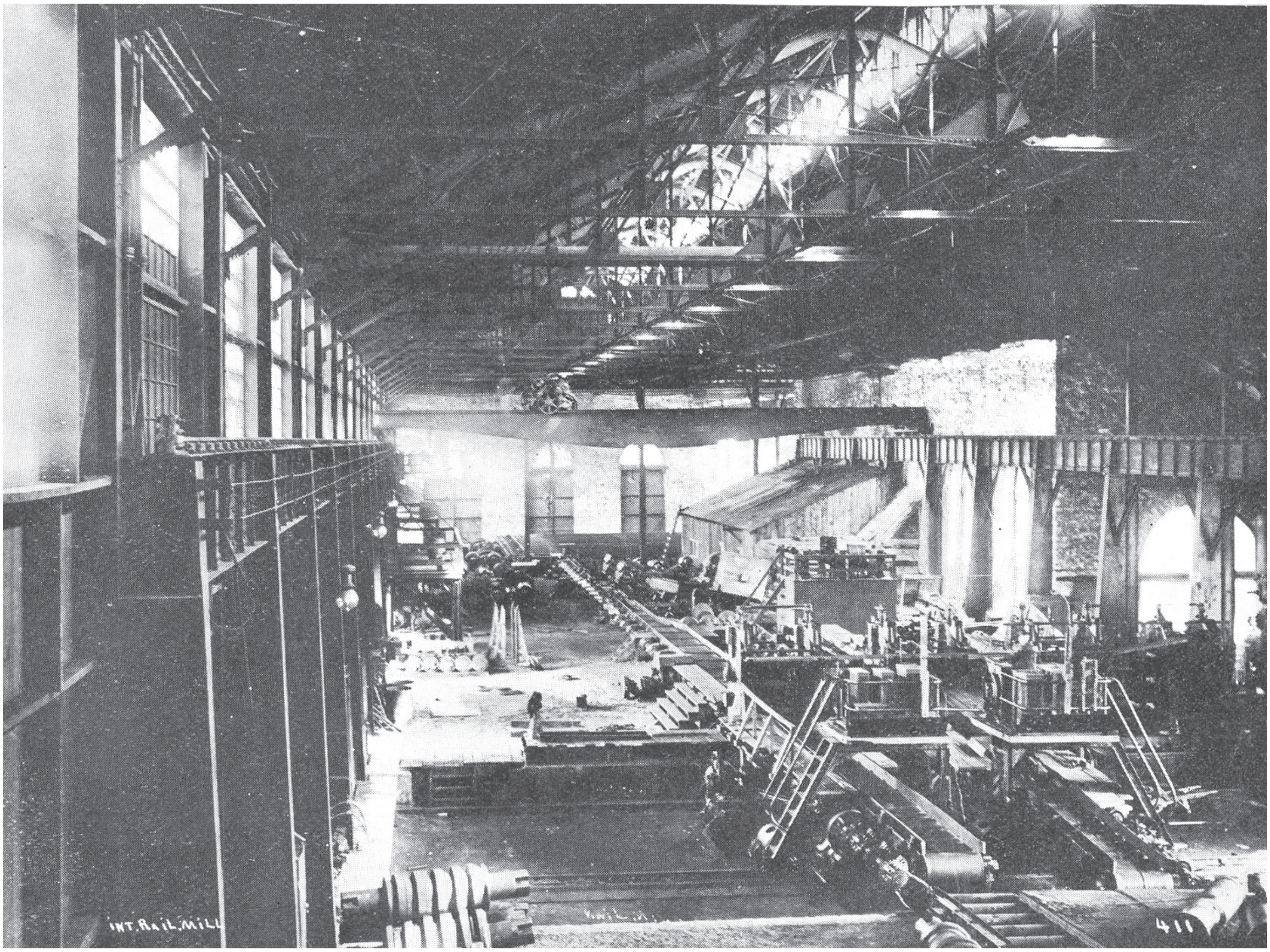


Figure 6: Interior of the rail mill at Sault Ste. Marie, circa 1908 (Mines Branch 1908, 326)

The financial challenges of the interwar period brought Algoma to the point of bankruptcy. It was saved by the involvement of ambitious New Brunswick investor James Hamet Dunn (1874–1956). Beginning in the mid-1920s, Dunn invested in the heavily indebted company. By 1927, he effectively controlled it, and appointed a board of directors. Over the latter half of the 1930s, he returned the company to solvency, owing, in no small part, to the desire of the federal and provincial governments to maintain a viable steel industry in Ontario.[35]

Algoma throve under the tight supply management system brought on by the Second World War. During this period, Algoma attracted over $20 million in government investments — 80 percent of the public funds earmarked for capacity-building in the steel industry, and more than the other steel producers combined. Through the acquisition of a 44-inch blooming mill and a 25-inch continuous billet mill, the company gained the capacity to produce large structural elements.[36]

The death of James Dunn in 1956 was followed by a period of relative prosperity and technical improvement. Most notably, the company became an early adopter of the continuous casting process which resulted in a significant energy savings. In 1967, the company became the first to continuously cast structural I-beams. By the mid-1980s, the plant was facing significant foreign competition and lower demand. Dofasco of Hamilton, Ontario purchased Algoma in 1988 from Canadian Pacific, its previous owner. A long-term investor in the company, Canadian Pacific had obtained a controlling interest in 1975. It bailed on the investment in 1991, with a $713-million loss. After repeatedly restructuring, the plant returned to profitability between 2004 and 2006. It was purchased by the Indian Essar group in 2007, and continues to face financial challenges.[37]

THE HAMILTON MILLS — STELCO AND DOFASCO

As Algoma's operations were developing in Sault Ste. Marie, steel production was likewise emerging in Hamilton, a busy port and industrial centre on Lake Ontario. Stelco's antecedent, Hamilton Blast Furnaces, was founded by American interests after the City of Hamilton offered land on Burlington Bay and investment in a new blast furnace for smelting iron. In 1899, the company, which had established a blast furnace, puddling furnace, steel plant, and spike factory, merged with Ontario Rolling Mills. The resulting operation, the Hamilton Blast Furnace Company, would form the core of Stelco's operations.

Stelco, the Steel Company of Canada, was a conglomerate founded in 1910 out of five existing companies across Ontario and Quebec. This arrangement was encouraged by the Canadian government.[38] Despite early management difficulties arising from the merger of former competitors, the new company expanded quickly, establishing the world's second electrically powered blooming mill, as well as the first electrically powered rod and bar mill to be installed in North America. Stelco acquired a controlling interest in American iron ore fields and, by 1918, had installed new open hearth furnaces, a new sheet mill, and modern coke ovens. By 1921, Stelco equalled the combined size of Algoma and DOSCO.[39]

Like other steel producers, Stelco throve under the supply management scheme of the Second World War. It acquired, for instance, a 63.5-tonne electric arc furnace and a 2.8m (110-inch) plate mill, which became operational in 1941. Along with smaller plate mills at Dofasco and DOSCO, they provided material for the Allied ship building effort.[40] A metallurgical laboratory, first established in 1931, was tasked with developing new alloys and materials for building British military equipment. Adapting these British designs to local materials and engineering standards proved a significant challenge.[41]

During the 1950s and 60s major advances took place at the Stelco Hamilton plant in iron smelting and steel making. In 1967, a new research centre was founded in neighbouring Burlington, Ontario.[42] A series of research-based improvements led to the development of a low-slag smelting practice thatbecame standard among steelmakers globally.[43] Where its rival Dofasco renovated its steelmaking operations by adopting the Linz-Donawitz converter technology (the LD Process later to be known as the Basic Oxygen Furnace or BOF process), Stelco initially sought efficiency through a novel method for producing direct reduced iron (DRI) in a rotary kiln. Experimentation with the "SLRN Process," named after the joint developers, Stelco, the Lurgi engineering firm of Frankfurt, as well as the Republic Steel and National Steel companies in the U.S., began in the late 1950s.

Traditional ironmaking requires the use of blast furnaces and coke ovens to produce hot metal, a process that removes impurities through slag after iron is reduced to a liquid state. The direct reduced iron (DRI) method uses a gas or coal-fired kiln or shaft furnace to remove oxygen from iron ore, producing a heavily reduced solid product known as "sponge iron." The method is much less energy-intensive than the blast furnace, less polluting, and works in conjunction with electric arc furnace (EAF) steelmaking.[44] This proposed technology was abandoned by Stelco by the early 1970s, when the company shuttered its open hearth furnaces and moved over to BOF steel production. The DRI/EAF approach to steelmaking has been successfully applied around the world, including at the Montreal-based steelmaker, Sidbec-Dosco, discussed below.

Already a vast business with operations in several provinces, Stelco expanded significantly over the 1970s. It built a major new production facility, the Lake Erie Works, in Nanticoke, Ontario, which came online in 1980 — the last large integrated plant to be built in North America, a market increasingly crowded with EAF minimills. Some saw the Lake Erie plant as a vast over-investment founded on an unrealistic estimate of growth in domestic steel consumption.[45] The plant was to have been expanded over several stages. Due to lower-than-expected market demand for steel, only the first phase, with a capacity of about 2.09 tonnes of steel slabs per year, was completed.[46] Likewise, the accompanying planned community of Townsend, Ontario, which was expected to become a large centre by the new millennium, developed far more slowly than expected.

The Lake Erie project contributed to the development of the Stelco coilbox, a successful commercial technology arising from its newly-established research facility. It also represents a major example of a facility designed to comply with a new era of environmental regulation. The coilbox and the environmental design of the Lake Erie facility are discussed in the final chapter of this report.

The economic slowdown of the late 1970s sapped the company's resources and delayed the rollout of the new plant. Labour problems — a perennial issue at Stelco — resulted in long work stoppages, which lost the company considerable ground to its competition.[47] The 1980s and 1990s saw repeated efforts at institutional restructuring, a "dis-aggregation into a group of self-sustaining steel-related businesses."[48] Improvements in the 1990s, including major capital investments, were stymied by a further downturn in the early 2000s, as well as increasing competition. Stelco entered court protection in 2004, emerging in 2006. It was purchased by U. S. Steel in 2007. By this point, Stelco had shuttered a significant part of its Hamilton operations. U. S. Steel Canada, as Stelco was known until recently, has since separated from the management of its parent company following a lengthy and acrimonious legal process and has recently received government approval for a sale to Bedrock Industries, a U.S. firm.

DOMINION FOUNDRIES AND STEEL (DOFASCO)

Hamilton's second steel producer, Dofasco, is notable for at least two reasons. The first is an unusually benign relationship between labour and management grounded in an enduring profit-sharing arrangement, which has permitted the company to weather economic downturns more easily than its counterparts. The second is a commitment to maintaining an edge in value-added production that has made the company a rare Canadian steel-making success story (though it is now under foreign ownership).[49] Most notably, Dofasco was a very early adopter of basic oxygen steel (BOF) technology. These two characteristics were, in the view of Barry Strathdee, Dofasco's former manager of applied research, related in the sense that good labour relations meant that changes in workflow, required to efficiently implement new technology, were more readily accepted by workers.[50]

Dofasco emerged from an earlier railway products foundry, Dominion Steel Castings Company Ltd., which was founded in 1912 by American brothers Clifton W. Sherman (1872–1955) and Frank A. Sherman (1887–1967). The pair had come to Hamilton to take part in the burgeoning railway industry and to take advantage of a government tariff structure that shielded producers from American competition. In 1917, when wartime expansion permitted the acquisition of open hearth furnaces, the Company was renamed Dominion Foundries and Steel Company.[51] Dofasco also produced forgings and munitions while investing in a heavy plate mill used to roll steel slabs into plate. By the beginning of the Second World War, Dofasco would be Canada's only producer of armoured plating.[52]

During the interwar period, demand for heavy rolled steel declined, so the company diversified into tinplate production for the consumer market. In 1935, it built Canada's first cold reduction mill. The wartime increase in demand permitted the company to continue to diversify, for instance, by establishing the world's first continuous annealing line. By the end of the Second World War, Dofasco was supplying half of Canada's demand for tinplate. In the late 1940s, it built Canada's first electrolytic tinning line, which greatly reduced the amount of tin consumed over the hot dip method. In 1954, it began producing galvanized steel by purchasing another company and, a year later, built the first continuous galvanizing line and installed the first of four 142-cm (56-in.) rolling mills to produce the wide strip needed for car manufacturing. It also increased its capacity in the area of finished steel products

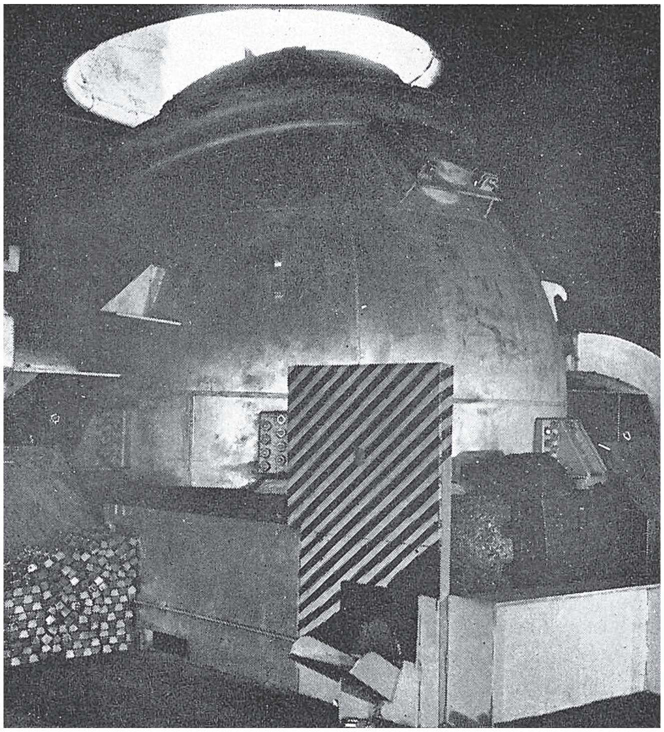


Figure 7: The LD furnace installed at Dofasco in 1954 (McMulkin 1964, 1029)

by developing new coatings, producing pre-painted steel, and, in 1964 building the first Canadian silicon steel plant. In 1973, it acquired a pipe plant in Alberta to manufacture products for the energy industry. [53]

During the Second World War, Dofasco had installed Canada's largest electric arc furnace (EAF) to produce hot metal for steel production. In order to avoid the impurities of steel produced from scrap, which led to difficulties in the electrolytic tinning process, Dofasco decided to become an integrated mill in the late 1940s. It became Canada's fourth integrated mill in 1951 with the construction of a blast furnace at Hamilton Harbour. In 1954, the company installed the first Linz-Donawitz (LD) furnace in North America and the second in the world outside of Austria.[54]

LD technology, developed in Austria in the late 1940s, is a refinement of the earlier Bessemer converter, replacing the atmospheric air blown through tuyeres in the bottom of the vessel with oxygen delivered through a water-cooled "lance" located within the mouth of the vessel. Through implementing this process, Dofasco developed a series of associated technologies, including oxygen production, gas-scrubbing, and new refractories. The company became a stopping point for steelmakers from across the world as interest in the technology spread.[55]

Dofasco also supported the application of Air Liquide's porous plug when the technology was installed in a steel ladle in 1970. The system was used to bubble argon gas through molten metal in order to promote the mixing necessary for a uniform product. Later, as discussed in the third chapter, the porous plug was widely adopted, as were related bottom-injection technologies, such as the shrouded tuyere, that were also developed by Air Liquide.[56]

In 1988, Dofasco acquired Algoma in order to increase capacity in coke making, ironmaking, and steelmaking to meet global demand for cast steel slabs. This was not a successful venture. Labour problems and global recession brought on a period of financial instability and layoffs. Nevertheless, technical advancement did not stop, and Dofasco entered the new millennium with the most modern assets of any North American steel company. In 2006, the company was purchased by Arcelor, which was itself purchased by Mittal, creating ArcelorMittal, headquartered in Luxembourg.[57]

SIDBEC-DOSCO AND THE QUÉBÉCOIS STEEL INDUSTRY

Plans for a Québécois steel industry were, in large part, a product of the ambitions underlying Quebec's Quiet Revolution. An assertive Quebec, in charge of its economic destiny, was presented as an alternative to the patronage politics of the province's long-lived Conservative government, led by Maurice Duplessis. The liberal government of Jean Lesage (1912–1980), elected in 1960, came to power pledging major investments in industry. *Sidérurgie du Québec* (Sidbec) was to be the key to these major industrial projects. The new government's most notable accomplishment was the nationalization of the province's hydroelectric production in 1962, a process led by then Minister of Natural Resources, René Lévesque. The success of this operation encouraged the Quebec government to proceed with a government-led steel industry.

Hopes were also raised by the development of the "Labrador Trough," a significant iron ore belt in Labrador and Northern Quebec, which started in the mid-1950s. Early work in this area had been carried out by the laboratories of the Federal Government's Mines Branch beginning in the 1940s.[58] In 1962, a report commissioned in France predicted a sufficient market for the production of 500,000 tons (454,000 tonnes) of steel per year. That year the *Société générale de financement* (SGF) was founded, largely with the purpose of financing the new steel industry.[59] Sidbec was established in 1966 with $223 million from the SGF. In 1968, Sidbec acquired assets in Montreal and Etobicoke, recently built by Dosco, for the production of secondary steel products.

Sidbec's electric arc furnace was completed in 1971 and a new $100-million direct reduction plant, incorporating the Midrex process, began operations in 1973.[60] This was the world's first "greenfield" (newly built without existing facilities) DRI plant.[61] This made Sidbec-Dosco one of Canada's integrated steel companies, albeit one that relied on electric furnace technology rather than the open hearth or converter furnaces in use by the traditional integrated plants.

The Sidbec 2 phase, which added a second, larger DRI plant, two new EAFs, and a larger continuous casting plant, began operation in 1977. With a capacity of 600,000 tonnes per year, it was then the world's largest DRI plant.[62] These projects, incorporating the natural gas-fired MIDREX DRI technology developed in Portland, Oregon, were carried out by Canadian engineering firm Hatch. This was a notable early instance of a "turnkey" facility provided by a Canadian engineering company.[63]

Sidbec-Dosco went through periods of major financial losses in the early 1990s, ultimately costing the Quebec government over $1.5 billion over its thirty-year history. Experience has shown DRI steel production to be highly sensitive to the cost of natural gas, though some countries, such as India, use gasified coal. DRI operations tend to appear in oil-rich areas such as Venezuela, the Gulf States, Iran, and the U.S. Gulf Coast.[64]

In 1994, Sidbec-Dosco was privatized, its assets sold to Ispat International, which also pledged to make major capital upgrades and maintain to 75 percent of jobs.[65] In 2004, Ispat Sidbec became Mittal Canada, the same Luxemburg-based entity (now Arcelor Mittal) that would purchase Dofasco two years later.

NICKEL PRODUCTION IN, AND BEYOND, THE SUDBURY BASIN

The province of Ontario contains one of the world's richest sources of nickel, the Sudbury basin — a roughly oval ring of about 60 by 27 kilometres on either axis. Geologists consider the deposit to be the result of a meteor that struck the earth 1.85 billion years ago. Metallic minerals in this area consist of pyrrhotite (iron sulphide), pentlandite (iron-nickel sulphide), and chalcopyrite (copper- iron sulphide), varying in their proportions, in the ratio of copper to nickel, and in sulphur content.[66] The extraction of usefully pure copper and nickel from these sulphide ores was one of the most important areas of research for Canadian metallurgists in the twentieth century.

Noted as a magnetic anomaly by a provincial land survey in 1856, the area was further explored by the Dominion Land Survey. During subsequent decades, the Canadian Copper Company, the Orford Copper Company, and several others established the first mines. The ore was first recognized for its copper content. In 1886, attempts to smelt Sudbury ore at the Orford refinery at Constable Hook, NJ (now Bayonne, NJ), in the United States led to the discovery of nickel in the ore — a frustrating inconvenience at the time.[67]

The battleship age soon created significant demand for nickel in the form of alloyed nickel steel armour plating, first developed in Britain in 1889. Orford Copper, led by Colonel Robert M. Thompson (1849–1930), an American engineer and businessman, established a lucrative contract supplying nickel to the U.S. Navy.[68] Further industrial uses for the metal were also emerging: In 1901, Thomas Edison (1849–1931), seeking a source of nickel electrodes for a newly developed battery, sent a team to Sudbury in an unsuccessful attempt to establish nickel claims in the area around Falconbridge.

The sulphide ores of Sudbury proved challenging and costly to smelt. Separating the combination of copper and nickel sulphides presented a singular technical challenge. By the turn of the twentieth century, repeated Canadian attempts had failed. In 1911, David Browne, an American metallurgist working for the Canadian Copper Company, described the profound difficulty of processing the Sudbury ores:

> *Considering the heat of formation, nickel would be expected to follow the iron easily and completely into the slag. Instead of doing so it displays a most extraordinary reluctance to part from the copper, the two metals cling together in a deathless affinity, so much so that 1 lb. of nickel passing into the slag drags 1.25 lb of copper with it.*[69]

The Orford process, first patented in 1893, was the first of a series of advances in separating and refining Sudbury nickel that continued to accrue over the first quarter of the twentieth century — an evolution driven by increasing demand for nickel used to produce high strength and high temperature steel alloys.[70] Over this history of metallurgy at Sudbury, local producers have also developed methods to extract copper, cobalt, iron ore, platinum and other precious metals.

For much of the twentieth century, Canada's Sudbury reserves made it the world's primary source of mined and refined nickel. More recently, other abundant sources have emerged such as the sulphide ore of Norilsk in Siberia, and laterite ores in Indonesia and the Philippines. In 2015, the Philippines produced 23 percent of the world's mined nickel while Indonesia produced 14 percent. Canada and Russia each produced about 11 percent. Canada was also the fourth-largest producer of refined nickel behind China, Russia, and Japan.[71]

In certain respects, the rise of production from tropical and subtropical laterite is also a Canadian story. Laterite ores, which fall between 1 and 3 percent nickel content, are lower in grade than the Sudbury sulphide ores. Yet they represent the majority of the world's nickel reserves.[72] They can be recovered comparatively cheaply through open pit mining, though extraction is typically more expensive and more energy-intensive than is the case with sulphide ores.[73] Technology for extracting nickel from laterites for further refining was developed by Inco for projects in Indonesia, New Caledonia, and Guatemala, and by Falconbridge for projects in the Dominican Republic.[74] Canadian research in this area began at Inco in the early 1940s.

Canadian investment in foreign laterite projects was motivated primarily by a desire to meet foreign demand, first from Japan and later from China, for nickel used mainly in steel production. The pursuit of these laterite deposits, and the development of technologies to process them, is a topic that deserves its own separate treatment. The discussion below focuses primarily on the Sudbury region along with other, more recently developed, Canadian deposits.

INCO (NOW VALE CANADA)

For most of the twentieth century, the International Nickel Company (Inco Ltd. after 1976) was the largest nickel producer in the world. The product of a series of mergers, its present incarnation as Vale Canada represents the majority of nickel production within Vale's multinational operations, currently the second-biggest in the world. As the largest of the three major Canadian nickel producers, Inco has played a significant role in developing Canada's metallurgical industry.

In 1902, a downturn in the nickel market forced several of the mining companies established at the Sudbury basin to form the International Nickel Company, based in New Jersey.[75] During this early period, Canadian ore was shipped to a refinery previously established by the Orford Nickel Company in Bayonne, New Jersey, where the essential knowledge needed to process the nickel-copper sulphide ore had been developed toward the end of the nineteenth century. American antitrust laws later compelled the International Nickel Company to base itself in Canada, with its American component as a subsidiary.[76]

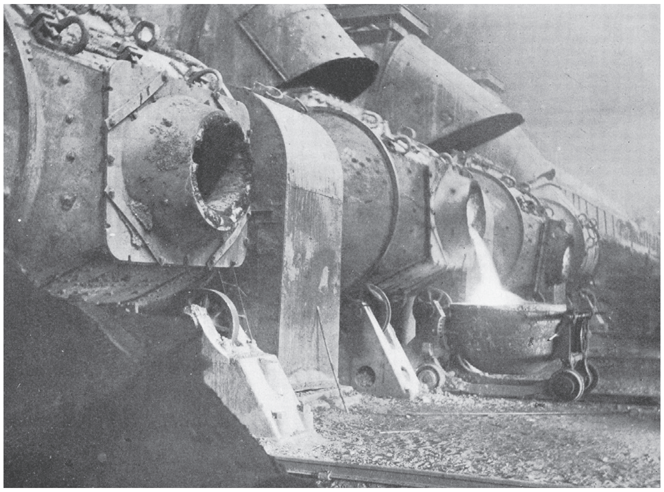


Figure 8: Peirce-Smith converters at Inco's Copper Cliff smelter circa 1907 (Mines Branch 1908, 382)

Following the outbreak of the First World War, demand for nickel grew. Reports that Canadian nickel was reaching imperial Germany through the United States — officially a neutral country throughout much of the war — led the Canadian government to pressure the company into centralizing all nickel production in Canada.[77] In 1918, Inco opened the first successful Canadian nickel refinery at Port Colborne, Ontario, near supplies of hydroelectric power at Niagara Falls.[78] It operated first on the Orford process, then on the Hybinette process, both developed earlier at the Bayonne refinery of the Orford Nickel Company.

In 1924, Inco acquired a close competitor, the British American Nickel Company (BANCO), headquartered in Ottawa, which had been set up by the British government to meet wartime nickel demand. BANCO's refinery, completed in 1920 near Ottawa, had employed the Hybinette electrolytic method. With this acquisition, Inco gained the North American rights to that process.[79] Inco's Canadian operations ran as a subsidiary until a merger with Mond Nickel in 1929. Established in 1900, Mond had been a major British competitor that shared access to the Sudbury Frood mine. It ran a smelter at Coniston in the Sudbury district, which operated until 1972, as well as a refinery in Clydach, Wales, which remains in operation.

Smelting had taken place in Sudbury as early as 1888, when The Canadian Copper Company — part of the consortium that became Inco in 1902 — built a blast furnace to smelt Sudbury ore. In 1930, this Copper Cliff smelter was refurbished as a vast and modern structure incorporating reverberatory furnace smelting, Peirce-Smith converters, and a facility for electrolytically refining copper.[80] Beginning in the 1940s, Dwight-Lloyd sintering machines were used to transform nickel sulphide to nickel oxide for shipment to the Port Colborne Nickel Refinery. After 1961, this was replaced by fluid bed roasting. The Copper Cliff smelter also produced blister copper which was transported to the nearby refinery to be cast into copper anodes and electrolytically refined.[81]

The Copper Cliff smelter, known for its incandescent slag pours, became perhaps the most iconic metallurgical facility in Canadian history. Spewing sulphur dioxide and metal particulates, it poisoned the local vegetation, producing the "lunar landscape" for which the Sudbury region was once famous.[82] In the 1970s, the 380-metre-high Inco "Superstack" — still the second tallest freestanding chimney in the world — was built to disperse sulphur gases high in the air.

Precious metals present in the Sudbury ore have been an important revenue source for Inco since the company began processing them at the Port Colborne refinery in the 1920s. In particular, Inco has been a major producer of platinum group metals (PGMs), notably platinum, palladium, rhodium, ruthenium, and iridium. In 1924, Inco built its Acton refinery in West London, UK to process

Inco's Famous Superstack

In 1972, Inco built what was then the world's tallest chimney. At 380 m, Inco's $25-million "Superstack" quickly became emblematic within Canadian culture, fairly or unfairly, as a representation of the mining industry's impact on the environment.

Smokestacks are structures for diluting emissions by distributing them over a wider area. The longer it takes for particles to descend to the ground, the less concentrated they will be. To proponents of the measure, this was a cost-effective way to reduce local pollution in accordance with provincial law; it was undeniably effective in this regard. To critics, the structure was a monument to corporate cynicism meant to reduce measurable concentrations of pollution by spreading it around.

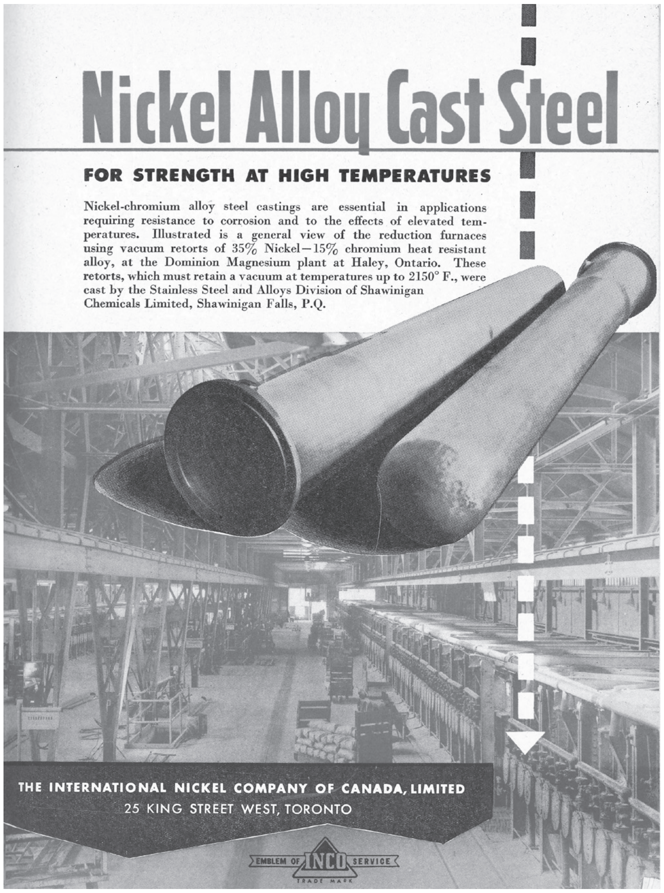
In the early 1990s, following the enactment of stricter environmental regulation meant to curb acid rain pollution, Inco built new infrastructure to scrub emissions released through the stack. This greatly reduced its dramatic plume.The stack is scheduled to be decommissioned and replaced by two smaller stacks as part of Vale Canada's latest round of emission-reduction measures. At that point, it will be placed in care and maintenance mode. As there are no immediate plans to dismantle it, it is likely to remain a tourist landmark — and a reminder of an earlier era of environmental policy — for some time.[83]

Figure 9: The dramatic plume of the Superstack and the surrounding barren landscape, photographed in 1980 (Courtesy of Vale Canada)

PGM concentrate from the Port Colborne refinery. Still in operation as the Vale Acton Precious Metal Refinery, this is one of a very few PGM refineries in existence.[84]

Another important Port Colborne product is cobalt, a metal currently used primarily for alloying and in battery production. Production of cobalt from Sudbury ore began during the Second World War. Cobalt concentrate was refined at Inco's Clydach refinery. In 1982, an electrolytic process for refining cobalt was introduced at the Port Colborne refinery as part of an overall system for recovering precious metals.[85]

In 1937, with the opening of a process research laboratory at the Copper Cliff refinery, Inco became the first of the major Canadian metals company to launch a research-and-development program. Benefits of this approach accrued quickly, building on the earlier innovations of the Orford Smelter in Bayonne, and making Inco's R&D system a major center for Canadian innovation in metallurgy. Between 1943 and 1948, a physical matte separation process was developed and implemented at Copper Cliff to more efficiently separate copper sulphide from nickel sulphides, and the cumbersome, high-temperature, chemical Orford process was discontinued. This was a major Canadian contribution to the smelting of nickel-copper sulphide ore.



Nickel Alloy Cast Steel

FOR STRENGTH AT HIGH TEMPERATURES

Nickel-chromium alloy steel castings are essential in applications requiring resistance to corrosion and to the effects of elevated temperatures. Illustrated is a general view of the reduction furnaces using vacuum retorts of 35% Nickel—15% chromium heat resistant alloy, at the Dominion Magnesium plant at Haley, Ontario. These retorts, which must retain a vacuum at temperatures up to 2150° F., were cast by the Stainless Steel and Alloys Division of Shawinigan Chemicals Limited, Shawinigan Falls, P.Q.

THE INTERNATIONAL NICKEL COMPANY OF CANADA, LIMITED
25 KING STREET WEST, TORONTO

Figure 10: An advertisement for Inco nickel alloy steel. This advertisement shows the vacuum retorts used in the Pidgeon process for producing magnesium (see p. 98). (Inco 1947, 5)

By 1940, Inco had begun to research processes for extracting nickel from laterite ores. By the 1960s and 1970s, Inco was actively developing a number of overseas projects. The most significant of these was the Soroako project located on the Indonesian island of Solawesi. Soroako was a massive, protracted, and expensive project, in part because it required the building of a hydroelectric plant when the oil crisis of the 1970s suddenly raised the price of energy. The plant began production in 1978.[86]

The energy crisis also put an end to the Fenix nickel project, an open pit laterite mine and processing plant located in Izabal Department, Guatemala. The Fenix project had been under development since 1960. Revived in 2004, when Inco's holdings were purchased by a Vancouver-based development company, the project has since drawn a succession of Canadian mining companies into Guatemala's bloody conflict between local elites and its broad Indigenous underclass. A further international effort, Vale Canada's Goro project in New Caledonia, has faced similar ongoing challenges. Two major Canadian sulphide ore projects, one in Thompson, Manitoba, and the other in Voisey's Bay, Newfoundland, are described below.

A commitment to research and innovation among the nickel producers is evident in the emergence of an "oxygen culture" at Inco. This began with the development, during the 1940s, of the oxygen flash smelting furnace at the Copper Cliff smelter as tonnage oxygen was first being applied to metallurgy. Various other oxygen technologies were implemented in subsequent decades, culminating in the installation in 1971 of two top blown rotary converters (TBRCs) in 1971 to complement the newly-developed pressure carbonyl process for nickel refining.[87]

Such measures were enacted for pragmatic reasons. Flash smelting lowered energy costs while enabling the production of liquid sulphur dioxide for sale to industry. The pressure carbonyl process assisted in the recovery of platinum group metals. Over the long term, the adoption of these more efficient processes have helped the company reduce emissions, and have contributed to improvement in the Sudbury landscape.

In 2006, Inco was purchased by the Brazilian mining giant Vale. As part of this arrangement, Inco (now Vale Canada Ltd.) is run as a separate nickel mining division which also manages Vale's existing nickel operations in Brazil. This has resulted in some streamlining of metallurgical operations. Copper refining continued at the Copper Cliff smelter until 2005, when it was considered more efficient to ship copper anodes to the CCR refinery in east Montreal. This facility, created by the Noranda mining company, is discussed below.[88]

OTHER CANADIAN INCO OPERATIONS:

Thompson Manitoba Smelter/Refinery

A nickel operation was established by Inco in Thompson, Manitoba, following the discovery of a major nickel deposit in Northern Manitoba in 1956. The community of Thompson was itself established in 1957 as part of an arrangement between Inco and the Manitoba government. The Thompson area was to become Canada's second major nickel source.

The Thompson smelter and refinery was opened in 1961, becoming the world's first integrated nickel facility. For smelting, it used fluid bed roasters to prepare the sulphide flotation concentrate for electric arc furnaces. Much like the Port Colborne refinery, it employed the Hybinette anode casting/electrowinning method to produce nickel. The Thompson process differed somewhat in that it employed sulphide anodes, that is, anodes in a less-refined state than those for the majority of refining done at Port Colborne. This process had been previously developed and tested at the Port Colborne refinery at an integrated plant opened in 1958.

The Thompson refinery has remained in operation using this method of electrolytic refining to the present day. It was scheduled to close in 2015 due to the loss of feed material to the recently-built Long Harbour facility in Newfoundland, as well as stricter federal standards for SO_2 emissions. As of this writing, the refinery will remain open until 2018.

Long Harbour, Newfoundland, Refinery

Vale Canada's Voisey's Bay project arose from the discovery of a major nickel-copper-cobalt ore deposit on the Atlantic coast of the Labrador Peninsula. After bidding against several rivals, Inco purchased the rights to the deposit in 1996 for 4.3 billion dollars. Following considerable delays needed to resolve land rights issues and environmental concerns, the mine began producing in 2006.[89]

In order to approve the project, the Newfoundland government stipulated that a refinery be constructed in the province rather than having ore concentrate from the Voisey's Bay project shipped to existing facilities in Thompson and Sudbury. It also required that the amount of concentrate refined in Newfoundland be equal to the amount shipped outside the province. Despite concerns about the economic feasibility of the arrangement, Inco agreed to build a refinery in 2002.

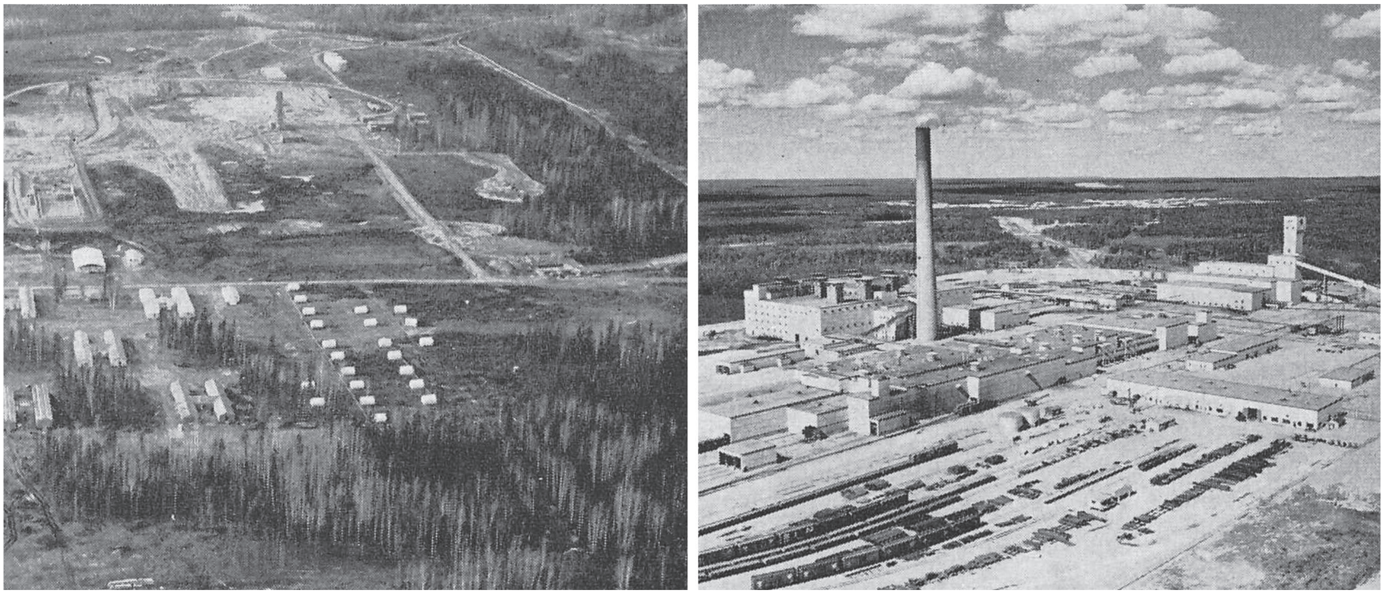


Figure 11: The site of the Thompson nickel operation in the early stages of construction in 1957, and in 1961 when the plant was opened (Anon. 1964, 1147)

In 2009, after initial test projects had been completed, construction began on a hydrometallurgical facility in Long Harbour, Newfoundland.[99] The facility began production of finished nickel in 2014, using concentrate from Vale's operations in Indonesia. It began operating on concentrate from Voisey's Bay in January of 2016.[91]

FALCONBRIDGE/XSTRATA/ GLENCORE

Falconbridge (now Glencore Sudbury Integrated Nickel Operations) has historically been the second major player in the Sudbury area. The company was founded in 1928 in the town of Falconbridge, Ontario, by American investor and prospector Thayer Lindsley (1882–1976). Lindsley owned a large mineral exploration company called Ventures Ltd., of which Falconbridge was originally a part. This vast and complicated company accumulated numerous mining properties while initially exploiting few of them. Falconbridge, which eventually assimilated Ventures Ltd., was its most important asset.[92]

In 1929, Falconbridge acquired a nickel refinery in Kristiansand, Norway. The refinery had been established in 1910 by a group that included Victor Hybinette (1867–1937), inventor of the Hybinette process for refining nickel from sulphide ores. By acquiring the refinery, Falconbridge gained access to this important process. The facility is still in operation as Glencore Nikkelverk. In 1930, the company built a smelter to produce cast nickel-copper matte for shipment to the Kristiansand refinery.[93] Ore fed to the smelter was sorted by hand until a mill was built in 1933.[94]

Falconbridge was, at this point, a relatively small operation compared to Inco. During the Second World War, it lost its refining capacity when Norway was occupied by Germany. Falconbridge ore was processed by Inco until the facility was recovered. Following the War, while Inco faced the threat of antitrust legislation from the U.S. government, Falconbridge was favoured by several big contracts from the U.S. government, which had determined to build a reserve of strategic metals.

