CANADIAN CHEMICAL NEWS
L'ACTUALITÉ CHIMIQUE CANADIENNE

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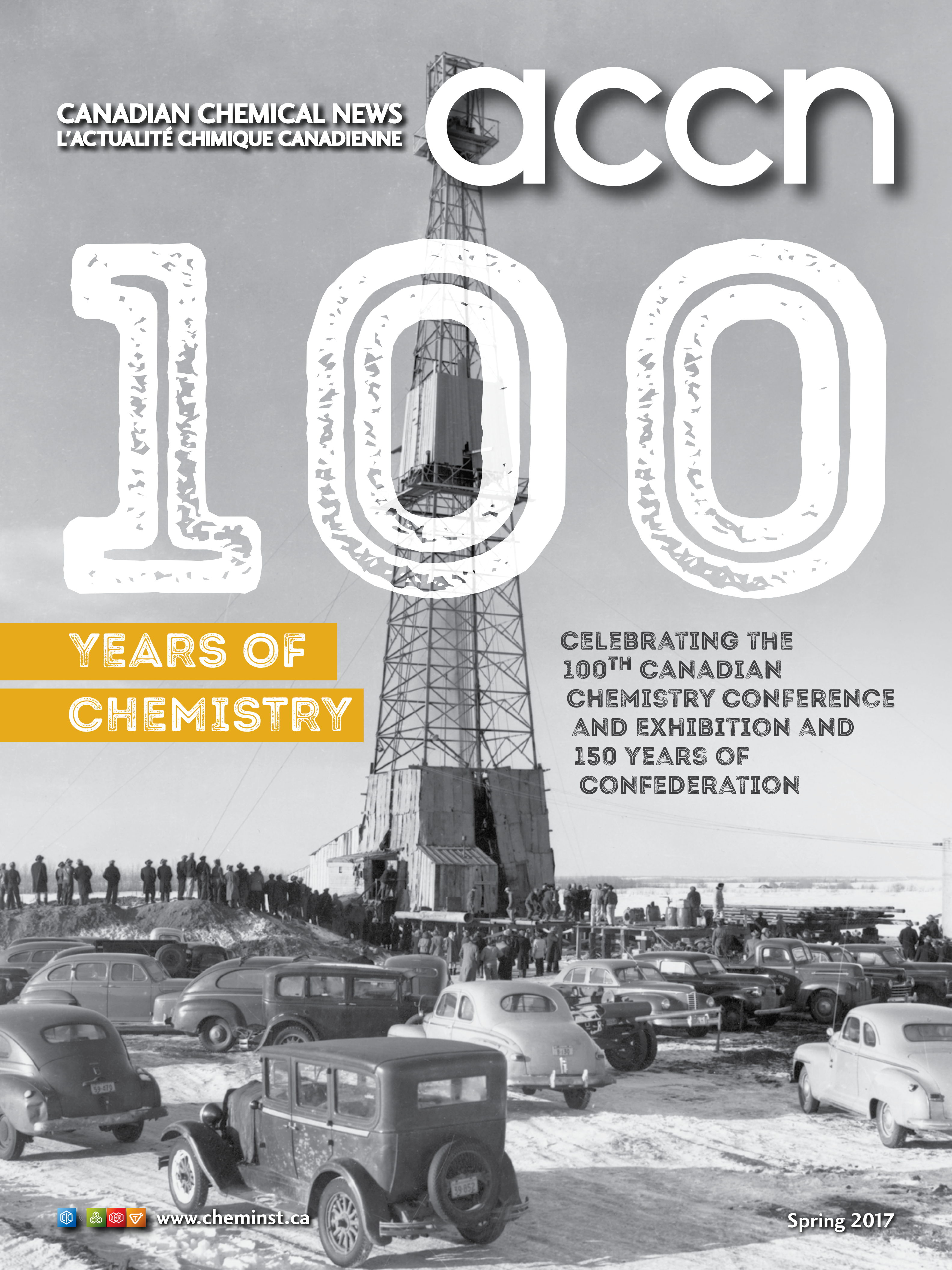

100 YEARS OF CHEMISTRY

CELEBRATING THE 100TH CANADIAN CHEMISTRY CONFERENCE AND EXHIBITION AND 150 YEARS OF CONFEDERATION

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Spring 2017

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Cover: Opening day of Imperial Oil's Leduc No. 1 discovery well in Leduc, Alberta. The find made in 1947, resulted in a boom in petroleum exploration and development across Western Canada. The discovery transformed the Alberta economy, with oil and gas supplanting farming as the primary industry. The discovery ultimately made Canada a major exporter of oil. Photo Credit: Glenbow Archives 6F-18

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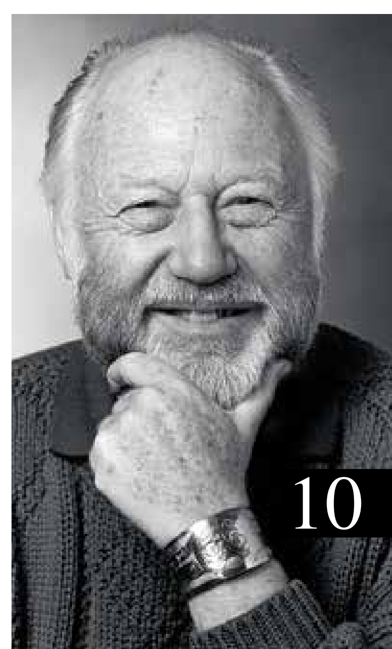

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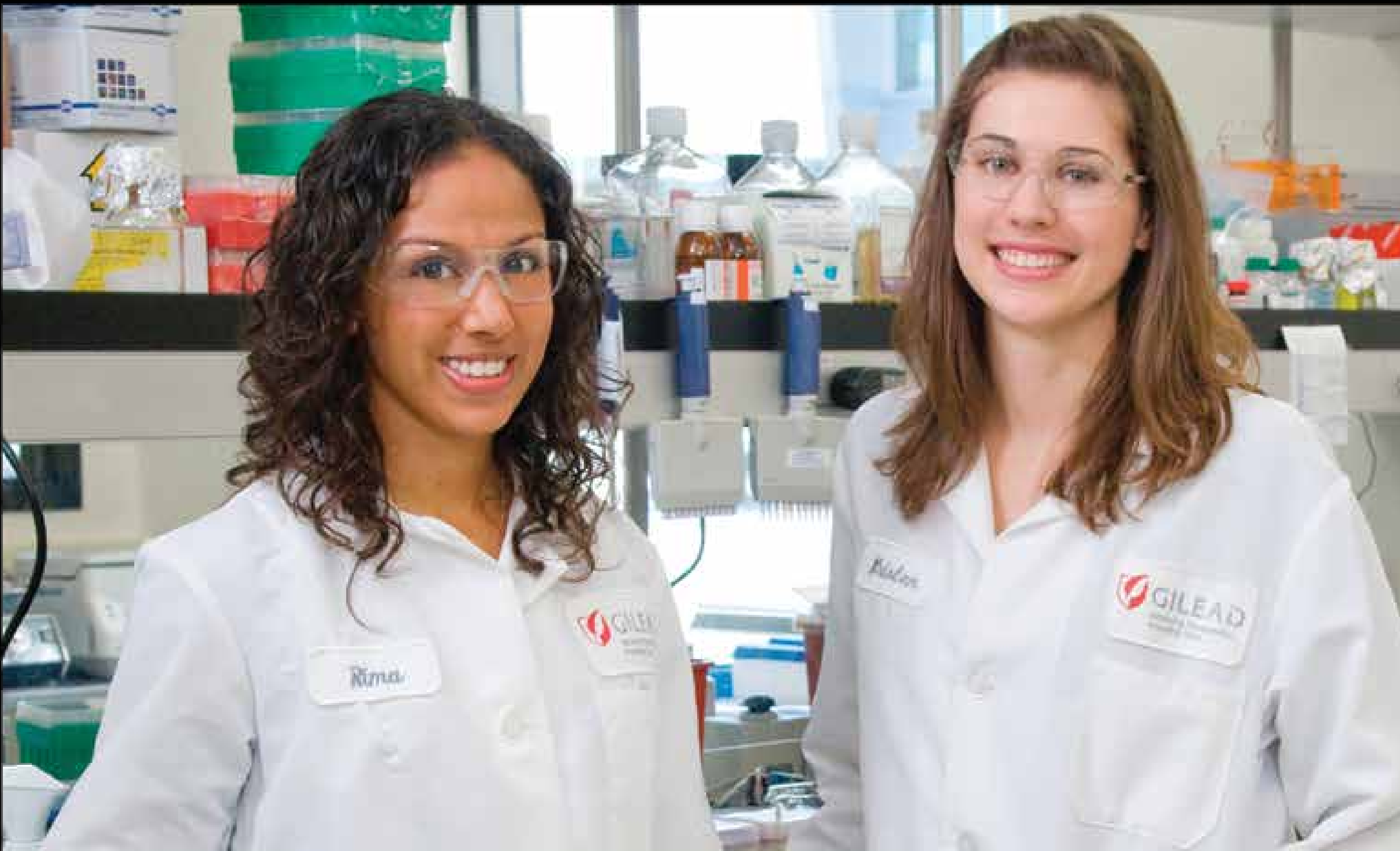
MICHAEL SMITH FOUNDATION FOR HEALTH RESEARCH



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TALLULAH PHOTOGRAPHY

This special anniversary issue of the *Canadian Chemical News (L'Actualité chimique canadienne, ACCN)* is a celebration not only of Canada's 150$^{\text{th}}$ confederation but the 100$^{\text{th}}$ Canadian Chemistry Conference and Exhibition. That these two milestone anniversaries align in such an auspicious manner reminds us of how closely intertwined chemistry and chemical engineering have been to Canada's economic and social development ever since the nation's birth on July 1, 1867.

Just a few years earlier — in 1858 — James Miller Williams struck oil while digging a water well in southern Ontario, ushering in the Age of Petroleum. Commonly called "black gold," it was the cherry on top of Canada's bounty of wood, water, fish and minerals. As the 19$^{\text{th}}$ century evolved into the 20$^{\text{th}}$, chemistry and chemical engineering flourished, pushing innovation in the booming oil and gas sector, automobile and petrochemical industries. Canadian innovation even helped saved the Allies in the 1940s when Polymer Corp. was founded in Sarnia, Ont. to make synthetic rubber for the Second World War military effort.

Other notable accomplishments in Canadian chemistry receive their due in this issue. These include the country's eight winners of the Nobel Prize in Chemistry as well the game-changing innovations nurtured within our post-secondary institutions, such as University of Toronto's Geoffrey Ozin's breakthroughs in nanochemistry and Université de Montréal's James Wuest's advancements in modular molecular design. *ACCN* also presents some of the remarkable achievements of our women chemists. These include Parisa Ariya, who is advancing studies into atmospheric chemistry and climate change, as well as Françoise Winnik, an expert in amphiphilic materials and their self-assembly for the synthesis of characterization of stimuli-responsive polymers.

As the 20$^{\text{th}}$ century merged with the 21$^{\text{st}}$, a new environmental challenge came to the fore — climate change, caused by the burning of fossil fuels, which is also implicated in local health effects such as the inhalation of fine particulate matter. This is chemistry's and chemical engineering's next great challenge: finding innovative ways to mitigate the impacts of current and past actions while developing alternative and sustainable forms of energy to replace oil and gas. This, of course, is green chemistry and *ACCN* discusses its birth and evolution.

ACCN also presents an essay on Responsible Care, one of the country's greatest international achievements. Developed by Canadian chemists, Responsible Care raised the bar for best practices in manufacturing, environmental safety and industrial disaster preparedness. It could be said that the greening of chemistry is, in and of itself, Responsible Care. Another auspicious alignment — one to carry us into the 22$^{\text{nd}}$ century. accn

ACCN *welcomes letters to the editor at accnmagazine@cheminst.ca. Letters should be sent with the writer's name and daytime phone number. All letters will be edited for clarity and length.*

Simply the BEST

John C. Polyani of the University of Toronto says that our nation's "generous welcome to immigrants" plays a part in this nation's illustrious Nobel Prize in Chemistry history.

By Patchen Barss

In chemistry, as in every branch of science, major breakthroughs happen rarely. Knowledge creation more typically comes from the incremental advances of diligent scientists toiling in obscurity.

Every so often, though, this slow progress builds pressure, like tectonic plates straining against one another. Then, "the big one" hits. A researcher makes a truly transformative discovery, sending shockwaves across their field, often changing the landscape for people far from the academic epicentre.

The Nobel Prizes recognize the lucky, diligent and talented researchers who make these kinds of seismic advances. Of the 175 people who have been awarded the Nobel Prize in Chemistry, eight were Canadian or had strong Canadian connections.

The stories of these eight scientists' research — and their lives — are all different. But some common themes emerge: immigration, emigration, collaboration and mentorship. Some were born here, some came from away and some just passed through. Somehow, though, Canada played a role in their success. "Canadians I know are a very friendly and open group, who tend to be more low-key and freer from hype than many others," says Rudolph A. Marcus, Chemistry Nobel Laureate of 1992.

Openness matters but geography also helps, says John C. Polanyi, who shared the 1986 prize with two United States-based researchers. "A generous welcome to immigrants plays a part," Polanyi says. "But we should not forget our greatest cultural asset: proximity to the US."