Between 1950 and 1957, the U.S. government spent $789 million purchasing nickel. Several major government contracts, sometimes involving bonuses well over the market value, greatly assisted the company's development. Between 1953 and 1963, the year of its most significant contract with the U.S. government, production rose from roughly 14,500 tons to 32,000 tons (13,200 to 29,000 tonnes).[95] Falconbridge was, by the mid-1950s, the second largest nickel producer in the world.[96] To accommodate this increased capacity, the Sudbury smelter was significantly expanded at the end of the 1950s.[97]

Overseas expansion began in the late 1960s when the company's subsidiary in the Dominican Republic, Falcondo Dominicana, began work on a facility for producing ferro-nickel from lateritic ore for processing in Norway. From the late 1970s through the 1980s, the Sudbury smelter implemented a number of efficiencies and environmental improvements. Several new technologies, including methods for processing laterite ore from the Dominican Republic and improvements to the Norwegian refinery, were developed, adapted, or tested at Falconbridge's research facilities near Toronto.[98]

In the 1980s, Falconbridge expanded into other commodities, notably acquiring the Kidd Creek copper mine and metallurgical facility in Timmins, Ontario.[99] New mines were opened in the Sudbury area in the early 1990s. Between 1996 and 1998, a new mine and mill was established at the Raglan deposit on the Ungava peninsula on the northern tip of Quebec, a project carried out in consultation and partnership with the Inuit communities of the area.

Like Inco, Falconbridge also produces a great deal of cobalt, which has been processed at its Norway refinery since 1952.[100] Beginning in the 1980s, the Falconbridge smelter in Sudbury became an increasingly important processor of secondary materials. This includes both nickel scrap and cobalt scrap recycled from alloys. A significant proportion of both materials produced by Falconbridge now comes from recycled materials.[101]

In 2003, Falconbridge merged with Noranda, a major Quebec-based copper company discussed below. In 2006, the combined company was acquired by Xstrata, a Swiss multinational headquartered in London.[102] In 2013, Xstrata merged with Glencore, another Swiss-based multinational, forming Glencore plc. Falconbridge's former mines and smelter in Sudbury are currently run under the company name Sudbury Integrated Nickel Operations.

SHERRITT GORDON MINES (NOW SHERRITT INTERNATIONAL)

The last major player in the Canadian nickel mining industry to emerge was Sherritt Gordon. It was founded in 1927, largely through the actions of Eldon Leslie Brown (1900-1998), a Toronto-born mining engineer who joined the company when it was formed. Under Brown, the company discovered a significant Copper-Nickel deposit at Lynn Lake, Manitoba, over 240 km north of the company's copper operation at Sherridon Manitoba.

The establishment of the refinery at Lynn Lake, as well as several other large projects, was made possible by the prior completion of Hudsons Bay Mining and Smelting's copper mine and metallurgical complex at Flin Flon, Manitoba. This project, built between 1927 and 1930, required the construction of a railway connection between The Pas and Flin Flon. This 135-km branch line from the Canadian National line was a hugely ambitious project through inhospitable terrain. Its completion opened up other areas of Northern Manitoba to large mining projects.[103]

The end of the Second World War, and the nearing exhaustion of its copper mine, prompted the company to begin drilling and analyzing the Lynn Lake ore in 1946.[104] Having secured financial backing for a major mining project, Brown was able to convince the federal government and the Canadian National Railway to build a railway line from the Sherridon mine to Lynn Lake. A major operation was undertaken to move the company's Sherridon property, including seventy-three homes and a milling plant, to Lynn Lake along a winter road.

After both Inco and Falconbridge refused offers of partnership, the managers of Sherritt Gordon set out to find an effective method of smelting and refining the ore themselves.[105] Limited supplies of fuel in remote Northern

Figure 12: The "A" shaft mine complex and housing at the remote community of Lynn Lake, Manitoba. Date unknown. (Courtesy of Sherritt International Corporation)

Manitoba made the pyrometallurgical/electrolytic route taken by Inco and Falconbridge unattractive. In 1947, the superintendent of the Sherridon mill — where a means was being sought to concentrate the Lynn Lake ore — sent samples of nickel concentrate to Professor Frank Forward (1902–1972) at the Department of Mining and Metallurgy of the University of British Columbia. Forward made the first exploratory steps towards processing the concentrate through an existing leaching process.[106]

Forward's initial tests convinced Eldon Brown to pursue a hydrometallurgical approach. This eventually led to development work on a novel ammonia pressure leach process. By 1950, two pilot plants were running successfully in Ottawa. In 1952, following the completion of a third pilot plant, the refinery's design was finalized Fort Saskatchewan, Alberta, was chosen as the site for the refinery: it was along the CNR railway and boasted access to the Port of Vancouver and to natural gas supplies for ammonia production.[107] The Fort Saskatchewan refinery opened in 1954 and has been repeatedly upgraded since.

The Lynn Lake mine was exhausted in 1976, but the Sherritt Gordon refinery continues to operate on nickel concentrates from across Canada and from various international producers. The refinery's versatile method has also been applied to the extraction of a number of metals, from cobalt to gold, and has been licensed widely throughout the world. This process, developed in cooperation with several other companies and research labs, is discussed in the third chapter. The community of Lynn Lake has been sustained by the discovery of several new ore bodies, though it is currently undergoing a major demographic decline.

COPPER IN CANADA

Smelted since prehistoric times, copper acquired an important new application with the spread of electrical and telephone infrastructure beginning in the last decades of the nineteenth century. By the turn of the twentieth century, an efficient method had been developed for processing copper sulphide ores: Copper ore would be concentrated before being smelted in a reverberatory furnace to produce a furnace matte of iron and copper sulphides. The matte would be purified in a Peirce-Smith horizontal converter. Air would be blown through the molten metal and silicate flux added to further remove iron and sulphur impurities in the form of sulphur dioxide gas and iron-rich slag. The resulting blister copper, over 98-percent pure, would be further refined in an anode furnace before being cast into anode plates. Shipped to a refinery, these anode plates would be electrolytically refined to a final level of purity.

In 2015, Canada was the world's ninth largest producer of mined copper at 695,637 tonnes, and the seventeenth largest producer of refined copper at 331,000 tonnes. Chile led the world in mined copper, and China in refined copper.[108]

The mining and smelting of copper were relatively widespread in Canada's early industrial development. One count finds nearly 50 smelters put into production between 1849 and 1960. Most early smelters were small and built near mine sites in order to reduce the cost of shipping concentrate to the refinery. This system was superseded by the improvement of transport networks and the emergence of large, sophisticated smelters, able to process a range of concentrates from different mines.[109]

In the early part of the twentieth century, a major copper mining industry emerged in British Columbia that produced a number of smelters.[110] This was the culmination of the nineteenth-century mining boom that brought prospectors in search of placer gold to British Columbia, spurring infrastructure growth and opening the path to developing more challenging deposits. The mining boom in the Boundary region of British Columbia's central interior, near the border with Washington, was especially significant. Over the first decades of the twentieth century, mining towns such as Greenwood and Phoenix blossomed as the region became a major source of copper within the British Empire. As local mines were exhausted and smelters closed, the boom towns declined.

Two copper smelters are especially significant: the Granby smelter at Grand Forks and the British Columbia Copper Company smelter in the town of Anaconda, south of Greenwood. These facilities were located in the same region as the Cominco lead-zinc facility at Trail. The Granby smelter was, for a period following its opening in 1900, the largest non-ferrous smelter in the British Empire, and the second largest in the world. Much of the investment, equipment, and expertise involved in establishing these facilities came from the United States, or through Canadians partnering with American engineers and mining experts. The blister copper product was refined in the United States. Both facilities closed amid the glut of base metals and falling prices that followed the end of the First World War.[111]

A notable aspect of Canadian copper production is its link to nickel production through the copper-nickel ores of Sudbury. Two of the six smelters operating in 1960 belonged to Inco and Falconbridge respectively.[112] In Inco's case, copper concentrates were converted to blister copper at the Copper Cliff smelter before being transferred to the Copper Cliff refinery for casting into copper anodes and

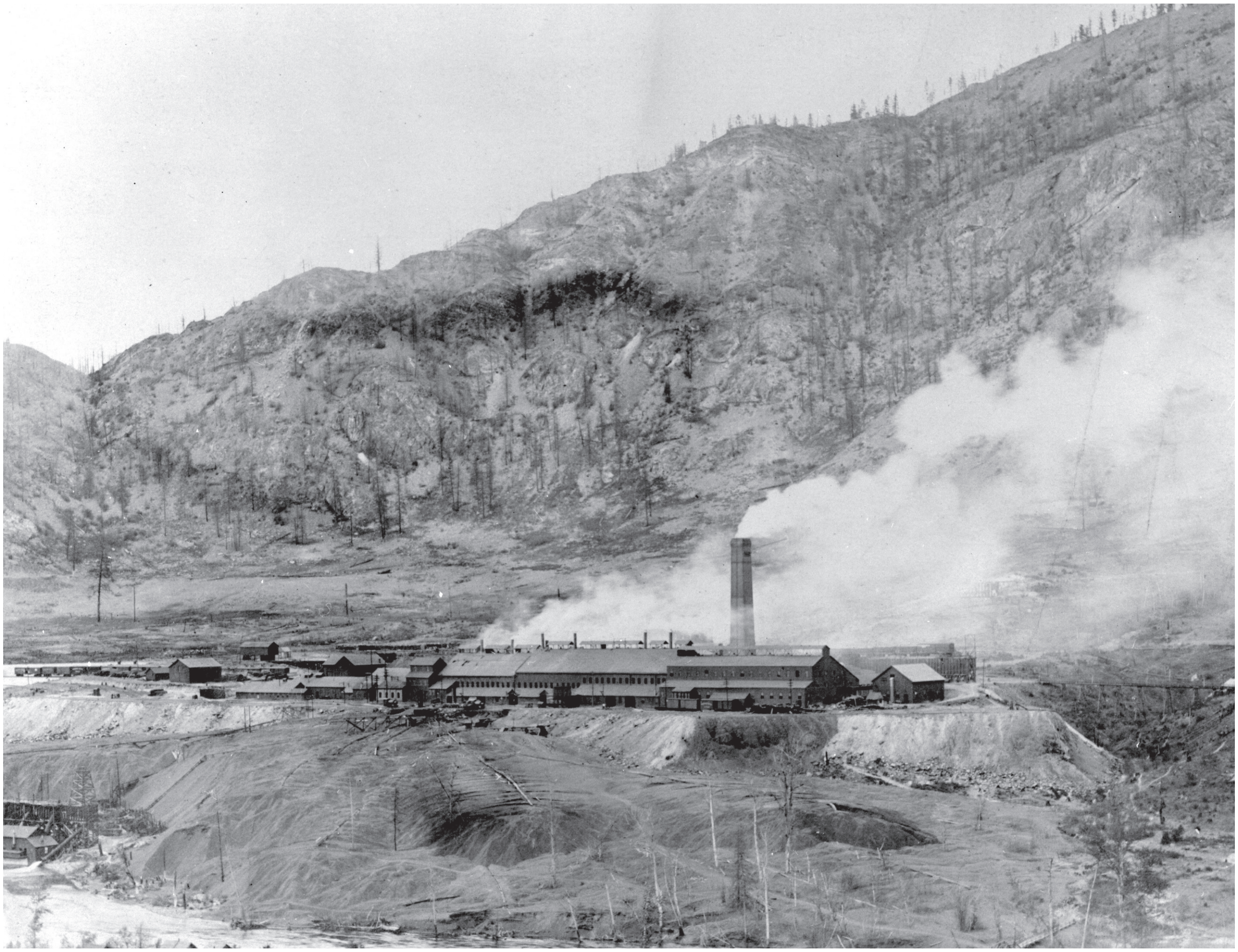


Figure 13: The Granby smelter at Grand Forks, B.C. The photo is undated, but shows an early stage in its development. (Royal B.C. Museum, 198604-010)

electrolytic refining. Inco's copper refinery was closed in 2005. Anodes are now cast in the smelter and transferred to the Noranda refinery in Montreal East.[113] In the case of Falconbridge, nickel-copper Bessemer matte is sent to the Kristiansand refinery in Norway.

Since the 1960s, copper smelting has advanced substantially towards improved energy efficiency, automation, and the capture and conversion of sulphur dioxide emissions to sulphuric acid. Three notable Canadian contributions to this area are discussed in the third chapter: Inco's flash furnace provides much greater efficiency than the older reverberatory furnace. The Noranda process reactor, developed starting in the 1970s, greatly simplified the smelting of copper concentrates, increasing productivity and permitting the capture of sulphur dioxide gas. The Gaspé tuyere puncher, developed at the Gaspé smelter, has also improved the efficiency of copper smelting operations.

Below we will trace the progress of one major Canadian copper producer, Noranda, which developed from a single productive mine in the western townships of Quebec into an international mining empire. The Noranda story is especially significant because of the company's scale, its longevity, its engagement with large-scale, sophisticated refining operations, and its research contribution to metallurgy. The efficiency of the Noranda process has ensured that the Horne smelter remains the only major copper smelter still operating in Canada.[114]

COPPER PRODUCTION AT NORANDA

In 1921, Edmund Horne (1865-1953), an experienced gold prospector from Nova Scotia, staked his claim to a gold deposit that he had discovered several years earlier while prospecting by canoe in eastern Quebec.[115] In 1922, this claim was purchased by the newly-formed Noranda Mines Ltd., led by James Y. Murdoch (1890–1962), a 32-year-old Toronto attorney specializing in mining law.[116] Murdoch was to lead Noranda until 1956, overseeing its expansion into a major Canadian mining company. He would remain the company's chairman until his death in 1962.

In 1923, diamond drill exploration of the Horne claim revealed that the gold deposit discovered by Horne covered rich and extensive deposits of copper sulphides. This unexpected find proved sufficient to convince the Canadian government to provide road and railway connections to the remote site. By 1924, Rouyn was the site of a booming mining camp. By 1927, the town was incorporated and the railway arrived.

The impact of Noranda on Quebec's metallurgical output was enormous. In 1926, before Noranda's Horne mine began operation, Quebec's mineral output was worth just under $1.9 milion. Ten years later the figure had exceeded $30.6 million.[117] By the end of the Second World War, the figure had risen to $150 million.[118] Unlike previous mining and smelting operations, Noranda had ambitions to become an integrated company.

The Horne smelter, built by an American engineering firm, was commissioned in 1927. It was joined in 1930 by an American-built electrolytic refinery located near the dockyard area at the east end of Montreal. The new enterprise, Canadian Copper Refiners, included a reverberatory furnace for casting anodes and a furnace for casting copper into bars.[119] The Montreal refinery was initially run by experienced American managers.

By 1939, Canadian Copper Refiners was the country's second largest copper refinery with a capacity of 102,000 tonnes per year. By 1960, this had risen to 194,000 tonnes. Noranda acquired full ownership of the plant in 1953. Two decades later, after further expansion, it was considered among the most advanced copper refineries in the world.[120]

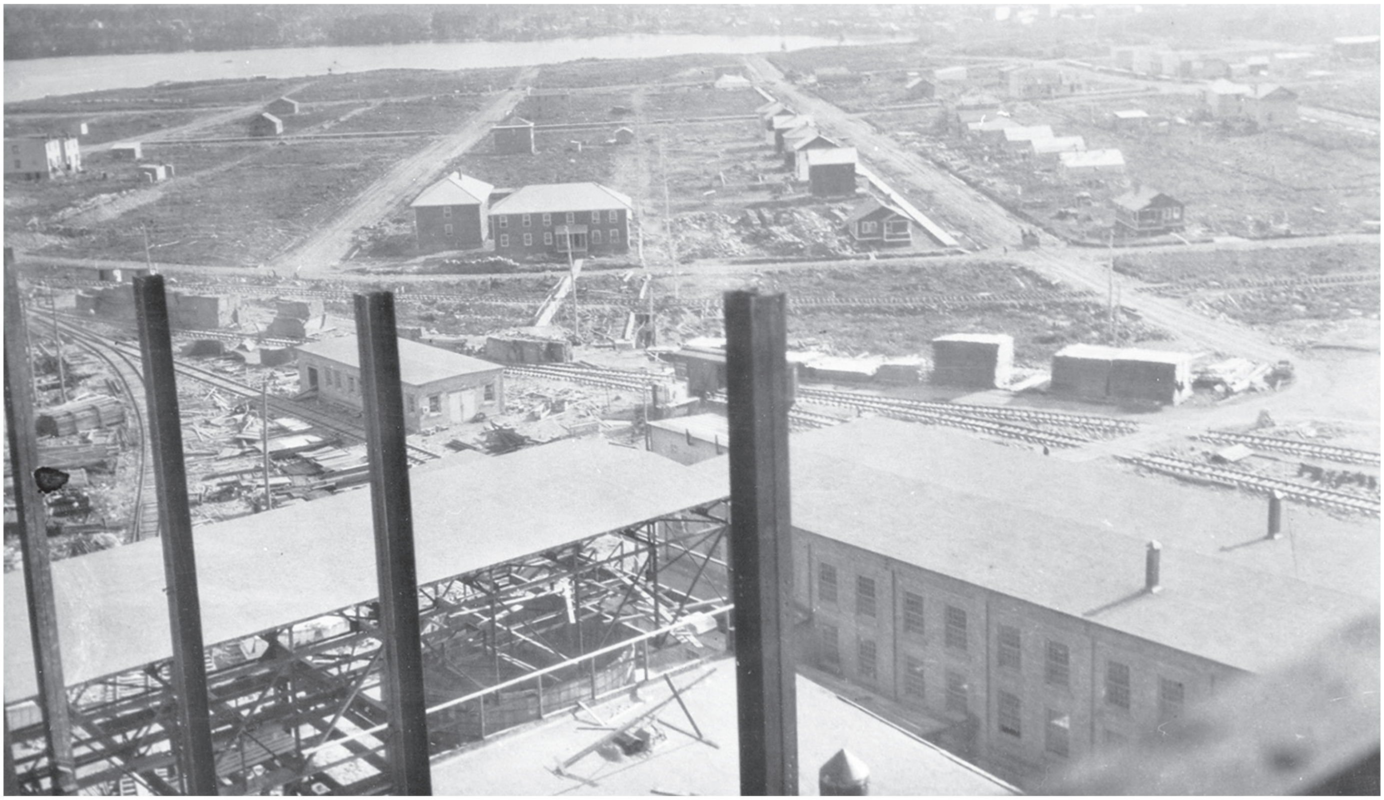


Figure 14: The town of Rouyn as viewed from the roof of the newly-built Horne copper smelter, c. 1927 (Library and Archives Canada/Canada. Dept. of Interior, PA-044300)

Canadian Copper Refiners (now named CCR) remains the only copper refinery in Canada. Over the years it has undergone numerous upgrades to improve its capacity, most recently in 2000.

In 1930, Noranda extended its operations into finished copper products with the purchase of a mill, located near the Montreal smelter, for producing copper rod and wire. It also purchased part of the Canada Wire & Cable Company based in Leaside, Ontario.[121] As the company grew through repeated acquisitions, copper production would become only a part of a business empire built on mining and smelting several metals.

A second major copper operation was developed on the York River in Quebec's Gaspé Peninsula. As with the development of the town of Rouyn-Noranda, this involved the development of a new community, Murdochville, named after the company's president, James Murdoch. In 1955, a concentrator and smelter was opened by Gaspé Copper Mines Ltd., a subsidiary of Noranda. The addition of a sulphur dioxide capture for acid production was a novel feature for that period, now standard on all smelters. The Gaspé smelter is notable for the invention of the Gaspé tuyere puncher, an automated system that was widely adopted at copper smelters throughout the world. The facility was modernized and expanded beginning in 1991 in an effort to focus on smelting operations in the face of declining local ore reserves. It closed in 2002 with the company citing low commodity prices and increasing environmental requirements.[122]

By 1968, after a period of rapid expansion, the Noranda Group of Companies consisted of five smelting and refining plants, fifty-two manufacturing plants, and fifty-four other entities. It operated twenty-five mines, producing a range of metals, including gold, iron, zinc, and molybdenum. Its manufacturing operations ranged from pulp mills to auto parts plants. Noranda-owned companies operated in several Canadian provinces and a number of countries.[123] Aggressive acquisitions would take the company into several new markets throughout the 1970s and 1980s.

Like other major Canadian metal companies, Noranda established research-and-development facilities around the middle of the century. The Noranda Technology Centre, located in Pointe Claire, a suburb of Montreal, opened in 1961. It was here that, in the mid-1960s, development of the Noranda process reactor began. First implemented at the Horne smelter in 1973, this was the first commercial-scale copper furnace to both smelt and convert copper in a continuous process.[124] It was joined in 1989 by a large plant for converting SO_2 gas to commercial sulphuric acid, and in 1997 by the Noranda continuous converter. Both were part of Noranda's successful SO_2 abatement plan. The technology centre also developed a series of sensor technologies for measuring and quantifying metallurgical operations.

One new research-based technology in particular, the Magnola project to produce magnesium from asbestos mine tailings, proved an expensive failure that contributed to Noranda's debt problems and eventual takeover. The project began as a joint venture initiated with Lavalin Industries (now SNC-Lavalin) in 1988. The following years saw the construction of a test plant and, in 1995, a demonstration plant financed as a joint venture between SNC Lavalin, Société Générale de Financement du Québec (SGF), and Aisin Seiki Co. Ltd., a Japanese manufacturer of auto parts. Aisin Seiki and SNC Lavalin eventually dropped out of this arrangement. SGF and Noranda together invested $1.3 billion in constructing and starting up a full-scale plant in Danville, Quebec. The plant came online in 2000 and was beset by technical problems. Meanwhile, Chinese producers had begun to flood the magnesium market. In 2002, Noranda took a write-down of $630 million of the value of the plant.[125] The plant was put on standby in 2003 pending an improvement in the market. It was closed and dismantled in 2006.[126]

Noranda suffered from labour troubles and low commodity prices throughout the late 1980s and early 1990s. In the late 1990s, it sold a number of its holdings to focus on metals and mining, further concentrating on its core copper and nickel operations amid rising debt in the early 2000s. In 2005, Noranda was taken over by Falconbridge. In 2006, it was acquired by Xstrata (now merged with Glencore), a global mining and trading firm based in Switzerland.

ALCAN: CANADA'S ALUMINUM INDUSTRY IN QUEBEC AND BRITISH COLUMBIA

Aluminum is the most abundant metal on earth, and the third most abundant element in the earth's crust. However, it is only efficient to produce when naturally concentrated in bauxite ore, typically found in the tropics. Smelting aluminum requires nearly ten times more energy per tonne than is needed to produce steel because aluminum's bond with oxygen is especially strong. Consequently, Canada's aluminum industry emerged in Quebec and coastal British Columbia, two areas with an abundance of hydroelectric power.

Canada's aluminum industry has historically been dominated by a single company, Alcan. Following a familiar pattern, it was founded mainly by Americans in pursuit of new opportunities. Over time, an independent Canadian industry evolved. This process was greatly assisted by a management decision, made in the late 1920s by Alcan's American parent company, to place its former Canadian subsidiary in control of its existing global business empire.

In 2015, Canada was the world's third largest producer of primary aluminum, with about 2.9 million tonnes, behind China and Russia. China dominated world production at 30.5 million tonnes.[127] Since 2000, China's share of global aluminum production has grown from 11 percent to 50 percent and continues to climb, driving down prices.[128] Among the challenges of the aluminum business, albeit one with a considerable environmental upside, is the fact that the metal is recycled using a fraction of the energy of primary smelting.

Aluminum production may be broadly viewed as a two-step process. First, aluminum oxide (alumina) powder is extracted from bauxite ore at an alumina plant. This is still typically done using an evolved version of the hydrometallurgical Bayer process, invented in 1898 by the Austrian Chemist Carl Joseph Bayer (1847-1904). In the second step, alumina is reduced to aluminum using electro-reduction in the Hall-Héroult cell.[129] The Hall-Héroult process, originated simultaneously and independently in 1886 by French inventor Paul Héroult (1861–1914), and American inventor Charles Martin Hall (1861–1914), has provided an effective means for producing liquid aluminum. The principle of the Hall-Héroult cell has remained essentially unchanged, though the configuration of the cells has varied through time, and across the industry. Over the years, these cells have evolved to operate at higher energies, while becoming more efficient, and producing fewer emissions.[130]

In an aluminum smelter, many cells (also known as pots) are arranged together to form a series electrical circuit. The Rio Tinto Alcan smelter in Alma, Quebec, for instance, operates 430 of the company's AP30 type cells in line, with a heavy electrical current flowing from one to the next, through conductive "buss bars." A cell basically consists of a long, flat, rectangular carbon lining, which acts as the electrical cathode, onto which the molten aluminum deposits. The carbon cathode is surrounded externally by refractory brick contained within a steel shell. Within this vessel, anhydrous aluminum oxide (alumina) is continuously added to a molten bath of cryolite, which is a crystalline mineral, so as to form the electrolytic bath. This dissolution process allows the alumina to enter the bath at about 1000ºC, versus its melting point of over 2000°C.

To begin the smelting operations, the cell is preheated and charged first with the molten cryolite bath to which alumina powder is added through steel "fettling" tubes. Flat, pre-baked carbon anodes are lowered into the bath, with current flowing through the bath from the anode blocks to the cathode lining. The molten liquid is electrolyzed, such that aluminum gathers at the cathode in the base of the vessel, while the released oxygen reports to the anode, where it combines with carbon to form carbon dioxide. The molten metal is periodically tapped and replaced with alumina in a continuous process that pauses only when one of the cell's anodes have been consumed and requires replacement. Computer control systems automate the charging process and help minimize the electrical resistance within each cell by controlling the depth of the electrolytic bath.[131]

Cells typically last from five to eight years before they require refurbishment. Modern smelters usually include anode plants, incorporating large bake furnaces, for fabricating the consumable carbon anodes. These are made from coke and coal pitch — a by-product of coke-making in the steel industry — as well as from material recycled from used anodes.[132] The carbon anode used in Rio Tinto Alcan's current AP60 cells weighs 1,420 kg and is consumed in 28 days.

ALUMINUM PRODUCTION IN QUEBEC

Canada's aluminum industry emerged relatively quickly. In 1901, only fifteen years after the Hall-Héroult process was first developed, commercial production of aluminum began in Canada with the establishment of a smelter in Shawinigan, Quebec. This was the product of collaboration between American and Canadian industrialists seeking to develop Canada's hydroelectric resources. Earlier ventures in the Niagara Falls region had made it "the electrochemical centre of the world."[133] Similar efforts were underway to develop hydroelectric projects at Shawinigan Falls on the Sainte-Maurice River in order to establish a new industrial centre and to produce cheap electricity for existing industries in Montreal. This project attracted the attention of the American aluminum conglomerate the Pittsburgh Reduction Company, later to be known as Alcoa.[134]

The Shawinigan smelting venture, essentially a Canadian branch plant, was named the Northern Aluminium Company. It was renamed Aluminum Company of Canada (later Alcan) in 1925. By that time, production had started at a second smelter at Arvida (now part of the City of Saguenay) near the Saguenay River. The Arvida project was a major undertaking that involved building the world's largest hydroelectric plant in Isle-Maligne, as well as a port on the Saguenay River and a rail link. Alcoa established a new town, Arvida, initially consisting of 270 houses. Named for Arthur Vining Davis (1867–1962), the president of Alcoa, Arvida was very much a company town.[135]

Alcan was, at this point, largely a company of French Canadian labourers and Anglophone — mostly American — managers.[136] This situation was changing slowly as French Canadians worked their way up into managerial positions. The earliest of these was Melchior Carrière (d. 1942), who worked at the Shawinigan plant in 1901, eventually becoming superintendent of production before being transferred to Arvida in 1933, where he worked as a general foreman. In later years, when the Canadian company became more culturally independent, Alcan's Quebec operations embraced the French language and became increasingly linked to Quebec culture and identity.[137]

In 1928, the Aluminum Company of America underwent a restructuring that saw the running of the bulk of its international operations placed within the rubric of its former Canadian subsidiary. The reasons for this move are complicated. They revolve around the management decisions of Alcoa's director, Arthur Vining Davis (1867–1962), who first commercialized the Hall-Héroult process along with its American inventor, and who would continue to oversee American aluminum production through the Second World War.

The decision was based mainly on a desire to avoid ongoing trouble with American antitrust legislation as well as to more easily access the British market: Canadian companies, based in the British Empire, traded with England on much better terms.[138] The 1928 split between Alcan and Alcoa placed the Montreal head

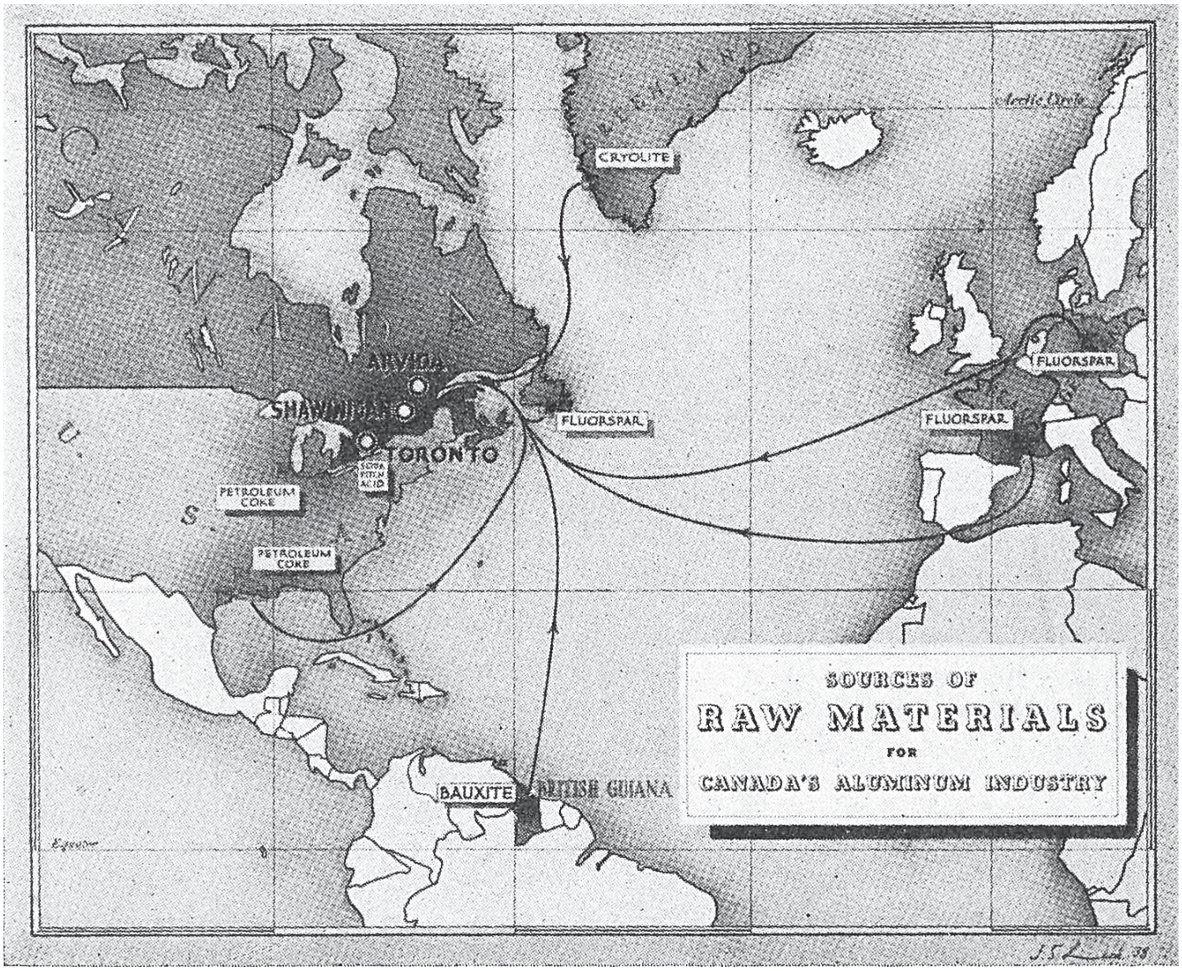


Figure 15: Map showing sources of raw materials for Canada's early aluminum industry (Cameron 1939, 457)

office at the head of Alcoa's global empire. Thereafter, Alcan managed an international system of mines, refineries, smelters, transportation, and finishing mills. A number of these operations were in the developing world. Montreal's place within this global network has been described in an extensive three-volume institutional history written by Duncan C. Campbell, which is cited below.[139]

Wartime Aluminum Aerospace Material Production in Kingston, Ontario

One of the principal applications of aluminum over the twentieth century has been aerospace materials. Political tensions building up to the Second World War raised interest at Alcan in improving existing production facilities to produce aerospace materials. These included heat-treated and non-heat-treated sheet, as well as various extrusions of aerospace alloys. By the late 1930s, the British Air Ministry was contemplating the production of aerospace materials in the colonies while Canada's administrators were seeking to develop industrial expertise in this high tech industry.[140]

In 1939, Alcan acquired a new property on the outskirts of Kingston, Ontario, and signed a contract with the British Air Ministry to expand aluminum production and to administer a factory, owned by the British Government, for producing aluminum aircraft materials. All equipment was to be purchased in Britain.

The Kingston plant operated 24/ 7 to fulfill the contract with a crew of workers, most of whom had been, in the words of Alcan manager R. E. Powell, "pitching hay last fall." An enormous forging mill, necessary to produce solid aluminum propeller blades, was installed by 1941, with thirteen installed by the end of the war. The impact could be heard throughout Kingston. Peak production for the plant was 16,000 propellers and half a million aluminum parts per month.[150] As the war continued, and British aluminum manufacturing plants survived the Blitz unscathed, production increasingly went to the United States. Canada itself produced 16,000 military aircraft.

Wartime production also saw the construction of a new aluminum casting foundry in Etobicoke.[151] This infrastructure is part of a broader story of wartime light metal production, which includes the development of the Pidgeon process for producing magnesium described in the third chapter. The extent to which these projects survived to contribute to Canada's Cold War aircraft production is worth studying in detail.

Figure 16: Propeller production at Alcan's Kingston plant in January of 1943 (Ronny Jaques/Library and Archives Canada/National Film Board Fonds, e000762922)

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Formerly dependant on American sources, Canadian alumina production began at Arvida in 1936 after an earlier novel "dry" alumina plant, based on a pyrometallurgical Alcoa technology, had proven a costly failure.[143] The concurrent expansion in the production of finished aluminum goods helped the company to flourish. A cable mill producing electrical transmission lines was established at the Shawinigan smelter in 1902. Not long after, a manufacturing plant was established in Toronto. When this period of productivity was followed quickly by the economic collapse of the 1930s, the company expanded its production of secondary goods to see itself through the depression.[144]

The aluminum industry expanded significantly during the Second World War. With both the United States and Britain at war, Alcan was given contracts demanding a five-fold expansion in production.[145] This required the rapid building of several new smelters in Quebec, major renovations to existing smelters, as well as rapid completion of new hydroelectric operations at Lac Manouane, Passes Dangereuses, and the massive Shipshaw plant at Chute-à-Caron. The many challenges faced during the war included the rapid resettlement of thousands of new workers and the submarine threat to Alcan's bauxite shipments to Canada.[146]

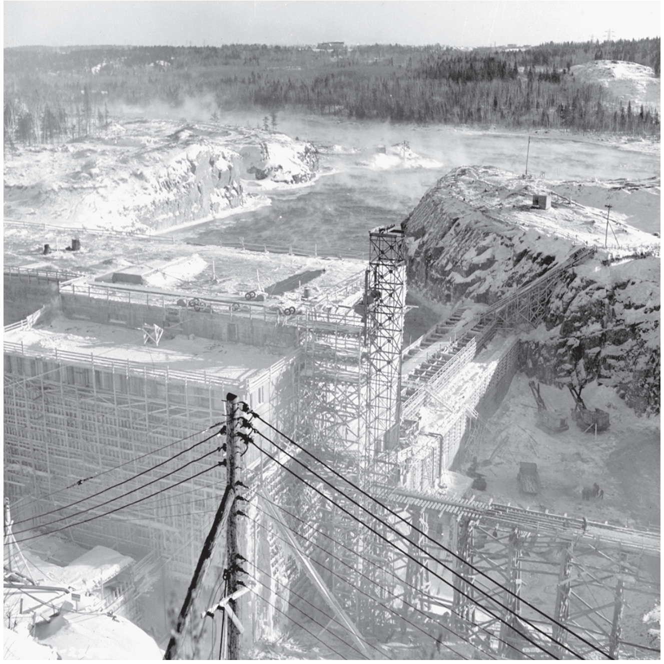


Figure 17: Construction of the Shipshaw hydroelectric plant during the Second World War, part of the massive wartime expansion of Canada's aluminum production (Ronny Jaques/ Library and Archives Canada/National Film Board Fonds, e000760993)

Canadian aluminum production continued to increase during the Cold War period, permitting more obsolete infrastructure to be renovated and new projects to be undertaken. As with other metal companies, Alcan and Alcoa invested in research that led to automated processes and new smelting technologies. Initially, much of this was obtained through Alcoa and other aluminum producers with established research and development infrastructure. Research and development facilities were established at Kingston in 1942, and Arvida in 1950.[147] Especially notable is research work in the Arvida laboratories during the 1950s and 1960s on the "monochloride" method for producing aluminum from bauxite concentrate without the use of the Hall-Héroult cells. In 1967, research on this ambitious process was discontinued after it proved too costly.[148] However, research into the "non-consumable anode" continued well into the 1980s.

The research centre at Arvida, now called the *Rio Tinto Alca–Centre Recherche et Développement Arvida*, remains an important site for research and development in aluminum. Together with the NRC Aluminium Technology Centre and the University Aluminium Research Centre, it forms part of a research cluster called Aluminum Valley/ *Vallée de l'aluminium*. The Rio Tinto Alcan centre at Arvida has notably developed the AP60 cell which is currently the world leader in cost and efficiency.[149]

THE KITIMAT-KEMANO PROJECT IN BRITISH COLUMBIA

The most significant Canadian development in Alcan's post-war history has been the establishment of a hydroelectric dam at the western end of the Kemano River along with a smelter at Kitimat on the nearby Douglas Channel. Hydroelectric power from the Kemano dam would support the development of Kitimat as a new industrial city of 50,000.[150] The project was planned and expedited to take advantage of the considerable demand for aluminum created by the Korean War.

The project, constructed after considerable planning between 1951 and 1968, involved several major feats of engineering. The most impressive, and ultimately controversial, was the construction of two penstock tunnels, over 7.5 m in diameter and 3.2 km long, that would carry water through a 2133-m mountain from the reservoir to a power station 853 m below. The power station housed eight generators producing 112 megawatts each. These were completed in December of 1953, and by August of 1954, the first ingot was cast in the newly built smelter.[151]

Figure 18: A penstock liner is hoisted up the mountain. It will be used to line the tunnels carrying water from the Nechako Reservoir to the Kemano powerhouse. (Tramway landing on 1600′ level, 23-Jan-54. Alcan ID no. KR-1576. Alcan Collection. Courtesy of the Kitimat Museum & Archives. KMA No. 987.3.3)

Early work on the smelter was beset by problems, and plans to expand the project to its planned capacity were eventually put on hold.[152] The project has long generated controversy as it is built on salmon spawning grounds that support a major fisheries industry in Canada and the United States.[153] In 1995, amidst much controversy, the partly finished Nechako Completion Project, a planned expansion to the capacity of the Nechako dam, was halted by the BC government over public concerns that increased diversion from the reservoir would affect salmon stocks.

Like other Canadian giants of the metals industry, Alcan has become a subsidiary of a foreign multinational amidst a recent period of consolidation. In 2007, following a failed hostile takeover bid from Alcoa, the Anglo-Australian mining company Rio Tinto purchased Alcan for $38 billion. Following the merger, Alcan's facilities for producing value-added goods were sold to pay for the deal. In 2015, the Rio Tinto company transferred the head office of its Alcan subsidiary from the historic "Maison Alcan" to a newer office building in Montreal. It has since dropped the historic Alcan name.

LEAD AND ZINC AT TRAIL, BRITISH COLUMBIA

The development of a major metallurgical complex at Trail, in Canada's westernmost province, is an important part of the early history of Canadian metallurgy. Established just 22.5 km north of the border with the United States, the Trail smelter was soon adapted to treat the abundant zinc-lead-iron sulphide ore of the Sullivan mine near Kimberly, British Columbia. Over the course of its evolution, the company that began as the Consolidated Mining and Smelting Company of Canada Ltd. (known, over much of its history, as "Cominco") emerged as a dynamic Canadian metallurgical giant, opening new mines, establishing partnerships oversees, and continuously modernizing its metallurgical facility at Trail.

The environmental challenge of operating a metallurgical facility in this period is especially evident in the history of the Trail complex. The operation's legacy has had an international dimension, given the smelter's proximity to the American border. Changing standards, along with a growing awareness of the dangers of various environmental pollutants, have obliged the company to contend with the environmental consequences of more than a century of metallurgical operations. Ongoing pressure to improve environmental performance, and the technological solutions that it engendered, has shaped the company through time and has enabled it to remain competitive and viable.

As with other large Canadian metallurgical companies, the development of research facilities has been critical to resolving such challenges. The unusual complexity of the ore from the Sullivan mine — specifically the challenge of efficiently extracting both lead and zinc concentrates — proved an impetus for innovation. Lead and zinc are often found together in nature, and the need to treat these two metals in combination is the historical basis for the importance of Cominco's Trail complex.

LEAD AND ZINC IN CANADA

Zinc has been used since the first century CE as an alloy of copper to produce brass. Its production in Canada, and elsewhere, has been accelerated by periods of war when brass was needed for steel and cartridge casings. Since the galvanizing of iron and iron alloys was invented in the nineteenth century, the process has become the primary use for zinc. Galvanizing provides a protective coating against rust. It is applied one of several different ways that differ in their level of exposure protection and amount of zinc used. These include "hot dip" plating in a molten zinc bath, suitable for outdoor exposure, and galvanizing by electrolysis, which uses less zinc while providing protection suitable for indoor use. In 2015, galvanization accounted for 50 percent of the zinc consumed worldwide, with brass and other alloy production accounting for 34 percent.[154]

The first Canadian attempts to smelt zinc were made in 1905 and 1906, when the Canadian Metal Company in Frank, Alberta, sought to capitalize on zinc ores recently discovered nearby in British Columbia. The method, which involved firing a mixture of calcined ore and coke in multiple horizontal clay retorts to drive off zinc vapour, proved uneconomical. This method of smelting using a horizontal retort furnace was standard technology over much of the first half of the twentieth century, and was significantly improved over that period.[155] An attempt by the Canadian Zinc Company in Nelson, British Columbia, beginning in 1908 and employing an electric smelting method, also failed. The first successful effort involved an electrolytic process that was implemented at Trail, and is discussed below.[156]

In 2015, three Canadian refineries produced 683,052 tonnes of zinc metal. These were: the Trail smelting complex; the Hudbay Mineral smelter in Flin Flon, Manitoba, which began operation in 1930 under the name Hudson Bay Mining and Smelting; and the plant, currently managed by Glencore and known as CEZinc, founded as Canadian Electrolytic Zinc in Valleyfield, Quebec, in 1963. The latter is the second-largest zinc refinery in North America. Two other zinc refineries also produced zinc: The Imperial Smelting Furnace, opened in 1966 near Belledune, New Brunswick, and subsequently converted to a lead smelter; and the Kidd Metallurgical Site, opened in 1980 in Timmins, Ontario, which has closed entirely.[157]

In 2015, Canada was the fourth-largest producer of refined zinc, accounting for 5 percent of world production. Its refineries processed mainly imported concentrates. China was the world's largest producer accounting for a remarkable 44 percent of metal output. South Korea, the next-largest producer, accounted for 7 percent. Canada was then the ninth-largest global producer of mined zinc.[158] Notable among Canadian lead-zinc mines is Cominco's former Polaris zinc-lead mine on Little Cornwallis Island in (what is now) the territory of Nunavut. From 1982 to 2002, the mine operated 1,120 km north of the Arctic Circle, the world's northernmost mine.

Lead was first smelted in Canada in 1889 in the city of Vancouver, though this smelter quickly failed due to the sulphur and lime content of the ore. That year, the Kootenay Smelting and Trading Syndicate began construction of a lead smelter near Revelstoke, BC. Briefly successful, it was shut down after less than a year when it ran out of useable local ore. A copper blast furnace established at Nelson, British Columbia, in 1896 was, by 1902, used increasingly to process lead concentrates. This operated until 1908. The next successful Canadian lead smelter was at Trail.[159]

Lead, a metal with a relatively low melting point, has been used since prehistoric times in oxide form as a pottery glaze and as cast metal. Currently, the vast majority of lead is used in manufacturing lead-acid batteries. Because of a significant decline in mined lead in Canada over the past decade, Canada currently refines significantly more lead than it mines: in 2015, Canada refined 268,864 tonnes of lead, while mining only 4,031 tonnes. Roughly half of the refined lead produced in Canada is derived from recycled sources — chiefly batteries. Most of the remainder is produced from imported concentrates. In 2015, Canada was the eighth-largest exporter of refined lead, producing about 2 percent of the world's total. China was the world's leading producer at 42 percent.[160]

THE COMINCO STORY

British Columbia's gold rush, which began in the mid-nineteenth century, left in its wake a population skilled at prospecting and mining. It also created the infrastructure to transport ore from increasingly remote locations in the British Columbia interior. Cominco grew out of the mining town of Rossland, in the West Kootenay region, which boomed following the discovery of copper-gold ore in 1890. By 1895, Rossland had a population of nearly 2,000. Local ore was transported to a smelter in Montana through a complicated route involving horse drawn wagons, paddle wheel steam ships, and trains.

To address these transportation difficulties, the operators of the Le Roi copper-gold mine in Rossland hired an experienced American developer, Fritz Augustus Heinze (1869–1914). Heinze's task: to build a local smelter for transforming copper and gold ore into a crude metal suitable for further refining in the United States. The Trail Smelter was constructed on the Columbia River between 1895 and 1896 along with a railway to transport ore from the Rossland Mines. In 1896, both mine and smelter were transferred to Dominion ownership with the incorporation of British Columbia Smelting and Refining Ltd.[161]

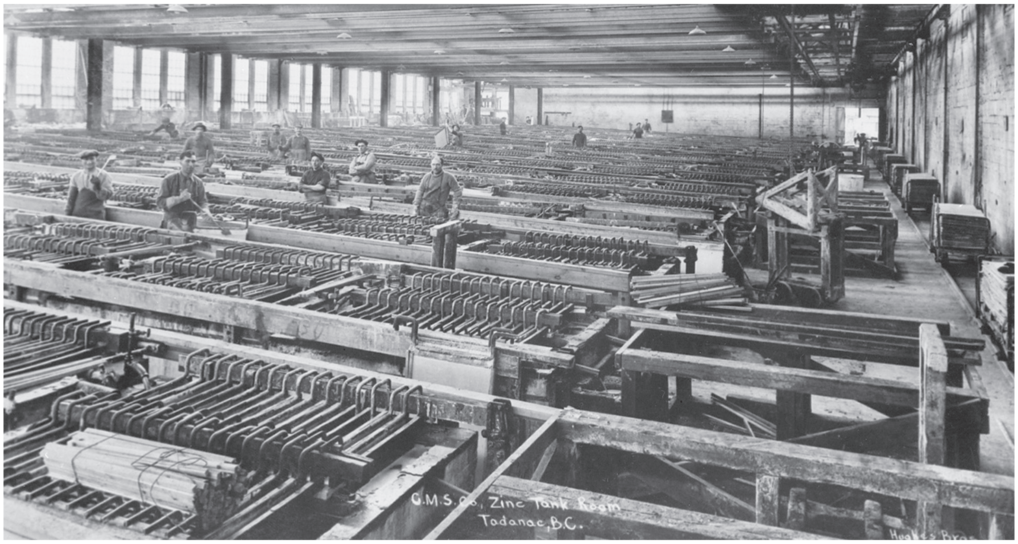


Figure 19: Tank room for electrolytic refining of zinc at Trail, B.C. in 1926 (Canada. Dept. of Mines and Technical Surveys/Library and Archives Canada, PA-015521)

In 1897, the Dominion company sold its assets to the Canadian Pacific Railway (CPR), which was primarily interested in acquiring its railway lines. The CPR placed the smelter under the management of Walter Hull Aldridge (1867–1959), an experienced smelter manager from Montana. The smelter flourished under Aldridge's leadership. In 1898, a lead blast furnace was established to process the local lead-silver ores. By 1901, three such furnaces were in operation. The crude lead bullion was shipped to San Francisco for refining.[162] In 1902, the Betts electrolytic process was established at Trail to refine the lead bullion locally. This was the world's first commercial application of the Betts lead electrorefining process.[163] This process remains in use at Trail today.

1906 saw the formation of the Consolidated Mining and Smelting Company of Canada (CM&S), which united the assets of the existing plant at Trail, the War Eagle and Centre Star mines at Rossland, and the St. Eugene mine at Moyie. Facing limited reserves from its existing mines, the new company set about examining mining possibilities in the vicinity. In 1909, it obtained a lease on the Sullivan lead-zinc mine at Kimberly, BC. This had been discovered in 1892, but had remained unexploited because of the complexity of its zinc-lead-iron sulphide ore.[164] This mine was to prove the most abundant source of lead in the British Empire during the First World War. Silver associated with lead also provided a significant revenue source for much of the life of the mine.[165] The Sullivan mine was also among the most abundant sources of zinc in the world at that time.

Initially, the zinc content of this ore was considered too expensive to process using existing pyrometallurgical processes. Consequently, experimentation on the electrolytic production of zinc began at Trail in 1912. The following year saw the construction of an experimental electrolytic zinc plant that operated until 1915.[166] The outbreak of the First World War created significant demand for zinc-copper alloys used in making brass cartridges and shell casings. CM&S was initially granted a contract from the Imperial Munitions Board for 35 tons (31.8 tonnes) of zinc per day. This figure increased throughout the war.[167] A new electrolytic zinc plant began operation in 1916. Expansion of electrolytic metallurgy obliged the company to acquire and expand its hydroelectric facilities on the Kootenay River — the company's ownership of this cheap and abundant supply of energy was one reason behind its long-term success. During the war, the company also opened Canada's first copper refinery. Reporting on the considerable expansion that had taken place at the Trail facility during the early phase of the war, S. G. Blaylock, a CM&S general manager, noted:

> *The Trail plant today is probably as complete a metallurgical works as there is on the continent. Of course I do not mean to say by any means that it is as large as some. We employ about 1,600 men and are making electrolytic copper, copper sulphate, electrolytic lead, lead pipe, shrapnel, wire, electrolytic zinc, gold, silver, sulphuric acid and hydrofluosilic acid. All of these, with the exception of lead, gold, and silver, have been accomplished since the war started, and were caused primarily by the need for the material by the munitions board.*[168]

Anticipating a drop in the demand for zinc at war's end, as well as a corresponding oversupply in the United States, the company sought a more economical means for processing Sullivan ore. The bottleneck in existing zinc production was the tedious manual sorting process used to select ore fit for smelting. This led the company to place Canadian metallurgist Randolph W. Diamond (1891–1978) at the head of a five-person team to study the problem of separating the Sullivan ore into its individual mineral components. Developed between 1917 and 1920, a new concentrator employing a novel method of differential froth flotation was opened near the Sullivan mine at Kimberly, British Columbia, in 1923.[169]

Froth Flotation and the Complex Ores at Trail

Froth flotation was one of the key developments in twentieth-century mining and metallurgy, permitting the exploitation of ores that had earlier been unworkable or economically unviable. It dramatically reduced energy requirements and smelting costs due to the much higher grade of concentrate produced by the froth flotation process. It also permitted the recovery of fine particles that had previously been lost during the milling process. Though largely invisible to the public, this seemingly modest technology has produced a vast worldwide economic benefit. Although still very early in its development, froth flotation was adopted by Cominco in order to process the complex lead-zinc-iron ores of the Sullivan mine. The development of the differential flotation process used by Cominco was the first large-scale implementation of differential flotation anywhere.[170]

Froth flotation involves the mixing of fine mineral particles with water to form a slurry. This mixing process takes place within a flotation cell or tank. Various chemical agents are added to perform functions such as producing froth, or changing the chemical behaviour of particular mineral particles within the slurry. For instance, a collector chemical is added to selectively alter the natural hydrophobicity of a given mineral, thereby increasing the hydrophobicity of wanted minerals and allowing them to be selectively "floated." In some cases, chemicals are also used to supress the flotation of unwanted minerals.[171] A bubbling system forces air through the slurry. The hydrophobic particles adhere selectively to the bubbles, which rise to the top of the tank where they are gathered from the surface. Before flotation can take place, ore must be milled to an extremely fine consistency such that the individual particles ideally consist of a single mineral. The development of froth flotation therefore led to advances in milling technology.

Initially, bulk flotation was used to selectively recover a single economic mineral from pulverized ore. As the process evolved throughout the early twentieth century, methods of differential flotation were developed by which different minerals within a concentrate could be selectively and sequentially separated from each other — a more technically complicated task. However, such a process was necessary to economically gather the lead and zinc-containing mineral components within the Sullivan ore.

This process was implemented at Cominco by Randolph W. Diamond, a metallurgist who had studied at the University of Toronto before joining the Anaconda mine in Butte, Montana. Anaconda was one of a number of mining centres actively working on froth flotation. Diamond joined Cominco in 1917, and was placed at the head of a team charged with developing a flotation process for the Sullivan ore. This presented challenges not yet encountered by the mining industry. The galena (PbS) and sphalerite (ZnS) sulphide minerals were very finely associated, as was the iron sulphide in the ore. The ratio of iron sulphide in the ore to the lead and zinc minerals was also higher than in earlier successful flotation efforts. By the end of the following year, though, a 544-tonne- (600-ton) per day test mill incorporating a three-stage process was successfully operated. After a lengthy development period, the process was formally implemented in 1923 at a facility near Kimberly, B.C.[172] This method of processing the ore from the Sullivan mine opened the way to the development of Trail as a major metallurgical centre.

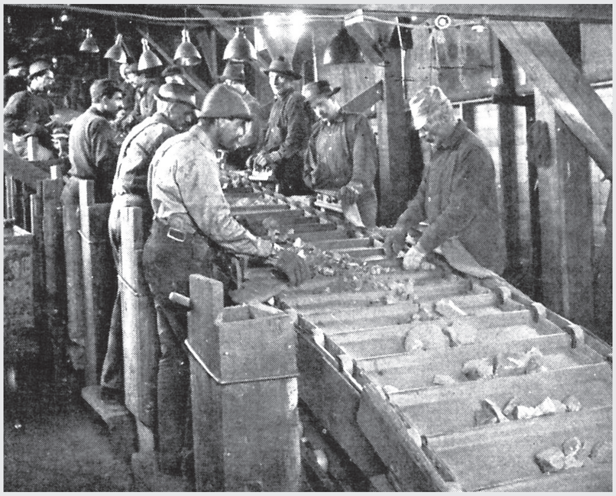


Figure 20: (Left) Workers sort ore by hand in the early years at Trail. (Right) A worker samples a flotation tank at Kimberly, c. 1960. (Cominco, 1960, 5, 10)

As a result of this new flotation process, Cominco became one of the world's largest lead and zinc producers in less than a decade.[173] However, this increased capacity produced a corresponding increase in sulphur dioxide emissions, which nearly doubled from over 4250 tonnes per month in 1924 to over 8150 tonnes in 1929. The result was a cross-border dispute with the United States that led to major efforts to reduce smelter emissions. One consequence of these efforts was the development of facilities to produce sulphuric acid, and, by reacting it with phosphate rock, to produce phosphate fertilizer. By 1930, three sulphuric acid plants had been built. This was followed, in 1931, by a fertilizer plant. "Elephant Brand" fertilizer, familiar to Canadian prairie farmers, is a little-recognized part of the material legacy of Canadian mining and metallurgy. Cominco's diversification into new chemical markets continued after the war. By 1960, in addition to being the largest producer of fertilizer in the world, Cominco produced sulphuric acid, sulphur dioxide, anhydrous ammonia, aqua ammonia, ammonium nitrate, chlorine, and caustic soda.[174]

During the Second World War, ammonia produced at Trail in the ammonium phosphate fertilizer plant was used to make explosives for the war effort. Production of ammonia was expanded under government contract and new plants were built at Trail and Calgary. The company also opened new mines in British Columbia to produce tungsten for armour-piercing projectiles and mercury used in bomb detonators. As part of its electrochemical research program, the company had investigated the production of heavy water—a form of water incorporating the hydrogen isotope deuterium. As a result, it was chosen as a site for wartime production of this experimental material. An electrolytic hydrogen plant, completed at American expense in 1943, was used as a source of heavy water for the Manhattan project and later for the Canadian nuclear program.[175]

Figure 21: A Cominco worker fills 36-kg (80-lb) bags with ammonium nitrate fertilizer (Cominco 1960, 21)

Other innovations that took place at the Trail refinery included the introduction of a slag fuming furnace to recover the significant amount of zinc contained in the slag from the lead smelting circuit. The first such furnace was started in 1927 at the International Smelting Company in Tooele, Utah. The Trail slag fuming furnace, started in 1930, was the second to be put into operation. The slag fuming process involves a water-jacketed furnace into which solid and molten slag is charged. Pulverized coal is injected through submerged tuyeres. At the temperature of the liquid slag, zinc is a vapour. The gases escaping from the bath are cooled and volatilized metallic zinc is captured as an oxide.[176]

During this period of rapidly increasing productivity, the company launched a major expansion of its surveying efforts in order to develop new mines. A fleet of company aircraft was used to survey areas of Canada's north. The Con gold mine, purchased in 1938, and the Pine Point lead-zinc mine on the south shore of Great Slave Lake, in production from 1964–1987, were both products of this early phase of exploration.

The company also expanded internationally over the second half of the twentieth century. It developed significant mining and metallurgical operations in the United States. This process began in 1965 with the acquisition of the Montana Phosphate Products Company (MPP), which had provided phosphate rock for fertilizer production. Cominco also built an electrolytic zinc smelter and zinc refinery in Calcutta. In 1964, it joined with Mitsubishi Metal Mining Company to build a lead smelter in Japan. In 1994, Teck Cominco took majority ownership of the newly privatized Cajamarquilla electrolytic zinc smelter in Peru, which it sold in 2004. The company also purchased interests in mining companies in Spain and Australia.[177]

In 1989, the Red Dog lead-zinc open pit mine began operations above the Arctic Circle in Northwestern Alaska. This development was made possible through an innovative profit-sharing agreement with the local Iñupiat people. By 1991, concentrates from the isolated mine were being processed at the Trail smelter. The Red Dog mine is currently one of the three largest zinc deposits in the world and is a significant source of revenue for the company. Ore from the Red Dog mine was essential for replacing concentrates from the Sullivan mine which was exhausted in 2001.

Smoke Across the Border: The Trail Smelter Dispute

Beginning in the mid-1920s, the rapid growth of smelting and refining operations at Trail produced significant levels of sulphur dioxide gas that poisoned vegetation and damaged farmland along the Columbia River. With the American border being only nineteen kilometers south of Trail, local American farmers and lobbied the U.S. government to seek compensation from the Canadian company. The resulting legal cases were to establish, for the first time, international regulations on trans-border air pollution. Efforts to resolve the matter drew on the expertise of Canadian university scientists, government officials, and the recently established National Research Council. Significantly, it was the first foreign policy episode that Canada handled independently of Britain.[178]

Several cases regarding smelter pollution within the United States had established the principle of "polluter pays." In Canada, the owner of the Trail smelter, the Canadian Pacific Railway, had compensated local farmers or purchased their land. In Washington, laws preventing foreigners from owning property encouraged farmers there to resist the company's offers in the hope that the U.S. government would come to their aid. In order to resolve the dilemma, both countries turned to the International Joint Commission (IJC), established in 1909 to resolve water and boundary issues. This commission awarded the American farmers $350,000 in 1935. A second decision awarded a further $78,000 in 1937. Both settlements were well below the farmers' expectations. The case was closed in 1941.[179]

In certain respects, this case reveals a form of international solidarity within the mining and metals industry. American industry leaders and university experts, wary of establishing a precedent that could penalize American smelters in other regions, offered information and support to Trail's Canadian owners.[180] Meanwhile, the Canadian government committed itself to supporting the Trail smelter. The head of the NRC and high officials from the Departments of Agriculture and Mines formed an Associate Committee on Trail Smelter Smoke to coordinate this endeavour. Judicial efforts were supported by technological improvements. By 1933, Canadian lawyers provided data showing the effects of SO2 abatement efforts. By 1937, the company had put in place sulphur dioxide capture technology that cut emissions by two thirds.

The issue of trans-border pollution from the Trail smelter did not end in 1941. Although SO2 emissions diminished, the smelter continued to dump smelter slag into the Columbia River, a practice that ended only in 1995. In 2012, a Washington court found Teck Cominco's American branch liable for the cleanup of slag and effluent that had accumulated on the U.S. side of the border.[181]

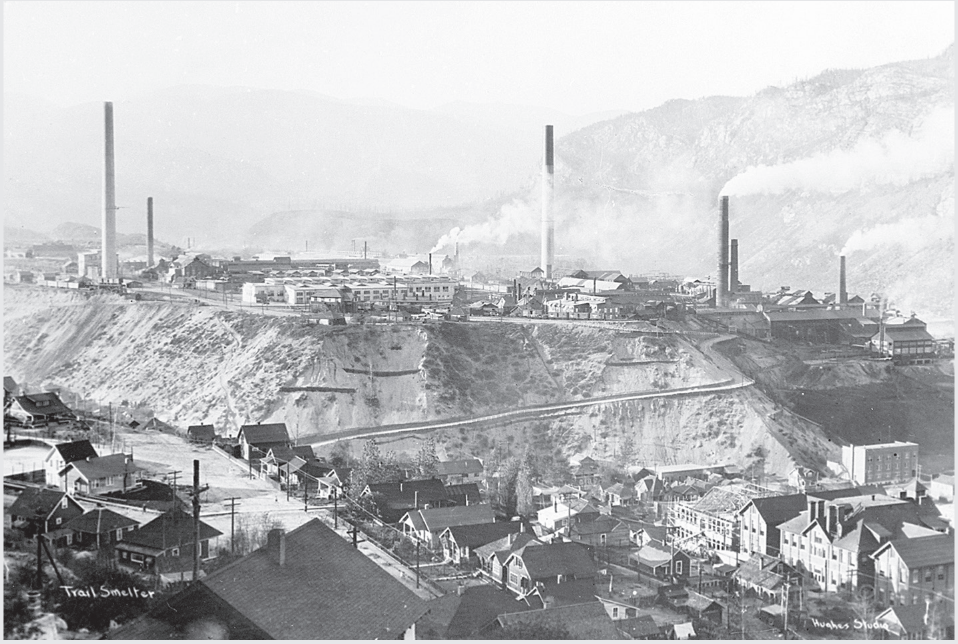


Figure 22: The Trail smelter on the banks of the Columbia River in 1926 (Library and Archives Canada/Canada. Dept. of Mines and Technical Surveys / PA-015534)

Teck, a Vancouver-based mining company, took control of the much larger Cominco in 1986 when, along with two European partners, it purchased CP Rail's controlling share. The arrangement permitted Teck to significantly reduce Cominco's debt, and to bring undeveloped ore bodies, notably the Red Dog mine, into production.[182] In 2001, the two companies merged when Teck purchased the remaining share. Teck is currently the world's third-largest producer of mined zinc, and, through its ownership of the Trail complex, operates a highly integrated mining and processing business.

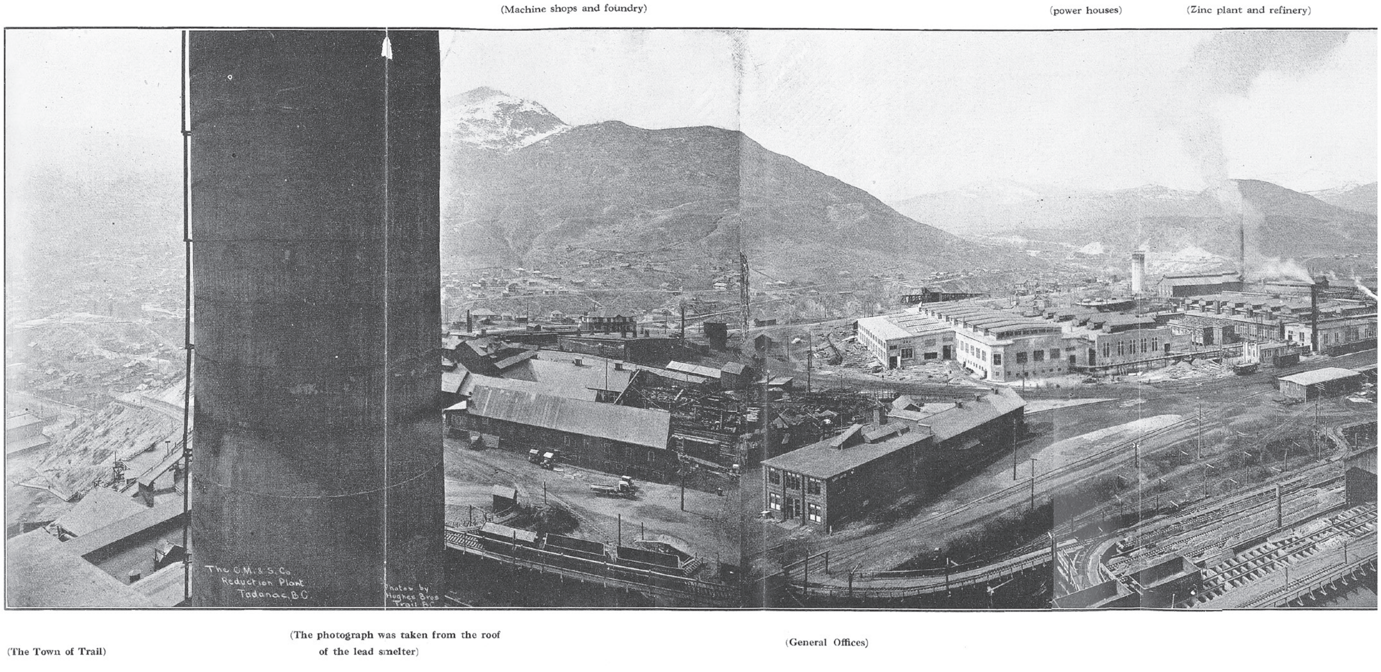
Beginning in the mid-1970s, major upgrades at the Trail complex replaced obsolete infrastructure, improved efficiency, and reduced a significant environmental footprint. A new acid plant and zinc roasters were installed in 1970. A modernization program, formally launched in 1977, began with the zinc side of the operation. Pressure-leaching technology, developed in the 1970s in partnership with the Canadian mining company Sherritt Gordon Mines Ltd. (now Sherritt International), was implemented beginning in the 1980s.[183] New zinc electrolytic and casting facilities opened in 1981 and a new zinc smelter, including an automated zinc electrorefinery, began operation in 1985.

Improvements to the lead smelter were beset with difficulties. Cominco initially adopted a Queneau-Schuhmann-Lurgi (QSL) reactor developed by the German company Lurgi Chemie GmbH. This two-chamber bath smelting technology, which incorporated oxygen injection through nitrogen-cooled tuyeres, promised to replace the existing sinter plant and blast furnace with a single vessel, while greatly reducing energy consumption and virtually eliminating ambient dust and gas emissions.[184] This reactor, which began operation in late 1989, was shut down in March of 1990 after it proved unsuitable for the circumstances at Trail, especially the requirement that the reactor process large amounts of stockpiled residue from the zinc operation. Because of the failure to implement this system at Trail, the older method of blast furnace smelting continued until 1997.[185]

That year, a Kivcet flash furnace (also called the Oxygen Flash Cyclone Electro Thermal Process) began operation. This technology, first developed in Kazakhstan in the 1980s, is an example of a successful metallurgical innovation developed within the Soviet Union. Kivcet is a two-stage process. The first stage features a reaction shaft in which sulphide concentrate is flash smelted using injected oxygen. A partition beneath the bath allows the molten lead and slag to flow into a second chamber containing an electric furnace. Here, carbon electrodes apply continuous heat to maintain a sufficiently high temperature for the lead bullion and molten slag to separate.

A new slag fuming furnace was also built to receive molten slag directly from the Kivcet furnace.[186] This served both to conserve energy and to greatly reduce the emission of dust-born lead. As is typically the case in upgraded smelting operations, emissions were reduced by creating contiguous, enclosed stages. This approach eliminates pollutants released during the transfer of material from one furnace to another.[187]

The failure to implement the QSL technology at Trail, and its subsequent replacement by the Kivcet process,



was, and remains, a highly sensitive topic within Teck Cominco, and in the metallurgical community generally. It was a very expensive and prolonged episode that drew in outside engineering companies and resulted in litigation. Metallurgists who comment privately on the episode point to the fact that QSL technology has been successfully implemented in three existing plants in Germany, South Korea, and China. They also point to the decision to replace the injection of powdered coal with natural gas—likely over safety concerns regarding the explosive potential of coal dust—as a major contributing factor to its failure at Trail.

In recent decades, Teck Cominco has had to contend with the legacy of over a century of pollution at the Trail site. Following the controversy over sulphur dioxide emissions that began the 1920s, the issue re-emerged in the 1970s, with the discovery of significantly elevated levels of lead in the blood of children living in Trail. Further medical research resulted in a significant lowering of the "level of concern" for lead levels. This motivated a systematic health study of the Trail community in 1989, which found that soil contamination, along with lead levels in household dust, were the determining factors behind the elevated lead levels in children.[188]

In the wake of the 1989 study, a community task force was formed that was composed of community, company, and government representatives. This committee oversaw a topsoil replacement program for affected properties near the smelter site. It also addressed other local nuisances arising from the smelting complex, from noise to odour. The final replacement of blast furnace smelting by the Kivcet furnace in 1997 brought about an 80 percent reduction in lead emissions from the Trail smelter.[189] Lead levels among infants at Trail, last measured in 2016, remain significantly higher than the latest Canadian average (4.3 micrograms per decilitre versus 0.8).[190] The World Health Organization considers that there is no safe level of lead exposure.[191]

In 1995, a slag-collection system was introduced to capture lead smelter slag that had previously been released into the Columbia River.[192] Decades of dumping smelter slag, along with a series of accidental discharges from Trail plants, were the basis for a series of recent fines and legal judgements against the company. A groundwater treatment plan, meant to remediate ammonia-contaminated groundwater resulting from decades of fertilizer production, was scheduled to come online in 2016. Two new acid plants, the first of which opened in 2014 and the second of which will open in 2019, will reduce sulphur dioxide emissions by a further 20 percent.[193]

In 2006, the Trail complex began recycling e-waste. It also has the notable capacity to recycle and reprocess the lead from lead-acid batteries and the glass screens of obsolete CRT televisions using its Kivcet furnace. Batteries are the largest source of lead recycled at Trail.[194] An older slag fuming furnace was used to recover metals such as gold, silver copper, zinc and nickel from shredded electronic components. Trail's e-waste recycling capacity was subsequently expanded with investment in a new slag fuming furnace completed in 2014. However, e-waste recycling has since been abandoned.

The year 2016 marked 120 years of continuous smelting at Trail. Still Canadian-owned, Teck Cominco remains a holdout among the foreign-owned large base metals companies discussed in this chapter.

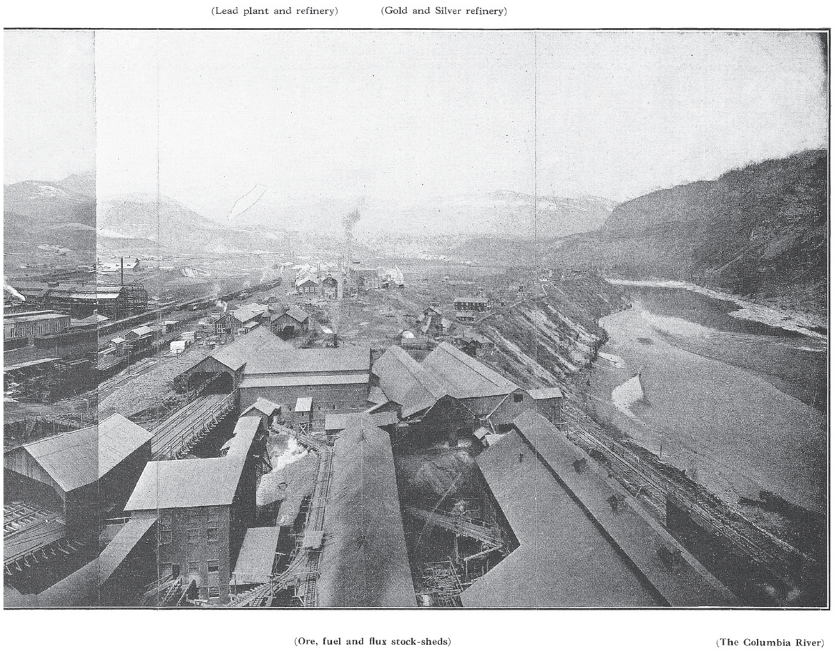


Figure 23: A panoramic view of the Trail complex taken from the roof of the lead smelter in 1925 (Anon. 1925, 872)

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CHAPTER TWO

THE COMMUNITY OF CANADIAN METALLURGISTS

CHAPTER 2 THE COMMUNITY OF CANADIAN METALLURGISTS

A Canadian scientific community formed between about 1850 and 1960.[1] Over this period, a community of professional mining engineers and metallurgists was founded to encourage the development of a metals industry. Professional bonds and identity were fostered through professional organizations, notably the Canadian Institute of Mining Metallurgy and Petroleum (CIM), and its Metallurgical Society. This chapter examines the development of this community in order to understand the origins of Canada's contribution to the field of metallurgy.

The mining community celebrated and encouraged the development of scientifically trained Canadian professionals. The CIM's original bylaws of 1908 reflect a fundamental distinction in status between "members" and "associates." The two categories distinguished business people from professionals, according full voting rights only to professionals. These were seen to be part of an emerging community of experts who would, it was hoped, bring certainty and prosperity to the business of mining and metallurgy in Canada.

As the frontiers of European settlement expanded, mining ventures proliferated. These schemes were prone to exaggerated claims and inflated expectations. In the 1920s, the Toronto Mining Exchange, among the world's largest, was considered to have been "routinely, almost preposterously, crooked." The Toronto-based *Financial Post* routinely warned against the dubious promise of mining stocks—a recurring issue in Canada.[2] Credibility, in the eyes of government, investors, and the mining community, would come from the ongoing processes of professionalization, regulation, and university training.

A fundamental tension pervaded the early Canadian metals industry: on the one hand, its emergence was closely bound to a broader national project. Governments intervened to establish local industries, to establish self-sufficiency in critical metals in times of war, or to ensure domestic supplies of steel for building national infrastructure. On the other hand, Canada depended on Americans for expertise, and was perennially reliant on American markets and venture capital.

Figure 24: Members of the Canadian Mining Institute and the Mining Society of Nova Scotia visit the Dominion Iron and Steel Works in Sydney, NS, during the first leg of their 1908 cross-country tour of Canadian mines and metallurgical facilities. (Anon. 1908, 31)

The professionalization of the mining industry, and the development of local facilities supporting metallurgical research, was driven, in large part, by concerns about sovereignty. Expertise in smelting and refining local ore, as well as in developing finished materials and products, was seen as essential to obtaining value from Canadian resources that would otherwise accrue to foreigners. As industries became established, both public and private facilities were developed with the intention of keeping those industries competitive.[3] The foundation of the National Research Council in 1916 added an important voice advocating for industrial research on the part of Canadian universities and private companies.[4]

Canada exited the Second World War with the understanding that its research efforts had been impeded by a poverty of industrial research laboratories run by Canadian businesses. Those that existed in Canada tended to be owned by foreign multinationals, which were seen as being less amenable to performing industrial research in the Canadian national interest.[5] This concern drove the post-war emergence of several industrial research laboratories among the Canadian metals companies, as well as further collaboration between government defense research institutions and private companies.