Sidney Altman

Until Sidney Altman discovered otherwise, conventional thinking said that all enzymes — biochemical catalysts that accelerate the thousands of chemical reactions required to sustain a living organism — were proteins. Altman, working with American Thomas Cech, discovered first that some enzymes are a combination of a protein and an RNA string and subsequently that some RNA molecules can serve an enzymatic function with no protein component at all.

Because RNA existed before proteins, Altman's discovery helped explain how life might have arisen in the first place. RNA enzymes also have the potential to treat or prevent viruses including those that cause the common cold. Montreal-born Altman shared the 1989 Nobel Prize with Cech for their joint discovery and characterization of RNA-based enzymes.

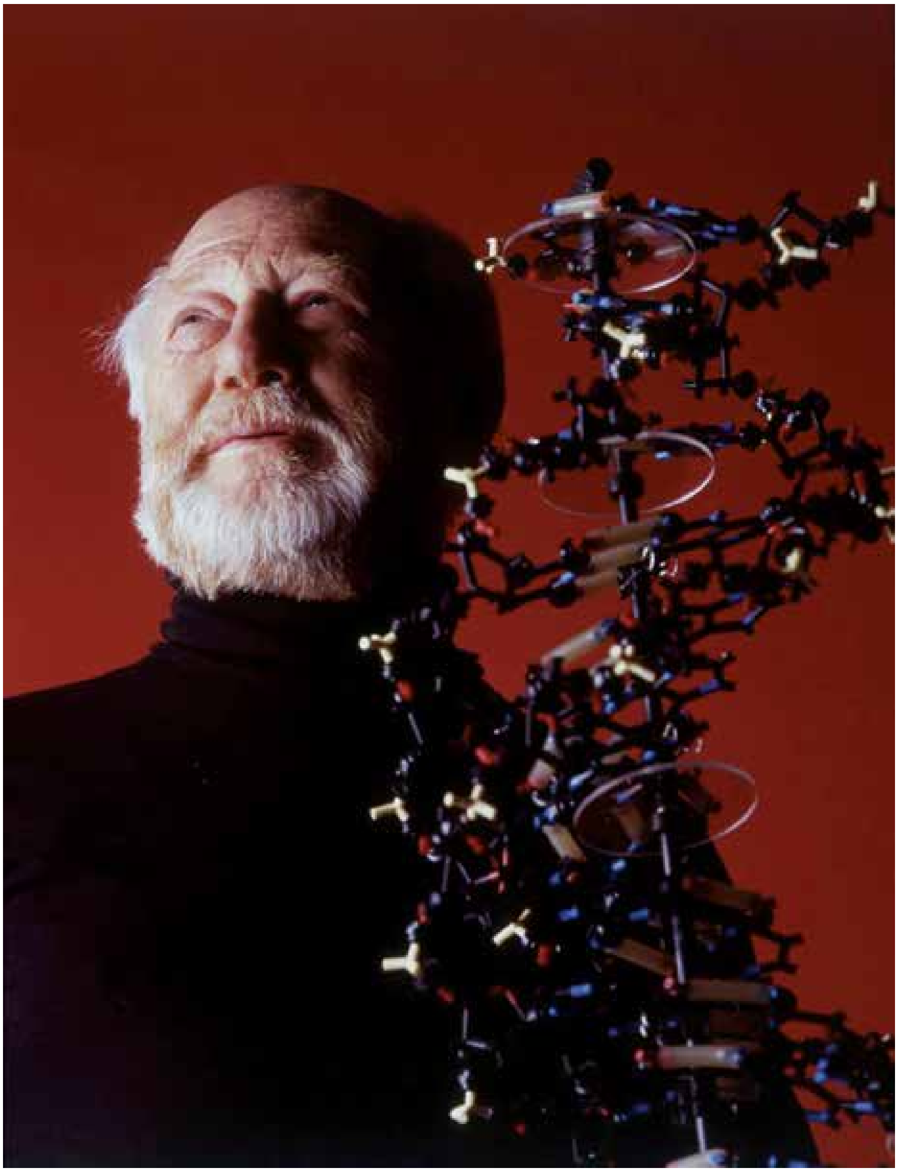
William F. Giauque

William Francis Giauque was born in Niagara Falls, Ont., spent his childhood in Michigan and returned to Canada for high school. His path to the 1949 Chemistry Nobel, though, really began when he recrossed the Niagara River once more, taking a job at the Hooker Electro-Chemical Company in Niagara Falls, New York. Giauque's research focused on the third law of thermodynamics, which stipulates that the entropy system approaches a minimum as that system approaches absolute zero.

Giauque developed a magnetic refrigeration technique that cooled atoms to within a degree of absolute zero, which helped him establish conclusively that the third law is, in fact, a basic law.

Gerhard Herzberg

Gerhard Herzberg won the Nobel Prize in Chemistry in 1971, nearly 40 years after fleeing Nazi Germany with his Jewish wife and research partner Luise Oettinger. First, at the University of Saskatoon and later at the National Research Council, Herzberg made this country a leader in spectroscopy, the study of how light and matter interact.



DINA GOLDSTEIN

University of British Columbia biochemist and businessman Michael Smith shared the 1993 Nobel Prize in Chemistry with American Kary Mullis for their work developing site-directed mutagenesis.

While Herzberg advanced the field as a whole, his Nobel-winning research centred on molecular spectroscopy, which uses the light-absorption and emission patterns of molecules to determine their electronic structure and geometry. Most notably, his study of free radicals — unstable molecules which often exist only temporarily during chemical reactions — led to his Nobel Prize.

Rudolph Marcus

His eponymous Marcus Theory explains the rate at which an electron can jump from an electron donor to an acceptor. The theory explains how atoms swap electrons and how this electron transfer drives chemical reactions.

Marcus Theory helps researchers understand many major chemical processes ranging from photosynthesis to corrosion. Born in Quebec, Marcus received his PhD from McGill University in 1946. At McGill, and later in the National Research Council's postdoctoral program in Ottawa, he expanded from his early experimental research into the realm of theory, developing the insights that would earn him the 1992 Nobel Prize. He is currently a Kirkwood-Noyes professor at the California Institute of Technology.

John C. Polanyi

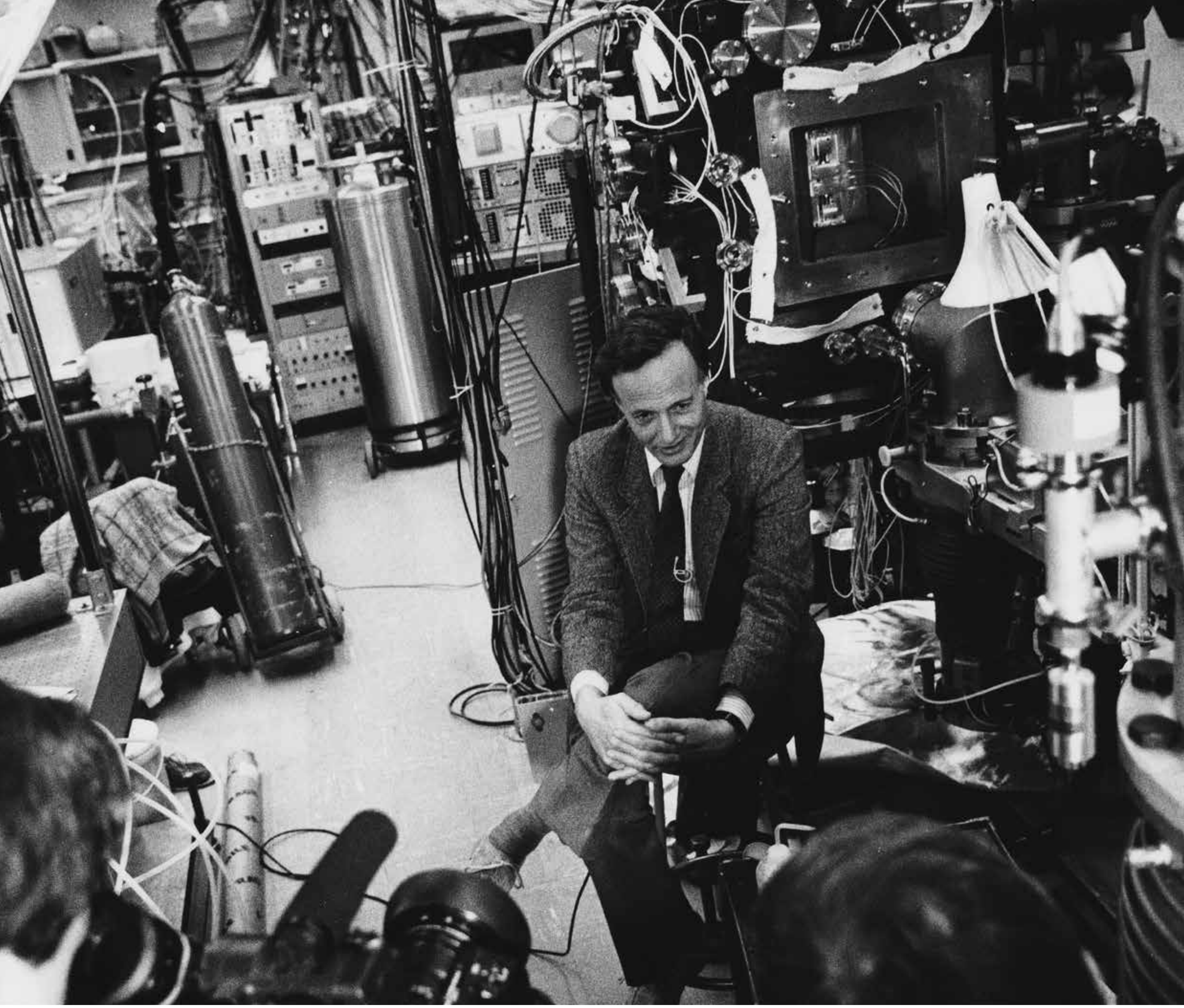
British ex-pat John Polanyi first came to Canada during the Second World War and moved back and forth between the two countries until he took a postdoctoral fellowship at Canada's National Research Council. Under the mentorship of Gerhard Herzberg, Polanyi became immersed in chemical kinetics. He joined the University of Toronto in 1956, becoming a full professor in 1962.

Polanyi's Nobel-winning work involved using weak infrared radiation, emitted from recently formed molecular compounds, to glean information about those compounds' quantum mechanical energy states. Effectively, this method allowed researchers to track in real time molecular motion of molecules and atoms as they formed new materials. Polanyi shared the 1986 Nobel Prize with American Dudley Herschbach and Taiwan-born Yuan Lee.

Ernest Rutherford

While Ernest Rutherford was born in New Zealand and died in England, his journey as a researcher included a critical stint in Montreal. Rutherford made several major discoveries, any one of which would have been the pinnacle of a lesser researcher's scientific career. He determined that atoms comprise a dense, charged nucleus surrounded by empty space and orbiting electrons. He discovered the existence of protons and hypothesized the existence of neutrons. These kinds of advances earned him the epithet "the father of nuclear physics."

In 1898, though, Rutherford began a highly productive nine-year stint at McGill University. During that time, he authored or co-authored 69 papers related to the nature of radioactive decay, including discovering distinctive alpha, beta and gamma rays, that the process of radiation transforms one element into another, and that radioactive decay happens at a predictable rate, which laid the foundation for carbon-dating ancient rocks and fossils. Rutherford's work at McGill formed the primary basis for his winning the 1908 Nobel Prize in Chemistry.



John C. Polanyi in his University of Toronto laboratory in 1986, the same year he won the Nobel Prize in Chemistry for research into chemical kinetics.

RUSSELL MONK

Michael Smith

British-born Canadian biochemist Michael Smith shared the 1993 Nobel Prize in Chemistry with American Kary Mullis for their work developing “site-directed mutagenesis,” which allows researchers to introduce specific, engineered mutations into a DNA sequence.

Smith immigrated to Canada in the 1960s. While working at the University of British Columbia in the 1980s, he developed a technique to identify and alter genes in DNA strings, swapping out specific amino acids and inserting the resulting modified strings back into an organism. Artificial mutation became both a powerful research tool, allowing scientists to test the effects of particular mutations on genetic structure and behaviour, as well as a valuable technique to engineer proteins for industry, medicine and other commercial enterprises.

Henry Taube

Hailing from Neudorf, Sask., Henry Taube was the first person born in Canada to receive the Nobel Prize in Chemistry. As a master’s student at the University of Saskatchewan, he studied under Gerhard Herzberg, establishing the foundations of his research into oxidizing agents and coordination chemistry. Notably, he realized that key processes in organic chemistry had analogs in inorganic chemistry. This insight led to his discovery that metallic ions can join into complexes, within which electrons transition indirectly from one ion to another by way of an additional “bridge” molecule. This work led to Taube receiving the Nobel Prize in 1983. accn

Women ON TOP

Female chemists and chemical engineers are making enormous contributions to science in Canada and around the world.

By Victoria Corless

Women have — often quietly and anonymously — contributed to scientific innovation since time immemorial. When Marie Curie became the first woman to receive the Nobel Prize for physics in 1903, the achievement marked a significant turning point for women, representing global acknowledgement of their contributions. Since then, women scientists have made remarkable progress and many of the obstacles women have uniquely faced have been reduced with each successive generation. While difficulties such as lingering gender stereotypes remain, and women continue to be under-represented in STEM fields, many do occupy prominent positions, including in chemistry and chemical engineering.