The editors of a recent survey of Canadian developments in mining and metallurgy posit a "golden age" covering a period lasting roughly from 1950 to the 1990s. This represents a period of significant progress in the area of research and development. It also resulted in a professionalization of the discipline, with the founding of a journal, a major annual metallurgical conference, and various international exchanges and joint conferences to permit the flow of ideas across boundaries.

One important consequence of this "golden age" was the emergence of the Canadian mining industry as an attractive place for the world's engineers to make a living. During the post-war years and the cold war, many educated people migrated to Canada from areas of economic uncertainty or political upheaval. These engineers found places in the in-house and government laboratories.

The period's decline may be attributed to several factors, including the effects of globalization on a Canadian industry impeded by growing competition and foreign ownership. Concurrently, private and public investment in research capacity declined as profitability fell.[6] To some extent, this lost capacity in private research has been replaced by industry partnerships with universities and by contract arrangements with specialized engineering firms.

As noted, this report focusses on professional metallurgists at the expense of a broader perspective on metallurgical work. In Canada, metallurgical research generally takes place in several interrelated sectors discussed below: university and government research laboratories, operations and research facilities run by the large mining companies, and, increasingly, independent engineering companies and research laboratories.

If these institutions provide the primary professional context of the metallurgists, then the worker's equivalent has been the labour union. Unions have played a powerful role within Canadian industry and society in general, and a complete historical account of the development of mining and metallurgy must include them. The experiences of workers in mines, mills, smelters, and refineries will be covered in a separate report dealing with labour.

Certain aspects of the intersection between labourers and metallurgists are worth noting here in order to delineate shifting professional boundaries. Most evidently, there has been a notable change in the professional purview of workers. A labour historian might refer to a "de-skilling" of labourers in the metals industry which has taken place as smelting, milling, and other metallurgical operations have become increasingly automated through the proliferation of sensors, computers, and labour-saving machinery. As in other industries, these changes have been imposed by engineers and other professionals seeking efficiency and quality control.

The adoption of new research-based technology has varied from company to company. It has, to a certain extent, been mediated by the relationship between management and labour. Metallurgists associated with Dofasco have noted, for instance, that the relative labour peace at that company encouraged innovation.[7] On the other hand, John C. McKay, retired director of research and development as Stelco, wrote in his unpublished memoir that he believed a "blacksmith culture" prevailed at the company. He notes that:

> *Your status within the company stemmed from your level of process and product know-how and ability to assert this questionable expertise with the weight and certainty of papal authority. Decisions based upon scientific knowledge and upon considered deliberation fell into the category of ineptitude.*[8]

Perhaps the golden age of mining and metallurgy, refers, in part, to a period during which a coherent group of academically-trained professionals were able to supplant this pre-existing "blacksmith culture" in a then-flourishing industry. This would coincide with a period, which gained momentum in the 1950s and 1960s, when research facilities owned by mining companies began to proliferate, while university-trained academics were increasingly employed in the field. In a paper on the development of converter technology at Inco, long-time Inco engineer and manager Sam Marcuson describes a period of intense technological change:

> *Technology spread through the young industry like wildfire. As our industry matured, the rate of change slowed. Management is more cautious. Modern installations required environmental approvals and licensing. Extensive converter hoods have improved the atmosphere but limited visual inspection of the bath. Automation has reduced the arduous demands and today a converter can be remotely operated. In the 21st century, the calculations of the machine are overwhelming the intuition of the operator; the requirement for conformity is outpacing the value of uniqueness.*[9]

It is worth bearing in mind, as we turn, in the third chapter, to several technologies related to automation and computer control, the extent to which these advancements supplanted the operator's skill.

Legend of the Ring: Metal in Symbolic and Ceremonial Objects

The history of metallurgy is often embodied within the makeup of ceremonial or symbolic objects. One such object is the iron ring given to Canadian engineering students as part of their graduation ceremony. The first iron rings were distributed in 1925 at the University of Toronto. The ceremony has since been adopted across Canada and at various American colleges.

It is a common misapprehension that the metal used in these rings come from the wreckage of a partly-completed bridge on the St. Lawrence River at Quebec City that collapsed on August 29, 1907, killing 75 workers. The destruction of what was to be the largest cantilever bridge in the world was a major event for the Canadian engineering community. It has since been widely used as a case study for faulty engineering practice.

Though untrue, the legend makes a kind of moral sense. The ring is meant to symbolize both entry into a community and the moral responsibility associated with the engineering profession. The small committee which led the ensuing Royal Commission was made up of leading Canadian engineers. Among them was John Anderson Galbraith (1846-1914), professor of engineering at the University of Toronto. Galbraith's notes on the hearings survive at the University of Toronto Archives and Records Management Services (UTARMS) alongside his lecture notes from 1902–1906 on topics such as "iron and steel" and "stresses and strains in materials and structures."[10]

Such legends are quite common. The widely-held belief that the British Victoria Cross medals are made from bronze cannon captured during the Crimean War has recently been disproved.[11] War medals are especially significant symbolic objects, hence great attention is often given to their material and fabrication. In 2006, CANMET laboratories were involved in the two-year process of developing and producing Canada's latest Victoria Cross medals.[12]

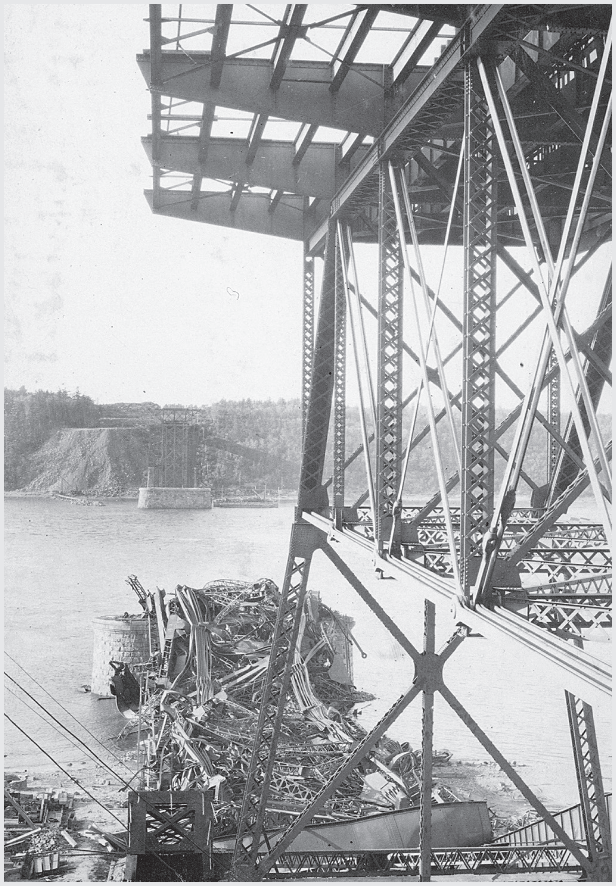

Figure 25: The ruins of the steel bridge over the St. Lawrence in 1907 (Dept. of Mines and Resources/ Library and Archives Canada, PA-020614)

Another aspect of that earlier culture is also changing: its identity as a field of masculine labour. One notices, for instance, that notable pyrometallurgists are sometimes referred to as "hot metal men."[13] The phrase evokes the danger of foundry and smelter work. Metallurgists do work in close contact with molten metal and heavy machinery. Accidents happen on occasion. In 1947, for instance, a metallurgist working at the Mines Branch was killed, and another injured, in a hydrogen explosion while preparing a magnesium-zirconium alloy.[14]

Broadly speaking, one would place metallurgy with other chemical and engineering disciplines under the rubric of "Science, Technology, Engineering, and Mathematics" (STEM). These are all topics requiring a rigorous academic specialization once culturally associated with masculine aptitudes. In recent years, we have seen that, given comparable encouragement and opportunity, women thrive to the point that they now outnumber men in a number of university-level STEM disciplines.

Nevertheless, women's involvement in STEM fields has tended to focus on areas such as biology and medicine. Mining and metallurgy, long culturally associated with working-class masculinity, is behind the curve in female representation, though this is changing.[15] This process of transition is documented, to a certain extent, in the MetSoc Legacy Project interviews, in which all subjects are asked about the presence or absence of women in their fields. The answers, often insightful, sometimes reveal the cruelty faced by female engineering students in the relatively recent past. Likewise, a recent project entitled *Women of Impact*, sponsored by CIM and several industry groups, celebrated the careers of pioneering women in the field of metallurgy. The accompanying book of published interviews is cited below.[16]

It's worth noting that while historical objects related to teaching and research in science and medicine are routinely found in university museums and other collections, the history of engineering is more often neglected. The material culture of metallurgical research would be fascinating to explore in detail. Laboratory teaching and research has required teaching foundries, small-scale flotation cells and mills, stress testing equipment, analytical instruments such as tunnelling electron microscopes and x-ray machines, computer equipment and software, and a variety of other apparatus. Industrial development traditionally involves building furnaces of increasingly larger scale, from laboratory experiment to test plant. Listings of metallurgical research facilities in Canada over time would be a useful starting points from which to begin a search for material evidence to document this history.

METALLURGICAL RESEARCH AT CANADA'S UNIVERSITIES

Owing, in large part, to the demands of the railway industry, the latter half of the nineteenth century saw the role of Canadian universities expand beyond educating prosperous students in the liberal arts and longstanding professions such as law and medicine.[17] Several universities established "practical" programs related to surveying, mining, and engineering, while expanding teaching in areas such as chemistry, geology, and physics.[18]

Technical training in mining and metallurgy arrived in Canada during the last half of the nineteenth century. In 1871, McGill University became the first Canadian University to teach metallurgy in its Department of Mining Engineering.[19] Other engineering programs explicitly related to metallurgy appeared elsewhere in Canada in the early twentieth century.[20] Early mining engineering programs focussed primarily on extractive metallurgy and ore dressing.[21] As Canadian industry developed, so too did the need for training in areas of physical metallurgy along with the development of capacity in specialized research.

The early technical colleges and schools of mines were not research institutions and did not offer postgraduate degrees. Canadian universities still focussed mainly on teaching rather than research.[22] By the turn of the twentieth century, only McGill and the University of Toronto had achieved an international reputation for research in mining and metallurgy. Thomas Sterry Hunt (1826–1892) was a professor of chemistry and mineralogy at Université Laval and later a lecturer at McGill. Hunt worked closely with James Douglas (1837–1918), a successful miner and lecturer at a McGill-affiliated college in Quebec. Together, Hunt and Douglas patented a hydrometallurgical method for extracting copper in 1869. The process was not effective, but it stands as the first product of Canadian research in this area.[23]

Many of the early professors were immigrants from Europe or the United States. Hunt, for instance, had been born in Connecticut and studied at Yale before being employed by the Geological Survey of Canada in Montreal. Dr. Alfred Stansfield (1871–1944), the first professor of metallurgy at McGill, was born in England and studied at the Royal School of Mines in London. Over time, the Canadian community of metallurgical engineers counted academics trained in Canada alongside a broader pool of foreign-born professionals from a developing polyglot research community.

Inquiries made by the newly founded National Research Council during the First World War raised concerns about the research capacity of Canadian universities. Robert Fulford Ruttan (1856–1930), professor of chemistry at McGill and member of the NRC, later noted that, "Scientific research in Canada was practically confined to the laboratories of two or three of our universities, and one or two departments of Government."[24]

Wartime expansion of Canada's research capacity, the booming metals industry in the 1950s and 1960s, and a growing concern for engineering research following the launch of Sputnik gave impetus to metallurgical teaching and research at Canadian universities. This period also witnessed a major expansion of specialized laboratories dedicated to metallurgical research, as well as closely related fields such as nuclear technology. By the 1960s, metallurgy was taught at ten Canadian universities and several metallurgical departments had emerged.[25] Francophone education in metallurgy was also underway. The discovery of copper ore at Noranda encouraged the creation of the School of Geology, Mines, and Metallurgy at Université Laval in Quebec City in 1938.[26] In 1958, a metallurgical engineering department was founded at the École Polytechnique de Montréal. As these programs gained institutional traction, they were able to attract a well-rounded faculty teaching a range of specialized subjects.

A number of important metallurgical technologies were developed at, or in collaboration with, university research labs. These include contributions made by the Department of Mining and Metallurgy of the University of British Columbia to the Sherritt-Gordon pressure leach process in the 1950s, as well as the development of the F*A*C*T System for modelling thermodynamic data, which was created at McGill and École Polytechnique beginning in 1976. Major work at all Canadian universities in the field of metallurgy since 1960 is surveyed by Mike Wayman and Hani Henein in the 2011 commemorative volume, *The Canadian Metallurgical & Materials Landscape 1960 to 2011.*[27]

Over the second half of the twentieth century, an overall materials engineering field gradually subsumed the recently developed departments of metallurgy. Over time, this has become a nearly universal phenomenon. For instance, the metallurgical engineering program at McGill became "metals and materials" in 2001, and then simply "materials engineering" in 2007.[28] Queens Metallurgical Engineering Program became the Materials and Metallurgical Engineering Program in 1990. It was ended in 2011, its faculty continuing to teach within the Department of Mechanical and Materials Engineering and also the Department of Mining.[29] At the University of Toronto, what had, since 1964, been the Department of Metallurgy and Materials Science became the Department of Materials Science and Engineering.

Such changes reflect, no doubt, the emergence of new advanced materials with properties comparable to, or better than, those of the metals and their alloys. Modern materials of various kinds are increasingly combined as laminates and composites that make optimal use of their physical properties. These changes also reflect the diversification of Canadian manufacturing and the declining influence of major metals industries that had largely motivated the formation of these departments. Nevertheless, metallurgy continues to thrive as a graduate specialization as well as within university-based research centers focused on particular metallurgical concerns. Examples include the Centre for Characterization and Microscopy of Materials (CM)^2 at École Polytechnique, the Canadian Centre for Welding and Joining at the University of Alberta, and the McMaster Steel Research Centre.[30]

Metallurgical teaching and research at Canadian universities have had a long association with both government research facilities and with industries. In 1943, for instance, Dr. Lloyd Montgomery Pidgeon (1903–1999), who had recently become known for his metallurgical contribution to the allied war effort, was made both professor and head of the Department of Metallurgical Engineering at the University of Toronto.[31] Following his work for the NRC in developing a process for producing pure magnesium, Pidgeon became a successful academic, overseeing a series of appointments that ushered in a very productive period of metallurgical research at the University of Toronto. More recently, the Canadian government has supported metallurgical research through the provision of NSERC Industrial Research Chairs in areas such as steelmaking, welding, and aerospace materials.[32]

Academia worked with industry to foster metallurgical research from a very early period. In 1909, Alfred Stansfield, professor of metallurgy at McGill, formed a partnership with J. E. Evans of Belleville, Ontario, who had been developing a method for smelting titaniferous magnetite ore directly to tool steel using an electric furnace. This arrangement involved building an electric furnace at the McGill campus capable of producing a half ton (over .45 tonne) of tool steel per day.[33] A close study of the business entanglements of professors of metallurgy would, no doubt, turn up many similar examples of business arrangements and consulting work.

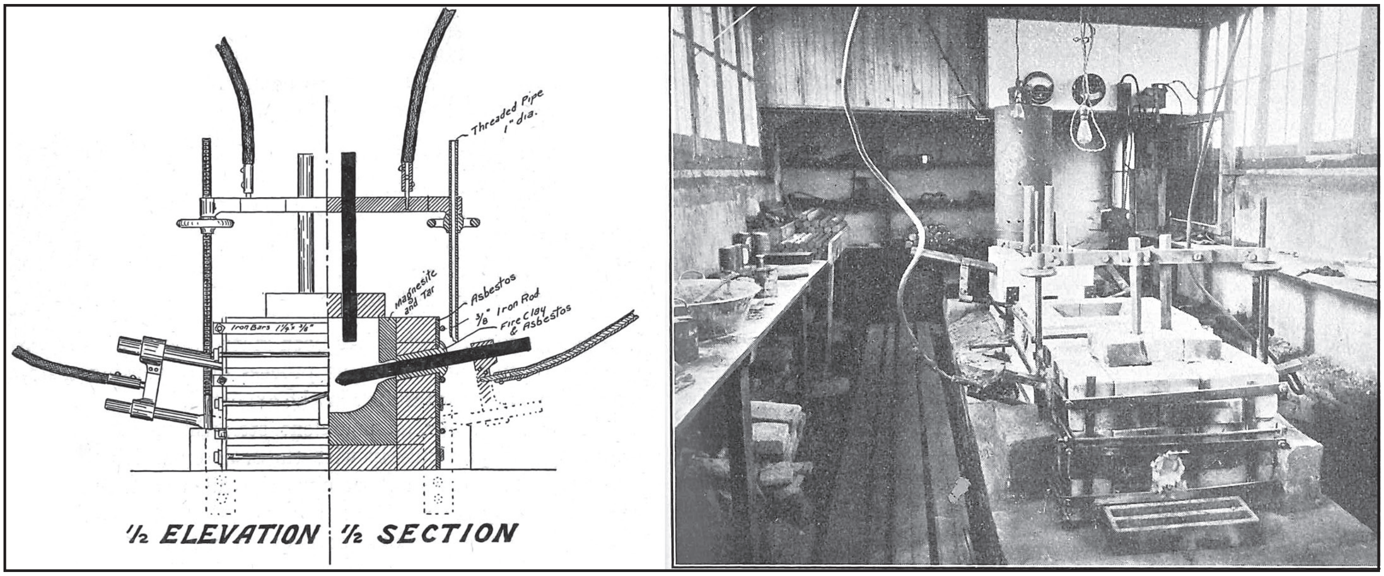

Figure 26: Evans' electric furnace in diagram and in his workshop (Stansfield 1910, 164, 165)

Several universities have, over time, developed close bonds with particular industries. Metallurgy and materials research at Carleton University in Ottawa has long been associated with the aerospace industry, particularly through the Mechanical and Aerospace Engineering program operating in collaboration with the National Research Council Institute for Aerospace Research (NRC-IAR).[34] The McMaster program in Metallurgy and Metallurgical Engineering was encouraged and supported by the local steel companies, Stelco and Dofasco. Both companies endowed chairs. ArcelorMittal Dofasco still endows a chair in ferrous metallurgy while Stelco now supports the Associate Industrial Research Chair in Steel Product Application in partnership with NSERC. Likewise, Ford and GM have both endowed research chairs at Windsor in partnership with the NSERC Industrial Research Chair program, which is intended to encourage cooperation between industry and academia.[35]

Some companies have actively involved PhD students in their R&D activities, a process that fosters good communication between industry and academia. Inco's J. Roy Gordon Research Lab (now Vale Base Metals Technical Excellence Centre), has supported industrial research projects in the field of pyrometallurgy in partnership with the University of Toronto, McMaster University, and the University of British Columbia. These partnerships have produced papers co-authored by academics and Inco researchers.

The Centre for Chemical Process Metallurgy (C-CPM), founded in 1988, was a particularly notable example of collaboration between academia, government, and industry. This included industry partners from the mining and metallurgy sector, Inco Ltd., Falconbridge Ltd., Western Mining, Hatch Associates Ltd., Ontario Hydro Technologies, and North American Refractories Company (NARCO). Eight university departments from seven Canadian universities were involved in the consortium. The federal CANMET laboratories and Ontario's provincial ORTECH laboratories (privatized in 1999) were also affiliated. The C-CPM supported and coordinated collaborative projects in areas such as mineral processing, hydrometallurgy, pyrometallurgy, process modelling, and environmental projects. The centre was shut down in 2010 due to a decline in industrial support.

Among metallurgists, there have traditionally been certain cultural differences between those in academic and industrial fields, though these are complicated and difficult to generalize. Those interviewed for the Legacy Project have expressed a variety of opinions on the topic. In general, one might surmise that whatever cultural gap once existed has diminished with pressure for increased collaboration between university researchers and industry on the one hand, and an increasing reliance on university research amidst declining industrial research capacity on the other. Moreover, faculty often have industrial work experience and continue to work as consultants.

MINING AND METALLURGY AT GOVERNMENT LABORATORIES

Over the course of the twentieth century, federal and provincial governments established a number of institutions designed to encourage and facilitate various facets of Canada's mining industry.[36] Here, we focus on the two most prominent federal institutions, the National Research Council (NRC), and the Mines Branch, which evolved into the Canada Centre for Minerals and Energy Technology (Canmet). The mandates of both institutions have historically extended well beyond mining and metallurgy. The NRC has done both pure and applied research in areas deemed relevant to the national interest, though it has increasingly been steered toward industrial partnerships. The Mines Branch/Canmet has carried out research in a wide variety of areas, including mining and metallurgy, alongside the development of fuels, explosives, and various economic minerals.

While both institutions are important for their contribution to the development of Canadian metallurgy, the Mines Branch/Canmet has had a closer and more direct relationship with the Canadian metallurgical community. For instance, between 1945 and 2011, the presidency of the Metallurgical Society of the CIM has been held by a Mines Branch/Canmet member fourteen times, whereas only a single president is identified with the NRC. The NRC has tended to contribute to metallurgical research in specialized areas such as nuclear or aerospace research.

The metallurgy-related projects taken on by these institutions over more than a century are such that only a very general description is possible. A more detailed examination of this topic would begin with a systematic study of the relevant annual reports. This survey would also provide a good sense of the cutting edge of Canadian metallurgical research over time. The federal laboratories were among the first, for instance, to apply x-ray and electron microscope analysis to metallurgical study, and to put these resources at the service of industry. An examination of metallurgical research at Canada's national laboratories would reflect broader Canadian themes, from changing defense initiatives to the emergence of environmental concerns, as well as the importance of evolving technologies such as semiconductors and efficient batteries.

THE NATIONAL RESEARCH COUNCIL

The first significant step towards an overall organizing body for scientific research in Canada began with the federal government's foundation of the Honorary Advisory Council on Scientific and Industrial Research in 1916 — the name "National Research Council" was officially applied in 1924. Its purpose, like that of similar organizations founded in Britain and Australia during the First World War, was to survey and extend research capacity as well as to assist the Dominion government in directing research for the war effort.[37] Since its foundation, the council's activities have included the advancement of Canadian metallurgy, especially through cooperation with industry.

Despite considerable growth in resources and staff, the NRC has suffered from a number of systemic tensions. Its purview has historically been vast, encompassing fields ranging from medicine to agriculture. The variety of its projects is the result of a mandate situated uneasily between pure and applied research. This was especially the case following the acquisition of dedicated laboratory facilities in the late 1920s. Its efforts have occasionally intersected with those of departmental laboratories within various branches of government. A great deal of metallurgical research, for instance, has taken place at both the NRC facilities and the several laboratories of the Mines Branch (now Natural Resources Canada), discussed below. Meanwhile, university laboratories have played an ever greater role, heightening the competition for research dollars and industrial partnerships.

The NRC's first report, published in 1918, was a call to action. It noted the lack of private research capacity, the underfunding of research at the universities, and the lack of trained Canadians needed to fill existing positions.[38] Part of its original mandate was aimed at addressing this latter shortcoming by supporting emerging researchers. After its first decade, the council had distributed several hundred scholarships and fellowships, while 155 students had graduated with the council's financial help.[39] This was intended to encourage Canadian students to do postgraduate work in Canada rather than in the United States. Between 1917 and 1937, the discipline of engineering received the second greatest amount of funding, behind physics.[40]

In spite of early optimism and the influence of a prestigious council, little progress was made towards the goal of establishing a laboratory until 1925. That year, the council used its temporary quarters in Ottawa to determine whether locally mined magnesite was suitable for replacing imported material as a refractory lining for steel furnaces. The effort proved successful, providing the initial impetus towards a Canadian industry in basic refractory linings.[41]

New laboratory facilities opened on Sussex Street in 1932.[42] This represented a decisive step towards independent research.[43] The council then suffered a severe cut in its budget brought on by the Great Depression. Towards the end of the decade, funding increased again and the council began looking for long term projects.[44] At the request of the BC government, for instance, it investigated the effects of emissions from the Trail smelter. This work, completed in 1937, resulted in a substantial payout to affected farmers in the United States—an important episode in the environmental history of the Canadian mining industry.[45] The mid-1930s marked a period of revitalization and growth that culminated in a prominent role for the council during the Second World War.

The founding of nuclear research was a particularly notable interwar development at the NRC, with eventual consequences for Canadian metallurgical research. Metallurgists studying materials used in nuclear technology tend to inhabit different institutional spheres than those involved in mining and other commercial activities. Nuclear research in Canada began in the early 1930s following a discovery of pitchblende ore by the LaPine brothers of Renfrew County, Ontario, while prospecting around Great Bear Lake in the Northwest Territories. This made possible the work of Dr. George C. Laurence (1905–1987), who, in 1930, was hired to establish a laboratory for the study of radiation within the Division of Physics at the National Research Council. Born in Charlottetown, Prince Edward Island, Laurence had received his PhD under Ernest Rutherford (1871–1937) at Cambridge.[46]

Laurence's research into nuclear fission over the subsequent decade ultimately led to Canada's participation in the Anglo-American nuclear research group in 1942, to the establishment of new laboratory facilities in Montreal, and to the hosting of a number of eminent researchers from the UK, many of whom remained in Canada to continue its indigenous nuclear program.[47] In 1944, Canada committed itself to exploring the peaceful uses of nuclear power. The NRC's Montreal laboratory was tasked with advancing ongoing work on heavy water reactors then being carried out in the United States. The Cominco smelter at Trail, British Columbia, had incidentally contributed to this process by supplying electrolytic hydrogen for the American production of deuterium. Trail would eventually become Canada's first source of indigenous deuterium.[48]

The CANDU Fuel Bundle and Research into Zirconium Alloy

The various fuel bundles developed for use in Canada's CANDU reactor project represent decades of research in reactor fuel technology carried out by hundreds of people and costing hundreds of millions of dollars.[49] The study of zirconium alloy and the processing of uranium dioxide represent an important aspect of Canadian metallurgy.

Early trials in AECL test reactors used uranium metal as fuel, though this was found to be dimensionally unstable during reactor operation.[50] In 1955, uranium dioxide was selected as a fuel for the CANDU reactor and an extensive program was launched to determine the optimum configuration of the fuel and its housing. The fuel bundle consists of a series of zirconium alloy tubes (fuel elements), each containing pelletized uranium dioxide fuel, arranged in a cylindrical bundle.

The original bundle was designed for the Nuclear Power Demonstration (NPD) reactor, built near the Chalk River research facility, which went critical in 1962. Since then, the bundle has gone through numerous iterations, each small change reflecting significant research aimed at optimizing the productivity, reliability, and lifespan of the fuel system. A fascinating microhistory could be written on the various changes and experimental modifications made to this superficially simple-looking object over the decades.

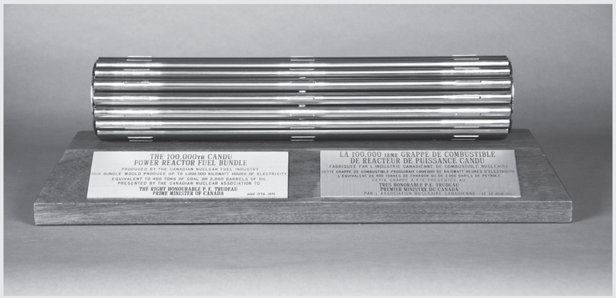

Figure 27: Reactor fuel bundle in the collection of the Canada Science and Technology Museum (Artefact no. 1989.0002.001)

The metallurgical properties of the fuel bundle embody the initial Canadian choice of a heavy water reactor design that requires the use of materials with a low neutron-absorption cross-section. Much of the CANDU reactor core, including the fuel bundles themselves, is consequently made of zirconium alloy. Because of the importance of this material to the CANDU technology, Canadian nuclear engineers have become world experts on its properties. In particular, the alloy's behaviour under extended neutron bombardment — conditions encountered only in a nuclear reactor — required significant testing until a fuel system could be developed that was free from problems such as cracking of the tubing or jamming of components due to metal creep.[51]

By August of 1944, work had begun on what is now the Chalk River laboratories in order to move potentially dangerous nuclear activities out of downtown Montreal. On 22 July, 1947, the NRX reactor came online. It was then the world's most advanced research reactor. In April 1952, a new crown company, Atomic Energy of Canada Limited (AECL), was formed to develop Canada's nuclear industry. Nuclear research was consequently transferred away from the NRC's Atomic Energy division.[52]

The period preceding the Second World War also produced one of the more notable developments in Canadian metallurgy. In 1937, Dr. Lloyd Pidgeon, working at the NRC's research laboratory, began to explore methods to produce magnesium. Canada, at that point, no longer produced this strategically important metal. During the Second World War, Pidgeon's method for producing magnesium through reduction with ferrosilicon would significantly increase magnesium production among the allied nations.[53]

The Second World War witnessed the development of many other defence projects that required the establishment of several new laboratories. Like the collaboration that eventually produced Canada's nuclear energy program, these projects were often undertaken in cooperation with, or at the behest of, Britain or the United States. One example was Canada's contribution of cold-weather testing facilities in Winnipeg for Britain's turbojet engine program. These were used to simulate circumstances encountered in the upper atmosphere. This effort provided the basis for a highly-successful indigenous engine program which, in the postwar years, was to foster a great deal of metallurgical research.

In the late 1950s, the NRC established high temperature chemistry labs on the campus of Dalhousie University, with Dr. C. R. Masson (1922–1988) as director. Masson is recognized as a pioneer in the fundamental aspects of the structure and properties of metallurgical slags. Following post-doctoral studies with Masson's group, several individuals went on to hold faculty positions in metallurgy departments within Canadian Universities.

The postwar years saw major government investment in research related to industrial assistance and defence projects. The council's budget more than doubled between 1945 and 1950.[54] Following the end of the Second World War, the NRC played a leading role in encouraging the development of private industrial research capacity in Canada.[55] In the late 1950s, Noranda contracted the NRC to optimize the flue system on its newly-developed converter. Noranda and the NRC also collaborated in developing an instrument to measure the progress of a copper blow.[56]

During the 1960s, Canada's continued backwardness in industrial research capacity caused growing concern. The NRC, then the most extensive network of laboratory facilities in the country, was criticized for performing too much "in-house" research while failing to adequately support industry.[57] In response, the Industrial Research Assistance Program (IRAP) was developed. Collaboration with the mining sector continued. In the early 1970s, the NRC Control Systems Laboratory worked with Noranda to develop a computerized process control system for the Noranda process for continuous copper converting. This effort was later abandoned in favour of a less sophisticated system.[58]

In 1978, the council's role in granting funding for science and technology research was passed to the Natural Sciences and Engineering Research Council (NSERC) — a significant reduction in the NRC's influence. Meanwhile, other areas of research formerly led by NRC laboratories, including biotechnology and nuclear research, were passed to other institutions. The National Research Council Institute of Aerospace Research (NRC Aerospace) remains an ongoing hub of research that has frequently included cutting-edge metallurgy.[59] One result of this shrinking mandate has been that the agency has become more tightly bound to the IRAP program.[60] Recent decades have seen a decline in the NRC's budget, while the percentage committed to IRAP has continued to climb. In this sense, the NRC has evolved in the direction of other longstanding research bodies directly intended to support industry, notably the Mines Branch and its successors.

THE MINES BRANCH AND CANMET

The first national scientific institution was the Geological Survey of Canada, whose mandate included the identification of economic minerals across the vast Canadian landscape. The survey had its origins before Confederation, when, in 1841, the Legislature of the Province of Canada allocated £500 to a survey of the province. From the beginning, the survey embodied a tension between providing an overall mineral map of Canadian territory and evaluating promising areas for economic minerals. Many, witnessing rapid development in the United States, wished the survey to act as a kind of consultancy for the mining industry.

Confederation expanded the survey's budget, significantly increased its staff, and led to its reorganization. Over the last quarter of the nineteenth century, the survey was further entrenched as a government institution becoming, in 1890, a department of the civil service. The 1890 act of parliament obliged the survey to publish statistics on Canada's mining and metallurgical industries. In 1907, an act of parliament established the Department of Mines, with the survey as one of two departments within it. The second, the Mines Branch, took over the survey's previous mandate of gathering statistics.[61]

The Mines Branch of the Department of Mines was also responsible for investigating mining practices, the character of ore bodies, as well as for carrying out "chemical, mechanical, and metallurgical investigations for the mining industry." Chemists and chemical equipment from the survey were transferred to the Mines Branch.[62] It was, in other words, a fledgling national research body meant to study ores and develop processes of potential economic benefit. Despite the government's evident interest in promoting and improving mining, the Mines Branch initially focussed mainly on the processing of metals and fuels, as well as physical metallurgy. Mining emerged as an area of study around 1950.[63]

The first head of the Mines Branch, the German-born Dr. Eugene Haanel (1841–1927) had worked in the United States before earning a doctoral degree in Germany. In 1873, he began teaching at Victoria University (then located in Cobourg, Ontario). In 1900, while teaching in Syracuse, he agreed to move to Ottawa to begin planning for the Mines Branch.[64]

Initially working for the Department of the Interior, Haanel's first task was to set up an assay office for testing gold in order to encourage Canadian gold processing. This was established in Vancouver in 1901 with a staff of five. The vast hydroelectric potential of Central Canada drew Haanel to organize magnetic surveys of iron ore resources as well as to investigations of electric smelting technologies. Another key area of interest was the concentration of ore using methods such as flotation and magnetic separation. Along with a search for new Canadian iron deposits, this was part of an effort to wean Canadian steelmakers off American ore. In 1903, the iron ore program received its first laboratory space in Ottawa.[65]

During the First World War, the laboratories of the Mines Branch worked on electrolytic refining, as well as the concentration, through flotation, of minerals, notably molybdenum. Mined near Ottawa for processing at the Mines Branch's laboratory, molybdenum was alloyed with steel for armour plating.[66] Facilities in place by 1917 included a metallographic laboratory for examining steel, as well as test equipment for studying the processing of ore.[67]

Throughout its early years, the Mines Branch assisted mining companies in developing milling and smelting

Dr. Haanel's Electric Furnace

In 1906, Dr. Eugene Haanel presented a report to the Faraday Society detailing his attempts to smelt Canadian magnetite ore using a test-scale Héroult electric furnace installed at Sault Ste. Marie, Ontario. Haanel, who had previously surveyed Canadian iron ores, wished to determine whether magnetite ores of "comparatively high sulphur content but not containing manganese" could be made into marketable pig iron at the mine site in areas poor in coal, but with abundant supplies of water power.

Haanel's experiments grew out of the excitement surrounding the development of the Hall-Héroult electric furnace, which was then being applied to the smelting of aluminum. Other metals were also subject to experiments involving the process. Haanel had previously travelled to Europe to witness tests of electric iron smelting in Switzerland and France. The results of these tests were inconclusive, with wide variations in the amount of energy used, and the quality of metal produced.

Haanel's experiments involved eight different ores from across Ontario and Quebec. Lacking coal, he used charcoal as a reducing agent. The furnace, its modifications, and Haanel's experiments are described in a report published in 1906.

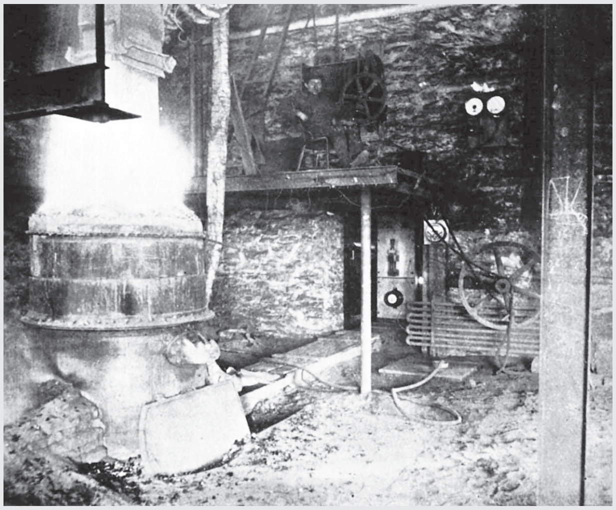

Figure 28: Haanel's electric furnace at Sault Ste. Marie (Haanel 1906, 121)

When Haanel conducted his experiments, the scale of the project was too small, and the technology too immature to attract the attention of industry. Haanel's experiments are regarded as noteworthy for their prescience. Decades later, electric furnaces would proliferate, albeit for use with steel scrap, or, in some cases, with highly concentrated and reduced ore. Haanel's experiments are also notable as one among numerous early attempts to make use of Canada's hydroelectric resources.

operations. This was especially the case during the interwar period when the mining of precious metals flourished.[68] Between 1929 and 1933, Canada was the second largest producer of gold in the world. Much of this came from Ontario and was processed using techniques developed at the Ore Dressing and Metallurgical Laboratory of the Mines Branch.[69] In 1930, a substantial new metallurgical laboratory with semi-industrial scale equipment was completed as part of the continued effort to concentrate and smelt marginal Canadian iron ores.

The Mines Branch changed its focus in 1930, with the discovery of pitchblende ore in the Northwest Territories.[70] As was the case at the NRC, the discovery prompted the Mines Branch to begin looking for a method to process the ore. In 1933, the El Dorado Company opened a refinery in Port Hope, Ontario, to process concentrate from Great Bear Lake based on a flowsheet developed by the Mines Branch.[71] El Dorado would continue to operate the mine and the refinery until both were nationalized in 1944.

After this period, the Mines Branch began recruiting new researchers to improve the analysis and processing of uranium-bearing ores.[72] The Radioactivity Division of the Mines Branch continued to collaborate with the El Dorado Company on developing a pressure acid-leaching method for processing uranium. This method was first used at Port Radium in 1952 and quickly adopted at several other uranium mines.[73] The Mines Division was later involved with the development of the Zircalloy tubing used in CANDU reactors.[74]

A new ore-dressing building had been completed in 1938, one of several new facilities created just before the outbreak of the Second World War. The war itself provided further impetus to this period of expansion. The Physical Metallurgy Research Laboratories (PMRL) was founded in 1940, with new facilities finished in 1943. Located at 568 Booth Street in Ottawa, the PMRL was the best-equipped laboratory in the country. It included melting furnaces, a foundry, rolling and casting equipment, as well as extensive testing facilities.