History and current trends underline the need for women who are passionate about science, who speak out and aspire to bring about progressive change in society, to be acknowledged and celebrated. Their stories, struggles and successes should be shared as a way to help empower aspiring young female scientists in Canada and around the world. The *Canadian Chemical News* has reached out to six remarkable women — all leaders in the chemical sciences — whose stories should not only serve to inspire budding young female scientists but their male counterparts as well. Clearly, becoming a world-class scientist is no longer dependent upon one's gender.

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Women chemists worked at the Imperial Oil Limited's research laboratory in Sarnia.

AGENT OF CHANGE

Parisa Ariya is a James McGill professor of Chemistry and Atmospheric and Oceanic Sciences and chair, Department of Atmospheric and Oceanic Sciences at McGill University. Ariva is also the associate editor of Geochemical Journal.

As a child, Parisa Ariya recalls her mother's extensive library, which instilled a love of reading as well as a perpetual curiosity. Encouraged by a feminist father and an aunt who encouraged her to be an "unapologetic woman," Ariya put into motion her desire to serve community, society and act as an agent of change.

As an academic, she has made significant contributions to the fields of atmospheric chemistry, climate change, sustainable technology and environmental health. The impacts of her research have been widely highlighted in scientific journals as well as United Nations Environmental Protection reports. Ariya has indeed become an agent of change, helping craft Canadian and international policies such as the Joint EU panel on Climate Change, the Arctic Contamination Program Assessment, the Canada Clean Air Act and the Canadian Environmental Protection Act. As well, surface technologies developed by her lab to reduce or eliminate the emission of airborne pollutants, such as carbon dioxide, trace metals and aerosols, have been integrated into industrial plants within Canada.

Ariya encourages other women to push themselves as they embark upon their careers, even though some areas may be daunting. Challenging fields like chemistry require dedication but choosing a career you are passionate about makes the work enjoyable, especially if you aspire to improve the lives of others, she says. "We should always contribute to society to make it better; a life without giving is not a life that is well lived."

BATTLING ANTIBIOTIC RESISTANCE

Karine Auclair is an associate professor, McGill University Department of Chemistry. She uses chemical tools to study and manipulate biological systems, with special interest in antibiotic resistance, enzymes and green chemistry biocatalysis.

As a high school graduate, Karine Auclair had initially intended to study chemistry abroad. However, a mix-up in the mail, resulting in a lost student visa, forced Auclair to remain close to home. This seemingly unfortunate event led her to her first mentor, Prof. Francois-Xavier Garneau at the Université du Québec à Chicoutimi. Auclair recalls: "he took me under his wing, encouraged me to become a professor and guided me along. We became very good friends and remained so until he passed away." She met her second mentor, Prof. John C. Vederas, while completing her PhD in bioorganic chemistry at the University of Alberta.

Auclair's current research at McGill takes advantage of chemical tools to manipulate biological systems. "Antibiotic resistance is the worst threat to our health system and we must act before it becomes detrimental to modern medicine." Among her successes, Auclair has demonstrated novel and selective activation of prodrugs in bacteria using CoA biosynthetic enzymes and the resensitization of bacteria to host immune response using small molecules. In addition to her research interests, as well as teaching, Auclair loves the outdoors and especially competitive horse jumping. Auclair has worked hard to ensure she maintains a balance between work and her personal life. "The most important challenge facing women are unconscious biases against them," Auclair says. "Aim very high and allow yourself to go for your dream job."

THE ART OF CHEMISTRY

Jillian Buriak received her PhD from the Université Louis Pasteur in Strasbourg, France. She became a tenured associate professor at Purdue University in Indiana in 2001 then joined the University of Alberta and the National Institute for Nanotechnology as a full professor two years later. Buriak is the Canada Research Chair (Tier I) of Nanomaterials for Energy.

As an ambitious young student at Harvard University, Jillian Buriak began her education as a math major, "loving its beauty," but eventually found herself at a crossroads. Inspired by her first and only female chemistry professor at Harvard, Cynthia Friend, Buriak realized her true passion was chemistry. "Knowing what the world is made of and how things fit together, coupled with the hands-on nature of laboratory work, made it seem more like art *and* science."

While pursuing her PhD in homogeneous catalysis, Buriak noticed the early stirrings of nanoscience and materials chemistry in the literature and transitioned to the field during her post-doctoral placement at the Scripps Research Institute in La Jolla, Calif. Since establishing her own research group, Buriak has become a true innovator. Applications of her research range from tackling the world's greatest challenges in renewable energy through the development of novel and inexpensive photovoltaic materials to solving complex problems in medicine such as tissue regeneration with self-assembling polymers. Her multidisciplinary research has resulted in more than 9,000 citations. Buriak also plays a prominent role in publishing, most recently becoming editor-in-chief of the American Chemical Society's *Chemistry of Materials* in 2013.

Buriak emphasizes the importance of courage and aiming high and pushing outside one's comfort zone where "we are forced to climb a steep learning curve, which is a healthy way to challenge ourselves and will ultimately help to achieve our goals."

HELPING STUDENTS ACHIEVE PURPOSE

RACHEL SANDERS

Laurel Schafer undertook graduate studies at the University of Victoria, followed by a two-year NSERC Post-Doctoral Fellowship at University of California, Berkeley. She began her independent career at the University of British Columbia in 2001, becoming a professor in 2012. Schafer is a leader in the field of catalyst discovery and a Canada Research Chair in catalyst development, a fellow of the American Association for the Advancement of Science and an associate editor for the American Chemical Society journal, Organometallics.

From an early age, Laurel Schafer was surrounded by strong women. On the family farm near Wellesley, Ont. she observed her grandmother carrying out the daily chores, while admiring her mother's dedication to everything she took on at work, home or in her local district. There were no limitations, Schafer realized, on what women could do, whether it was performing demanding physical labour or making decisions that impacted family and community.

As she built her career as a chemist, Schafer's mantra became, "just because you don't see it being done, doesn't mean it can't be done." Her tenacity and willingness to seek the unknown fuelled creative and original research, developing novel organometallic catalysts to carry out difficult transformations in small molecule organic chemistry. One of Schafer's complexes is commercially available while others show promise for potential translation to a broad range of user groups. Although proud of her research, Laurel's legacy, she feels, is one that is defined by her students. "My goal is to help each student realize their full potential and move forward with purpose and focus. Students that graduate with well-honed tools to build a successful career are the focus of my program."

INVENTIVE CURIOSITY

PETER CALAMAI

***Molly Shoichet** is an award-winning, biomedical engineer and professor in the University of Toronto's Department of Chemical Engineering & Applied Chemistry as well as the Institute of Biomaterials & Biomedical Engineering, with a cross-appointment to the Faculty of Medicine. Shoichet holds the Tier I Canada Research Chair in tissue engineering.*

As a student at the Massachusetts Institute of Technology (MIT), Molly Shoichet's original plans to undertake a medical degree took a swift turn during an advanced organic chemistry lab. The task? To synthesize a polymer. This small moment sparked a lifelong interest that led to, rather than a medical degree, a B.Sc. in chemistry. "I thought that polymers were very interesting and took several courses at MIT to enhance my knowledge. This led to research projects and then to a PhD in polymer science and engineering," says Shoichet. Despite her passion for chemistry, her fascination for medicine continued unabated. She entered the field of regenerative medicine, working in such biotechnology labs as CytoTherapeutics (now Stem Cells Inc.) in California, and advancing the frontiers of materials science and medicine.

In her current work, Shoichet and her team use polymers as scaffolds for human cells and tissues. "We invent materials that promote tissue healing and regeneration when combined with therapeutics or cells," Shoichet says. "This is important for personalized medicine and drug screening. Our legacy will be our inventive curiosity." In addition to her substantial contributions as a researcher, Shoichet is also passionate about science communication and has co-founded *Research2Reality*, a social media campaign that showcases innovative research in Canada. "Our challenge is to engage girls and boys, young women and men, to explore and create new solutions to old problems." Her best advice to aspiring scientists: "There are many opportunities to make a difference. Make sure to 'lean in' and take your seat at the table."

MATERIALS MAVEN

***Françoise Winnik** is a professor in the Faculty of Pharmacy and Department of Chemistry, Université de Montréal. She is also editor-in-chief of the American Chemical Society journal Langmuir and principal investigator at the International Center for Materials Nanoarchitectonics National Institute for Materials Science in Japan. Winnik is a distinguished professor in the Faculty of Pharmacy and Department of Chemistry, University of Helsinki, Finland.*

Born in France at a time when the expectations of women were modest, Françoise Winnik attributes her ambition and much of her success to her parents. "When I went to school there was the possibility of taking typing classes. My mother was adamant that her daughter would not become a secretary — that she would never learn to type," says Winnik. "I still haven't quite mastered it," she says jokingly.

For Winnik, a successful career in chemistry has required not just ambition but intelligence, creativity, ingenuity, balance and, above all, flexibility. Never one to shy away from new challenges, perhaps one of Winnik's strongest qualities is her ability to adapt. Initially trained as an organic chemist, Winnik went on to complete post-doctoral studies in medical genetics at the University of Toronto then became interested in polymer chemistry during her time with Xerox Research Centre of Canada. Since entering academia in 1993, Francoise has become a leading expert in amphiphilic materials and their self-assembly for the synthesis of characterization of stimuli-responsive polymers and is investigating biomedical applications such as *in vivo* imaging of nanoparticles. "A researcher sees interesting problems and works to solve them. Over the course of an entire career, one will work on several topics that collectively will make an impact," Winnik says. accn

THE GREENING OF CHEMISTRY

Chemists who can incorporate inherently safer design into every step of innovation — the essence of green chemistry — are the future.

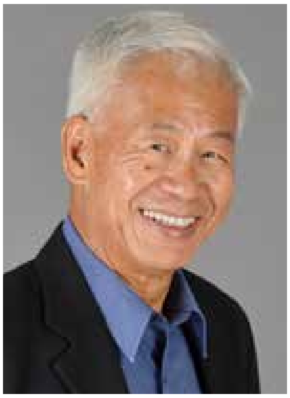
By Laura M. Reyes

Green chemistry seems to be everywhere these days is a sentiment you'll hear throughout the chemistry community. Depending on the context, this is either mentioned with pride at our collective accomplishments or with a subtle undertone of perplexity. Just about everyone seems amazed at the rapid increase in individuals and organizations that affiliate themselves with green chemistry.

Even the term "green chemistry" is a fairly recent development. Its beginnings can be traced back to 1998 and the publication of the 12 Principles by Paul Anastas and John Warner in their book *Green Chemistry: Theory and Practice*. The ideas behind green chemistry, however, are not new — chemists have always sought to find ways to use fewer resources, reduce the toxicity of their products, improve process efficiency and create less waste. But the gathering of these ideas under one umbrella, while giving it a name, enables us to prioritize their collective incorporation into everyday chemistry research and education. In doing so, we can ensure that Canadian chemists of the future have the proper training and resources to carry out innovative chemistry in a way that is inherently safer, more environmentally responsible and more efficient.

Research roots

Green chemistry in Canada found its early leadership in Tak-Hang (Bill) Chan, now professor emeritus at McGill University. In 2000, Chan established the Canadian chapter of the Green Chemistry Institute with the help of Anastas, followed by the Canadian Green Chemistry Network



Tak-Hang (Bill) Chan

(CGCN) in 2002. The CGCN connected individual academic researchers and government scientists whose work related to green chemistry, gathering previously isolated efforts into one united group.

As a researcher at McGill, Chan had worked on replacing organic solvents with water, publishing the influential book, *Organic Reactions in Aqueous Media*, with his then doctoral student Chao-Jun (CJ) Li in 1997. A few years later, in 2003, Li himself would be hired at McGill, followed by Audrey Moores in 2006, as the start of a series of strategic recruitments that would turn into the large hub of green chemistry researchers that exists at the university today.

Throughout Canada, the early and mid-2000s saw the establishment of green chemistry research groups at various universities, accompanied by the incorporation of green chemistry content into the undergraduate curriculum by research and teaching faculty alike.

The first green chemistry courses were offered at McGill and at York University in 2002, created by Chan and John Andraos, respectively. They were soon followed by other institutions; notable examples included Philip Jessop at Queen's University, Andrew Dicks at the University of Toronto, Francesca Kerton at Memorial University and Jason Clyburne at St. Mary's University. The majority of these examples have been elective courses, which has the disadvantage of adding to the perception that green chemistry is a separate afterthought to "non-green" chemistry. However, many faculty are now building on the significant advancements that have been made by seamlessly integrating this same content into existing courses and labs.

Opportunities for graduate students

The growing presence of green chemistry-focused research groups has also provided graduate students with the opportunity to gain working experience in this area. McGill is again a leading example within Canada, as it not only has an impressive concentration of green chemistry researchers and but is also home to the highly collaborative NSERC CREATE in Green Chemistry program. Through its annual workshop and case competition, the program brings together graduate students across chemistry, engineering and management to build business cases for green chemistry technologies, while giving participants an excellent opportunity to experience the need for collaboration across disciplines. In 2009, Li co-founded the Centre in Green Chemistry and Catalysis with Université de Montréal professor André Charette. This network, affiliated with all of Quebec's major universities, further catalyses green chemistry work across the province.

At many institutions, though, there remains a gap in the resources that are made available to graduate students who simply wish to learn about green chemistry. A group of a dozen graduate students at the University of Toronto, myself included, responded to this gap in our own education by founding the Green Chemistry Initiative (GCI) in 2012. The GCI is a student-led organization that provides researchers with educational resources and professional development opportunities. Seminars and annual symposia invite Canadian and global leaders in academia and industry to showcase how the underlying principles of green chemistry are implemented across a variety of sectors. The GCI has also organized case studies and workshops, which allow participants to gain hands-on experience in applying their knowledge to real examples of chemical processes and technologies.

In the past few years, the GCI has also collaborated with teaching faculty in undergraduate curriculum development. As a result of this combined effort, in 2016 the University of Toronto became the first school outside of the United States to sign Beyond Benign Green Chemistry Commitment, pledging to provide all undergraduate chemistry students with a working knowledge of green chemistry and toxicology as an integral part of their education. The success of the GCI has inspired students to start similar organizations at various institutions – including McGill, the University of British Columbia and Thompson Rivers University, as well as a few others internationally.

The future of green chemistry

Outside of academic programs, the growing emphasis on green chemistry is reflected in the Canadian chemistry community as well. GreenCentre Canada, a not-for-profit organization established in 2009, is a global leader in the development and commercialization of early-stage green chemistry technologies. The Chemical Institute of Canada, through its Canadian Green Chemistry and Engineering Network, recognizes the contributions of individuals and organizations with annual awards.

An education that includes green chemistry provides chemists with highly valuable skills that extend far beyond the immediate association with environmental benefits, being taught to consider not only a stand-alone chemical reaction but also its resource inputs and waste outputs, as well as the safety, efficiency and cost of chemical processes. Canada needs, and will benefit from, chemists who can incorporate inherently safer design into every step of innovation. It is not a question of whether or not green chemistry has a future but rather recognizing that green chemistry is the future. accn

SPARKS *of* GENIUS

Canadian universities have nurtured home-grown research that changed the world of chemistry forever.

By Patchen Barss

Chemistry research in Canada pre-dates Canada itself. In the 1840s, decades before confederation, British ex-pat Henry Holmes Croft became the first chemistry professor at the University of King's College, the precursor to the University of Toronto. Croft developed a method of removing sulphur from Sarnia oil wells, making it safe for household lamps. He was a pioneer in forensic chemistry, championing the arsenic-detecting "Marsh test" that ultimately foiled many an arsenic-poisoning plot.

Croft was also a beloved teacher and mentor who encouraged his students to embrace new ideas and innovative approaches to research. The creative culture he fostered spread to university after university across the country. As Canada celebrates its sesquicentennial, we look at a few of the many areas — famous and not — where this country has punched above its weight in chemistry research.

NATURAL SCIENCE AND ENGINEERING RESEARCH COUNCIL OF CANADA (NSERC)

Axel Becke

Axel Becke

Like many Canadian chemistry researchers, Axel Becke came from somewhere else. Born in Germany, he studied at Queen's and McMaster before establishing himself at Dalhousie University in Halifax. A highly cited and much-honoured computational chemist, Becke is best known for his work in density functional theory. His fundamental work on determining the electronic structure of atoms and molecules now drives applications ranging from drug discovery to nanotechnology.

Becke's work is a testament to the capacity of small-scale creativity: he has authored or co-authored 80 papers, two of which made *Nature*'s list of the most cited science papers of all time.

Kelvin Ogilvie in his Acadia University chemistry lab in 1988.

Ronald Gillespie

McMaster University professor emeritus Ronald Gillespie (together with Australian Ronald Nyholm) developed valence shell electron pair repulsion theory. The two Ronalds demonstrated how to predict the geometry of a molecule from the number of electron pairs surrounding its central constituent atoms. They first put forth their simple, elegant "VSEPR theory" in 1957. Since then, the theory has been developed and refined, becoming a fundamental component of freshman chemistry classes around the world.

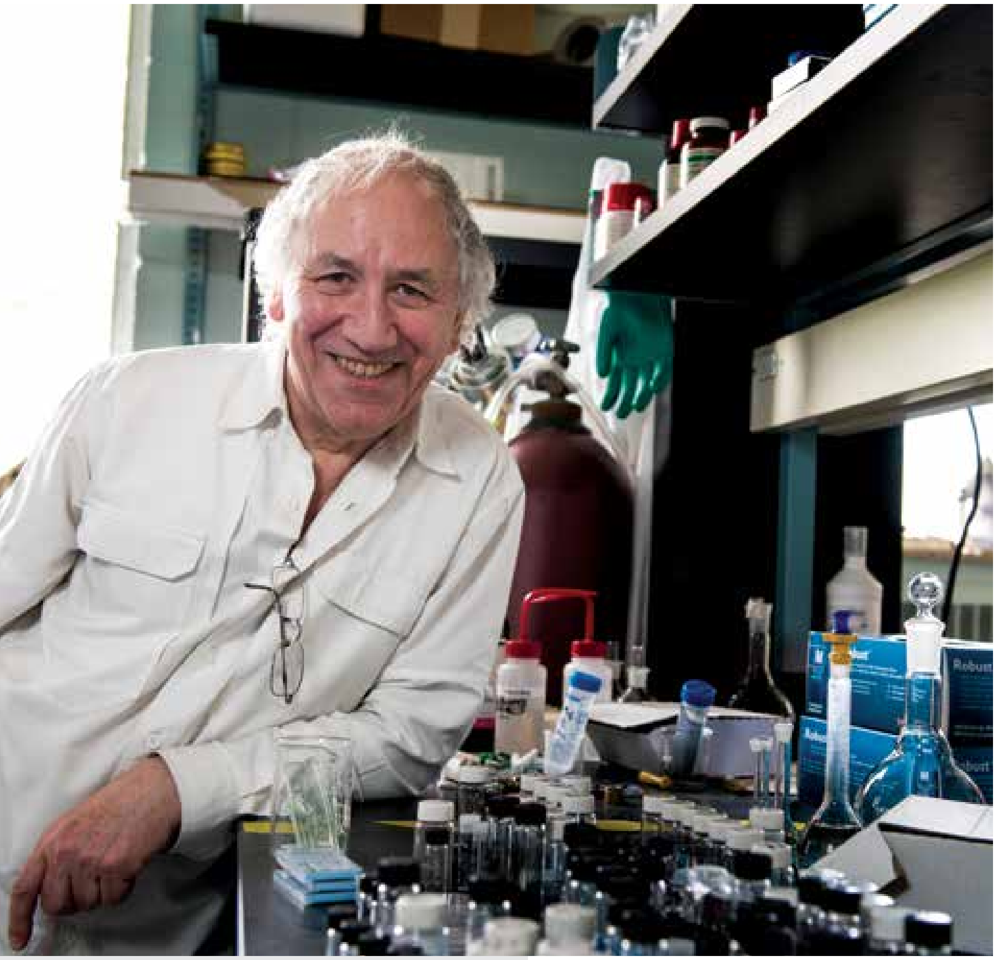
Jiri Cizek and Josef Paldus

In the 1960s at the University of Waterloo, Jiri Cizek and Josef Paldus made their mark by borrowing a method from nuclear physicists to describe many-bodied systems and applying it to the field of quantum chemistry. Their work adapting and developing coupled cluster theory helped make it one of the most widely used, flexible and effective means of calculating a wide range of atomic phenomena.

Cizek and Paldus, both of whom had strong mathematical backgrounds, originally used the technique to calculate the ground state energies of closed-shell atomic nuclei. In the ensuing decades, though, further refinements have made it the go-to technique for calculating excited states, including in open-shell atoms, as well as for many other properties such as phase transitions, spontaneous symmetry breaking and topological excitation.

Kelvin Ogilvie

Born in Nova Scotia, and a former chemistry professor at the University of Manitoba, McGill University and Acadia University, Kelvin Ogilvie is a quintessential icon of Canadian chemistry research. Now a Canadian senator, Ogilvie has a storied research career, the pinnacle of which came in 1981 when he revealed the "gene machine," an instrument that automated the process of manufacturing custom strands of DNA. Not only was this a boon for biochemistry research but it also made possible the large-scale manufacture of materials such as insulin and human growth hormone that previously had been harvested from limited natural sources.



TERENCE SCARNICCHIA

Geoffrey Ozin

Edgar William Richard Steacie

Few Canadian chemistry researchers have names more recognizable than Edgar William Richard Steacie, whose eponymous Steacie Prize for Natural Sciences is awarded each year to a promising young scientist or engineer in Canada.

Although many scientists know Steacie best as a passionate advocate and statesman for Canadian research, he was equally renowned for his research in free radical kinetics. Steacie came to McGill University as a student in 1920 and remained there for much of his research career, advancing techniques for measuring rates of chemical reactions and revealing the mechanisms behind them.

Geoffrey Ozin

The University of Toronto's Geoffrey Ozin has gained worldwide renown as one of the fathers of nanochemistry, which is the study of atomic and molecular structures at the nanometre size. At this scale, systems transition between classical and quantum properties, exhibiting many unusual and varied behaviours.

In the 1970s, Ozin pioneered methods for manufacturing and manipulating metals, crystals and other constructs at the nanometre scale. That work helped create this new branch of chemistry that now finds application in biomedicine, polymer chemistry, product synthesis and a host of other areas.

Reuben Sandin

Reuben Sandin taught and researched chemistry at the University of Alberta from 1922 to 1965 and carried on as professor emeritus until 1988. A pioneer in the wide-ranging subject area of halogen organic chemistry, who did his major work in the 1940s, Sandin was known both for synthesizing chemicals used to treat cancer and also for creating some of the first stable bromonium and iodonium ions. These ions are important intermediates in materials synthesis and are still used to manufacture many industrial and pharmaceutical chemicals.

Like so many Canadian chemistry researchers, Sandin was also a revered teacher. Not only did more than 200 of his students acquire PhDs in chemistry but his work also helped Canadian universities assume a leadership role in organ halogen research that continues to this day.

James Wuest

Chemists have long sought the holy grail of being able to produce materials molecule-by-molecule, precisely engineering properties such as charge, porousness, flexibility and conductivity. James Wuest's laboratory at Université de Montréal is dedicated to advancing techniques for modular molecular design. They have developed new methods for exploiting weak interactions to control molecular association. They have also become world leaders in explaining how properties change as individual molecules assemble into larger structures.

Although the lab's primary focus remains on fundamental research, the team's discoveries also have inarguable commercial potential. Wuest's methods make it possible to construct catalysts, porous solids for storing and separating gases, new pharmaceuticals and components of photovoltaic cells. accn

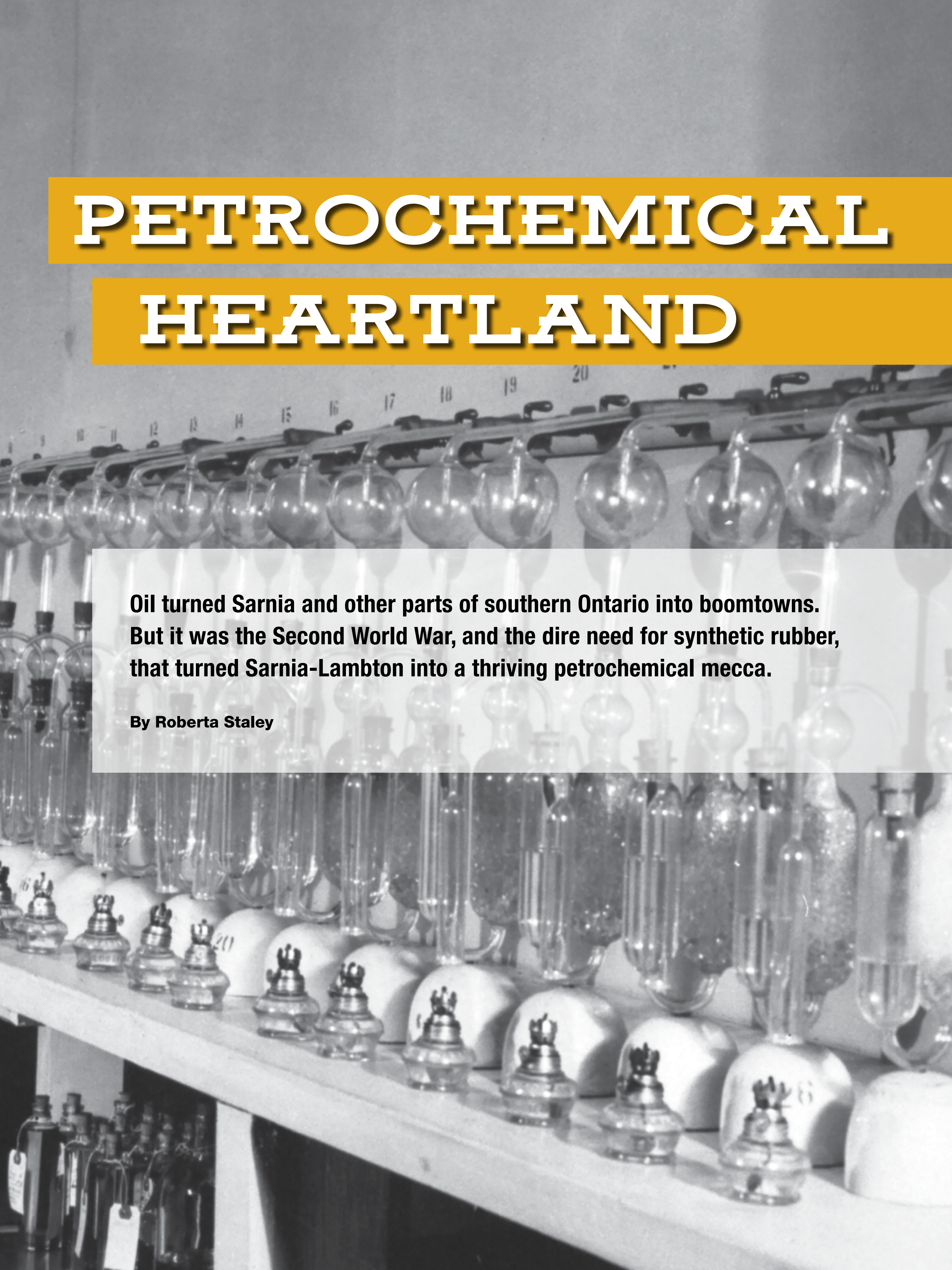
Gordon Paterson checking gasoline samples for the presence of sulphur at the Imperial Oil refinery in Sarnia, circa 1933-34.