The Mines Branch undertook a variety of wartime projects, including developing armour-piercing projectiles, improving the service life of tank treads, and developing reliable control cables for aircraft. The productivity of the small group of researchers at the PMRL ensured that they were given priority after the war. Postwar work continued to focus on defense concerns in areas such as the x-ray analysis of light metal castings, the welding of aerospace materials, metallurgical problems associated with pipelines, and the operation of naval vessels in the arctic.[75]

Post-war activity at the various Mines Branch laboratories created opportunities to collaborate with industry. In 1957, for instance, metallurgists from twenty-three companies used the mill belonging to the Mineral Processing Division.[76] Research into titanium extraction, ultimately abandoned, was carried out using slag from the Quebec Iron and Titanium Corporation (QIT), as well as a pilot-scale demonstration plant provided by the Shawinigan Water and Power Company of Montreal.[77] Sherritt Gordon took advantage of ongoing research on metal powders to investigate the use of nickel powder in coinage.[78] The Mines Branch also worked with Air Liquide Canada on the initial development of the Savard-Lee shrouded tuyere.[79]

Companies working in many areas of metal production also received assistance testing ore samples, developing new flowsheets, and optimizing existing ones.[80] New instruments were developed to improve ore sorting and dust sampling in mines, while metal analysis was carried out using electron microscopy and x-ray diffraction to study grain structure.[81] Further analytical work was done on stress testing and various forms of corrosion.[82] By 1964, 35 percent of the research carried out at the Mines Branch was done for industry, the rest for government.[83]

Between approximately 1952 and 1965, the budget of the Mines Branch nearly tripled.[84] A great deal of research was done by the Mineral Processing Division on the concentration of ore through grinding, flotation, and separation, as well as electric smelting to permit smaller mining companies to smelt their ore in Canada.[85] Work was carried out on developing Canadian production of steel

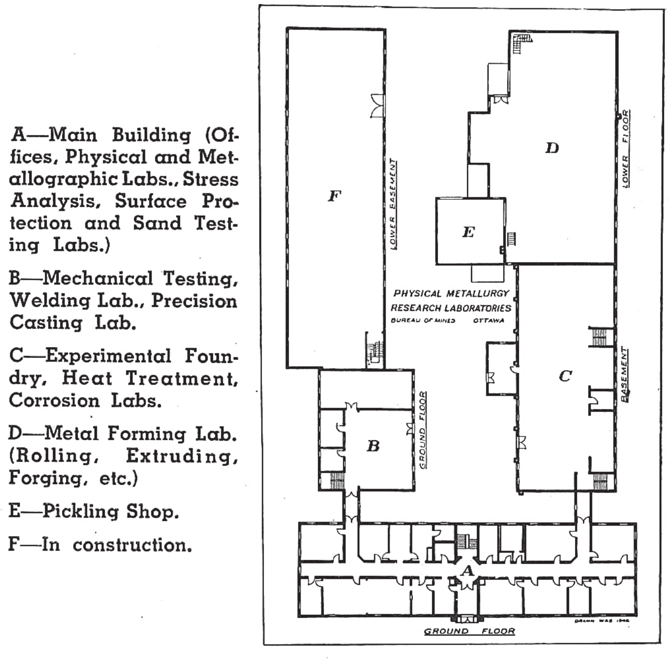

Figure 29: Layout of the Physical Metallurgy Research Laboratories of the Mines Branch in 1946 (Meier 1946, 20)

additives for alloying, as well as on finishing processes such as forming and welding.[86] The Mines Branch continued to work on improving iron casting at their foundry, focussing particularly on the problem of metal penetration of casting sands and toughened steel castings for the developing oil sands industry.

In 1975, the Mines Branch was renamed the Canada Centre for Mineral and Energy Technology (Canmet), part of Natural Resources Canada.[87] Its various divisions have since undergone a series of organizational changes. In 1986, the PMRL became the Metals Technology Laboratory (MTL), recently relocated to the newly-built McMaster Innovation Park in Hamilton, Ontario.[88] In 1995, the Mineral Sciences Laboratories and Mining Research Laboratories were consolidated to become the Mining and Mineral Sciences Laboratories (MMSL).

Work has continued in a variety of industrially-related areas including pollution control, pipeline development, and the creation of new steel alloys and light alloy casting methods for the automotive industry. Assistance to mining companies has continued. For instance, Canmet collaborated with Inco in testing hydrometallurgical processes of potential use to the Voisey's Bay project.[89] As with the NRC, Canmet has undergone significant reductions in funding and staff over recent decades.

PROVINCIAL LABORATORIES, PRIVATE LABORATORIES, AND THE ROLE OF ENGINEERING COMPANIES

In addition to federal and university research laboratories, which are mostly dedicated to performing fundamental research and development, there exists an extensive network of provincial research facilities, independent laboratories and development centres, and metallurgical engineering companies. In several cases, the latter have emerged from the privatization of provincial labs, or from laboratories formerly developed by the large Canadian mining and metals companies. This migration towards independent research and engineering is, in part, the result of diminishing investment in novel metallurgical research on the part of government and the mining industry.[90] Specialized independent companies focus largely on optimizing existing processes on a contractual basis, or on supplying proprietary technology to the mining industry. They have become an important source of employment for metallurgists.

Records relating to private research and engineering are less accessible than those of publicly funded research at government laboratories and universities. What information does survive is threatened by the increasing use of digital information at the expense of traditional corporate libraries and archives. In an era of corporate mergers, Canadian companies are subsumed within multinational entities with separate identities and institutional histories. As part of the ongoing Mining and Metallurgy Legacy Project, the Canada Science and Technology Museum is working to identify and preserve this archival legacy. One objective of the Mining and Metallurgy Oral History Project is to record the memories of researchers in this field. Certain other primary records have emerged, for instance, Jock McKay's unpublished memoir of a long career within Stelco's research and development program.[91]

The research facilities of the major mining and metals companies have historically varied in their ambition and capacity. Process control laboratories were developed near metallurgical plants to optimize and upgrade existing facilities. Dedicated research laboratories have a much broader mandate to develop and evaluate future technologies. Some may undertake the sort of pure research associated with university or government labs. In other cases, major companies may forego large-scale research facilities altogether. For instance, Algoma accomplished important advances in continuous casting without formal research facilities.[92]

The scale of research and development by the large mining companies has declined in recent years. Fundamental research at privately funded institutions has increasingly given way to private-public arrangements with universities and government labs. For some, this change represents an evident decline in research capacity. The editors of the MetSoc publication, *The Canadian Metallurgical & Materials Landscape: 1960 to 2011*, noted their fear that "the resulting competitive advantage enjoyed by Canadian companies for so long will shrink due to the closures of what were once world-class metallurgical development facilities."[93] There has also been a significant reduction in the number (and, in certain areas, capacity) of Canadian engineering companies serving the metals industry over the past half century.[94]

The early lack of domestic research and development was widely noted by policy makers during the first half of the twentieth century. The first report of the National Research Council, issued in 1916, found only twenty-seven private research laboratories in the country — a sobering statistic.[95] Richard Steacie (1900–1962), president of the NRC from 1952–1960, advocated for greater investment in research on the part of Canadian industry. Steacie's observations to the London-based journal *New Scientist* in 1959 could be taken to summarize the historical circumstances facing Canadian industry generally:

> *The situation is far from easy. Strung out as we are in a long thin line next to a much larger and more highly industrialized neighbour, afflicted with relatively small markets and the competition of industrial giants, the situation which has developed is in every way a logical one. The most encouraging feature of the situation has been the strong trend in the last ten years toward some degree of self-sufficiency in research even in companies controlled from abroad. This trend has been particularly marked in the chemical industry and conspicuous by its absence in certain other major industries which shall be nameless. It is very encouraging to see more and more Canadian companies starting research laboratories for the first time, and to see the substantial growth of some of the older laboratories.*[96]

By the 1960s, progress towards indigenous research had been underway for some time in Canada's metallurgical sector. In 1937, Inco established Canada's first metallurgical process research laboratory at Copper Cliff.[97] Other such facilities followed in subsequent decades at Alcan, Falconbridge, and Cominco. In 1961, the Diefenbaker government launched tax incentives for industries willing to engage in research. By 1963, an NRC survey found over 400 Canadian firms had active research projects. Research expenditure by Canadian firms nevertheless remained low, as novel technology from abroad could typically be acquired more cheaply than that developed locally. The emergence of research facilities around this period may be noted in a list of major private R&D centers belonging to the companies discussed in the first chapter:

Arvida Research and Development Centre	1946–present	Jonquière, Que.	Now Rio Tinto Alcan–Centre Recherche et Développement Arvida/CRDA.
Dofasco Research Department	c. 1956–1993	Hamilton, Ont.	Some R&D capacity exists at the ArcelorMittal research center in Hamilton.
Falconbridge Development Laboratory	1952–1986	Richvale, Ont.	Moved to Falconbridge Technology Centre. Partly sold to employees, becoming Lakefield Research, and subsequently bought by SGS Lakefield Research.
Falconbridge Technology Centre (now Xstrata Process Support)	1986–Present	Falconbridge, Ont.	Xstrata Process Support is now a commercial centre working on projects worldwide.
Inco Copper Cliff Laboratory	c. 1937– 1967		Inco's pilot plants at Port Colborne were also actively involved in R&D.
Inco J. Roy Gordon Research Lab (now Vale Base Metals Technical Excellence Centre)	1967–present	Mississauga, Ont.	In 2013, transition from research centre to technical support centre was substantially complete.
Noranda Research Centre (renamed Noranda Technology Centre in the early 1990s)	1961–2003	Pointe Claire, Que.	Consolidated with Falconbridge Technology Centre after merger.
Teck Cominco Technical Research Centre (now Applied Research and Technology [ART] group)	1957–Present	Trail, B.C.	One of three centres in Teck's technology division, including CESL Limited in Richmond, British Columbia, and Product Technology Centre (PTC), in Mississauga, Ontario.
Stelco Research Centre (later Steltech)	1967–1993	Burlington, Ont.	Most workers transferred to Hatch.

Figure 30, Table: R&D centres of the major base metals companies.

Such a list may be misleading because it overlooks smaller facilities, often at the plant site, where much research in areas like process control, process optimization, and quality improvements is carried out. More importantly, while several of these facilities still exist, their staffs have been significantly reduced and their research capacity curtailed. An example of this trend is the Inco J. Roy Gordon Research Lab, once among the world's leading research laboratories dedicated to nickel. The laboratory now employs only about thirty-five people who focus primarily on technical support. Yet, even at this reduced level, the Inco laboratory is still among the largest of its kind in the country.[98]

At their peak, these facilities embodied an ambition on the part of mining companies to invest in the development of new processes and technologies. We have already seen several important examples developed in such facilities during the "golden age" of Canadian metallurgy. These include the Noranda Process Reactor, developed at the Noranda Research Centre, the oxygen flash furnace developed by a Copper Cliff research group in the late 1940s, the carbonyl process developed at Inco's Port Colborne Research Station #1, and the Stelco coilbox developed at the Stelco Research Centre. It is worth considering whether the decline of such facilities has hindered a national culture of innovation in metallurgical engineering.

The causes of this decline in private research are, no doubt, numerous, complicated, and open to speculation. Foremost among these was a period of repeated recessions, beginning in the 1970s, which caused mining companies to cut costs.[99] In the period roughly spanning 1970 to 1990, Canadian mining companies continued to support research and development in order to reduce energy consumption, to comply with environmental regulations, to optimise process control, and to increase productivity. It may be the relative success of these efforts, combined with a period of economic uncertainty, industry consolidation and foreign ownership that has led to a recent decline in research and development in favour of incremental optimization of existing technology. Consolidation, especially with foreign multinationals, has made some of these existing research sites peripheral within larger corporate structures.

Tighter margins resulting from increased competition and other factors may encourage an aversion among the big mining companies to the risk inherent in technology development—or, at least, a willingness to outsource that risk to private companies, which incubate new technology at their own expense. Prominent failures such as Noranda's billion-dollar Magnola magnesium project in Danville, Quebec, serve as cautions against substantial commitments to bold, in-house technological projects.

To a certain extent, the decline of large in-house research facilities represents a diversification of the metals industry, in which engineering companies have taken over responsibility for designing and building metallurgical infrastructure such as smelters and refineries. For the past half-decade or more, Canadian metallurgical engineering companies have been acquiring, and privately developing, technologies for sale in Canada and abroad. These companies, specializing in "Engineering, Procurement, and Construction Management" (EPCM) supervise the building of new metallurgical facilities, sometimes on a turnkey basis.[100] The mining company then pays a royalty for using this intellectual property.[101]

Numerous Canadian companies have operated in this field since the 1960s.[102] In many cases these engineering consulting groups were formed by engineers let go by mining company research centres or by manufacturers during the economic downturns of the 1980s and 1990s. Engineering companies have an advantage over the larger mining companies in acquiring, developing, optimizing, and reselling technologies; they are able to resell their technologies to several mining companies whereas mining companies have comparatively limited opportunity to reuse and resell proprietary technology.

The outstanding example in this field is Hatch, founded by Canadian metallurgical engineer Dr. Gerald G. Hatch (1922–2014) in 1956. Over time, Hatch has acquired the rights to a range of technologies. For instance, in 1993, it obtained the Stelco coilbox, along with several other technologies, when it acquired Steltech — Stelco's technical engineering branch. Hatch has also developed a number of in-house technologies using its own research and development facilities. These include copper cooling elements for smelting furnaces.[103] Two technologies owned by Hatch, the coilbox and the copper refractory cooler, are described in the third chapter.

Like the mining companies themselves, metallurgical consulting and engineering companies have undergone a process of consolidation that has resulted in fewer, larger players. They currently face mounting foreign competition in developing new projects abroad. Their emergence represents an efficient means of developing and marketing intellectual property. This permits mining companies to concentrate their limited remaining engineering resources on business, safety, and quality issues rather than designing mines, concentrators and processing plants. Nevertheless, engineering companies are primarily involved in process engineering. The loss of the more fundamental R&D capacity of the research centres once run by mining companies must be made up for by university, government, or other private research labs.

Some metallurgical research and development capacity has also been provided by provincial laboratories. These were established over the twentieth century to assist local industries and to drive development of "leading edge" technologies. The first to establish such an organization was Alberta, which founded the Alberta Council of Scientific and Industrial Research in 1921 under the auspices of the University of Alberta. This became the Alberta Research Council, currently the largest provincial research organization in the country.[104] Other provincial research councils have included the British Columbia Research Council (BCR, incorporated in 1944), the Nova Scotia Research Foundation Corporation (NSRFC, established in 1946), the Saskatchewan Research Council (SRC, established in 1947), the New Brunswick Research and Productivity Council (RPC, established in 1962), the Industrial Technology Centre (ITC, established as the Manitoba Research Council in 1963), the Centre de Recherche Industrielle du Québec (CRIQ, established in 1969), and, most recently, the Research and Development Corporation (RDC), established by Newfoundland and Labrador in 2011.[105]

Like their federal counterparts, these bodies have generally been conceived with broad mandates to assist local industries in areas ranging from textiles, to software, to fishing, to renewable energy. Over time, they have differed in the extent of their engagement in metallurgical research. Provinces with significant metals industries, especially Ontario, Quebec, and New Brunswick, have been the most active in this area. A number have developed facilities to advance research in process technology that is applicable across a range of industries, including metallurgy.

Among the more important provincial research facilities in this area is the COREM technological park in Quebec City. COREM was formed in 1999 through a transfer of assets from the existing Centre de recherche minérale (CRM). It has built on the earlier body's considerable metallurgical work across a range of areas, but especially those developed to assist the steel industry. This research group, which enjoys significant metallurgical testing facilities, is a consortium of a number of mining and metals companies that have joined forces to develop and transfer leading-edge technology to industry.[106]

Also of particular note is the history of the Ontario Research Foundation (ORF), established in 1928. Like the National Research Council, the Ontario Research Foundation has been closely involved in research and development surrounding the processing of nuclear fuel. It developed a specialization in process engineering generally. Over its history, it has undergone an evolution that is broadly representative of a number of other provincial research bodies. In the 1980s, ORF was renamed ORTECH, a change that reflected an increasing focus on development and application rather than research, which was seen as the primary domain of the universities. Having cultivated ties to various industries over many years, the organization served both as a service to industry and as a means for post-doctoral students to transition to industry.

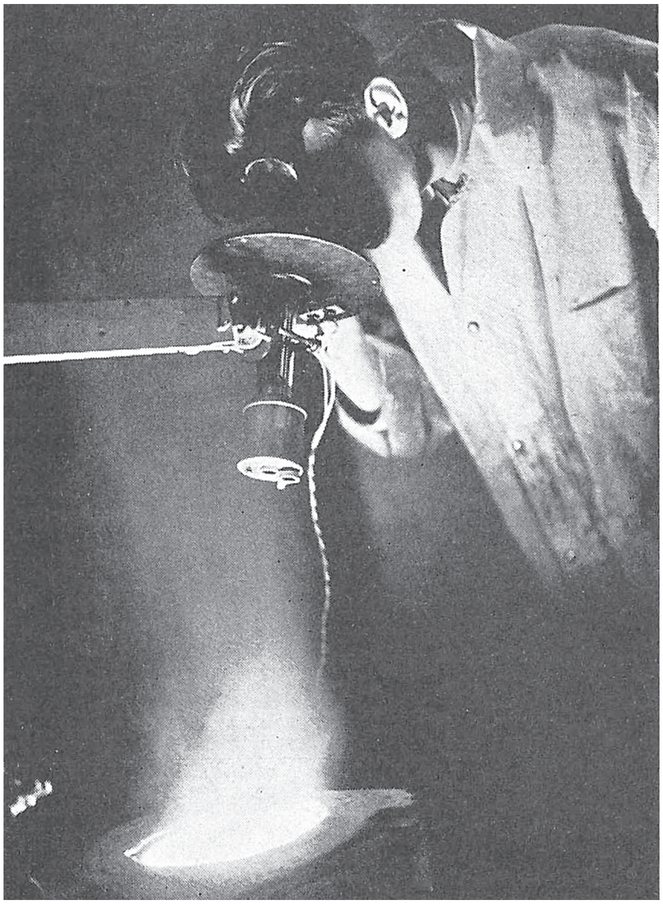

Figure 31: A researcher uses an optical pyrometer to study an induction test furnace at the Ontario Research Foundation in 1938. (Anon 1938, 144)

In 1999, ORTECH, which then employed 235 people, was privatized by the Ontario provincial government and split into three entities, one of which was encompassed the former Process Technologies division.[107] Part of the reasoning behind this privatization, beyond creating an entity that was self-financing, was to remove a restriction that had previously limited ORTECH's operations: the fact that it was not permitted to compete with local private sector companies.[108] This new entity, called Process Research ORTECH Inc. (PRO) has since become a major Canadian research centre for process mineralogy, materials research, and clean technology. Other provincial laboratories have undergone a similar process of transformation, undergoing a shift in mandate towards commercialization of research and development, or outright privatization.[109]

Ursula Franklin (1921–2016): A Critical Voice in Engineering and Metallurgy

Over the course of the twentieth century, the progress of metallurgy, and the fortunes of the metals industry generally, has been influenced by the ebb and flow of international conflict. In Canada, as elsewhere in the industrialized world, pacifists and other peace activists have criticised government involvement in engineering projects related to defense and nuclear energy. Ursula Martius Franklin was a prominent dissenting voice within the community of Canadian engineers and metallurgists who publically questioned society's use of technology, while arguing for the ethical responsibilities of scientists and engineers.

Ursula Maria Martius was born in Munich on September 16, 1921. Her mother was Jewish and her family was persecuted during the Holocaust. Late in the war, Ursula was interned in a forced-labour camp where she suffered injuries that afflicted her throughout her life. In 1948, she received a PhD in experimental physics from the University of Berlin. She obtained a post-doctoral scholarship to study at the University of Toronto in 1949. During her studies, she married and became a member of the Quaker community of Christian pacifists.[110]

Between 1952 and 1967, Ursula worked at the Ontario Research Foundation in areas such as the magnetic analysis of metals, corrosion research, and the development of alloys for the Canadian metals industry. While there, she conducted ground-breaking research on the effects of nuclear testing on the human body. She collected baby teeth from friends, family, and colleagues then tested the teeth for the presence of strontium 90 — a carcinogenic radioactive isotope produced in atmospheric nuclear detonations. Her work in this area reflected a lifelong commitment to pacifism and social justice, and contributed to the creation of the Partial Nuclear Test Ban Treaty.[111]

Between 1967 and 1989, Ursula taught at the Department of Metallurgy and Materials Science at the Faculty of Engineering of the University of Toronto — the first female professor in that department. During this period she worked with the Royal Ontario Museum in the field of archeometry, the scientific study of archaeological artefacts. Using techniques such as chemical analysis, x-ray analysis, and electron microscopy, she investigated historical metallurgical techniques.[112]

Figure 32: Ursula Franklin at the University of Toronto in 1980 (UTARMS, A2012-0009/009)

Ursula Franklin was widely celebrated as a pioneering female engineer, a feminist, an educator, a public intellectual, and a prominent pacifist. She conveyed her views on society and technology in numerous books, articles, lectures, and interviews. Her scientific research of past metallurgy, as well as her own experience as a practicing engineer, informed her views. She believed, for instance, that the adoption of particular technologies did not set societies along inevitable paths; civilizations worked with metals in particular ways according to their differing circumstances.[113] She likewise believed that the warlike and unjust aspects of modernity could be moderated through a careful and critical approach to technology. She maintained that scientists and engineers have a special responsibility in this enterprise.[114]

Ursula's writing provides many stories that draw insight from her metallurgical research. One, recounted in a 2001 speech to the Royal Society of Canada, involves her time as a young metallurgist at the Ontario Research Foundation during which she was involved in an effort to develop a "stainless copper" alloy for the Noranda company:

> *I was able to develop what looked like promising prototype alloys, and the Ontario Research Foundation took out a patent on them. Among its industrial clients, Noranda was interested and opted for a year's trial of the best of these alloys. In such tests, small coupons of the alloys are exposed for a year to representative or harsher environmental conditions and then evaluated regarding the state of their exposed surfaces. This procedure was followed. One exposure site was in Quebec, in East End Montreal close to the Noranda plant. The other was around Noranda's headquarters in Birmingham [Alabama]. A year later we looked at the coupons. East End Montreal looked pretty good, or, as one says around here, "not too bad." On the other hand, the coupons in Birmingham were awful. The stuff looked as if it had chicken pox. There were heavy localized corrosive attacks on the coupons and no lovely green patina at all.*
>
> *The end of the tests coincided with a big corrosion conference in Birmingham to which I was invited. There was great conclave about the tests. This was the mid-1960s and I was quite young at the time. All the other participants were men, and they were all much older than I. After they looked at the results and tut-tutted about them, they said, "Well, you know, it's a beginning. Please go back to it. We will give you another year to develop a better alloy, one that will withstand the conditions we have here in Birmingham." I looked at the coupons and could only say, "No way. What is on those coupons is in the lungs of your children. You don't need better alloys; what you need is better air."*[115]

PRO is currently one of a number of commercial research centres which, like the metallurgical engineering companies, perform functions that were once more typically done in-house by the mining companies. These include SGS Lakefield Research in Lakefield, Ontario, and Kingston Process Metallurgy (KPM), in Kingston, Ontario. Both have developed international reputations. Lakefield Research was founded in 1945 as a subsidiary of Falconbridge. In 1995, its managers purchased the company. In 2002, it was acquired by the Swiss multinational SGS. KPM was founded in 2002 to provide process optimization and development to mining, metallurgical, and chemical industries.

PROFESSIONAL ORGANIZATIONS: CIM

While metallurgy is practiced in a variety of Canadian contexts, one way to study the community as a whole is to examine the professional body representing the overall discipline. For the past century, much of this community has been represented by the Canadian Institute of Mining, Metallurgy, and Petroleum (CIM). Formed in the nineteenth century as a lobbying organization by the mining community, and formalized by an act of parliament in 1898, the CIM has evolved over the twentieth century to encompass a range of industrial activities related to mining.

The earliest evidence of interest in a distinctly metallurgical section within the CIM dates to 1904, when a series of petitioning letters encouraged the formation of a special committee to look into the matter. In 1916, a metallurgical section was finally established, and, in 1920, it was agreed to add "metallurgy" to the institute's name. This was recognition, in the words of Alfred Stansfield, McGill University's first professor of metallurgy, that "as time has gone on Canadian metallurgy has become more diverse, more important, and less closely related to mining."[116]

The Metallurgical Section faded away before the Second World War to be revived again in 1944 as a Metallurgical Division composed of four technical committees: Hydrometallurgy, Pyrometallurgy, Physical metallurgy, and Electrometallurgy.[117] By 1997, this arrangement had grown to seven technical sections, all of which have developed their own institutional networks and symposia:

- Environment
- Hydrometallurgy
- Light Metals

- Management in Metallurgy
- Materials
- Minerals Science and Engineering
- Pyrometallurgy

The Metallurgical Section grew in importance over the post-war years, becoming, in 1967, the Metallurgical Society (MetSoc). In addition to the technical committees, MetSoc developed several standing committees to organize such things as membership and student activities. The Historical Metallurgy Committee, founded in 1978, has collaborated in the preparation of this document and has commissioned several earlier publications. As of 2002, MetSoc had over 1,300 members. Its most significant contribution to the Canadian metallurgical community has come in the form of two key institutions: a journal and an annual conference.[118]

In 1962, the first annual Conference of Metallurgists (COM) took place at McMaster University in Hamilton, Ontario. This conference launched the *Canadian Metallurgical Journal*, (currently the *Canadian Metallurgical Quarterly–Canadian Journal of Metallurgy and Materials Science*). This was initially intended as a venue for publishing conference papers as the existing CIM Bulleting was deemed inadequate for these purposes. Assistance in publication, not forthcoming from the NRC, was eventually provided by the Mines Branch, which agreed not to interfere in the editorial process.[119] This arrangement continued until the fifteenth volume, after which the journal went through a series of publishers. As with other Canadian scientific and engineering journals, the *Canadian Metallurgical Quarterly* has long struggled to maintain its viability against the attraction of larger journals, typically based in the United States.

A solid understanding of the professional direction of the CIM through time would require a survey of its archival material and, after 1908, the material chosen for publication in the *Bulletin*. A useful overview has been provided by E. Tina Crossfield in a sponsored history of CIM prepared for the institute's 100th anniversary in 1998. It is clear, for instance, that from its foundation, CIM played an important integrative role, bringing together professional mining engineers, academics, business people, and members of the Geological Survey of Canada. It was a venue for those concerned with the prosperity of the mining industry to seek common positions and to resolve conflicts. For instance, delays at the GSC in publishing its annual reports created tensions between the survey and the mining community over the first decade of the twentieth century.[120]

B. E. F.
FLANDERS BRANCH
CANADIAN MINING INSTITUTE
FIRST (and we hope the last) Annual Dinner
IN THE DUG OUT
37 Grande Place, SOMEWHERE IN FRANCE [redacted]
PASSED FIELD CENSOR 801
THURSDAY EVENING
MARCH 2nd., 1916.
Ne vous méfiez pas!
Des oreilles amies vous écoutent.
Carriages at 10.30 (Gott strafe the Town Major)

MENU

WHAT WE ARE TO HAVE
SOUP
Desecrated Vegetable
FISH
Sardines à la B. E. F. Canteen
ENTREE
Maconochie Ration
(Multum in Parvo)
GAME
Jugged Hare
(if D. R. O. 1225 is cancelled)
JOINT
Bully Beef à la C. A. S. C.
SWEETS
Marmalade Biscuit
Chlorinated Water
Ration Rum (perhaps)

WHAT WE WOULD LIKE TO HAVE
POTAGE VELOUTE
VOL AU VENT
Aux Champignons
POISSON
Sauce Verte
FILET DE BOEUF
Légumes
Asperges en Branches
Sauce Mousseline
VOLAILLE TRUFFEE
Aux Petits Pois
FRUITS
DESSERTS
CAFE

Figure 33: A "dinner in the dugout," part of a good-humoured report from the wartime Flanders branch of the Canadian Mining Institute (Anon 1916, 439)

Perhaps not surprisingly, given the origins of many successful players in the early Canadian metals industry, the CIM based its governance on the older, and much larger, American Institute of Mining Engineers (AIME). The membership of AIME, and the CIM's British cousin, the Institute of Mining and Metallurgy, was restricted to members with academic credentials. As a consequence, despite the relative diversity of the CIM's membership and the rather small community of academically trained Canadian engineers, the CIM's bylaws, drafted in 1907, created a distinction between "technical" members (engineers and other university-trained professionals), who were permitted to be members, and "non-technical" members, employed commercially, who were classified as associates. Only members were permitted to vote and hold office.[121] In other words, university-trained professionals were to speak for the group.

This status distinction generated much debate over the length of the CIM's first century. When the matter first emerged in the early 1920s, the CIM's secretary, George Cleghorn Mackenzie (1877–1931), an Ontario-born mining engineer, made the case that the Institute's founders had desired it to represent the industry as a whole and that, in any case, the institute had relatively few professionally trained members. In 1921, its membership was 1,576, hardly two percent of the total workforce within the mining industry.[122]

> *I wish to emphasize again the fact that, if the Institute is to expand logically along industrial lines, we must secure many more members from amongst the business men who have invested their money or are directing the investments of others, prospectors, salaried employers, and public spirited citizens—and, in fact, take in all reputable persons who wish to identify themselves with us. It is believed that a large number of new members could be secured if the Institute would accept them as full members and thus place them all on the same footing.*[123]

There was to be no easy solution to the matter. It was addressed, not to everyone's satisfaction, with a series of amendments that created five classes of members. After lengthy debate beginning in 1938, a further series of amendments was adopted in 1942, creating six classes of members: member, junior member, corporate member, associate, junior associate, and corporate associate.[124] At this point, members and associates were given equal power within the organization. In 1990, after considerable work on the part of the bylaw committee, the classes of membership were again reduced to four with the associate status finally dropped.[125]

Just as the institute bound together various facets of the mining industry, it brought regional interests together into a federated system as Institute branches were founded by members from across the country. The process began in 1902 with the establishment of branches in Sherbrook, Quebec; Kingston, Ontario; and Nelson, British Columbia. These were soon joined by others.[126] In May of 1916, a humorous exchange took place over the formation of an Institute branch in the trenches of Flanders, Belgium.[127] There are currently over forty CIM branches organized into three Canadian and one international district. The latter includes branches in Dakar (Senegal), Lima (Peru), Santiago (Chile), and Ouagadougou (Burkino Fasso), with ongoing activities in China and Hong Kong.

Just as with the question of membership, the problem of how to share administrative power and distribute funding between the branches and the Montreal headquarters has generated considerable debate over time. It has also made the Institute a more representative organization. From early on, the institute has worked with the regions to promote Canadian industry beyond Central and Eastern Canada. In 1908, for instance, a summer excursion, lasting from August 24 to October 2, took several hundred institute members and other dignitaries, along with twenty-five overseas delegates, on a tour of mines and metallurgical facilities from Nova Scotia to British Columbia.[128]

The institute has also provided a means for the Canadian metallurgical community to communicate with foreign organizations, to exchange ideas, and to forge partnerships. Canada's proximity to the United States, along with its historical ties to the British sphere, has served it well in this respect. The early institute hosted the second Empire Mining and Metallurgical Congress in 1927, as well as the sixth, which took place in 1957, and the tenth in 1974.[129] MetSoc has, in the past several decades, sponsored or organized a number of joint conferences with other national bodies, notably the joint Japan-Canada Seminar on Secondary Steelmaking in 1985 and 1994, as well as the joint Copper-Cobre conferences with Chile, Germany, Japan, and the United States, which have taken place every three or four years since 1987.

These international exchanges reflect, to a certain extent, the cultural diversity of the professionals working in Canada's metal's industry. A number of the retired metallurgists interviewed for the Legacy Project immigrated to Canada to take up academic positions or jobs in industry. The Copper-Cobre conference, for instance, was made possible by Carlos Díaz, whose business and academic experience in Chile permitted him to arrange intellectual and technological exchanges between the Canadian and Chilean copper industries.

Over time, the Canadian mining and metallurgical community have taken steps to document and celebrate their profession. The various commissioned histories and personal memoirs are examples. One especially notable recent project has been the Canadian Mining Hall of Fame (CMHF), which recognizes important contributors to Canada's exploration and mining industry. Established in 1988, the CMHF is organized by the CIM, the Mining Association of Canada, the Prospectors and Developers Association of Canada, and the *Northern Miner*, a longstanding Canadian exploration and mining newspaper. The CMHF consequently represents a variety of industry perspectives, from prospectors to professional engineers to bankers and financiers, in a common celebration of identity and memory in Canada's mining industry.

Exploring Occupational Health and Metallurgy through Sampling Instruments

The evolution of Canada's mining and metallurgy industry has been closely bound to the development of occupational health in Canada. The discipline of occupational health emerged largely from the need to study and improve sites such as mines and metallurgical facilities, where diseases involving longterm exposure to particulate and chemical irritants took an immense toll.[130]

Working conditions in Canadian metallurgical facilities were once deplorable. In an interview for the Mining and Metallurgy Legacy Project, metallurgist Roland (Roly) Bergman described his experienced working first as a smelter worker, then as a researcher, at the Inco Copper Cliff refinery while he pursued an engineering degree at the University of Toronto in the early 1950s. He noted: "You had a mask … I wore a mask that keeps the SO2 out, and some days you just couldn't see what you were writing because the smoke was so strong — the fumes from the sulphuric acid."[131] In a recent email communication, he added:

> *The smelter research group was located next to the converter isle. Working conditions were very poor. We had to use protecting masks to protect us from inhaling SO2. Environmental working conditions throughout the smelter were poor. We had to contend not only with SO2 but also with dust. During the summer holidays of 1953 I spent time in the sintering plant. Environmental conditions in this plant were pretty rough. There was dust everywhere. We had to shovel off the dust in front of the stack gas and dust sampling points before we were able to reach them. Working on the lower floors of the plant was not a pleasant experience with dust and hot sinter raining down on you.*[132]

In an effort to address an ongoing epidemic of lung disease among industrial workers, scientists and engineers had, by the middle of the twentieth century, devised various forms of air sampling apparatus to gather and study the particulate matter in the work environment — Bergmann's email mentions sampling points where area sampling instruments would have been located. They had also developed means to detect other nuisances, such as toxic chemicals and noise exposure. As of 1942, the Department of Physiological Hygiene at the University of Toronto's School of Hygiene offered a Diploma in Industrial Hygiene, permitting medical graduates to specialize in workplace safety.[133]

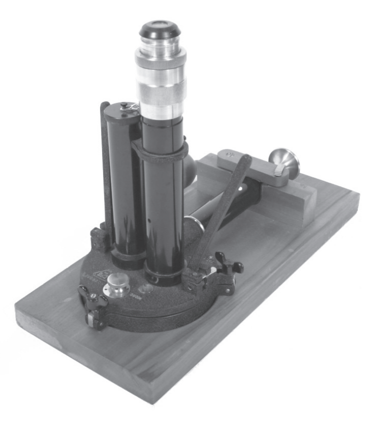

Figure 34: A Bausch & Lomb konimeter from the Gage Institute collection. This instrument was used in occupational health research to measure the quantity of inhalable dust in the environment. (UTSIC collection no. 2016.phlt.1.104.1-6)

Occupational health researchers at the School of Hygiene worked with Canada's metallurgical industries to measure risk and improve the work environment. In the 1950s, for instance, researchers began to study the effects of exposure to metallic dusts. By 1961, researchers at the school reported the results of animal experiments carried out using an apparatus funded by Inco.[134] This apparatus was tested using a Bausch & Lomb Konimeter (also known as a dust counter) which survives in the collection of the Occupational & Environmental Health Division of the Dalla Lana School of Public Health.[135]

Research and teaching at the school has involved the acquisition of many such environmental sampling instruments. This collection can shed light on the progress and evolution of occupational health in Canada as well as specifically within the field of mining and metallurgy. Area sampling instruments, for instance, have largely been replaced my small, battery-powered pumps, worn on a worker's clothing, that sample air from the worker's breathing zone. Newer, more sensitive instruments are able to detect a variety of pollutants, as well as chemical and biological hazards.[136]

Today, the work environments of Canadian mines and metallurgical facilities are vastly safer than in the past. In Canada, this was due in large part to legislation enacted following a series of high-profile cases involving dangerous work environments that emerged in the late 1960s and 1970s.[137] Many groups contributed to this progress: labour activists, government researchers and legislators, engineers of many stripes, and medical specialists, to name a few. The instruments belonging to the Dalla Lana collection provide a window into many decades of work in this field.

NOTES

1 Yves Gingras, *Physics and the Rise of Scientific Research in Canada* (Montreal: McGill-Queen's University Press, 1991): 6.

2 Robert Bothwell, *Eldorado, Canada's National Uranium Company* (Toronto: University of Toronto Press, 1984): 18-19.

3 For a brief exploration of Canadian concerns of foreign ownership and American investment, see: Mouat, "Canada's Mining Industry," 19- 25.

4 Gingras, *Scientific Research*, 36.

5 Wilfrid Eggleston, *National Research in Canada: The NRC 1916-1966* (Toronto: Clarke, Irwin & Company Ltd., 1978): 263-264.

6 Mouat, "Canada's Mining Industry," 22-24.

7 Barry Strathdee, from "Barry Strathdee — Full Interview," interviewed by William McRae, YouTube, August 24, 2015, video 24:00, www.youtube.com/watch?v=72xgZCTLYO4.

8 McKay, *Stelco R&D*, 8.

9 Marcuson, "Converter Operation," 121-122.

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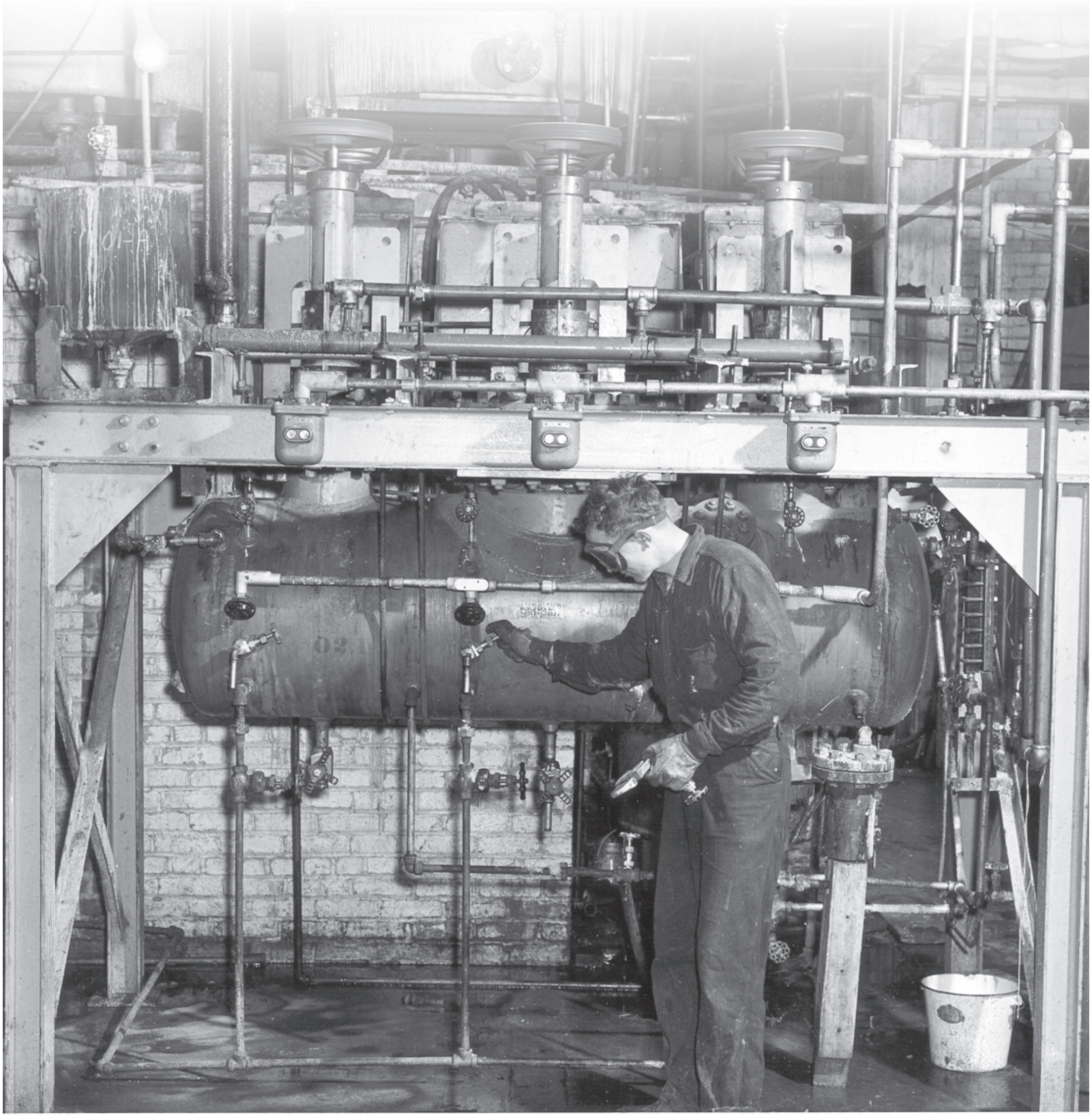
CHAPTER THREE

THEMES IN CANADIAN METALLURGICAL TECHNOLOGY



CHAPTER 3 THEMES IN CANADIAN METALLURGICAL TECHNOLOGY

The maturity of Canada's mining industry can be seen in its contribution to global metallurgical technologies. Accumulating rapidly after the Second World War and with the push towards domestic research and development in the 1960s, these contributions have been made in a variety of fields. This chapter builds on the previous two by examining some of the key Canadian developments in this area. Examples are drawn from technologies that have been recognized by MetSoc's Xstrata innovation awards, first established by MetSoc as the Falconbridge innovation awards in 1986.[1] As elsewhere, this approach cannot provide a complete account of Canadian development in the field of metallurgy, but it can represent something of the variety of the field.