GLENBOW ARCHIVES 11-1-4

PETROCHEMICAL HEARTLAND

Oil turned Sarnia and other parts of southern Ontario into boomtowns. But it was the Second World War, and the dire need for synthetic rubber, that turned Sarnia-Lambton into a thriving petrochemical mecca.

By Roberta Staley



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Hewers of wood and drawers of water is the oft-repeated narrative used to describe Canada's historical reliance on natural resources. It is true that Canada has been, and continues to be, dependent upon the land's natural bounty: oil and gas, coal, hydropower, fish, forestry, silver, copper, gold, diamonds, molybdenum, potash and rare earth elements. Yet, over the decades, the country also developed the infrastructure and expertise to transform these raw materials into value-added wealth streams.

One of the country's most highly developed industries, which expanded in concert with the growth of that most distinctly Canadian natural resource — oil and gas — was Sarnia's Chemical Valley in Lambton County in southwestern Ontario, the epicentre of Canada's petrochemical sector.

Before the development of this industry, organic chemicals were mainly derived from coal, plant or animal-based materials. Wood was the basis for methanol and acetic acid. Coal, meanwhile, produced aromatics like benzene, toluene, naphthalene and ammonia, as described in the 1958 article, "Petrochemicals in Canada" published in *Chemicals in Canada*, the predecessor of the *Canadian Chemical News*.

Petrochemicals elbowed out wood and coal-derived chemicals, ending up in an array of consumer and industrial products, from rubber to fertilizers, solvents, plastics, paint and textiles — the artifacts of the 20th century's vast technological and consumer edifice. Sarnia's Chemical Valley in southern Ontario became the heartland of this vibrant sector of the Canadian economy.

The area now known as Sarnia has long been the home of the Aamjiwnaang First Nation. When European settlement began in the 1830s, the economy was primarily based upon hardwood lumber like oak, ash and elm. Sitting on the east bank of the St. Clair River, just south of where it receives the flow of Lake Huron, the area was also one of the world's greatest inland shipping routes.

Then, in 1855, asphalt producer James Miller Williams entered the refining petroleum business, unexpectedly striking oil three years later while digging for water. His discovery ushered in the Age of Petroleum, triggering the first North American oil rush to what became known as Oil Springs. In 1858 the *Sarnia Observer* wrote that oil "seems to abound over a considerable tract of land where it was discovered; and in fact that earth is so saturated by it, so that a hole dug 8 or 10 feet in width and the same depth, will collect from 200 to 250 gallons a day, the supply seemingly inexhaustible."

It's a gusher!

Later, in 1862, John Shaw discovered a gusher that brought in 3,000 barrels of oil a day and flooded nearby creeks and rivers, according to E. R. Rowzee's 1950 article "Sarnia, the birthplace of Canada's petrochemical industry" in *Chemistry in Canada*. By 1864 there were 27 refineries around Oil Springs and the nearby community of Petrolia. Refineries were also located in Hamilton, Woodstock and London, recovering mainly kerosene, which was used as a fuel for stationary engines and as a cleaning agent. Gasoline was a byproduct. Early refining methods were basic. According to R. W. Ford, who wrote "History of the Chemical Industry in Lambton County" in 1987 for the Sarnia Historical Society, a refinery in the mid 19th century consisted of "a large black iron pot with a source of heat underneath and a condenser for recovering the fluids that boiled off."

Refineries were erected in Sarnia too, with the St. Clair River providing water for factory cooling. In 1871, the Dominion Oil Company built a refinery. In 1896, it was

The general chemical laboratory at the Imperial Oil refinery at Sarnia, circa 1933-34. Researchers examine the oils for chemical defects and run special tests to determine lubrication properties.

rebuilt and operated by the Bushnell Oil Company, which became Imperial Oil one year later. The company laid claim to the boast of being the largest oil refinery in the British Empire.

Refinery technology improved and processes produced hydrocarbon mixtures that were suitable for petrochemical feedstock. However, the principal products continued to be kerosene, lubricating oils, waxes, gas and fuel oils and candles. Still, the nascent auto industry wasn't far away. In 1904, the Ford Motor Company of Canada was established and, by 1913, about 50,000 motor vehicles were traversing Canadian roadways. From 1918-1923, Canada became the world's second-largest auto producer, according to *The Canadian Encyclopedia*.

Petroleum wasn't the only feedstock. Southwestern Ontario sits on a huge salt bed that lies about 450 to 600 metres below the surface. Salt is a key ingredient in many industrial chemicals, including chlorine, sodium carbonate, liquid sodium for use in coolants and hydrochloric acid. Dominion Salt, which later became Sifto Salt, mined this mineral from 1903 until the early 1960s, according to Ford's Sarnia Historical Society article.

As Rowzee described in his *Chemistry in Canada* story about Sarnia's petrochemical industry, developments during the early 20th century continued apace, embracing the solvent dewaxing of lubrication oils and adoption of the suspensoid cracking process at Imperial's Sarnia refinery. Additional

CITY OF LIGHTS

Sarnia, Ont. may have been the epicentre of the petrochemical industry but Shawinigan, Que. was the heart of the electrochemical sector.

Located at the Saint-Maurice River in southwestern Quebec, Shawinigan was the centre for both the province's chemical industry and industrialization at the turn of the 20th century. Spectacular 50-metre-high falls gave the community its name and powered hydroelectric power plants built by the Shawinigan Water & Power Company (SW&P). Drawn by cheap electricity, Belgo-Canadian Pulp moved to Shawinigan in 1900, followed one year later by Pittsburg Reduction (Alcan) and Carbure Company of Shawinigan (Shawinigan Chemicals) in 1903, according to *The Canadian Encyclopedia.*

Shawinigan saw many national firsts: it was the first to produce aluminum in 1901 and the first to produce carborundum in 1908. It as also the first city in Quebec to have electric street lights, earning it the moniker "City of Lights."

During the First World War, SW&P produced acetone, which was used as a solvent to manufacture cordite, a component needed as a propellant in shells and bullets. After the war, research focused on developing chemicals for civilian use, including vinyl resins for use in plastics and adhesives.

Shawinigan Chemicals, an amalgamation of Canadian Electro Products and Canada Carbide, was the city's flagship company. During the Second World War, it produced the explosive 1,3,5-trinitroperhydro-1,3,5-triazine, called RDX, more powerful than TNT (2,4,6-trinitrotoluene). The company also made plastics, stainless steel and alloys for use in the mining and metallurgical industries. Over the next decades, Shawinigan Chemicals bought or entered into joint ventures with chemical manufacturing and marketing companies from around the world. It was bought out in the mid-1960s by Gulf Oil Corp., later renamed Gulf Oil Canada Ltd.

The 1960s saw a marked decline in the electrochemical industry. Today the city is focused on diversifying into areas like green technologies, software development and metal and mineral processing.

RISE OF SARNIA'S BIOECONOMY

Murray McLaughlin

Bioindustrial Innovation Canada (BIC), which was first formed in 2008, is located at Western Sarnia-Lambton Research Park on the grounds of the former Dow Chemical headquarters. It partners with Western University and the City of Sarnia to develop alternative energy technologies and industrial bio-products, forming a cluster of about 10 bio-chemistry companies as a complement to the petrochemical economy.

Former executive director of BIC, Murray McLaughlin, who once served as Saskatchewan's deputy minister for agriculture, says that its mandate is to facilitate commercialization of a world-scale hybrid chemistry cluster. This, McLaughlin says, is the development of bio-based chemical innovation that focuses on green technologies — building a sustainable industry around the petrochemical plants. "We're not displacing the petroleum industry," says McLaughlin. "We're there to complement it."

McLaughlin says that having a bio-based industry in place is helping reduce greenhouse gas and carbon dioxide emissions among all 19 petrochemical companies in Chemical Valley. He points to BioAmber, which uses plant-based sugars to make succinic acid in lieu of petroleum-based succinic acid. This compound is used in a range of products, including paints and coatings, adhesives, sealants, food additives, cosmetics phthalate-free plasticizers and pharmaceutical compounds, among others.

Since petrochemical industry jobs are declining, due largely to improved data capabilities and computerization, a bio-based cluster presents new alternatives, creating new industries, jobs and growing the community, says McLaughlin. This includes supporting local agriculture. Another company in Sarnia, Comet Biorefining, will be building a sugar mill using corn stover and wheat straw as a feedstock. McLaughlin says that this creates a new income stream for farmers who have formed Cellulosic Sugar Producers Co-op (CSPC) to look after the harvesting and transportation of the stover, which is the leftover stalks, leaves and corn cobs following harvest. The waste is made into sugar, which in turn is used by companies like BioAmber to make succinic acid and other biobased chemicals such as adipic acid. Comet's technology will change waste feedstock — underutilized due to a lack of conversion technologies — into a valuable new commodity. "It positions biomaterials to become competitive alternatives to petroleum-based products," McLaughlin says.

McLaughlin points to the growth of hybrid products that are made by blending a bio-based material and a petrochemical. One example is Woodbridge Foam's car seats, once entirely petroleum-based but now almost 20 percent soybean oil.

Ultimately, says McLaughlin, the creation and increased use of hybrid products will not only keep Sarnia-Lambton relevant as an economic driver in Canada but help mitigate climate change. "If we could reduce the utilization of petroleum by 50 percent and extend the life cycle of petroleum by that same amount, we could reduce greenhouse gas emissions by a huge amount."

innovations included the development of fluid catalytic cracking and the application of the processes of polymerization, isomerization and alkylation to improve petroleum products — especially as the demand for top-grade products escalated during the Second World War.

Isoprene and the war effort

The Second World War was truly "the catalyst for the petrochemical industry," says Bernard West, a chemical engineer and former chair of the Chemical Institute of Canada, who worked in Sarnia with Rhone-Poulenc, Imperial Oil and Polymer Corp. Isoprene — the monomer that forms the basis of natural rubber — had been isolated as early as the 1860s and by 1875, scientists in both Britain and France had discovered that isoprene could be polymerized. In the following decades, groups in Germany, Russia and the US experimented with various forms of synthetic rubber but natural rubber — cheap and abundant — remained in common use.

Then, on Dec. 7, 1941, two years after the start of the Second World War, Japan attacked Hawaii's Pearl Harbor. Singapore also fell to the Japanese, placing 90 percent of natural latex rubber-production capacity under control of the Axis powers. Suddenly, the Allied war effort was in jeopardy. In February 1942, Polymer Corp., a Crown corporation, was created with a mandate to build and operate an integrated synthetic rubber operation, wrote Rowzee, who was a manager at Polymer Corp. in 1950 when he wrote his *Chemistry in Canada* story. Sarnia was chosen as the location for the \$50 million plant, built by Dow Chemical. It was located near the St. Clair river water for cooling but also close to the only refinery that could supply the requirements for petroleum cracked gases and take back residual hydrocarbons. Other refineries supplied benzene and coal for the generation of steam and power. Although it took 14 months after the start of construction before rubber was produced, the success of this highly


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Aerial view of the petrochemical plant at the Imperial Oil refinery in 1964.

integrated plant and the rapid growth of the synthetic rubber industry became "one of the great chemical achievements of all time," Rowzee wrote.

Second World War hostilities ended in September 1945. A radically altered world was ready to embrace evolving technological advances. Sarnia's petrochemical industry ramped up, with an Enbridge pipeline delivering oil from Alberta for feedstock. The highly efficient Great Lakes shipping network became the conduit for exporting these products. DuPont built a polyethylene plant, while C-I-L constructed an ammonia and fertilizer plant.

By 1963, Polymer Corp. was producing 10 percent of the world's synthetic rubber. The 1950s and 1960s were, in essence, the golden age of Chemical Valley, says West, with Sarnians boasting the highest standard of living in Canada. In keeping with its contribution to the Canadian economy, Polymer Corp. was honoured in 1971 with an image of its industrial facility on the back of the Canadian $10 bill.

Oil prices soar

Then, an oil embargo by Arab petroleum-producing states shook global markets. Prices shot up; crude rose from $3 a barrel in 1973 to $12 a barrel by 1974. Sarnia adapted to the new challenges. Several companies: Polymer Corp. (later Polysar), DuPont and Union Carbide, along with the Canada Development Corporation, created Petrosar — now famous as NOVA Chemicals' Corunna site, according to a 2003 article in the *Sarnia Observer* by Scott Stephenson. Union Carbide also built a polyethylene plant, DuPont doubled the capacity of its polyethylene plant and Shell Chemical started to produce isopropyl alcohol and polypropylene plastic, Stephenson wrote.

From oil-based feedstocks to biomass

Eventually, however, by the late 1980s to 1990s, refineries in Sarnia began to close due largely to increased automation and outsourcing. A TransAlta pipeline bringing ethylene from Alberta was shut down. This, says West, was another major catalyst, causing Dow Chemical in Sarnia to permanently lock the factory gates. In order to stop further decline in the petrochemical industry, West and fellow board members of the Canadian Chemical Producers Association realized in the early part of the new millennium that action was needed. They decided to "look at how we could protect what is in Sarnia and see if we could figure out how to get it to grow again. There is a nice infrastructure ecosystem there, not only plants but maintenance and testing companies." This initiative, says West, planted the seeds for a shift in thinking and a move from oil-based feedstocks to ones based on biomass.

Today, the Sarnia-Lambton Petrochemical and Refining Complex still has 19 petrochemical plants that continue to produce products made from crude oil, natural gas, natural gas liquids and ethane that is brought in via pipeline. As West says, "the fossil-fuel industry is not going to disappear overnight. There are just too many drivers that affect it — too many people who rely upon the products that come out of that industry." Nonetheless, several factors, from increasing efficiencies that translate into fewer workers to growing consumer demand for sustainable products, as well as the spectre of climate change, means Sarnia will have to be flexible and continue to evolve technologically, chemically and economically in the future. accn


GLOBAL RESPONSIBILITY

Responsible Care, which was developed by the Canadian chemistry industry and subsequently adopted by 60 nations, brought about international standards related to manufacturing practices, environmental safety and industrial disaster preparedness.

By Peter Diekmeyer


Between November 1995 and June 1996, 109 Haitian children inexplicably developed acute renal failure, hepatitis and pancreatitis, leading to coma and death. Of the 87 youngsters who remained in Haiti for medical care, 85 of them died. Eleven were transported to the United States for intensive care; of these, three perished. A multi-national Acute Renal Investigation Team looked into the outbreak and discovered that the youngsters had developed the deadly symptoms after ingesting acetaminophen syrup. Further probing linked the fever and pain medication to glycerin, a raw material imported to Haiti that was used in the acetaminophen formulation. It was, investigators discovered, contaminated with 24 percent diethylene glycol, a common industrial compound that has been implicated in a number of previous mass poisonings around the world.

The extent of the tragedy, and the work of the investigators, were detailed in an April 15, 1998 article in *JAMA* titled “Epidemic of Pediatric Deaths From Acute Renal Failure Caused by Diethylene Glycol Poisoning.” The team’s final recommendation was simple but profound, “Good manufacturing practice regulations should be used by all pharmaceutical manufacturers to prevent such tragedies.” (The U.S. Food and Drug Administration eventually determined that the supposedly pharmaceutical-grade glycerine was made and contaminated in China.)

The loss of life should never happened. “If proper supply chain procedures had been followed, those deaths could have been avoided,” says Bernard West a member of the International Union of Pure and Applied Chemistry’s Committee on Chemistry and Industry. “The incident demonstrates the importance of continued efforts to implement safety procedures not just locally but internationally.” West should know. He, along with numerous Canadian chemical industry leaders, oversaw the pioneering work that led to the development of Responsible Care, a comprehensive set of chemical safety standards and practices that have been adopted in more than 60 countries.

Bob Masterson

Bob Masterson, CEO of the Chemistry Industry Association of Canada (CIAC) since 2015, has been heavily involved with the Responsible Care file over the years, leading the enactment of updated principles and guidelines that members adhere to. “The standards are voluntary but they exceed legislative provisions currently in force,” says Masterson. “Our members decided early that they would rather do too much than too little.”

Progress has been substantial, particularly in transparency, a key driver of public trust, Masterson says. CIAC members, for example, report data and advances related to all stages of the chemical usage process, from research through to disposal. Measuring advances in key metrics such as toxic and greenhouse gas emissions as well as air and water quality is a critical first step in identifying areas that need attention.

According to the CIAC's *Responsible Care Progress Report 2014*, member emissions fell by 88 percent to 31,000 tonnes by 2012 from 260,000 tonnes in 1992. That wasn't all. Discharges into water were cut by 98 percent and emissions of toxins targeted by the *Canadian Environmental Protection Act* fell by 89 percent. Chemical industry workplaces are also now healthier and safer than ever before — accidents are down by more than 70 percent during that same period.

Bhopal and the Mississauga Miracle

If there was one tragedy that indicated the need for enforceable international standards on environmental safety and disaster preparedness it was the Bhopal, India gas leak. The world's worst industrial disaster occurred in December 1984 when more than 40 tons of methyl isocyanate and other poisonous gases were released at a Union Carbide India Ltd. insecticide plant. Nearly 4,000 people died and many thousands more were injured or suffered premature death. Union Carbide, which tried to dissociate itself from legal responsibility, was accused of neglect regarding safety, training and maintenance.

West says that forerunners of the CIAC had initiated several attempts to set out guiding principles governing chemical use, dating back to the 1970s. One of the near-disasters highlighting the need for better disaster preparedness in Canada was the Mississauga, Ont. Canadian Pacific train derailment in 1979. The cars, which were carrying styrene, toluene, propane, caustic soda and chlorine, derailed at the intersection of Mavis Road and Dundas Street. Dubbed the Mississauga Miracle because no one died, the event was a wakeup call to industry leaders, local communities and governments, who realized that there was little clarity about who was in charge of safety and other issues relating to the incident.

As a result, the Canadian government sponsored a panel of 13 industry experts to oversee production of a report addressing safety issues. This led to the drafting of the six initial codes that would form the Guiding Principles of Responsible Care. These six codes (which have since then been boiled down to three) dealt with chemical research and development, transportation, distribution, waste management and community awareness and emergency management.

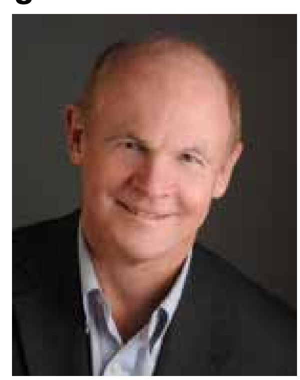
International buy-in is key

Jean Bélanger, who collaborated with West on the case study book, argues that international acceptance of the process is crucial. Global supply chains are increasingly interdependent and "that makes them more vulnerable," says Bélanger, whose actions as president of the CIAC between 1978 and 1996 (which during that time was known as the Canadian Chemical Producers Association) earned him the title of Father of Responsible Care. "If standards are weak in one country, it threatens progress made in all the others."

Canada, through its pioneering work in the field, led the internationalization process. For example, Bélanger was asked to brief Union Carbide's head office staff about advances made in Canada during the company's internal review process following the incident in Bhopal. A major milestone was met when the United States chemical industry adopted Responsible Care guidelines in 1988, because many of the largest chemical companies are headquartered there.

American companies extended the Responsible Care policies throughout their global subsidiaries, a process that vastly multiplied the impact of the initial commitment. Bélanger's briefing to Union Carbide officials soon led to a slew of international presentations and conferences in Europe, Japan, the United Kingdom and around the world. Bélanger's tireless efforts, which continue today, eventually won him an Order of Canada and led to his nomination to the United Nations Environment Program Global 500 Roll of Honour.

Actions on the ground matter



Richard Paton

According to Richard Paton, past CIAC president and adjunct professor in the Master of Public Policy and Administration program at Carleton University, there are several reasons why Responsible Care has had such an impact. Many of these relate to the methodologies through which the process has permeated sector workflows. "Responsible Care is the chemistry industry's continuing commitment to the betterment of society, the environment and the economy through the production of safer and sustainable products and services," Paton says. "The fact that the industry does this openly and with involvement by local and national communities adds considerable credibility to the process."

A key step in that process was the institution of independent verification processes

in 1988 by small groups that generally included a person with industry experience, an independent expert and a community representative. "We were asking CEOs to sign commitments to adhere to Responsible Care guidelines but many were wondering how they could be sure that these were being followed throughout the companies they led," says Paton. "Independent verification gave them that assurance." Incorporation of provisions related to sustainability into the Responsible Care guidelines, a process that Paton facilitated during the years between 2008 and 2010, was another key step in building public credibility.

Responsible Care as a corporate philosophy

Dave Emerson, president of Canada Colors & Chemicals (CCC), agrees that public credibility is crucial. "Our growth over the past years has been built in large part based on our Responsible Care philosophy," says Emerson, a CIAC board member. "For us these are not just rules and procedures that we adhere to. They form an integral part of how we do business."

CCC, a full-service provider of more than 5,000 commodity, specialty and ingredient products, and a compounder of plastics and manufacturer of sulphuric acid and sodium bisulfite, has a broad window into the range of needs and demands of major players across the sector. It also provides Emerson, who has been with the company since 1980 and has been its president since 2004, unique, on-the-ground knowledge of almost all aspects of chemical products production, distribution and use.

A CCC representative was part of the original committee to establish Responsible Care in Canada. The company was the also the first to be externally verified in 1992 for its adherence to RC practices, a process that all CIAC members now undergo every three years. "People in our community appreciate our efforts, especially younger employees," says Emerson. "They all want to work for a company committed to sustainability and social responsibility."

Continued growth opportunities

Decades after making their initial commitments to the Responsible Care process, the initial builders remain dedicated to supporting future actions and ensuring that stakeholders increase their commitment to guidelines while improving their understanding of how it relates to their business or facilities. Although Responsible Care has been active for more than 25 years, "it is not well understood, even in broader chemical associations such as IUPAC, academia, many chemical societies and certainly not by the public," says West. Nonetheless, it's a good story to tell, one that the Canadian chemical sector should be proud to share more broadly with colleagues around the world. accn

New PRESCRIPTION

Canada first became a player on the international pharmaceutical stage when Frederick Banting and Charles Best developed insulin for diabetics in the 1920s.

By Tim Lougheed

UNIVERSITY OF TORONTO

University of Toronto researchers Charles Best and Frederick Banting saved the lives of countless diabetics with their discovery of insulin in the 1920s.

Humanity's search for medicinal agents undoubtedly extends into our prehistoric past. Only since the 19th century, however, has this endeavour taken on the full trappings of scientific investigation. While plenty of diseases continue to afflict us, a huge portion of the world's population now enjoys an unprecedented quality of life in terms of health, for which drugs often deserve a significant part of the credit.

Such progress sometimes began with a comparatively simple innovation, such as the extraction of acetylsalicylic acid from willow bark to create Bayer aspirin, or the powerful anti-cancer drug Taxol, initially derived from the bark of the Pacific yew tree and subsequently licensed for production by Bristol-Myers Squibb.

Bayer and Bristol-Myers Squibb are among a handful of long-lived pharmaceutical manufacturers that now dominate this sector of the economy. They are, in fact, the survivors of a dramatic shift in the business model of drug manufacture during the 20th century. Prior to the First World War, a variety of smaller companies supplied the basic ingredients of various compounds, which were combined locally at pharmacies. This approach changed as post-war chemical engineering techniques made it far more cost-effective to produce patient-ready drugs for distribution from a few central locations. Smaller companies that could not make this transition fell by the wayside or were acquired by major corporations.

The research and development associated with pharmaceutical materials has similarly evolved. Among the iconic examples of such work is the discovery of insulin in the 1920s, a time when diabetes was likely fatal. University of Toronto investigators Frederick Banting and Charles Best began to produce insulin for distribution to patients. As the medical impact and commercial potential of this discovery became apparent, the firm Eli

Lilly partnered with the university to scale up manufacturing for a global market.

Canadian school children are taught this story as a way of illustrating how the country's scientific talent has contributed to health care. Unfortunately, it represents a rare exception to the way in which the process usually occurred. As drug manufacturing became concentrated in fewer corporate hands, these organizations preferred to keep most of their research in-house, rather than rely on outside academics whose findings could be published and become available to competing firms.

Regimes of secrecy and patent protection came to dominate the drug development process, one that regularly excluded scientists at universities and hospitals who might be working on the same problems. Such isolation of their R&D efforts may have been economically advantageous but it took a toll on pharmaceutical companies. In the absence of peer review and collaboration within the larger scientific community, elaborate internal review mechanisms replaced these open processes. It turned out to be an expensive system to establish and even more expensive to maintain. These costs could only be withstood if the end result was exclusive access to a highly profitable, mass-market drug. For several decades this outcome was obtained often enough to allow these giant enterprises to thrive. But as the 20th century closed, the rewards became fewer and further between while the costs grew relentlessly, ultimately forcing a radical transformation of the entire sector. "Until a few years ago, the business models of drug companies — in Canada and elsewhere — focused on internal drug development processes," says Declan Hamill, vice-president, Legal, Regulatory Affairs and Policy with Innovative Medicines Canada. "That model worked very well for quite a long time but for various reasons it has definitely changed."