These examples are presented alongside specific themes introduced earlier in this report in order to present technologies within their context and to use example technologies to represent a broader field of research. These groupings are somewhat arbitrary. Oxygen pyrometallurgy may be viewed as both a contribution to smelting and converting, as well as an environmental technology, insofar as it greatly increased energy efficiency and made possible the efficient capture of sulphur dioxide. The Stelco coilbox could be seen as a contribution to the efficiency of the automated steel mill; given that it is currently owned by the engineering company, Hatch, it could also be taken as a representation of the increasing role played by metallurgical engineering companies.

Historians of technology will recognize certain limitations to this use of Canadian innovation to representing metallurgical technology generally. Most fundamentally, by focussing on new inventions we risk obscuring other important fields that are not associated with an identifiable original Canadian discovery or invention. Certain areas of significant Canadian research and development may be overlooked if they are not readily associated with a particular novel development or invention. New inventions can also be a rather clumsy measure of innovation. Seemingly novel inventions are, more often than not, the result of incremental progress in several fields. Such progress is not bounded by national frontiers. For this reason, priority is often difficult to establish and multiple independent inventions are common across the history of technology.

Furthermore, there is no particular reason why a successful technology should be more historically instructive than an unsuccessful one.[2] Historians in areas such as science, medicine, and technology, no longer approach their topics as if the past were an imperfect stage in the development of the present, but rather view each particular time and culture as possessing circumstances favouring certain areas of inquiry and development. We cannot understand these coherently by studying only those technologies and ideas that have survived to the present day. By analogy, the failed technologies of the recent past — for instance, Stelco's efforts to collaboratively develop a kiln-reduced DRI process beginning in the late 1950s, or attempts by Alcan to implement a new aluminum smelting process in the 1950s and 1960s — can teach us just as much about the needs and circumstances of the industry as successful technologies.[3]

That said, in the developed and highly competitive fields of twentieth-century mining and metallurgy, novel technologies are invariably the result of highly evolved research programs or sophisticated work cultures open to innovation. Communities are built on identifiable landmarks and, within a community composed largely of engineers, successful technologies are landmarks worth celebrating. Museums, such as the one sponsoring this report, are likewise dedicated to celebrating subjects of national significance.

In interviewing metallurgists, one discovers that different metals industries have different approaches to technology. In certain ways, ferrous industries may be more technology-driven than nonferrous industries, where the establishment of new mining operations is all-important. For this reason, new technologies such as electric furnace smelting and oxygen pyrometallurgy have tended to be developed by steel companies before migrating to the nonferrous sector. On the other hand, much of the technology used by the steel industry is now provided by major suppliers. Nonferrous industries are more likely to require the engineering expertise of metallurgical consulting companies in process engineering.

Likewise, the circumstances within a particular company or facility may determine its openness to technological innovation. Metallurgists involved with Dofasco maintain, for example, that a comparatively benign relationship between labour and management made it easier to adopt new technology. Both Inco in Canada and Outokumpu in Finland independently developed flash smelting furnaces for copper, but it was Outokumpu — a smaller entity for whom the sale of technology was of much greater potential value — that successfully marketed its furnace. Similarly, the challenges facing remote facilities such as the Fort Saskatchewan refinery of the Sherritt Gordon Company, or Noranda's Gaspé smelter, may have contributed to a culture of innovation.[4]

In 1970, American metallurgist Herb Kellogg characterized the evolution of extractive metallurgy in a way that has stood the test of time. Kellogg identified three categories of progress: The Bigger and Better Process (namely the emergence of large, efficient facilities brought on by the need to economically process leaner ores), the New Process by Virtue of Engineering Design (notably new pyrometallurgical processes made possible by engineering research), and the New Process by Virtue of Novel Chemistry. We will see examples of the latter two categories in this chapter.[5]

Innovation in the metals sector has been driven by significant pressures already alluded to. Chris Twigge-Molecey of Hatch has listed the following "external economic, market, and political pressures facing the industry. Each, except the last, "has led to extensive research and development needs and a wide array of new innovations."[6]

- Starting in the 1960s, the environmental movement drove legislation that changed attitudes toward emissions and effluent discharges.
- Major increases in energy costs happened in the 1970s and 1980s.
- Workplace health and safety awareness and enforcement also gained momentum in the 1970s and 1980s.
- Economic stresses were caused by increased taxation.
- Competitive pressures were increased by the North American Free Trade Agreement (NAFTA) agreement in the 1980s and more recently the World Trade Organizaion (WTO) agreement.
- Over 80 percent of our metallurgical production capacity was sold to foreign interests in the last two decades.

The last factor is especially important in understanding the pace of change in Canadian metallurgy. With most major Canadian metals companies now foreign-owned, there are fewer places in Canada where practical metallurgical research is undertaken. Whether Canadian consulting engineering companies and university research can continue to sustain the expertise gained during Canada's metallurgical "golden age" is a question worth considering.

WARTIME RESEARCH AND THE PIDGEON PROCESS FOR MAGNESIUM

In considering the development of metallurgy as a field of research, one cannot ignore the influence of war and the preparation for war. We have already seen several examples, including the vast increase in aluminum production during the Second World War, the government-funded improvements to steelmaking capacity during both world wars, and the massive investments in nickel production made possible by America's Cold-War-era strategic metals stockpile. The story of magnesium production during the Second World War is both an important metallurgical innovation and a Canadian example of the manner in which the common national efforts of modern war can produce rapid technological change.

Magnesium was, for much of the twentieth century, the quintessential wartime metal. Demand for the metal spiked during times of war: it was used in incendiaries and other munitions, and later in lightweight aerospace castings. During these periods, the government sought to maximize production through wartime supply-management schemes. The Pidgeon process for refining extremely pure (over 99.95 percent) magnesium — through reduction using ferrosilicon — was developed at the NRC amid such circumstances during the Second World War. This significantly boosted the production of magnesium among the Allied nations, while providing the basis for a Canadian magnesium industry into the postwar period. China currently produces the vast majority of the world's magnesium using the Pidgeon process, though this method is now considered outdated and polluting relative to the methods used in many other jurisdictions.[7]

Canada first produced magnesium during the First World War, which closed off supplies from Germany, the metal's most advanced producer, while creating enormous wartime demand. Eight plants were established in North America to address the shortage. The largest among these was Shawinigan Electro Metals located in Shawinigan, Quebec, which operated from 1915 to 1919 using an electrolytic process. It closed down due to postwar oversupply.[8] The interwar period saw significant improvements in magnesium alloys, led largely by Germany, which pioneered the use of cast magnesium parts in aircraft where weight was critical. It was used primarily in place of aluminum in parts that were unstressed and not subject to heat.[9]

In the late 1930s, growing tensions in Europe kindled interest in reviving Canada’s magnesium industry. In 1937, the National Research Council (NRC) assigned a young research chemist, Dr. Lloyd Montgomery Pidgeon, to explore various means of producing metallic magnesium. Born in Markham, Ontario, in 1903, Pidgeon had graduated as a gold medalist in chemistry at the University of Manitoba in 1925. He obtained his MSc from McGill University in 1927, and his PhD in 1929. Afterward, he obtained a fellowship to study at the University of Oxford under Sir Alfred Egerton (1886–1959). Upon returning to Canada, he found employment with the NRC.

By the outbreak of war, Pidgeon had developed a novel method of reducing dolomite (calcium magnesium carbonate) with ferrosilicon in horizontal retorts to produce a metal of exceptional purity. In the “Pidgeon process”, as it has since become known, dolomite ore is calcined in a kiln to produce calcium and magnesium oxides.[10] This is ground with ferrosilicon, produced by heating silica with scrap iron in an arc furnace. The mixture is briquetted and charged into an electrically heated horizontal retort, the Pidgeon reactor. There, the mixture is heated to 1,200°C under vacuum conditions, producing a magnesium vapour that is drawn into a cooled jacket at one end of the horizontal retort. There it condenses, forming a “crown” of almost-pure magnesium metal.[11]

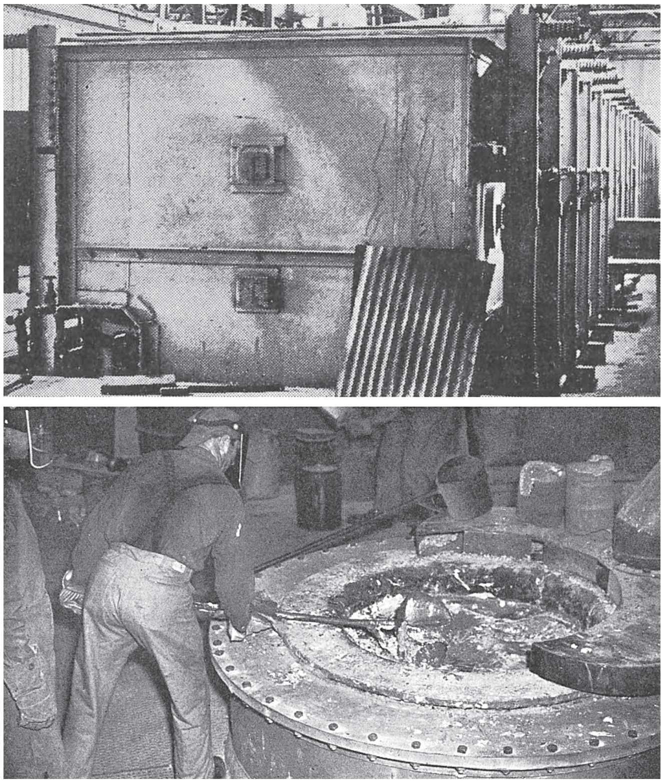


Figure 35: (Top) A bank of Pidgeon process retorts in operation during the Second World War. (Bottom) Crowns of magnesium gathered from the retorts are melted together and further refined in melting pots. (White 1944, 22)

As Pidgeon was developing this process, events in Europe led planners in Canada to fear for existing magnesium ore supplies from Greece.[12] Existing mining companies, led by veteran miner Robert J. Jowsey, commenced efforts to exploit deposits of dolomite in Ontario.[13] A pilot plant using the Pidgeon method, paid for by the Canadian government, was built in 1941 and operated by Dominion Magnesium. Professor Pidgeon was made research director of the operation. A full-scale plant was completed by December of 1942. The plant featured hundreds of the retorts operating in batteries.[14] An overall view of this facility can be seen in the advertisement shown on page 22.

These operations were located at Haley Station in Eastern Ontario, near both the Quebec border and highly pure deposits of dolomitic limestone, as well as abundant supplies of hydroelectric energy for heating the reactors. The plant included facilities for calcining the limestone, grinding and preparing the dolomite powder, refining, and casting.[15] Ferrosilicon was imported from elsewhere until after the war, when indigenous sources were developed.[16]

The Haley plant represented something of a showpiece for the wartime partnership between government, researchers, and the mining community. In about two years, the process had gone from the laboratory to a full-scale mining operation and refinery in an undeveloped location in the Ottawa Valley. The story generated a series of articles in Canada’s newspapers, with headlines such as “Canadian Magnesium Plant Fights in Air War,” and “Another War Metal Joins Up.”[17] The conglomerate of mining companies that set up the plant was permitted to retain the right to the Pidgeon process and, subsequently, to take ownership of the plant and operate it at a profit after the war.[18]

By the end of the war, the Dominion plant was producing more magnesium per month than Canada had used in its entire pre-war history, roughly 15 tons (13.6 tonnes) per day, or more than one million pounds (450,000 kg) per month.[19] The Americans had built five new plants producing 135 tons (122.5 tonnes) per day.[20] Magnesium castings were used throughout the aircraft industry. Such parts will be represented throughout the artefacts of the Canada Aviation and Space Museum and will, no doubt, be familiar to aircraft restorers working with the museum

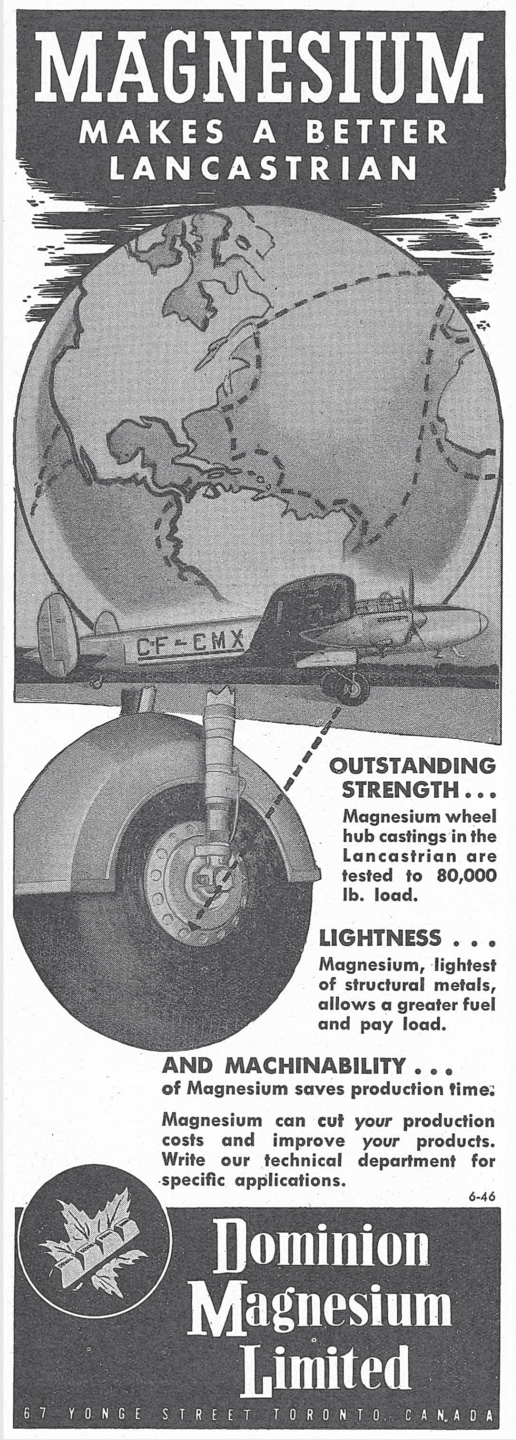
Magnesium Production at War's End

Even as the war in Europe was nearing its conclusion, Canada and its allies were looking to a postwar world in which the vastly increased production of magnesium metal would find a stable commercial market. The challenge was evident: wartime need had also substantially increased output among the other powers, while peace would significantly curtail munitions production. The end of the war saw the expected glut of magnesium in Canada, and it was not until 1947 that production was restarted at Haley Station.

In the years following the end of the war, one finds many hopeful references to possible civilian markets. As early as December 1945, the Globe and Mail cited the U.S. Magnesium Association as receiving "numerous inquiries" from commercial manufacturers. "Wheelbarrows, scooters, canoes, household furniture, baby buggies, skis, baseball masks, fishing rod cases, deep freeze units, and lightweight containers of all kinds" were reported to be in production, with new consumer goods in the way. Lightweight printing presses and car wheels made their appearance in the United States.

Many such articles were to be made available for the Canadian market once improvements were made to the Dominion magnesium plant. That market was to be limited, however. Canadian magnesium exports went primarily to Great Britain as they faced a 40 percent tariff in the United States. The Globe and Mail observed, somewhat optimistically, that "This is only one industry which shows that, given free enterprise, business men, engineers and manufacturers are poets and dreamers of dreams that come true."

An article in the Globe entitled "Claim Magnesium Will Reduce Human Fatigue," published in March of 1946, showed Torontonians handling products made of cast magnesium. Such dreams would not be substantially realized. Compared to aluminum, its main competitor, magnesium was more susceptible to electrolytic corrosion, was more expensive to fabricate, and less tolerant of stress. Commercial development of magnesium in consumer products was also hindered by the widespread belief that the metal was dangerously flammable.



MAGNESIUM
MAKES A BETTER
LANCASTRIAN

OUTSTANDING STRENGTH . . . Magnesium wheel hub castings in the Lancastrian are tested to 80,000 lb. load.

LIGHTNESS . . . Magnesium, lightest of structural metals, allows a greater fuel and pay load.

AND MACHINABILITY . . . of Magnesium saves production time.

Magnesium can cut *your* production costs and improve *your* products. Write our technical department for specific applications.

6-46

Dominion
Magnesium
Limited

67 YONGE STREET TORONTO, CANADA

Figure 36: A postwar advertisement promoting magnesium. The Lancastrian, a civilian version of the Lancaster bomber, illustrates the effort to transition to a peacetime economy (Dominion 1946, 38)

due to the susceptibility of magnesium parts to galvanic corrosion. As the war turned increasingly in favour of the allies, the surplus production of magnesium presented a conundrum for wartime planners. Hopeful predictions of a coming "light metal age" reappear throughout this period.[21]

While a significant civilian postwar market for magnesium failed to develop, Canadian production was sustained by continued military demand. In 1949, Dominion Magnesium acquired Light Alloys Ltd. of Renfrew, Ontario, the major Canadian producer of aerospace castings, which it operated as a wholly owned subsidiary. In 1952, it opened a new extrusion plant close to its foundry in Haley, Ontario, transferring trained foundry workers from Renfrew. The cancellation of the Avro Arrow project led to major layoffs, with the company declining from a peak of 500 workers to about 100 in 1960.

The Haley magnesium plant, which had nearly been closed in the 1960s, was sold to Falconbridge in 1967.[22] In 1971, it was again sold to Chromasco, which then adopted the name Timminco. It was closed in 2004 after 63 years in operation. It had been the longest-operating Canadian magnesium plant, and the second-to-last of Canada's magnesium operations to close. Magnesium production, like many other developments in the Canadian metallurgical field, was halted by the rapid growth of China as an industrial power.[23] Ironically, over the last ten years, Chinese implementation of the Pidgeon process has come to dominate world magnesium production. Over the same period, Canada has gone from a major producer of magnesium to producing none at all.

Meanwhile, Canada's place in commercial magnesium fabrication remains strong. One example of continued innovation in this field is the Institut de la technologie du magnésium (ITMg), based in Quebec City. ITMg is a non-profit research and development centre focused on cast and wrought magnesium technologies. These are finding increasing applications in the automotive industry as vehicle manufacturers seek to increase fuel economy by incorporating light metals.

The Pidgeon process is one of several Canadian innovations in the field of magnesium production. Others include the commercialization of a multipolar electrolysis cell, developed by Rio Tinto Alcan, which first emerged in the 1940s out of attempts to produce magnesium for use in aluminum alloys based on an electrolytic process. Another important technology was developed beginning in the late 1980s as a joint venture by Noranda and Lavalin Industries to extract magnesium from existing asbestos tailings in the Eastern Townships of Quebec. In 1995, a demonstration plant was built in Valleyfield, Quebec, as a joint venture by several companies. A full plant, Canada's largest commercial magnesium operation, was completed in Danville, Quebec, in 2000. It closed in 2003 due to serious technical problems and the plummeting price of metal (the latter a result of the growth in Chinese production).[24]

NICKEL SMELTING AND REFINING: AMERICAN ORIGINS AND CANADIAN CONTRIBUTIONS

The refining of Sudbury ore is one of the more prominent themes in Canadian metallurgy. More than a century of research, much of it in Canada, has gone into processing the complicated nickel-copper sulphide ore of the Sudbury region. None of the early smelting and refining processes necessary for "unbuckling the Sudbury nickel belt" originated in Canada.[25] As was the case in other areas, Canadian nickel production was initially dependant on better-established metallurgical centres, particularly those in the United States and Britain, for technical knowledge and capital investment.

The processes described below are instructive because they represent three alternate paths in the process of refining nickel. Electrolytic refining, chemical vapour transport, and pressure leaching have all been commercially viable alternatives used by Canadian companies.

COPPER/NICKEL SEPARATION AND THE HYBINETTE ELECTROLYTIC PROCESS

In 1893, the first step towards producing nickel from Sudbury ore was taken when Colonel Robert M. Thompson (1849–1930) of the Orford Copper Company refinery in Bayonne, New Jersey, patented a method for separating copper from nickel sulphide. This involved treating copper-nickel matte with sodium sulphide in converters. Copper sulphide dissolves preferentially in the sodium sulphide, generating an immiscible lighter liquid, most of which was skimmed from the converter. Upon cooling the nickel sulphide, any remaining copper-sodium sulphide formed a distinct solid layer easily separable from the solid nickel sulphide.[26] The resulting nickel sulphide was further treated with sodium sulphide to eliminate most of the residual copper. The copper-sodium sulphide was treated to produce blister copper. The "awful Orford" process, though slow and tedious, remained in use until a new matte separation process was implemented at Inco's Copper Cliff smelter in

1948. Long before that, demand from the U.S. Military for purer nickel — needed to produce hard steel alloy for armour plate — led Thompson to pursue a further refining process.[27]

In 1892, Thompson hired Victor Hybinette (1867–1937), a young Swedish-born chemist eager to become a working metallurgist. After a productive period of experimentation, Hybinette began working on an electrolytic process in which the smelter matte was cast into anodes, electrolyzed, and the nickel recovered from the cathode. The patent for the Hybinette process was awarded in 1905.

In 1920, a refinery run by the British American Nickel Corporation (BANCO), a company largely owned by the British government, was opened at Deschenes, Quebec, near abundant hydroelectric power sources. BANCO purchased the rights to the Hybinette process, with Hybinette himself playing a major role in setting up and running the operation. Though productive and efficiently run, low prices forced the corporation into liquidation in 1924. The assets were purchased by Inco, which dismantled the plant and implemented a modified version of the Hybinette process at Port Colborne. Anodes, each weighing about 227 kg (500 lbs), were cast, and nickel refined electrolytically, at Port Colborne into the 1980s.

In preparation for the opening of the new Inco refining facility in Thompson, Manitoba, in 1961, Inco developed a slightly different version of the Hybinette process that had been used at Port Colborne. This involved the use of sulphide matte anodes, a less-refined anode containing 76 percent nickel and 20 percent sulphur. Anodes at the Copper Cliff refinery typically contained 93.5 percent nickel and .6 percent sulphur. Its Norwegian refinery, part of a wholly owned subsidiary, also employed the Hybinette process. This refinery was acquired by Falconbridge in 1928.[28]

INCO PRESSURE CARBONYL (IPC) PROCESS

The Hybinette process remained in use at the Inco Port Colborne refinery long after it had become obsolete. It was finally shut down in 1984. Production shifted to the Copper Cliff nickel refinery, the world's first high-pressure carbonyl nickel refining plant, which was commissioned in 1973. The pressure carbonyl process had been in development for over a decade at the Port Colborne research station. This, in turn, had evolved from an earlier low-pressure carbonyl process dating back to the end of the nineteenth century.

The chemical principle behind the nickel-carbonyl process (also known as the Langer-Mond process) was developed by Carl Langer (d. 1935) and Ludwig Mond (1839–1909) in 1888 at the London, UK, research laboratory of the Mond Nickel Company. It was first used on a commercial scale to treat Sudbury sulphide matte in a refinery built in 1902 in Clydach, Wales. The process, as initially developed, involved passing carbon monoxide over a relatively pure nickel metal powder, forming, in the process, nickel tetra-carbonyl gas, $Ni(CO)_4$. The pure nickel was then deposited on seed material forming successive "onion skin" layers as the granules were brought into repeated contact with the gas

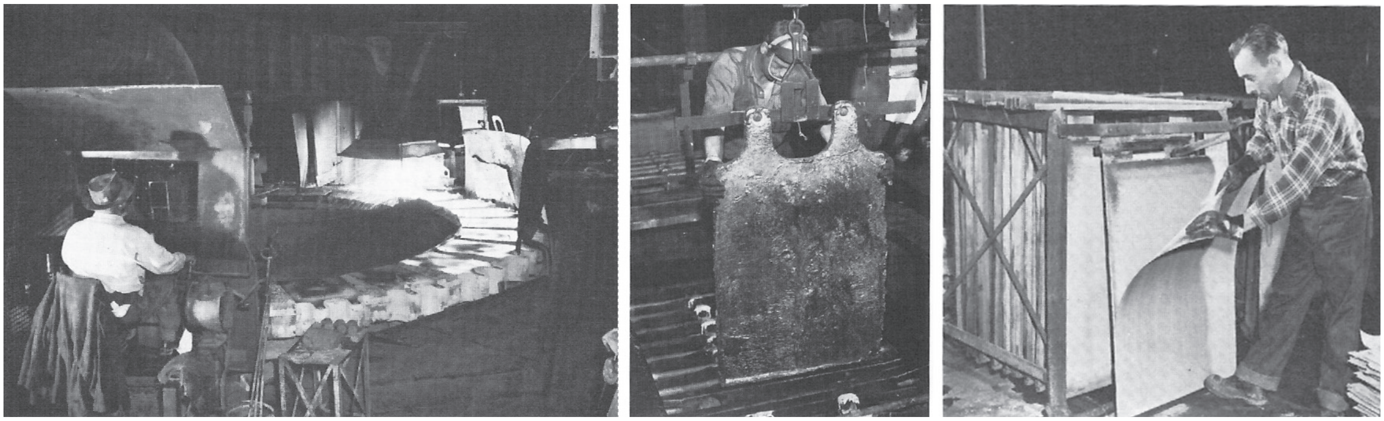


Figure 37: Operations involving the Hybinette process at Inco's Thompson refinery. (Left to right) Anodes are cast. Anodes are lowered into the electrolytic bath. Refined nickel is stripped from the cathode. (Boldt 1967, 346, 351-352, with permission from Vale Canada)

Incofoam

The exceptionally pure nickel powder produced by the carbonyl method has found a number of applications. Carbonyl gas can be used in coatings and the powder can be manipulated into various flakes and chains. Inco's research facility in Mississauga began exploring new material possibilities after the pressure carbonyl process was implemented.

Among these was Incofoam, a proprietary system for producing nickel foam of highly uniform structure in a range of pore sizes and thicknesses. First produced at the Copper Cliff refinery in 1994, the Incofoam process involved the deposition of carbonyl gas on polyurethane foam. The nickel atoms adhere perfectly to the surface at an atomic level. The foam was then burnt away in an annealing furnace.

Challenges involved in this process include the mechanical weakness of the hollow structures formed by deposition, structural damage caused by polyurethane "erupting" from the structure during the sintering process, and the toxic nature of the chemicals used.[29]

Incofoam found applications in electrodes for rechargeable batteries. Further applications were explored in areas such as catalysts (especially vehicle catalytic converters), and filters. Ultimately, the process proved overly complicated and expensive to implement. It could not compete with a much simpler, though far more labour- intensive process used in China to manufacture nickel foam for use in battery electrodes.

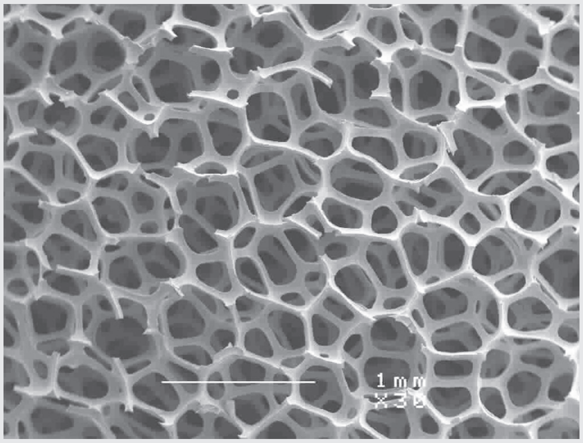


Figure 38: Photomicrograph of Incofoam (Courtesy of Vale Canada)

stream until they reached the desired size.[30] The process was difficult to commercialize and extremely toxic. Several people were poisoned by nickel tetra-carbonyl gas at the Clydach refinery, and Welsh nickel workers were found to have elevated levels of lung cancer during the facility's early years.[31] The refinery remains in operation.[32]

In 1961, development began on the Inco pressure carbonyl process at the Port Colborne research station. Building on the successful production of pig nickel in an oxygen-blown converter, the new process employed high-pressure rotating reactors, operating at 1000 psi, to convert the valuable nickel-to-nickel carbonyl from which it could be purified by distillation and the nickel recovered by thermal decomposition. The pressure carbonyl plant, installed in 1973 and still operational, consists of horizontal rotating reactors, each 13m long, in which the nickel carbonyl vapour is generated. The vapour is refined in a series of fractionating columns and is deposited as nickel powder in a decomposer section.[33]

The carbonyl plant recovers around 90 percent of the nickel from the crude nickel feed. The residue from the carbonylation reactors is treated separately in a specialized plant: the Copper Refinery Electrowinning Department (CRED) that came online alongside the carbonyl refinery in 1973. This uses a two-stage pressure leach system to recover remaining nickel, cobalt, and platinum group metals (PGMs), after which the copper residue is treated to produce electrowon copper. PGM concentrates are sent to Vale's precious metals refinery in the UK for further processing.[34]

SHERRITT INTERNATIONAL PRESSURE LEACH PROCESS

Developed through a collaboration between university and industrial researchers, the Sherritt International Ammonia Pressure Leach process represents the "birth of commercial pressure hydrometallurgy."[35] This highly versatile process has made Sherritt into a Canadian powerhouse in hydrometallurgical technology. Pressure leaching involves the dissolution of metal into a solvent medium within a pressure vessel known as an autoclave. Heat and pressure are used to increase chemical reaction rates. Once dissolved, materials can be selectively removed through further chemical processes.

Sherritt's ammonia-based process was initially developed over the late 1940s and early 1950s in order to process nickel-copper sulphide ore from the recently discovered deposits in Lynn Lake, Manitoba. Due to the remoteness and relatively small size of the Lynn Lake ore body, Eldon Brown, Sherritt's president and managing director, enlisted the help of Professor Frank Forward of the Department of Mining and Metallurgy at the University of British Columbia. Forward received the ore concentrate in 1947 and processed it using the existing Caron process, developed for treating nickel ores in Nicaro, Cuba. Forward had earlier worked on the development of this process while employed by the Freeport Sulphur Company. The results of this early work were promising enough to convince Brown to finance a test program based at UBC.[36]

Forward made several important discoveries during his early experiments. Most notably, in June of 1948, Forward performed a very small-scale experiment using nickel furnace matte, purchased to supplement the limited supply of Lynn Lake concentrate. This involved rotating the matte in a small vessel of ammoniacal/ammonium carbonate solution. Rather than simply dissolving the nickel metal in the matte, the solution dissolved the nickel sulphide as well. The process, significantly simpler than the Caron process, worked just as well when ammonia alone was used.

With this discovery in hand, attention turned to developing the process for operations under increased temperature and pressure, as well as to finding a way to separately recover copper and nickel from the solution. To implement the process, the assistance of a chemical engineering company was required. In December of 1948, Sherritt contacted the Chemical Construction Corporation (Chemico), an American company experienced in developing hydrometallurgical projects. Significantly, Chemico had recently developed a new method for depositing nickel metal from ammoniacal solutions.[37]

The two companies collaborated on a series of four increasingly sophisticated pilot plants, located in Ottawa, through which the commercial process was developed. This required several innovations, including a method for removing copper as copper sulphide from the first leach solution, as well as a process for depositing nickel onto seed particles for greater efficiency than had been achieved when nickel could be recovered only from the autoclave walls. The final major hurdle involved the development of a means to reduce the sulphur content in the final product.[38]

Work on these processes was greatly assisted by the hiring, in 1949, of Vladimir Mackiw (1923–2001), a Ukrainian-born chemist. Mackiw would rise within Sherritt Gordon Mines to become executive vice-president over a lengthy and distinguished career.[39] He was to assist in the development and running of the Ottawa pilot plants as part of a group consisting initially of two other Sherritt staff,

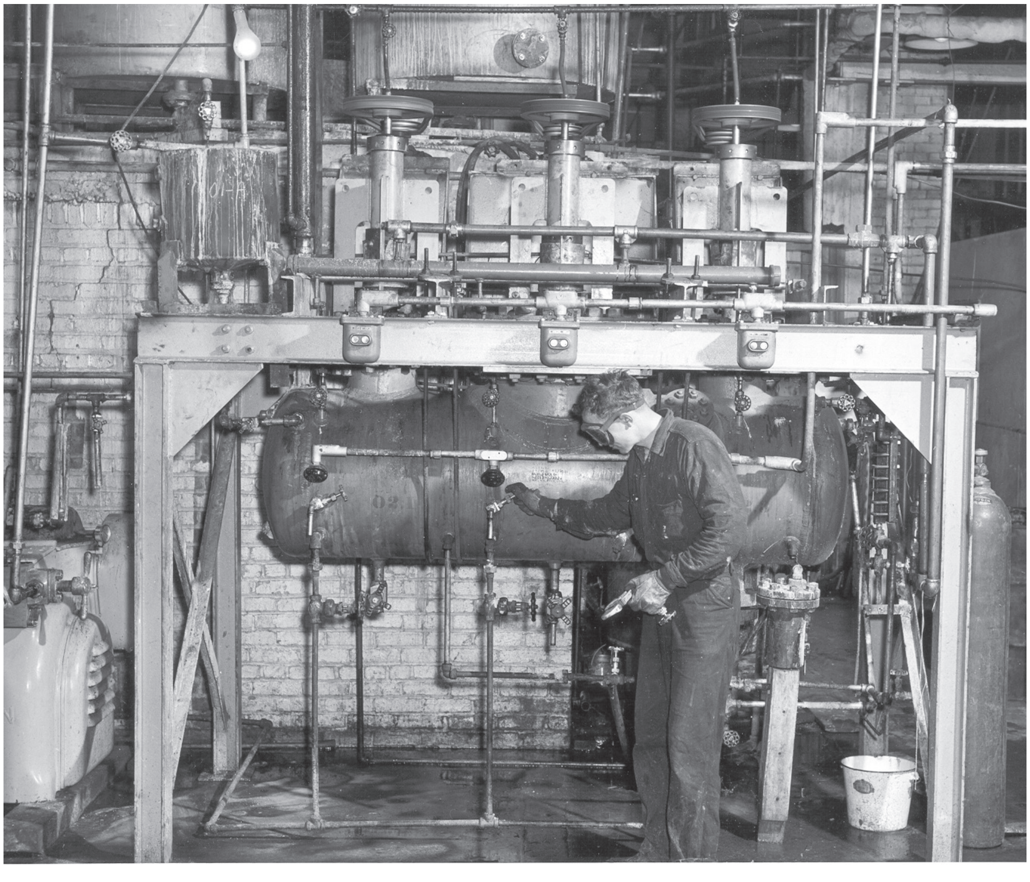


Figure 39: Researcher Neil Colvin takes a sample from a test autoclave at the Ottawa pilot plant during the development of the Sherritt International pressure leach process. (Courtesy of Sherritt International Corporation)

three engineers from Chemico, along with Frank Forward and an engineering graduate student from UBC.[40]

By 1953, a branch of the CPR railway from Sherriton had reached the Lynn Lake site. The fourth and final Ottawa test plant successfully processed 130 tons (118 tonnes) of Lynn Lake concentrate into 12 tons (10.9 tonnes) of nickel metal between April and September of that year. A full-scale refinery was completed at Fort Saskatchewan, Alberta, in May of 1954. The following year it was operating at design capacity. The process has since been improved, and the mill upgraded, several times. Major changes to the leaching process, notably a new method for recovering Cobalt, were implemented after 1991, when Sherritt began to receive shipments from mines in Moa, Cuba.[41]

In 1957, Sherritt International purchased all of Chemico's patents related to the process. Since it was first implemented, Sherritt had licensed the technology to several other companies, including Finnish nickel company Outokumpu, the South African company Impala Platinum, and Marinduque Mining in the Philippines. Sherritt also adapted the process to several different metals. The company built three zinc-processing plants across Canada, the first at Trail, British Columbia, in 1976; the second at Timmins, Ontario, in 1983; and the third at Flin Flon, Manitoba, in 1993. Sherritt developed pressure-leaching technologies for processing uranium, which were implemented at Key Lake, Saskatchewan in the early 1980s. It has also contributed to new pressure-oxidation technology for refractory gold ores, implemented at several locations worldwide, including Campbell Red Lake, Ontario, commissioned in 1991.[42]

ORIGINS OF OXYGEN PYROMETALLURGY IN CANADA: POROUS PLUG AND SHROUDED TUYERE

Over the course of the twentieth century, the application of tonnage oxygen improved many aspects of pyrometallurgy. Oxygen has several advantages over the longstanding use of atmospheric air. Most notably, it reduces heat losses. It also reduces several deleterious chemical effects introduced by nitrogen, which is the most abundant gas in atmospheric air. Canadian metallurgists have played an important role in advancing this research. As has so often been the case, this contribution has involved significant international collaboration and exchange. In this case, the collaborators were primarily French and German rather than American.

Oxygen pyrometallurgy in Canada was largely the result of a single company whose initial competence in the area of cryogenic oxygen production, and subsequent investment in research capacity, was essential to the development of several key Oxygen-related technologies. In 1911, the French company Air Liquide established a Canadian subsidiary based in Montreal. Air Liquide was founded in Paris in 1902 by George Claude (1870–1960), a French chemist who had improved the efficiency of a recently developed German industrial method of separating oxygen from atmospheric air by cryogenic cooling and liquefaction.[43]

Like many other industries, Air Liquide Canada benefited from the industrial expansion brought on by the Second World War. In addition, the Company's management, fleeing the Nazi occupation of France, settled at its Montreal operation. Following the war, the Canadian branch was well-positioned to work with the burgeoning metals industry in seeking new applications for tonnage oxygen. With its access to the hydroelectric resources of Eastern Canada — electricity being the main expense in oxygen production — and in partnership with a significant steel industry, Air Liquide was able to demonstrate to the global metals industry that efficiencies could be gained by building oxygen production facilities at the site of the metallurgical plant.[44]

In 1923, a prescient and oft-quoted report from the U.S. Bureau of Mines predicted that "The application of oxygen will revolutionize the art of smelting, and it will probably change the whole operation and equipment."[45] The technical obstacles were clear. First among these was price. Tonnage oxygen must be produced at a sufficient scale in order to be economical. This investment had to be justified based on metallurgical experimentation. Other technical problems included the rapid destruction of refractory linings when blowing oxygen into the bottom of the converter vessels.[46] The challenge of overcoming such difficulties would fall to a group of pyrometallurgists assembled by Air Liquide Canada in the postwar years.

The following section deals with both ferrous and non-ferrous applications of oxygen to pyrometallurgy. In Canada, as elsewhere, steelmaking was the first obvious application of tonnage oxygen, given the longstanding importance of bottom-blown converters using pressurized air. Canadian innovations in this area were applied to German furnace technology before being used in Canada. Our examination of non-ferrous applications focuses on the copper and nickel smelting operations at Inco, and the increasing application of oxygen technology to several aspects of their Copper Cliff operations.

THE SAVARD-LEE SHROUDED TUYERE

The Savard-Lee Shrouded Tuyere was developed by researchers at Air Liquide Canada tasked with applying tonnage oxygen effectively to steelmaking. The technology, which was developed over a period from 1947 to 1967, takes its name from an annular cooling shroud that surrounded the tuyeres, preventing them from overheating and damaging the refractory lining. The technology was first commercialized in Europe as the oxygen bottom metallurgy (OBM) process. It was subsequently implemented as the Q-BOP (a variation of the basic oxygen process) by U.S. Steel Corporation and was later incorporated into various smelting and converting operations involving copper, lead, and nickel.[47]

With the development of the Bessemer converter, which made industrial steel production possible in the nineteenth century, compressed air had been injected through the base of a converter vessel to oxidize impurities in the hot metal. Beginning in the 1930s, researchers in Germany, Austria, and Switzerland began to pursue a method for bottom-blowing tonnage oxygen rather than atmospheric air in the steelmaking process. These early efforts were unsuccessful: the life of the refractory lining was greatly reduced due to excessive heat developed around the tuyeres.[48]

A widely-adopted compromise was achieved with the LD process developed at Linz-Donawitz in Austria. This involved the injection of supersonic oxygen (later oxygen and lime) through a lance located within the mouth of the converter vessel. Although this solution continued to present several difficulties and inefficiencies, by the 1960s, oxygen steel production was well underway.[49] A number of Canadian steel producers had retrofitted open hearth furnaces for oxygen injection using lances, or had adopted the LD process, later called the basic oxygen process (BOP). As noted, the Hamilton steel company Dofasco was the first operational LD in North America, and second in the world outside of Austria.[50] Inco had already applied oxygen to the smelting of non-ferrous metals with the flash furnace described below. All of

Bathtub insight: The Porous Plug

Since the foundation of gas chemistry as a field of study in the late eighteenth century, flatulence has proven a recurring theme, albeit one most often used to mock chemists studying gas.[51] With the development of the porous plug, Canada can claim a somewhat more edifying twist on this theme.

In order to produce a homogenous batch of steel, the melt must be stirred. In 1947, while visiting a steel plant, Robert G. H. Lee, then a new employee of Air Liquide Canada, witnessed a ladle of molten steel being stirred using a steel ingot. He considered the practice unsafe.

Later, while soaking in the bath, a moment of flatulence brought to mind the possibility that the stirring could be done using bubbles of inert gas injected through the bottom of the ladle. Several years of research in collaboration with the laboratory of the Mines Branch in Ottawa produced a plug made of alumina, a suitably porous and heat resistant material.

Lee's notion was that the system could be used to stir steel in a ladle by bubbling argon gas through it. The system was first successfully demonstrated on a commercial scale using a steel ladle at Dofasco in the mid-1960s. The idea was counterintuitive; some steelmakers resisted the notion of cutting a second hole in addition to the regular nozzle exit in the bottom of a vessel meant to contain molten metal. At least one trial, involving a ladle at Algoma, failed.

Figure 40: An artist's rendering of the moment of discovery (Steel Irony, July 2012, courtesy of the Association for Iron and Steel Technology)

The porous plug has found application beyond steel making. It is used, for instance, to inject nitrogen in Inco's oxygen-top-blowing/nitrogen-bottom-stirring vessel, which is used to smelt copper sulphide from matte separation.[52] The porous plug also represents the first step along a path that would lead Bob Lee and other technicians at CLA towards the development of the shrouded injector.

these Canadian efforts were supported by Air Liquide Canada's technology for producing oxygen.

In the late 1940s, Air Liquide Canada's Montreal-based technicians were tasked with finding new markets for industrial gasses among the integrated steel producers. Canadians Guy Savard and Robert (Bob) Lee both became part of a research department called "industrial gas applications," which was founded in 1950.[53] An early product of this research was Bob Lee's porous refractory plug used to inject inert gas into the bottom of the steel ladle to stir the molten metal. This invention provided a promising early success for work by Air Liquide Canada's research team.

Beginning in 1951, the Air Liquide research team began working with the Canadian steel company DOSCO on a top-blown solution aimed at reducing the silicon content of hot metal. Work began on a bottom-blown solution when this effort generated unacceptable levels of red oxide dust. Further work was needed to determine the adequate pressure for oxygen injection, as too much oxygen made the process uneconomical.[54] Other cooling technologies, including copper tuyere linings of varying thicknesses, as well as steam injection, were also tested over an extensive series of trials taking place from the early 1950s to the late 1960s.[55]

The establishment, in 1963, of a Montreal-based research group, accelerated the development of the injector technology. Tests using a new experimental vessel installed at the Freeman Corporation foundry at Cap-de-la-Madeleine, Quebec, led to the development of a protective cooling shroud containing natural gas. This arrangement finally solved the problem of refractory wear around the tuyere openings by absorbing heat through the process of splitting the hydrocarbon molecules ("cracking"). A French patent was granted for the process that year.

Despite an initial lack of interest from steel companies in France and North America, the shrouded tuyere technology was eventually commercialized in collaboration with the Austrian steel company Eisenwerk-Gesellschaft Maximilianshütte (Maxhütte) of Sulzbach-Rosenberg, Germany, which required the technology to modernize its antiquated operations. A full industrial trial in 1967 was very successful, and a joint patent for the OBM process,

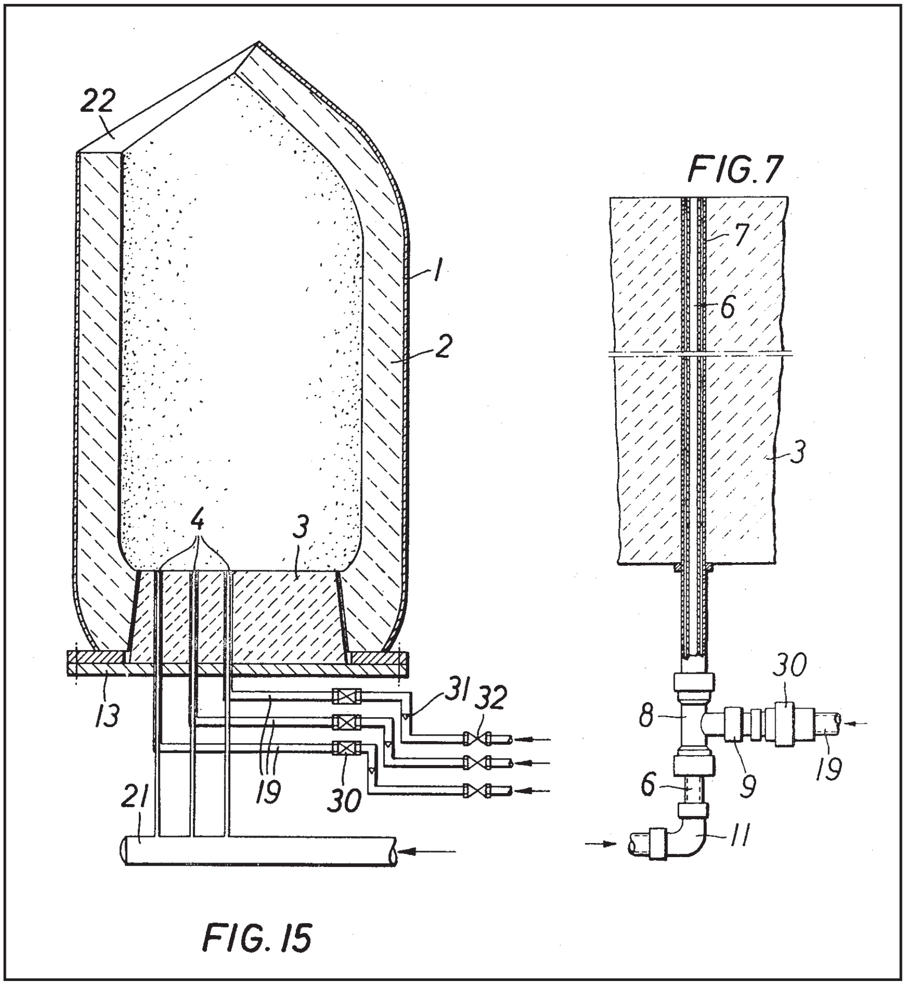


Figure 41: Patent illustrations show the shrouded tuyere as it was applied to the Maxhütte Thomas converter — a bottom-blown vessel used in steel production — in 1972. The illustrations show the shroud of hydrocarbon cooling gas surrounding the oxygen injector.
(Brotzmann et al. 1972, 3, 6)

incorporating the Savard-Lee shrouded tuyere, was granted in 1971. The process was widely adopted, though the existing top-blown BOF technology remained the most widely used system. It was later discovered that existing BOF units could be retrofitted for bottom blowing for increased efficiency.[56]

This technology has been further developed and incorporated into a variety of non-ferrous bath furnaces. For instance, new, more elaborate injector configurations were developed for the Queneau-Schuhman oxygen process (QSOP) technology, of which four examples were put in operation by the early 1990s, including an unsuccessful attempt by Cominco at Trail, British Columbia.[57] The Air Liquide shrouded injection (ALSI) technology, patented in 1995 by Alejandro A. Bustos of the University of British Columbia and Air Liquide, is an elaboration of the Savard-Lee injector used in both nickel and copper converting. This also eliminates the need for mechanical tuyere punchers. The shrouded tuyere slag-make Converting process, developed through a collaboration between Air Liquide Canada and Xstrata Nickel, was successfully implemented at the Falconbridge smelter in Sudbury.[58]

The influence of the Savard-Lee annular tuyere has been widely recognized within the metallurgical community. In 1992, the Savard/Lee International Symposium on Bath Smelting, a joint meeting of the Minerals, Metals, and Materials Society, the Iron and Steel Society, and MetSoc, was held in Montreal. The development of the Savard-Lee technology continues today, fifty years since it was first patented.

NEW PYROMETALLURGICAL PROCESSES: THE INCO FLASH FURNACE AND THE NORANDA PROCESS

When, in 1970, metallurgist Herb Kellogg identified the "New Process by Virtue of Engineering Design" as one of three technological trends defining modern metallurgy, he was referring, in part, to new, more intense and efficient pyrometallurgical processes that were then under development or had recently been developed. Two important examples of the role of Canadian mining companies in these improvements are the Inco Flash Furnace, the development of which began in the 1940s, and the Noranda process, which emerged in the early 1960s.

This process of intensification was related to the availability of tonnage oxygen for use in pyrometallurgical operations, a technology that made it possible to achieve higher temperatures than with atmospheric air alone. It was driven by the constant demand for efficiency, as well as by new environmental regulations that obliged mining companies to capture concentrated sulphur dioxide vapour and convert it to sulphuric acid for sale to other industries. Older, multistep processes involving blast furnaces, hearth roasters, reverberatory furnaces, and outmoded converters provided too many opportunities for fugitive emissions, and included steps that produced emissions too dilute to be economically captured and converted to liquid SO_2 or sulphuric acid.

These processes represent, to a certain extent, the maturity of metallurgy as a discipline during the postwar years, when it was increasingly becoming an area of academic specialization. They were the product of recently-developed engineering methods for quantifying metallurgical processes, and testing new smelting technologies using models, experimental analogies, and test systems of increasing scale. New technologies such as computer modeling and control, along with better sensors and instrumentation were also essential to their development. Both processes were developed, with assistance from creatively minded PhDs, in company research facilities.

The Inco flash furnace and the Noranda process each represent alternate paths in this generation of pyrometallurgy. The former, an example of flash smelting, involves the intense combustion of a mixture of oxygen and particles of dry sulphide ore while still airborne above the bath. The latter, an instance of bath smelting, functions like a traditional converter with the smelting of wet metal sulphide feed taking place within a bath of molten material. These technologies proved both efficient and versatile, their respective smelters remaining in operation while those relying on older technology have shut down. The Inco flash furnace was applied first to copper smelting then to the smelting of mixed copper and nickel sulphides. The Noranda process was developed for use with copper sulphides, but has since also been applied to a range of recycled copper-bearing materials, especially scrap containing high-value metals.

INCO OXYGEN FLASH FURNACE

The emergence of the oxygen flash smelting furnace has been described as "The quantum leap that allowed the smelter to stay below its SO_2 emission levels …" Developed during the 1940s at Inco's Copper Cliff operations, it brought about significant savings in costs and energy by replacing a great deal of the smelting flowsheet with a single efficient step that took advantage of the exothermic energy potential of sulphide ores.[59] This new technology also permitted the recovery of a great deal of the sulphur dioxide in strong gas stream as either liquid sulphur dioxide or sulphuric acid.

Inco's oxygen flash furnace replaced the existing roasting and smelting processes, initially for copper sulphide concentrate, and later for a mixed copper-nickel sulphide concentrate. Sulphide particles combust rapidly when the finely divided metal-sulphide feed, suspended in a stream of oxygen, is injected through burners. This generates all of the heat required by the smelting process. Silica sand is also added to the furnace feed to combine with iron oxides to produce a slag blanket over the molten matte. The concentrated SO_2 off-gas is captured through a central flue for reprocessing.[60]

Following the Second World War, researchers at Copper Cliff began to explore the possibility of implementing the relatively new technology of oxygen injection in place of coal in the reverberatory smelting process for copper-nickel sulphide concentrates. Inco's nickel-smelting process was then very polluting and inefficient, though representative of standard practice across the industry. Roasting of nickel sulphide, for instance, was "carried out in lamentably inefficient, environmentally hostile, multi-hearth roasters."[61] A flash smelting pilot plant was started in January of 1947 and showed promising results by June.[62] A positive report was submitted the following year by Roy Gordon, Copper Cliff's manager, and Paul Queneau, manager of R&D, showing significant energy and cost reduction advantages.

Paul Queneau's tenacity led to an agreement with Air Liquide Canada to build an exceptionally large oxygen plant adjacent to the smelter. Simultaneously, a liquid sulphur dioxide market was developed in the pulp and paper industry, where it replaced imported sulphur. In January of 1952, a test 500-tonne dry copper sulphide concentrate/oxygen flash smelting furnace came online.[63] The off-gas of highly-concentrated SO_2 was processed in the largest liquid SO_2 plant of the day. By 1954, the test plant was replaced with a 1000-tonne per day plant, where the commercial viability of oxygen flash smelting and tonnage oxygen production were definitively demonstrated.

Oxygen was also applied to enrich the combustion gasses of existing reverberatory furnaces used to smelt nickel concentrates. Conventional reverberatory furnaces using atmospheric air had suffered from inefficiencies due to the presence of nitrogen. Having been successfully applied to reverberatory furnaces, oxygen enrichment was applied to

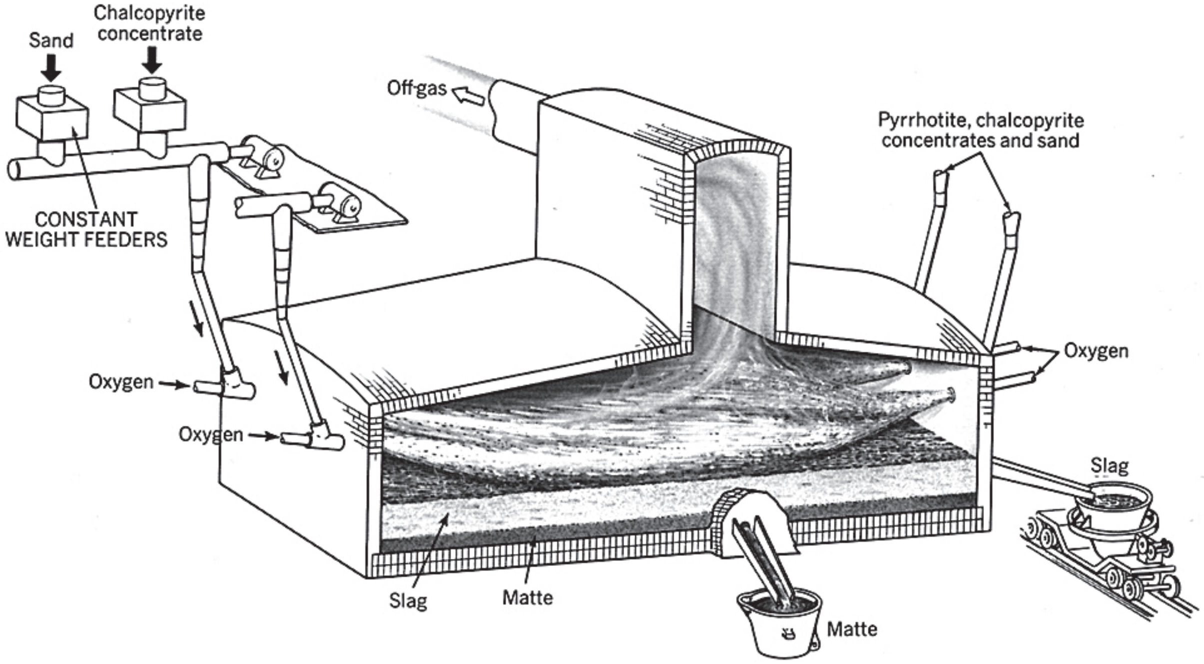


Figure 42: Inco's oxygen flash furnace circa 1967. At this point, the furnace was used to smelt copper concentrate. (Boldt 1967, 243, with permission from Vale Canada)

the Peirce-Smith converters then used to convert the product of the reverberatory furnace to metal. It was found that 33 percent of oxygen in the blower air would halve the ratio of nitrogen to oxygen, resulting in much greater fuel-efficiency. By the 1950s, experience at the Inco furnaces had shown that a ratio of 25 to 35 percent of oxygen in the blower air struck an optimal balance between fuel efficiency and the life of the furnace's refractory walls.[64] These oxygen-upgraded furnaces were eventually replaced by flash furnaces as part of the sulphur abatement program of the 1990s.

Success in smelting copper-nickel sulphides and copper conversion using oxygen was followed by further applications of oxygen enrichment. Inco metallurgists have characterized the emergence of this technology in the postwar years as the development of an "oxygen culture" at the Copper Cliff smelter.[65] In the late 1950s, it was shown that the top-blown converters, used for steel production, could be adapted to converting nickel sulphide matte.

In 1971, two of these vessels were installed at Copper Cliff to produce a "complex metal sulphide intermediate," which was then converted to copper-nickel matte. Following matte separation, the nickel sulphide fraction was processed to metal using the Inco pressure carbonyl process.[66] This also had the advantage of improving the capture of sulphur dioxide. Blister copper was also converted using a proprietary oxygen-top-blowing/nitrogen-bottom-stirring process implemented in the 1990s.[67]

Inco's oxygen flash furnace technology emerged alongside a contemporary and competing furnace developed by Outokumpu in Finland. The Outokumpu furnace initially employed pre-heated air, though tonnage oxygen was first incorporated by the Saganoseki copper smelter in Oita City, Japan, in 1970. The steady increase in the level of oxygen used in the Outokumpu furnaces has vastly improved the technology, leading to lower energy consumption and higher concentrations of captured sulphur dioxide.

A smaller company than Inco, Outokumpu had more incentive to focus on the marketing of its proprietary technology. Hence, while Inco has sold its two furnaces in the United States, the Outokumu furnace has seen wider adoption and has effectively become an industry standard for smelting copper.[68] The importance of Inco's flash smelting furnace lies both in its pioneering use of oxygen pyrometallurgy, through which it proved the efficacy of tonnage oxygen production, as well as its role in reducing the sulphur dioxide emissions that had blighted the Sudbury landscape.

THE NORANDA PROCESS

The Noranda process was one of the first commercially viable continuous copper smelting and converting processes.[69] It was nine years in development from the decision to pursue the concept in 1963 to the start-up of an 800 ton (726 tonne)-per-day prototype plant in 1973 at the Horne smelter.[70] Built by the engineering company Hatch, it was the first full-scale implementation of continuous converting. The facility has been optimized and improved to the point that it is currently capable of smelting 2,700 tonnes per day while producing matte rather than the originally intended blister copper. The authors of a recent survey of Canadian copper technology provide a succinct summary of its advantages:

> *The Noranda Process reactor, at one quarter the size of a reverberatory furnace, replaced eight hearth roasters, three reverberatory furnaces, a number of conventional converters and all the ancillary equipment related to these numerous units. In addition, the Noranda Process generated a high-strength sulphur concentration gas that allowed the economic production of sulphuric acid, and largely eliminated the use of fossil fuels for smelting copper feed material.*[71]

The benefits of a continuous process for smelting copper were already evident when engineers at Noranda took the first steps towards developing a new copper smelting and converting process in the mid-1960s. Inefficiencies in existing copper smelting and converting technology have been discussed above in the context of oxygen flash smelting. Patents related to the continuous conversion of copper date to the nineteenth century, and several companies were, by the 1960s, exploring this possibility. Nevertheless, none had devised a commercial-scale continuous process.

The initial concept for the Noranda continuous process was developed by Nikolas Themelis and Paul Spira, metallurgists at the Noranda Research Centre. They were later joined by younger metallurgists Peter Tarassoff, Phillip Mackey, and Paul Schmidt in developing the project.[72] Peter Tarassoff later described this early work as "bootleg research … supported by a sympathetic laboratory director." The first proposal presenting the results of these early tests to management was rejected. A second proposal in June of 1964 received the go-ahead for further testing.[73] The subsequent testing regime divided each part of the process taking place in the reaction vessel into separate components for empirical testing before a pilot plant was started in 1968.

The Gaspé Puncher

Many innovations in the field of metallurgy are developed by engineers at specialized research and development facilities, or other research centres. Important developments also emerge from within smelters or other metallurgical plants. This was the case with the tuyere puncher developed at the Gaspé smelter. At its base a relatively straightforward mechanical technology, the tuyere puncher would significantly improve the efficiency of the copper converters where it was adopted.

The tuyeres used for injecting air or oxygen through molten metal in a copper converter periodically become blocked by accretions. Unblocking them traditionally required that a worker use a punch bar to manually punch the tuyere open. This was a slow, dangerous, and labour intensive process that resulted in sub-optimal blow rates relative to the design of the furnace. The first mechanical puncher design, the Kennecott puncher, had emerged in the 1950s, though its effect was limited by the fact that it remained within the tuyere tube and restricted airflow.[74]

In the early 1960s, an idea for a superior mechanical puncher emerged at the Gaspé smelter. A prototype was constructed in the garage of one of the smelter workers. It was ready for testing in the spring of 1962. Installed on a few of the converter tuyeres, the puncher proved its usefulness in producing much better blow rates. An improved version was commissioned later in 1962. The mature design involved two pneumatically activated punch bars mounted on an assembly travelling on a track running parallel to the row of tuyeres. The operator sat in a cab positioned behind a shield.

The installation of the system on both Peirce-Smith converters at the Gaspé smelter resulted in improved production. Manufactured by Heath & Sherwood of Kirkland Lake, Ontario, over 250 have been sold globally. An automated version is also available that significantly increases the speed of the punching operation. Associated technologies have also emerged, such as a silencer, developed by Hatch, which virtually eliminated the piercing noise of escaping air as the puncher bar enters the tuyere through a ball valve.[75]

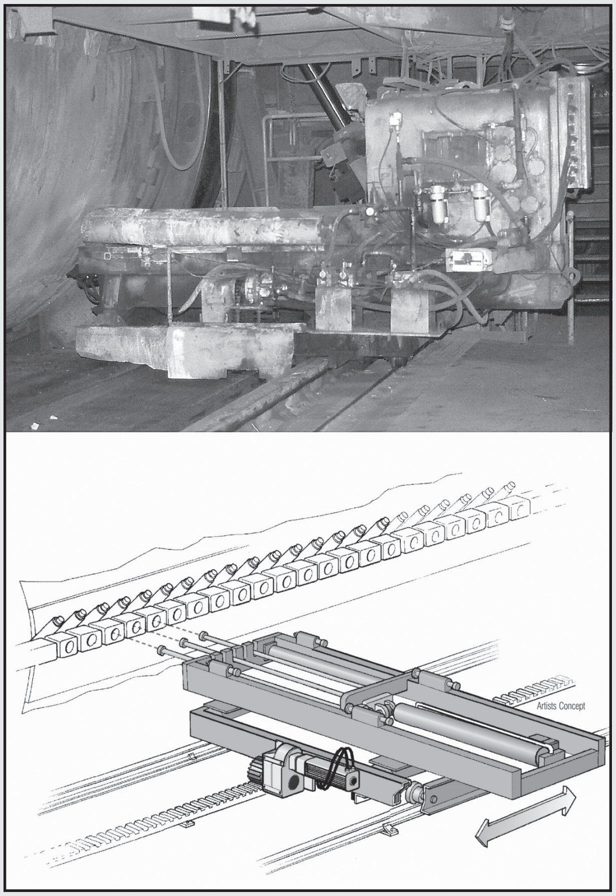


Figure 43: Top: The Gaspé puncher in operation at the Gaspé smelter. Bottom: An illustration of the automatic model of the puncher. (Images courtesy of Heath & Sherwood)

The reaction vessel was envisioned to be a lengthened Peirce-Smith converter. Oxidation was to take place along the length of the furnace with oxygen-delivering tuyeres at one end and slag and molten copper tapped at the other. Pelletized concentrate was delivered over the length of the furnace using a high-speed belt slinger at one end of the vessel. Burners were located at either end of the furnace.[76]

It was discovered that the slag remained relatively rich in copper, roughly 8 to 12 percent. While extensive tests were done in the pilot reactor, from 1968 to 1972, to develop a slag-cleaning zone at one end of the reactor, it was determined that the most efficient course required external cleaning of the slag. This was done by adopting an established copper recovery practice of slow-cooling the slag to promote the precipitation of copper particles, followed by grinding and flotation, which reduced the slag to tailings containing copper concentrations at or below .3 percent.[77] The process of arriving at an effective slow cooling method involved considerable experimentation and led to the patenting, in 1975, of a ladle cooling method.[78]

A persistent challenge involved impurities in the copper metal produced by the Noranda process, notably antimony, bismuth, and lead. This created problems in the electrolytic refining process and resulted in a relatively impure final product. As a result, in 1975, Noranda switched the furnace from production of blister copper to the production of high-grade matte.

In 1997, the Noranda reactor was joined by the Noranda continuous converter (NCV) as part of an ongoing effort to meet the company's SO_2 reduction goals. This was a proprietary converter, built using existing smelting equipment, developed incrementally over several decades. It replaced the two existing batch converters used to convert the liquid high-grade matte from the Noranda process to blister copper suitable for processing in an anode furnace prior to anode casting.[79]

By the late 1970s and early 1980s, the exhaustion of local mines meant that the Horne smelter was obliged to operate on a variety of custom copper concentrates and, increasingly, on metal scrap. The flexibility of the Noranda process, along with a great deal of research, made this transition possible. As of 2011, the Noranda reactor processed approximately 60,000 tonnes of electronic scrap in order to recover copper and other metals.

In the mid-1970s, Noranda management decided to license the technology. In 1977, three Noranda reactors were commissioned at the Kennecott Smelter in Salt Lake City, Utah. These were replaced by an Outokumpu flash smelting furnace in 1995. A small Noranda reactor was commissioned for Electrolytic Refining and Smelting in New South Wales, Australia, in 1991. This plant was closed in 2003. A Noranda reactor was commissioned at Daye, China in 1995. Two further projects were begun but not put into operation, one at the Hudson Bay Mining and Smelting (HBMS) smelter in Flin Flon, Manitoba, and one at Shenyang, China. In 2001, a hybrid Noranda process–El Teniente reactor was commissioned in Chile and has operated successfully.[80]

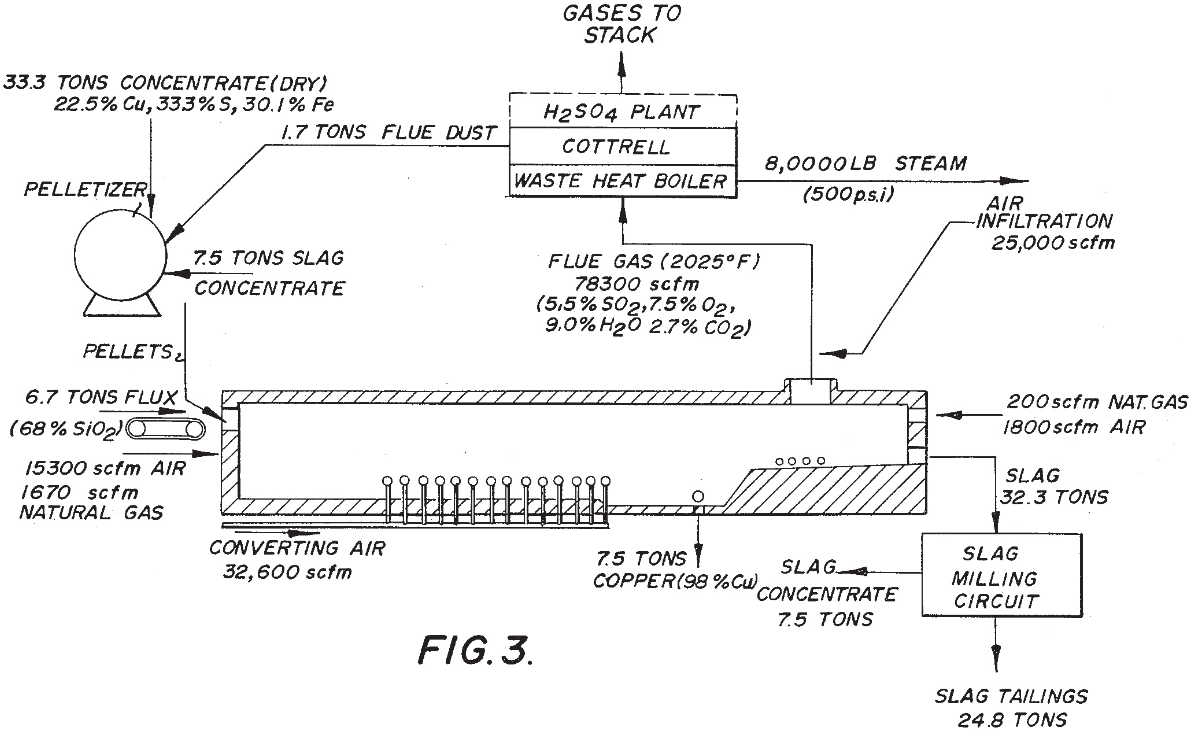


FIG. 3.

Figure 44: Patent illustration of the Noranda process reactor (Themelis and McKerrow 1974, 2)

THE ROLE OF METALLURGICAL ENGINEERING COMPANIES

Following industry downturns in the 1980s and 1990s, the development of metallurgical technology has fallen increasingly to specialized metallurgical engineering companies. Larger companies such as Hatch own and develop a series of proprietary technologies that are then licensed to clients. Technology in this sector tends to depend on the knowledge that individual consulting engineers have of their client's operational needs. The engineering company will develop a technology, based on a perceived need, to the proof-of-concept stage at its own expense. The client may then choose to fund a full-scale trial.

Below are two important technologies owned by Hatch. The first, the copper refractory cooling technology, was an early and important technology developed in-house by Hatch to solve major refractory problems at Falconbridge. The second, the coilbox, was developed by Stelco and acquired by Hatch in the early 1990s. The latter represents the shift away from in-house engineering capacity among the mining companies in favour of a greater reliance on metallurgical engineering companies.

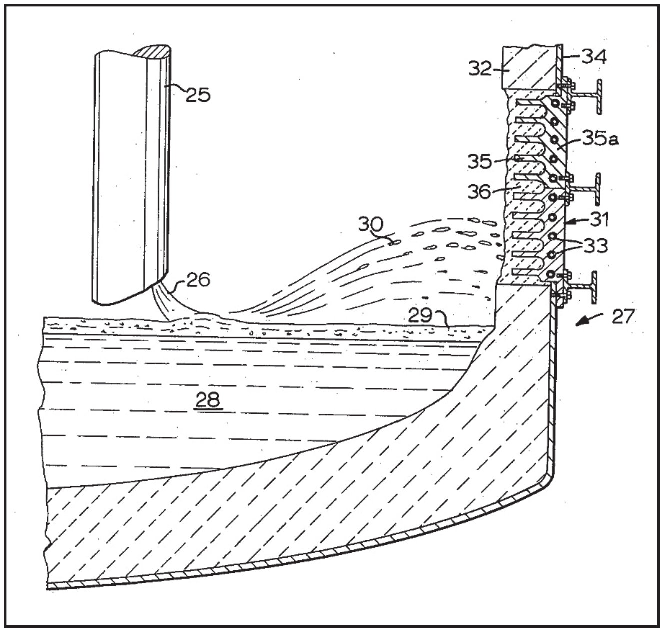


Figure 45: A side-view drawing from the original U.S. patent of the copper cooler. The coolers are shown installed in the arc-flare zone of an electric steel furnace, which is subject to intense refractory wear. Copper "fingers" (35) are embedded in the refractory material. Water channels (33) cool the solid castings. (Hatch and Wasmund, 1974, 5)

HATCH COPPER COOLERS

The electric furnace smelting of laterite nickel ore to produce ferronickel was developed by Falconbridge and commercialized at the Falconbridge Dominicana C. por A. mine in the Dominican Republic. On start-up, the superheated slag was found to be extremely aggressive to the furnace lining, resulting in premature failure. In order to protect the refractory linings, Hatch developed a method of actively cooling the refractory walls using "fingers" of copper, a metal with a high thermal conductivity.

In the Hatch system, copper cooling elements are embedded in the refractory brick in areas of a furnace that are prone to refractory erosion. The copper elements are themselves cooled by circulating water. This permits furnaces to operate at much higher powers and feed intensities, which maximizes production and lowers costs. The system also prolongs furnace life, which provides a significant cost savings given the potential revenue lost when a furnace is taken offline. This was not the first solution based on water-cooled refractory linings, but it incorporated a number of advances. For instance, its solid cast construction greatly reduced the possibility of dangerous water leaks into the molten bath.[81]

First applied in 1973, the technology evolved considerably over the past forty years. The "fingers" of the original design were supplanted by plates, which were, in turn, supplanted by the current waffle-type cooler design. Each generation provided a greater heat-transfer capacity. Major innovations have also taken place in the materials used, in the methods of fabrication, in associated sensors, instrumentation, and in related furnace-cooling technologies. This process of improvement took place as Hatch worked with clients worldwide to adapt the technology to new settings, to gather performance data, and to replace aging or damaged systems. This amounted to a cost-sharing arrangement, with clients agreeing to sponsor aspects of the system's development.[82]

As of 2011, the Hatch copper-cooling technology had been applied to over forty furnaces of various kinds around the world. These include the Kivcet lead smelting furnace that began operation at the Teck Cominco smelting complex at Trail, British Columbia, in 1997. The coolers are either installed in the design phase, or retrofitted during the repair or rebuilding phase of a particular furnace.[83] The widespread adoption of this cooling technology shows how the industry can benefit as engineering companies work with clients in a "hub and spoke" arrangement to reuse and develop a technology through multiple iterations.

STELCO HOT STRIP MILL COILBOX

The Stelco coilbox was a major improvement over the hot strip mill, which processes a steel slab into "hot-rolled coil" for transfer to further rolling mills. Emerging in the United States in the 1920s, the hot strip mill was a critical development in industrial steelmaking, transforming the labour-intensive process of flattening hot ingots in a rolling mill into a highly efficient but capital-intensive system. In it, the steel travels in an unbroken path through a series of steps that first heat the steel to over 1,200 °C, then reduce its thickness in roughing stands before it passes to the finishing stands, where it is reduced to the required final thickness. From there, it is cooled and coiled for shipment. The more space this path occupies, the larger and more expensive the overall facility.[84]

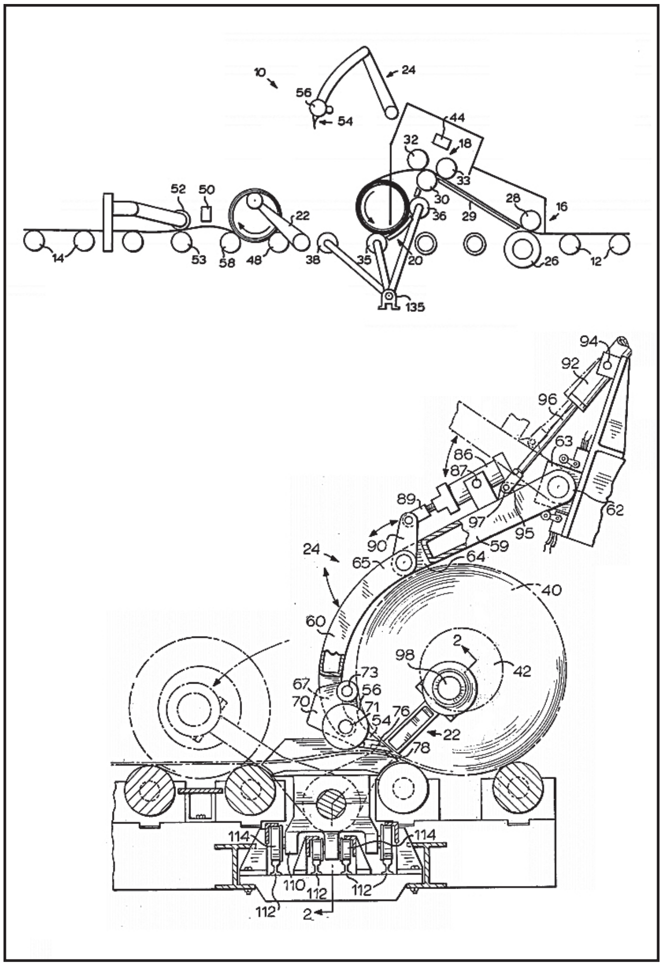


Figure 46: Two patent diagrams of the Stelco coilbox. Movement is from right-to-left of the top diagram. The roll is guided and formed by the bending rollers (30, 32, 33) and the coil cradle rollers (35, 36, 38). The roll is transferred to the finishing mill using the transfer arm (22). It is unrolled in the opposite direction with the aid of the peeler arm (24). (Smith 1977, 1,2)

Stelco's coilbox was the product of two factors: Stelco's $6-million research centre, opened in June of 1967, and the requirements of the Lake Erie Works hot strip mill, which began operation in 1980. Stelco's researchers were given the task of shaving 10 percent off the cost of setting up a hot strip mill. Initial plans involved laying out the mill in a "U" shape so that steel entered and exited at the same end, and the roughing and finishing mills shared a common machine room.[85] The coilbox provided an alternate solution: instead of going to a lengthy delay table between the roughing and finishing stands, the steel transfer bar coming off the roughing mill would be coiled before being transferred to the finishing mill.