Innovative Medicines, which until last year went by the name Rx&D, began life as the Canadian Association of Manufacturers of Medicinal and Toilet Products in 1914. Its founding members have long since disappeared or been acquired by one of its 50 current members and its name has changed several times over the years. Nevertheless, this trade association has been central to the often-complicated interplay between these businesses and the government agencies that set regulations to oversee the drugs that they market.

The largest of those businesses have invariably been Canadian subsidiary operations, a reflection of how the multinational character of the industry first emerged. Over the last two decades, many of these branch operations have been reduced or eliminated altogether as corporations coped with rising research expenses and reduced product lines.

Statistics Canada figures point to a steady decline in the number of Canadian pharmaceutical industry research jobs, which peaked in 2006 at just under 6,000 but by 2012 had dropped to around 3,300.

At the same time, the amounts that these companies spent on research and development have also declined, although relative to other parts of the economy they are still substantial. On the definitive list of top 100 Canadian R&D spenders assembled by RE$EARCH Infosource Inc. for 2012, fully one-fifth of the companies are in the pharmaceutical sector and their expenditures were considerable. Generic drug maker Apotex had increased its spending by 19 percent over the previous year to reach $207 million, for example, while Sanofi's spending had fallen by 19 percent but was still a sizeable $122 million.

These changes did not surprise Paul Lucas, who spent 16 years as CEO of GlaxoSmithKline Canada, where he had a front-row seat, watching the longstanding administrative structure of drug manufacturing run headlong into the biochemical difficulties of finding new products. At the beginning of Lucas's career, patent medicines were far fewer and untreatable diseases more common. Advances in scientific knowledge, along with new technology to unravel the molecular biology of receptors or blockers that could serve as drug mechanisms, irrevocably altered the pharmaceutical landscape in the 1980s and 1990s. "That was the golden age of pharmaceutical discovery and development," Lucas says. "You had the cholesterol-lowering agents, you had all the hypertensive drugs, you had a lot more antibiotics, migraine drugs, cancer drugs, HIV drugs."

In retrospect, Lucas adds, these breakthroughs captured most of health care's low-hanging fruit, dealing with problems that were comparatively easy to address with a specific agent. What is now being tackled are much less accommodating diseases, such as neurological disorders or complex cancers whose inner workings have so far resisted pharmaceutical fixes. At the same time, governments were responding to ever-more strident calls for public safety, which placed greater demands on how these products are tested and distributed. "The costs of regulation, getting drugs approved, running clinical trials — it really forced the industry to partner outside their four walls," Lucas says.

In-house pharmaceutical research activities subsequently built new bridges to the academic world in order to share some of the risks and opportunities associated with drug discovery. "It takes years to develop

Nuclear Magnetic Resonance scanning is among the activities conducted at Montreal's NEOMED Institute.

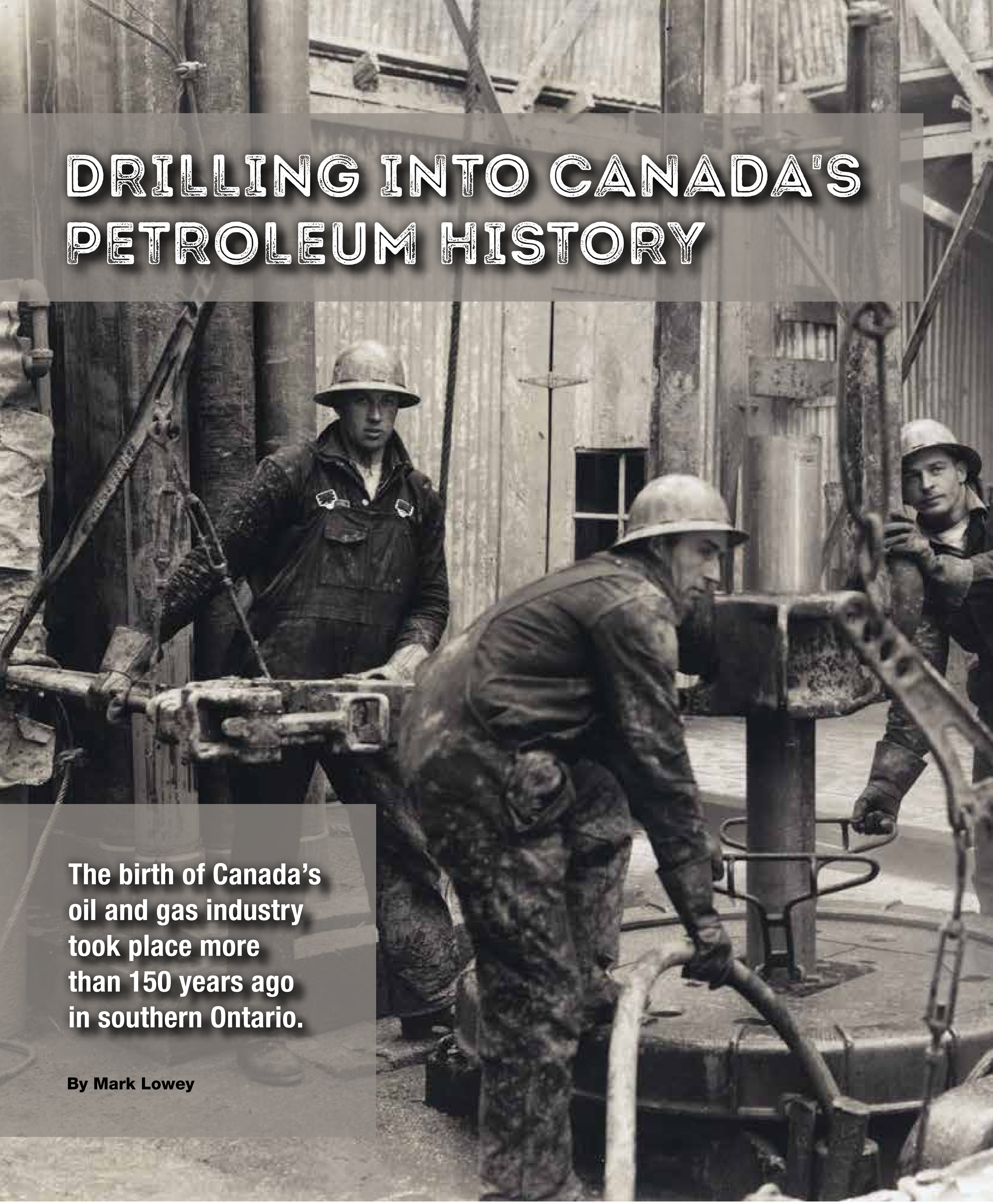
medicines and vaccines," says Hamill, adding that exploratory efforts almost invariably end in failure. As opposed to working behind closed doors, scientific inquiries open to a broader spectrum of researcher who can much more quickly determine what does not work. "Failing faster is an advantage," Hamill adds, pointing to savings in time, money and fruitless effort.

The result has been the emergence of partnerships pooling government support with academic and industry investigators on drug discovery projects that would otherwise be all but impossible to sustain. Such joint undertakings include NEOMED in Montreal (housed in a building vacated several years ago by AstraZeneca), the Medical and Associated Sciences (MaRS) Discovery District in Toronto and the Centre for Drug Research and Development in Vancouver. For Hamill, these sites represent the latest and most practical attempts to meet the objectives originally set by drug manufacturers. "They are examples of institutions that will result in new treatments for Canadians and others around the world," he says. "Canada should be proud of that."

For his part, David Allan, the 2017 winner of the Chemical Institute of Canada's Julia Levy Award for successful commercialization of innovation, feels that Canada can do much more to develop pharmaceutical discoveries. He works with companies in the life sciences and biotechnology that are trying to break into the pharmaceutical sector, something he did with his own firm YM Biosciences, which specialized in the development of hematology and cancer-related products. In 2013 he sold that company to Gilead Sciences, an American R&D giant whose revenues dwarf those of the largest Canadian banks. He marvels that Canada appears unable to spawn these kinds of independent enterprises in a country that punches well above its weight in a burgeoning field of research. "Toronto — just the city of Toronto — produces more peer-reviewed papers in medical science than any other medical centre in the world," he says. "Where are the companies? Where are those taking advantage of these basic knowledge resources to create companies of value?"

Allan contrasts this situation with Canada's place at the forefront of natural resources development, which he credits to a federal flow-through share program that heavily subsidizes risky investments in exploration and development. No such incentive exists to offset risky investments in drug discovery or biotechnology, he says, even though considerable amounts of public money have already been invested to lay the scientific foundation for growth in these areas. "Instead of encouraging investment in lesser-risk geological exploration, public policy should encourage capital for high-risk biological exploration to develop the vast dormant resource of Canada's basic medical research into medicines to benefit patients and provide a return on society's huge investment," he says. "Society needs to make a return on its investment, just like a pharmaceutical manufacturer does. That return only comes when a discovery or innovation is converted into a product that's useful to human health." accn

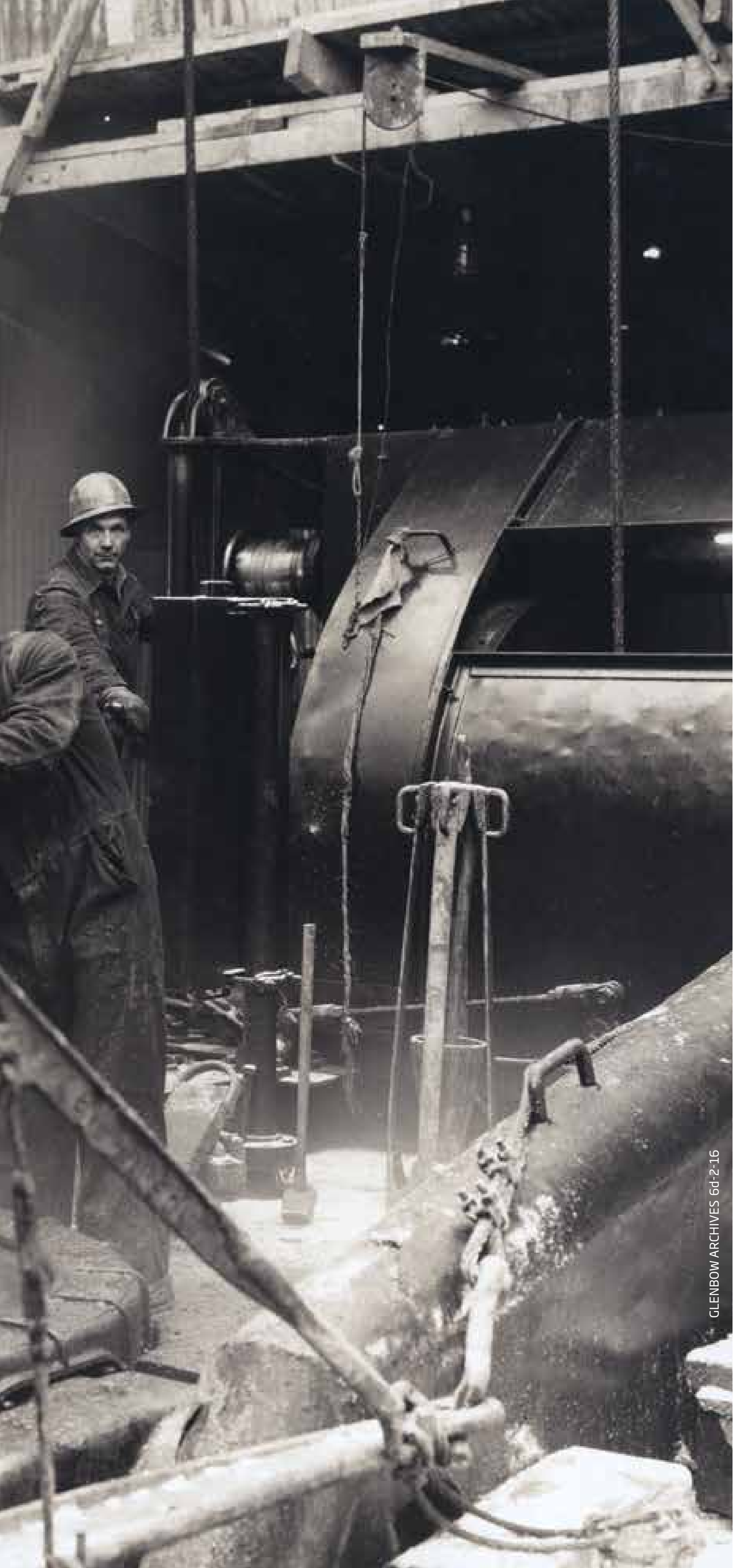
DRILLING INTO CANADA'S PETROLEUM HISTORY



The birth of Canada's oil and gas industry took place more than 150 years ago in southern Ontario.

By Mark Lowey

Roughnecks adding a joint of pipe inside the derrick at a Royalite well in southern Alberta's Turner Valley oil field, 1938.



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James Miller Williams, a carriage maker from Hamilton, Ont. and the founding father of Canada's petroleum industry, was drilling for water in 1858 when he struck oil at a site known as Black Creek in southern Ontario. The discovery became North America's first oil well and the area was renamed Oil Springs. Williams went on to found The Canadian Oil Company, creating facilities for petroleum production, refining and marketing — the first integrated petroleum company on the continent.