The concept was tried at the Stelco R&D test plant using test strip made of lead, a metal which, when cool, has similar properties to hot steel. These tests proved effective and a full-sized unit was built with substantial help from federal government subsidies to R&D projects. The first prototype, completed in 1973, was improved and modified over the subsequent two years, notably with the development of a hydraulic peeler arm that eliminated problems with the coiled steel sticking to itself. The coilbox had the significant (and, at first, unexpected) benefit of promoting heat retention and temperature homogenization, resulting in a more consistent finished product.[86]

The coilbox sold well, becoming a good revenue source for Stelco's technology department, Steltech, and justifying its investment in research and development. Due to delays in the commissioning of the Lake Erie plant, the first commercial implementation took place at BHP's Port Kembla Steelworks in New South Wales, Australia. BHP promoted the system and was awarded a $300,000 credit towards their $3-million licensing fee for every successful sale. Around thirty coilboxes were sold while Stelco owned the technology.

The coilbox is now owned by the Canadian engineering firm Hatch, which acquired it along with several other proprietary technologies, as well as most of Stelco's technical services group, during Stelco's sale of assets in the early 1990s.[87] Hatch has made numerous improvements to the design largely focusing on improving serviceability. These include the removal of the central mandrel of the original design. As of 2012, more than seventy units had been sold worldwide.[88]

SENSORS AND COMPUTERS

Together, computers and sensors form an interrelated technological system that has transformed the nature of metallurgical operations over the past half century. Computer technology is used throughout the field of mining and metallurgy, from running mills and automated mining equipment, to controlling reaction vessels, to modelling new metallurgical processes. MetSoc has issued four conference proceedings on computer applications since 1988. Computerization has become ubiquitous to the point that a subcommittee of MetSoc, formed specifically to represent computer applications, has since been disbanded as redundant.[89]

Processes that were once monitored and controlled by experienced operators are increasingly governed by computers and dynamic sensing systems. Among other consequences, this has lowered the barrier to entry into certain metallurgical industries. New operations may be set up by purchasing automated process control technologies from engineering companies with far less need for highly trained workers or established technical expertise.[90]

Sensors may detect a variety of signals given off by a metallurgical operation; light and sound are two common examples. In the latter case, vibrations produced, for instance, by argon mixing bubbles rising from a porous plug through a ladle of molten steel, or reducing gases shooting through concentrate melting in a blast furnace, will provide a constant source of information about the materials involved. In the case of light, an optical pyrometer can provide precise real-time information on the temperature of a pyrometallurgical process. The metallurgical environment is an especially interesting and challenging field of application for sensor technology, which is typically subject to intense heat, vibrational, or chemical stresses over long periods.

Improvements in sensing and computing technology have brought about a fundamental change in the way information is gathered about metallurgical processes. University of Toronto Professor Emeritus Alex McLean characterizes this as a progressive move from "sampling the system to sensing the signals." A sample will provide a relatively small amount of data, representing a given moment, which is taken to be indicative of the state of the overall system—a process that grows increasingly challenging with the move to increasingly precise alloys and material properties. Continuous, non-intrusive monitoring of signals, by contrast, provides ongoing information on a system's state that can be presented to an operator or incorporated into an automated control system. Computers are now used to model the chemical processes taking place in reaction vessels. This is done by using a database of existing experimental data to create a model of a particular phenomenon. Such models are used to predictively design new systems. Canadian engineers have played an important role in developing sensors and metallurgical modelling software.

THE NORANDA PYROMETER

The Noranda pyrometer was developed, beginning in the early 1980s, by the Noranda Research Centre in order to more effectively control the copper conversion process. A pyrometer is an instrument used to measure temperature by comparing the radiation from the incandescent surface of a substance to be measured with radiation produced at a known temperature. Precise knowledge of temperature is essential for controlling the reaction needed to achieve a consistent product and to prolong the life of the refractory lining. The Noranda pyrometer replaced an existing instrument, mounted on the fume-gathering converter hood, which was too far from the bath to provide an accurate temperature reading and required frequent cleaning.

The new pyrometer was placed in continuous view of the hottest region of the bath by sighting it through a tuyere using a periscope. Fibre optic cable directed this light from the tuyere body to a sensor and control system. The instrument was designed not to impede the tuyere punching process. The design's performance was not affected by the gradual restriction of the light entering the tuyere through the buildup of accretions.

The Noranda pyrometer was tested and applied to the Noranda process converter in 1983, with a second unit added later to the opposite end of the tuyere line. This two-unit configuration was used successfully on the Noranda Converter which began operation in 1993. The technology has also been applied to the Teniente copper converter technology developed in Chile.[91] The tuyere pyrometer concept was not without precedent. In the 1950s, for instance, tuyere pyrometers were in use on Bessemer converters used in steelmaking.[92]

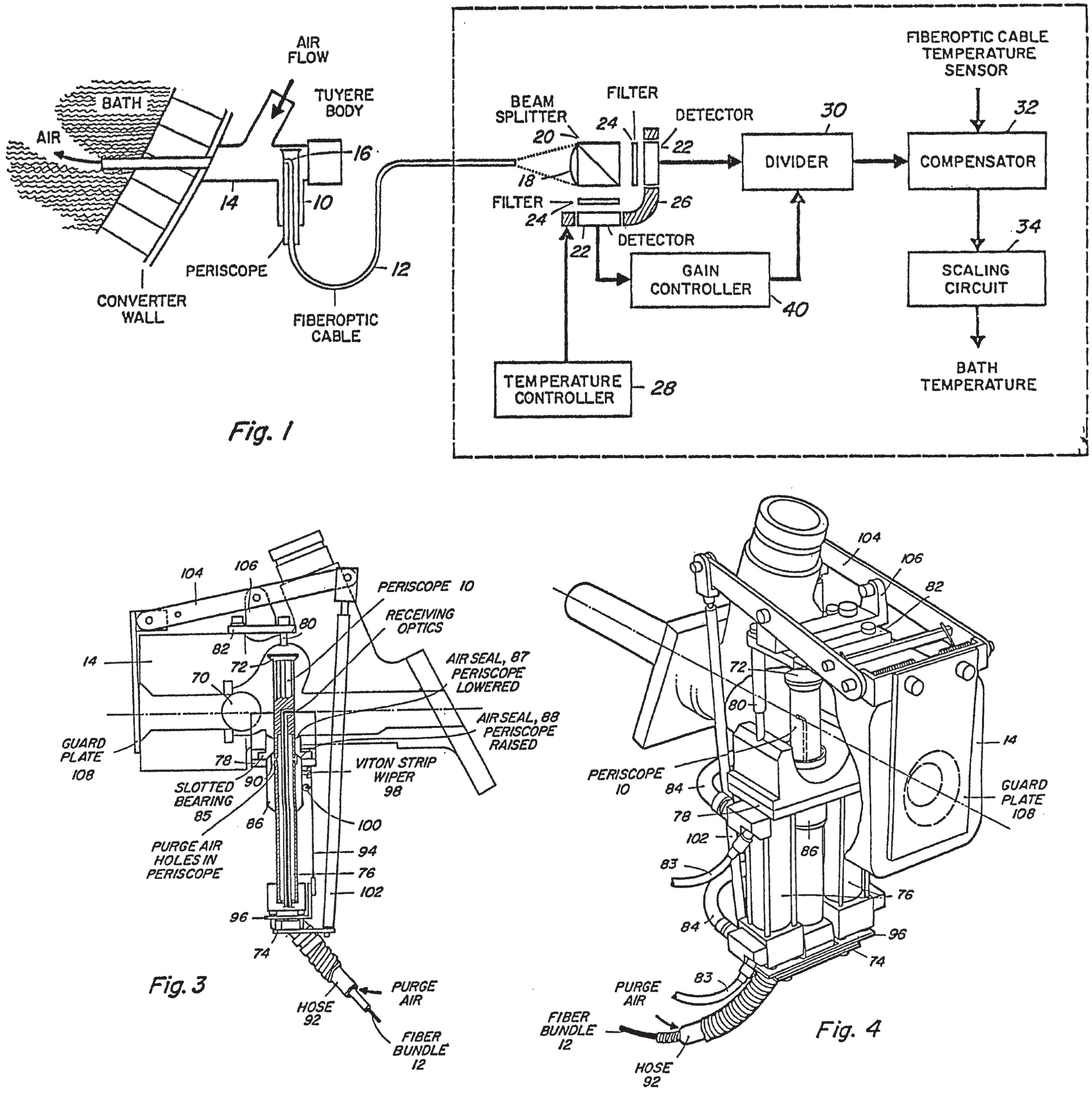


Figure 47: Patent illustrations showing the Noranda pyrometer. The retractable periscope is positioned in the tuyere body. (Lucas 1989, 15, 17)

F*A*C*T/F*A*I*T SYSTEM AND RELATED COMPUTER SOFTWARE

The F*A*C*T/F*A*I*T (Facility for the Analysis of Chemical Thermodynamics/Formulation Analytique Interactive en Thermodynamique) system encompasses a family of software programs and databases. Their purpose is to assist in performing thermodynamic calculations related to phase change in multicomponent systems, such as those present in the chemical reactions that take place in metallurgical operations and in other industrial and scientific applications. Over time, the system has evolved from graphing phase change to modelling complex processes. The curious arrangement of asterisks in the name was inspired by the then-current television series "M*A*S*H."

The system was developed, beginning in 1976, as a collaboration between Professors Christopher W. Bale and Arthur D. Pelton of École Polytechnique de Montréal and Professor William T. Thompson of McGill University. The initial work was supported by a cooperative grant from NSERC. Rights to the software were granted to Thermfact Ltd., and the program would later incorporate further commercial software, notably that of Dr. Gunnar Eriksson of Aachen University.

In 1984, the Centre de Recherche en Calcul Thermochimique/Centre for Research in Computational Thermochemistry (CRTC) was founded at École Polytechnique. Among its principal tasks was the improvement and development of the software. The F*A*C*T software has since been expanded with a series of modules and tools applicable to a wide variety of industrial fields.[93]

The software has been used in both undergraduate teaching and graduate research. It has been employed in a variety of commercial settings, although, like many other tools, its use will often go unreported in publication. In several cases, industry and government funding agencies have supported its development for commercial applications. From 2000 to 2003, for instance, fifteen companies joined with NSERC to support the work of Professor Pelton in extending the thermodynamic modeling of several important metallurgical processes. From 2004 to 2008, General Motors, Canmet and NSERC supported the development of databases and software for the development of magnesium alloys for the automotive industry. The aluminum industry supported aluminum modelling work around the same period.[94]

The computer technology underlying the F*A*C*T system has evolved considerably over time. The initial program, as developed in 1976, was written in FORTRAN and printed on punch cards. In 1979, an online system was established to permit off-site operators to use the software via telephone data links, notably McGill's highly successful MUSIC (Multi-User System for Interactive Computing) system.[95] In 1994, the software was imported to the DOS operating system and in 1999 to Microsoft Windows. The current iteration is FactSage, first developed in 2001. The software is currently licensed by over 250 research centres and a similar number of universities around the world.[96]

ENVIRONMENTAL TECHNOLOGIES

Technological improvements have been essential to the continued survival of Canada's metals industries, both in terms of the obligation to comply with stricter environmental regulation, and through making new projects acceptable to the public. From a certain perspective, any innovation that reduces energy consumption or increases efficiency may potentially produce an environmental benefit. Increased efficiency has always been a factor in industrial competitiveness, but the technologies implemented in the 1950s and 1960s for the purposes of increased efficiency, such as oxygen technology and sulphur dioxide capture, would also provide the means for the metals industry to comply with a new era of emissions legislation.

It is important to recall that environmental issues facing the metals sector extend beyond familiar problems such as heavy metal pollution and sulphur dioxide emissions. They include, for instance, light and noise pollution, odours, and aesthetic considerations, both within the plant and in relation to neighbouring communities. The construction of Stelco's Lake Erie steel plant, the last integrated steel plant built in North America, provides a good example of a facility built in the new era of environmental regulation that began to emerge in the early 1970s.[97]

An extended definition of environmental sustainability could also encompass further Canadian innovations. The development of fly-in/fly-out operations at the Beaver Lodge uranium mine in Northern Saskatchewan in the mid-1970s is noteworthy. Faced with the refusal of the province to approve the establishment of a mining community, a measure which had tended to displace northern workers from their communities before eventually resulting in a burdensome ghost town, Gulf Minerals Canada Ltd. established what may have been the first such mining operation in the world. The fly-in/fly-out method results in significantly less social and environmental disruption, and has since been emulated by mining companies worldwide.[98]

The two measures listed below are examples related to the reduction of hazardous chemical emissions from metallurgical operations. As with the Inco carbonyl process and the Sherritt pressure leach process described earlier, both of these technologies are examples of the application of chemical engineering to metallurgy.

INCO SO_2/AIR CYANIDE DESTRUCTION PROCESS

The Inco cyanide destruction process was developed at Inco's J. Roy Gordon Research Laboratory beginning in the mid-1970s and patented in 1984. The technology was developed as part of an effort to improve the milling process by using cyanide to selectively remove pyrrhotite (iron sulphide) from the smelter concentrate. Pyrrhotite rejection during the milling process was an important step in reducing sulphur emissions in the Sudbury area during this period. Before the tailings could be disposed of, however, the toxic cyanide had to be chemically removed. This was a familiar problem in the precious metals industry where cyanide had long been used to leach gold.

Inco engineers developed a method for accomplishing this task using chemical reagents that were relatively inexpensive: sulphur dioxide and air, with copper sulphide used as a catalyst. The process was continuous and economical. Though Inco did not opt for a cyanide-based process, their method was adopted by the precious metals industry and is now used worldwide. Before Inco's acquisition by Vale, the process was improved and marketed by Inco Tech, the technology division formed in 1973.[99]

ECO-TEC ACID PURIFICATION UNIT (APU)

Acids have numerous applications in metallurgical processes, from metal extraction, to aluminum anodizing, to pickling steel sheet. Modern environmental law has required that acid be neutralized before disposal — an expensive process that creates large amounts of solid waste. In 1977, Eco-Tec Inc. of Pickering, Ontario, founded in 1969 by graduates of the Faculty of Applied Science and Engineering at the University of Toronto, pioneered a method for purifying acid. The innovation was based on an ion-exchange technology known as "acid retardation." Eco-Tec's Recoflo system, which uses resin beads to separate acid from metal salts, made this chemical process viable for industrial applications.

The Eco-Tec acid purification unit has since become a widely used technology with over 400 examples sold to companies in more than sixty countries.[100]

NOTES

1 For a list of Falconbridge/Xstrata winners, see: Kapusta, Mackey, and Stubina,"Canadian Innovations," 469.
2 See, for instance: Edward Jones-Imhotep, *The Unreliable Nation: Hostile Nature and Technological Failure in the Cold War* (Cambridge, Mass.: MIT Press, 2017).
3 Campbell, *Global Mission*, Vol 3, 1431-1440; McKay, *Stelco R&D*, 74-84.
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7 Creber, Davis, and Kashani-Nejad, "Magnesium," 169.
8 Creber, Davis, and Kashani-Nejad, "Magnesium," 170-171.
9 Ernest V. Pannell, *Magnesium: Its Production and Use* (London: Sir Isaac Pitman and Sons Ltd., 1943): 122-124.
10 R. J. Jowsey, "New Process Kills Mystery of Magnesium," *Globe and Mail* (January 7, 1943).
11 Creber, Davis, and Kashani-Nejad, "Magnesium," 169
12 For an account of Jowsey's career, see: Anon., "Robert J. Jowsey, Mine Pioneer Helped Ottawa Get Magnesium," *Globe and Mail* (August 20, 1965): B4.
13 Eggleston, *National Research*, 195.
14 Eggleston, *National Research*, 198.
15 Creber, Davis, and Kashani-Nejad, "Magnesium," 170.
16 Anon., "See Demand Up for Magnesium; Prospects Good," *Globe and Mail* (March 31, 1953): 20. In 1953, Dominion Magnesium received an indigenous supply of ferrosilicon when a wholly-owned subsidiary, Electro-Reagents Ltd., opened a smelter at Beauharnois, Quebec, part of an area of significant hydroelectric production in what is now Greater Montreal.
17 Anon., "Another War Metal Joins Up," *Globe and Mail* (January 7, 1943): 42; Anon., "Canadian Magnesium Plant Fights in Air War," *Globe and Mail* (December 4, 1944): 13.
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20 Eggleston, *National Research*, 198.
21 Wellington, "Light Metal," 18; Anon., "Research Lab is ready for Postwar Problems: New Physical Metallurgical Laboratories Busy as Beehives," *Globe and Mail* (October 24, 1944): 15.
22 Anon., "Alloy Plant May Close, Ottawa Told," *Globe and Mail* (August 17, 1960): 20.
23 Creber, Davis, and Kashani-Nejad, "Magnesium," 171-173, 175.
24 Creber, Davis, and Kashani-Nejad, "Magnesium," 170.
25 Marcuson and Díaz, "Nickel smelting landscape," 34.
26 Marcuson and Baksa, "Colonel Robert," 277.
27 Queneau, "Development of Oxygen," 5; Marcuson and Díaz, "Nickel smelting landscape," 34.
28 MacKinnon, "Electrorefining," 181.
29 Vladimir Paserin et al., "CVD Technique for Inco Nickel Foam Production," Advanced Engineering Materials 6, no. 6 (2004): 455.
30 Marcuson and Díaz, "Nickel smelting landscape," 37.
31 Anon., "Nickel Carbonyl Poisoning," *Lancet* 1, no. 269 (1903):1841-1842; F. William Sunderman and John F. Kincaid, "Nickel Poisoning II: Studies on Patients Suffering from Acute Exposure to Vapors of Nickel Carbonyl," *Journal of the American Medical Association* 155, no. 10 (1954): 891.
32 For a description of the Lang-Mond process, see: Marcuson and Díaz, "Nickel smelting landscape," 33-38.
33 Kapusta, Mackey, and Stubina,"Canadian Innovations," 470.
34 For a detailed account of the CRED process, see Collins, "Hydrometallurgical," 300-301.
35 Chalkley et al. "A History of Sherritt," 1 of 5.
36 For a description of the Caron process, see: Kerfoot, "Pressure leach," 190.
37 Chalkley et al. "A History of Sherritt," 1 of 5.
38 Chalkley et al. "A History of Sherritt," 1 of 5.
39 "Vladimir Nicolaus Mackiw (1923–2001) Inducted in 2003," *Canadian Mining Hall of Fame*, http://mininghalloffame.ca/inductees/m-o/vladimir_nicolaus_mackiw (accessed January 30, 2016).
40 Kerfoot, "Pressure leach," 191.
41 Chalkley et al. "A History of Sherritt," 1 of 5.
42 Chalkley et al. "A History of Sherritt," 5 of 5.
43 For a concise description of modern industrial oxygen production, see: Fathi Habashi, "One Hundred Years of Liquid Air–Canadian Contribution," *CIM Bulletin* 96, no. 1069 (2003): 122; Phillip J. Mackey, "Oxygen in Non-Ferrous Metallurgical Processes: Past, Present and Future," in *Proceedings of the International Symposium on the Impact of Oxygen on the Productivity of Non-Ferrous Metallurgical Processes*, *Winnipeg, Canada, August 23-26, 1987*, ed. George Kachaniwsky and Chris Newman (New York: Pergamon Press, 1987): 9.
44 Mackey, *Oxygen*, 7.
45 Queneau, "Development of Oxygen," 5; Paul E. Queneau and Sam W. Marcuson, "Oxygen Pyrometallurgy at Copper Cliff — A Half Century of Progress," *JOM* 48, no. 1 (January 1996):14; Mackey "Oxygen," 12.
46 Fathi Habashi, "Pioneers of the Steel Industry: Part 7 Oxygen in Steelmaking," *Steel Times International* 36, no. 1 (2012): 44.
47 Joël Kapusta and Robert G. H. Lee, "The Savard-Lee Shrouded Injector: A Review of its Adoption and Adaptation from Ferrous to Non-Ferrous Pyrometallurgy," *Proceedings of Copper 2013* (Santiago, Chile, 2013), 1116; The two most substantial sources on the history of the shrouded tuyere are Mackey and Brimacombe, "Savard and Lee" (1992), and Kapusta and Lee (2013). The former deals largely with its application to steelmaking, the latter to non-ferrous metals. Kapusta and Lee's article includes a number of excellent images from the archives of Air Liquide Canada.
48 Habashi, "Liquid Air", 123; Mackey and Brimacombe, "Savard and Lee," 6.
49 Habashi, "Pioneers," 44; Mackey, "Oxygen," 12; Mackey and Brimacombe, "Savard and Lee," 6.
50 Mackey and Brimacombe, "Savard and Lee," 6-7.

51 See, for instance, the humorous 1802 etching, “Scientific Researches!” by James Gillray (1757–1815), which depicts Humphrey Davy (1778–1829) demonstrating the properties of nitrous oxide at his Royal Institution, or the mocking of the experimenters Pietro Moscati (1739–1824) and Marsilio Landriani (1751–1815) and in the Lombard journal Il Cafe in 1780. Simon Schaffer, “Measuring Virtue: Eudiometry, Enlightenment and Pneumatic Medicine,” in The Medical Enlightenment of the Eighteenth Century, ed. Andrew Cunningham and Roger French (New York: Cambridge University Press, 1990): 281.

52 Queneau and Marcuson, “Oxygen Pyrometallurgy,” 18-19.

53 Mackey and Brimacombe, “Savard and Lee,” 7.

54 Habashi, “Liquid Air”, 124; Mackey and Brimacombe, “Savard and Lee,” 9.

55 For a comprehensive and detailed list of these trials, see: Mackey and Brimacombe, “Savard and Lee,” 10-11, 13

56 Kapusta and Lee, “Shrouded and Lee,” 1120.

57 Kapusta and Lee, “Shrouded and Lee,” 1123-1128.

58 Kapusta, Mackey, and Stubina,”Canadian Innovations,” 479-480.

59 Marilyn Scales, “Sudbury Saturday night,” *Canadian Mining Journal* 123, no. 3 (2002): 33.

60 Boldt, *Winning of Nickel,* 244- 246.

61 Queneau, “Discussion,” 5.

62 Queneau and Marcuson, “Oxygen Pyrometallurgy,” 14.

63 Jan Edward Nesset, “Significant Canadian Developments in Mineral Processing Technology — 1961 to 2011,” in Kapusta et al., *The Canadian Metallurgical*, 260.

64 Queneau and Marcuson, “Oxygen Pyrometallurgy,” 17.

65 Queneau and Marcuson, “Oxygen Pyrometallurgy,” 17.

66 Díaz et al., “Innovation,” 335.

67 Queneau and Marcuson, “Oxygen Pyrometallurgy,” 18-19.

68 Queneau, “Discussion,” 4.

69 The first true commercial copper continuous smelting and converting process was the Mitsubishi process, commercialized at the Naoshima smelter in Japan in March, 1974.

70 Tarassoff, “Process R&D,” 428; Mitsubishi Materials Corporation, “History,” *The Mitsubishi Process*, www.mmc.co.jp/sren/History.htm (accessed March 20, 2017). It is notable that the Mitsubishi continuous copper production process was under development at this point. A semi-commercial plant was constructed at Onahama, Japan in 1970. The first commercial installation was completed in 1974.

71 Díaz et al., “Innovation,” 347-348.

72 Díaz et al., “Innovation,” 345.

73 Tarassoff, “Process R&D,” 412.

74 Nathan M. Stubina, “Thermal Processing: Pyrometallurgy — Non-ferrous,” in Innovative Process Development in Metallurgical Industry: Concept to Commission, ed. Vaikuntam Iyer Lakshmanan, Raja Roy and V. Ramachandran (Cham, Switzerland: Springer International Publishing, 2016): 70.

75 Díaz et al., “Innovation,” 343-345; P. L. Fowler, L. A. Mills and G. A. Balogh, “The Gaspe Mechanical and Tuyere Puncher and Converter Performance,” JOM 20, no. 9 (September 1968): 43-47.

76 Tarassoff, “Process R&D,” 420-421.

77 Tarassoff, “Process R&D,” 422-425. Copper recovery from slag was developed in Japan and Finland over the 1950s and 1960s. See p. 425 for illustrations of the various configurations of the pilot reactor.

78 Nesset, “Processing Technology,” 269-271.

79 Díaz et al., “Innovation,” 350-352.

80 Díaz et al., “Innovation,” 348.

81 Gerald Gordon Hatch and Bert Orland Wasmund, “United States Patent: 3849587 A — Cooling Devices for Protecting Refractory Linings of Furnaces,”(November 19, 1974), www.google.ca/patents/US3849587 (accessed March 17, 2017), 5.

82 Much information for this entry has been gleaned from private email exchanges with metallurgical engineers on the MetSoc historical committee, especially Chris Twigge-Molecey, a senior Hatch engineer.

83 Díaz et al., “Innovation,” 350-353.

84 For an articulate and opinionated account by Stelco’s former director of research, who was closely involved in setting up Stelco’s Lake Erie hot strip mill and developing its coilbox, see: McKay, *Stelco R&D*, 98-102.

85 McKay, *Stelco R&D*, 99.

86 McKay, *Stelco R&D*, 100; Brown, “Iron and Steel,” 74; Jonathan Aylen, “Where Did Generation V Strip Mills Come From? A Brief History of the Hot Strip Mill,” *Steel Times* (July/August 2001): 230.

87 Brown, “Iron and Steel,” 88.

88 McKay, *Stelco R&D*, 101-102.

89 Habashi, “Metallurgists,” 8.

90 Brown, “Iron and Steel,” 73.

91 Díaz et al., “Innovation,” 349-350.

92 See, for instance P. Leroy, “New Control Instruments for Bessemer Steelmaking,“ *JOM* 8 (June 1956): 764-768; cited in Díaz et al., “Innovation,” 349.

93 For an account of the development of software related to F*A*C*T system, see: Patrice Chartrand, Christopher Bale and Arthur Pelton, “Development of the F.A.C.T/FactSage System and Its Impact in Canadian Metallurgy,” in Kapusta et al., *The Canadian Metallurgical*, 396-412.

94 Chartrand, Bale, and Pelton, “F.A.C.T,” 412.

95 By the 1980s, McGill’s MUSIC software was used by 250 educational institutions around the world. There is a detailed Wikipedia article on the topic: Wikipedia Contributors, “MUSIC/SP,” *Wikipedia, The Free Encyclopedia* (November 28, 2015), https://en.wikipedia.org/wiki/MUSIC/SP (accessed on February 22, 2016).

96 Chartrand, Bale, and Pelton, “F.A.C.T,” 413-114.

97 For an account of the environmental measures involved in the Lake Erie Plant, see: Jack Young, “Sustainability in Iron & Steel.”

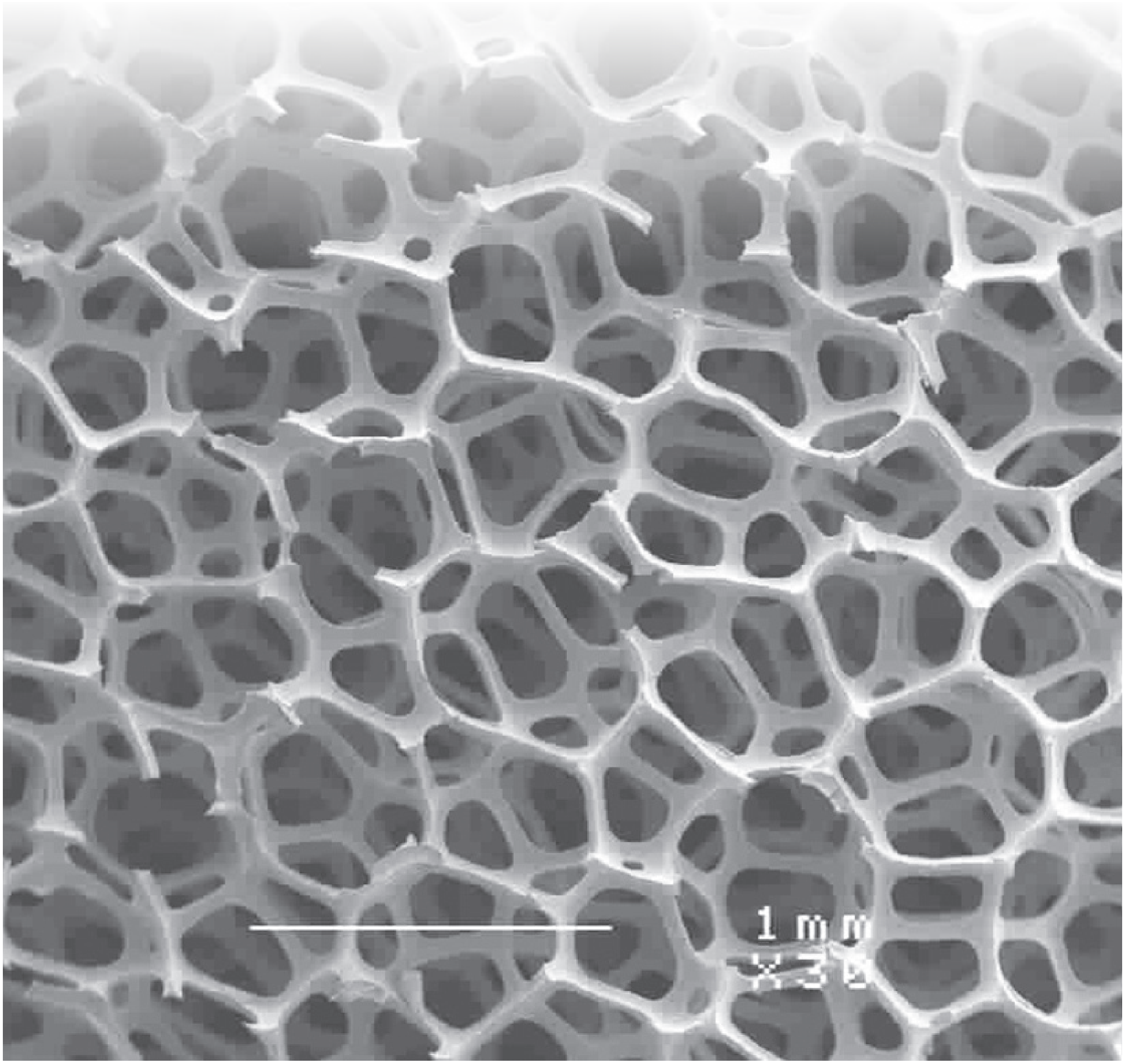
98 This claim was made by Chuck Edwards during an interview by TK on October 19, 2015. I have not been able to verify it as a world first within the mining industry, though the claim is plausible. The innovation was borrowed from the oil and gas sector where workers are routinely flown back and forth to offshore oil rigs. Keith Storey, “Fly-in/Fly-out: Implications for Community Sustainability,” *Sustainability* 2 (2010), 1169.

99 Kapusta, Mackey, and Stubina,”Canadian Innovations,”478-479; Jane Werniuk, “INCO R&D: Process Development, Product Development and Cyanide Destruction,” *Canadian Mining Journal* (April 1, 2012), http://www.canadianminingjournal.com/features/inco-r-d-process-development-product-development-and-cyanide-destruction/ (accessed on January 30, 2016).

100 Collins, “Hydrometallurgical,” 325.

CONCLUSION

INTO THE TWENTY-FIRST CENTURY



CONCLUSION INTO THE TWENTY-FIRST CENTURY

As this report is being completed in the summer of 2017, the resource sector has passed through one of its periodic downturns. Canada's continued reliance on its resource sector recently resulted in a rapid fall in the dollar, which renewed hope for a long-suffering manufacturing sector. The seemingly insatiable demand of the expanding Chinese economy for raw materials, and its enormous productive capacity, continues to fuel Canada's economy.

The longer history of Canada's metals industry may appear as a story with an unsatisfying denouement. Several of the major metals companies that we have explored are now foreign-owned — Teck Cominco remains a holdout, along with the major gold companies not included in this project. Private research centres, responsible for so many of the Canadian contributions to the field of metallurgy, have disappeared or have been greatly reduced in capacity. Government laboratories have suffered from cutbacks as well. Though Canadian companies maintain a leading role in the mining sector — especially in precious metals — Canada's metallurgical "golden age" may well be over.

It has been observed that as societies become wealthier, large-scale industrial projects become more difficult to develop. Living standards improve, labour becomes more expensive, and citizens grow less accepting of environmental disturbance. The process of obtaining a "social license" to proceed with major projects has consequently become lengthier and more challenging.[1] While vastly safer and less polluting, today's metallurgical plants tend to also require fewer people to operate due to automation. Communities are no longer obliged to accept a degraded environment or diminished health as the cost of economic survival. The armies of impoverished rural labourers that built hydroelectric plants and smelters in the Quebec wilderness, or the urban working classes that tolerated the smoke and noise of life in industrial Sudbury and Hamilton, have transformed themselves into today's university-educated middle classes.

With increased regulation, costs increase, as does the interval before investors see a return. It becomes cheaper to do business elsewhere. Industrial centres in the developing world now resemble, in certain respects, the North American and European industrial centres of the past. In many countries, like Canada, with a significant history of mining, the richest and most accessible deposits have already been depleted, or have been exhausted to the point that more distant reserves must be secured.[2]

Change is seldom unambiguously good or bad. Mining and metallurgy remains a small but important field for Canadian engineers and geologists, even as the scope of the industry has become increasingly global rather than national. Flourishing professional groups such as the CIM show that the Canadian metallurgical community remains strong and coherent. Moreover, a generation of engineers specializing in areas such as flotation, furnace design, or in the study of inclusions and grain boundaries, has trained a new generation of researchers extending the field into areas such as nanomaterials, biomaterials, and composites.

Without the decades during which mining and metallurgy sustained a vital part of Canada's engineering community, Canadian high-technology research would not exist to the extent that it does today, nor would engineers trained in Canada be so well represented among their international peers. Without decades of creative tension between environmentalists, aboriginal groups, labour unions, and mining interests, Canada would be a less just, less safe place, and its metals industries would be less sophisticated and less able to face global social and technological challenges.

There remains a tendency to imagine the resource sector as somehow separate from newer high-technology industries. Hopefully this report has shown that this is, in many respects, a false dichotomy. Not only are high-tech industries dependant on the materials provided by mining companies — materials produced to the ever higher standards required by industry — but the process of producing these materials economically has required the resource sector to develop and adopt sophisticated technological systems.

It should be recalled that this survey covers only certain themes relating to a single professional community: that of metallurgical engineers, along with their social institutions and the technological systems that they worked to develop. This is only part of the history of Canadian metallurgy. While other aspects have already been discussed in earlier CSTM reports — for instance the history of nuclear technology and precious metal mining — numerous aspects remain to be explored. By way of conclusion, what follows is a list of topics that could contribute to a more complete understanding of mining and metallurgy in Canada. This list includes subtopics that may either be considered part of a larger theme or treated separately.

- **Landscape and land use:** This is a series of topics focused around the industrial use of land along with the changing relationship between metal mining projects and the legal rights of landholders. An examination of landscape and land use could include the following themes.
    - *Surveyors, geologists, and prospectors:* An examination of the role of professional geologists, surveyors, and prospectors over time, along with their relationship to the mining community. This has been touched on, to a certain extent, in an earlier historical assessment on metal mining.
    - *Environmental regulation:* A history of the environmental impact of the metals industry and the ways in which this history has shaped environmental legislation in Canada and technological responses on the part of industry.
    - *Overseas operations:* A history of the increasing involvement of the Canadian mining and engineering communities in projects overseas. This topic is especially important to an understanding of the competencies involved in operating under foreign legislative and judicial systems, as well as to evolving norms of environmental regulation and social justice. It also relates to the development of certain technological competencies such as the mining of laterite ores.
    - *Arctic Operations:* A history of mining operations in Northern Canada. Canada is a pioneering nation in this area.
- **Labour history of Canada's metals industry:** An essential perspective in the development of Canadian mining and metallurgy is that of labour. As noted, the topic is critical to a proper understanding of technology and its impact on the workplace as well as to an appreciation of the often-unacknowledged competencies of workers. Metal production depended on such competencies in the era before automation and scientific quantification of metallurgical operations. Industry continues to rely on highly-skilled technicians to operate, maintain, and repair ever more complex systems.
- **Metal and Canada's First Nations:** A thorough examination of Canadian metallurgy would include an examination of metal use among Canada's First Nations along with the ways in which metals and metallurgical technologies have mediated the relationship between First Nations and settler communities. The pre-contact use of meteoric iron and natural copper, the exchange of metal trade goods and treaty medals, and the contentious history surrounding land rights and economic inclusion in the resource sector are all important themes.
- **Finished/value-added metal products:** This report has focussed mainly on the primary metallurgical operations such as smelting and refining at the expense of metallurgical operations related to the production of more finished products. As noted, this is a somewhat arbitrary distinction given the metallurgical challenge of producing materials such as sheet, pipe, plate, wire and castings to different specifications for different purposes. Often these have been produced by mining companies, integrated steel mills, and mini-mills, now described more appropriately as market mills.
    - *Metals and transportation:* From ship building to railroad manufacture, to aerospace, and the modern automotive industry, Canada has manufactured materials used in transportation for well over a century. Any of these topics could be the subject of a report, though automotive alloys and aerospace alloys/light metal production, in particular, have been the subject of recent and ongoing research. The latter could be approached in collaboration with the Canada Aviation and Space Museum.
    - *Household and commercial goods:* Large metals companies, such as Noranda, Stelco, and Alcan, produced large numbers of metal consumer goods and components for consumer goods. This came about both through the ownership of a large and diverse variety of businesses as well as through the production of value-added products from their core operations. One thinks, for example, of the Ardox Spiral Nail, developed at Stelco's R&D centre, or the ubiquitous Alcan aluminum kitchen foil. Both embody metallurgical technologies relating respectively to the wire mill, galvanization, and the rolling mill. The history of the contribution of Canadian metallurgy could also include areas of considerable contemporary interest such as research into rare earths and recycling of modern electronics and development of nano-materials.

NOTES

1 Marcuson et al., "Sustainability in Nickel," 69-70.
2 Habashi, "Metallurgists," 15-16.

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