Much of the Canadian oil and gas industry's history is like that first discovery: more business acumen and incremental innovation than paradigm-shifting invention. "In the Canadian petroleum industry, very little basic research is carried on; a few companies do development research, while most carry out some form of application research," states a 1960 article in this magazine, then called *Chemistry in Canada*. Not much has changed. There were some exceptions, most notably in the sour (containing hydrogen sulphide) natural gas industry and the heavy oil/oil sands sector, where the nature of the resource necessitated innovation.

"The reason why our industry has had a slow rate of innovation relative to other industries is simply that experimentation, testing and evaluation are very expensive," says Ian Gates, a professor in the Department of Chemical and Petroleum Engineering, Schulich School of Engineering at the University of Calgary. Even a field trial of new technology costs tens of millions of dollars and takes years to run, says Gates, who is leading a major study, titled *Reassembling the Oilsands: Industry, Technology, Society, Environment and Innovation*, looking into why the sector has been slow to innovate.

As for the petrochemicals industry, Canada represents only about one percent of the global chemistry sector, says David Podruzny, vice-president of business and economics at the Chemistry Industry Association of Canada. Arlanxeo, a global synthetic rubber company headquartered in the Netherlands, does world-class research and development in London, Ont. NOVA Chemicals employs more than 300 people in Calgary doing research and

Petroleum industry is heavy economic hitter

Canada's petroleum industry may have lagged historically in game-changing chemical innovation but its economic impact in indisputable. "Over the past five decades, this sector has been the lifeblood of Alberta's economy," says Todd Hirsch, chief economist at ATB Financial. As for the national economy, remember the wildfire in May 2016 that ravaged Fort McMurray in northern Alberta? It forced the temporary shutdown of several oil sands operations: Suncor Energy, Syncrude Canada, Shell Canada, ConocoPhillips Canada, Nexen Energy ULC and Athabasca Oil, knocking 1.2 million barrels a day offline, or more than 40 percent of provincial oil sands production. That was enough to drop Canada's real gross domestic product by an annualized rate of 1.6 percent during the second quarter, Hirsch says.

Robert Mansell, academic director and emeritus professor of economics at the School of Public Policy at the University of Calgary, says the oil and gas industry has, on average, accounted for about one-third of all business investment in the country. "It's the largest private investor in the Canadian economy." According to the Canadian Petroleum Producers Association, the industry invested $36 billion in 2016, down from a peak of $81 billion in capital projects in 2014. Half of Canada's exports of goods and services are related to oil and gas, Mansell says.

development on plastics and chemicals. But overall, "virtually all of the key discoveries and developments have taken place elsewhere," Podruzny says. "Canada has a good reputation for development of ways to improve on what was discovered elsewhere."

Still, there have been some firsts. In 1851, Ontario businessman Charles Nelson Tripp founded the International Mining and Manufacturing Company. It explored the asphalt beds and later the oil springs in Lambton County, Ont., for manufacturing oils, naphtha, paints and varnishes. Three years later, physician and geologist Abraham Gesner of Halifax opened his first plant — albeit in New York — to make keroselain, later known as kerosene. Gesner developed a fractional distillation method to produce the new synthetic lamp oil from coal, natural tar and, eventually, oil.

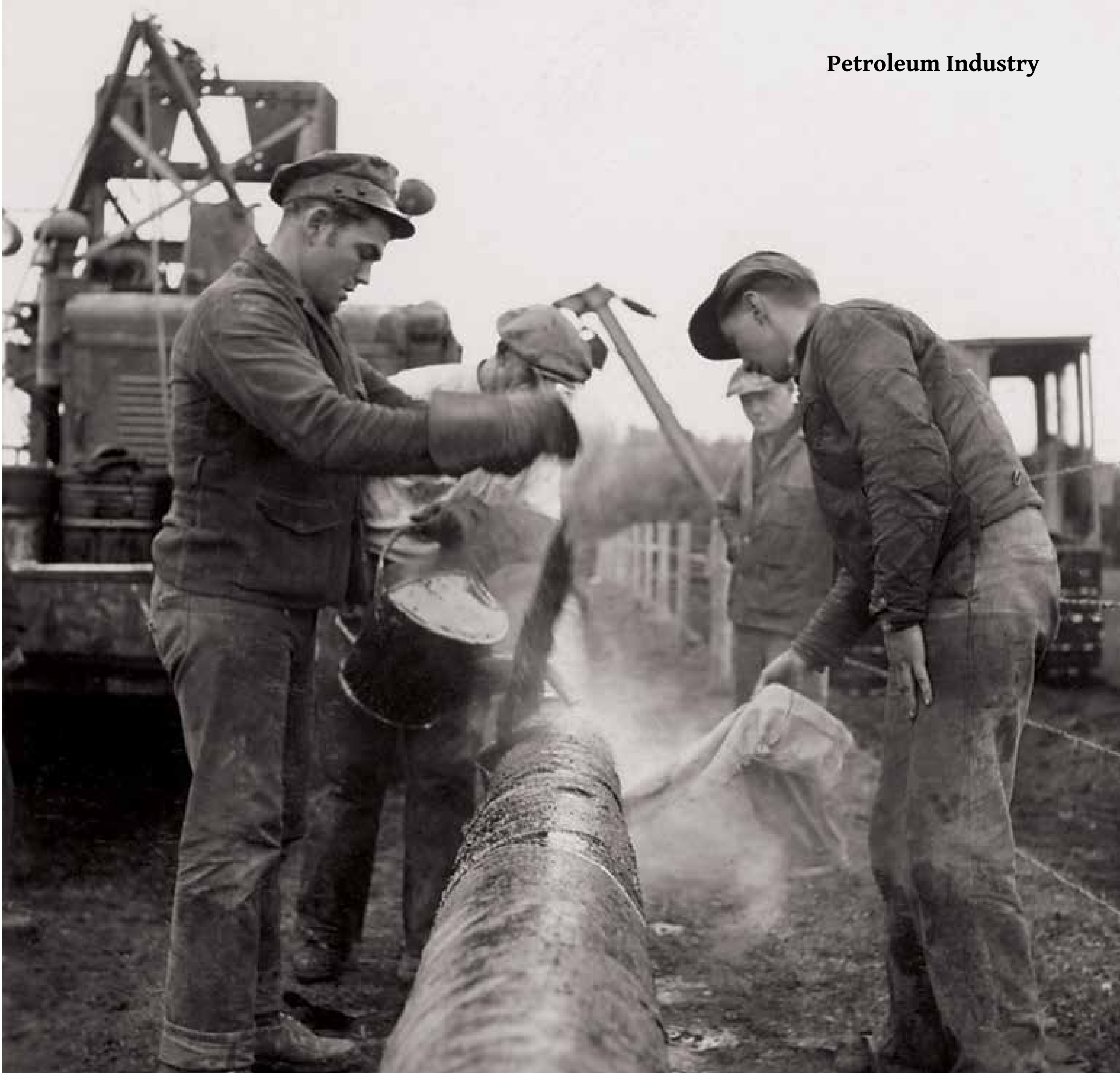
Eugene Coste, an entrepreneur from southwestern Ontario, began drilling for natural gas in 1889 in Essex County, Ont., to supply nearby communities with fuel for lighting, heating and cooking. After moving west, his Canadian Western Natural Gas Company constructed a 270-kilometre pipeline from Bow Island, Alta., to Calgary in 1912. At the time, it was one of the longest and largest-diameter gas pipelines ever built.

In 1924, the first plant in Canada to chemically scrub poisonous hydrogen sulphide (H_2S) from sour natural gas was built in Turner Valley, Alta. But it wasn't until 1952 that the first plant to remove H_2S from natural gas and convert it to sulphur — sold mainly for making fertilizer — was built at Jumping Pound west of Calgary. Joe Lukacs, then a young petroleum engineer and now president and CEO of Canadian Environmental Technology Advancement Corporation (CETAC)-WEST, worked on several of Canada's first sour gas-processing plants. The technology, designed and built in the United States, wasn't suitable for Alberta's high-H_2S natural gas and the harsh winter climate, Lukacs recalls. "Everything was blowing up because of freezing in pipelines due to hydrate formations." The problem with these ice-like plugs of gas and water was solved when Trajan Nitescu, president of Canadian Fina Oil, had twin pipelines heated with glycol buried alongside the gas-gathering pipeline, while Lukacs and Walter Nader, a chemical and petroleum engineer at the University of Alberta, calculated the thermodynamics equation to make it work. The late Don B. Robinson, a U of A chemical engineer, and his graduate student Ding-Yu Peng (now head of the Department of Chemical and Biological Engineering at the University of Saskatchewan), subsequently developed the Peng-Robinson Equation. This mathematical model predicts the effects of pressure, volume and temperature on the behaviour of hydrocarbon-based fluids. The famous equation is still applied in myriad processes and industries every day.

Lukacs went on to form Western Research in Calgary, where he developed the world's first automated system for continuously measuring sulphur dioxide emissions from gas-processing plants' stacks, along with technology to automate the sulphur-recovery process. "Those technologies were developed in Alberta and they're now being used all over the world."

Imperial Oil Company Ltd., established in 1880 when 16 Ontario oil-producing and refining companies merged, played a starring role in Canada's early petroleum and petrochemicals industries. Imperial Oil consolidated its refining operations in 1898 in Sarnia, Ont. The company, which had drilled 133 wells in western Canada without finding a major new oilfield, struck a gusher in 1947 at its Leduc No. 1 exploratory well south of Edmonton. That discovery marked the birth of the modern Canadian oil and gas industry.

Meanwhile, Canada's now-famous oil sands industry was developing in parallel.



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Workers laying pipe for pipeline from Leduc oil field to railhead at Nisku, Alta. near Edmonton in Leduc County, 1947.

In 1925, more than a century after explorer Alexander Mackenzie saw Chipewyan natives using natural bitumen seeps along the Athabasca River to caulk canoes, Karl Clark of the Alberta Research Council perfected a method using hot water and caustic soda to separate oil sands bitumen from sand. In 1964, Great Canadian Oil Sands (now part of Suncor Energy Inc.) won approval for the first of the modern oil sands projects and began production in 1967. Its plant pioneered such processes as separating the lighter hydrocarbon fractions and removing asphalt and sulphur to produce light, low-sulphur synthetic crude oil.

In the 1970s, Roger Butler, an engineer at Imperial Oil and later the first Endowed Chair in Petroleum Engineering at the University of Calgary, invented the steam assisted gravity drainage (SAGD) technique. The method is critical for accessing the estimated 140 billion barrels of bitumen that are too deep to be mined from the surface — comprising about 80 percent of Alberta's proven oil sands reserves. Using two parallel horizontal wells, steam is injected into the upper well and heated bitumen flows into the lower well.

As for the future, Gates expects to see new additives such as catalysts and nanoparticles and so-called smart hydraulic fracturing that will increase production of shale oil and gas and heavy oil and bitumen while reducing energy, water use and greenhouse gas emissions. "It's about having better, more robust processes, not just for the technology in the ground but also for the regulatory and environmental assessments and the social acceptance." accn

Safeguarding *the* central SCIENCE

Key figures in the field reflect the past and the future of chemistry that, as McGill University vice-chancellor Suzanne Fortier says, will surely be amazing.

By Tim Lougheed

At the time of confederation in 1867, chemistry was already well on its way to becoming a mature and powerful scientific discipline that would usher in profound changes in our world, from life-saving medicines and food production technologies to the kaleidoscope of materials that underlie the electronic marvels around us. The *Canadian Chemical News* asked three prominent observers of this discipline how they regard this rich past and where they see the field heading in the future.

HUMBOLDT FOUNDATION / DAVID AUSSERHOFER

Howard Alper

Nurturing the next generation of talent

For Howard Alper, distinguished university professor in the University of Ottawa's Department of Chemistry and Biomolecular Sciences, the history of Canadian chemistry includes a parade of outstanding discoveries and ideas. More importantly, it is a field populated by outstanding personalities. He points to towering figures such as Gerhard Herzberg, John Polanyi and Michael Smith, who earned Nobel prizes for their diverse contributions in areas such as the structure of free radicals, chemical kinetics and the foundation of site-directed mutagenesis. He also points to those who may not have won science's top honours but nevertheless made profound contributions, such as molecular pharmacologist Bernard Belleau, who pioneered the first effective drugs to fight AIDS in the 1980s and founded a company to carry on this research. "These are fantastic people," says Alper. "Recalling their names and work is an important way of celebrating what has gone on in Canadian chemistry over the past century."

Alper also regards the careers of these individuals as useful lenses to view the

MCGILL UNIVERSITY

impact of Canadian chemistry, not just for new science but also new technology. Our modern lifestyle owes much to these chemical innovators and Alper fully expects that influence to be apparent as we continue to benefit from the advent of new manufacturing processes, new materials, new types of food production and new medicines. ""Chemistry will be pivotal to the success of what is called the Fourth Industrial Revolution, as well as the rate at which it takes hold and accelerates," he says, adding that the momentum will rely heavily on how we educate the next generation of chemists. "The role of developing a strong chemistry curriculum for students is just as valuable a contribution to the discipline as any landmark discovery or invention associated with the science," he says. "Curriculum reflects and shapes the methodology of the field and the way in which people will explore it."

Alper points out that while traditional chemical principles occupy the core of this teaching, a great many other areas are now connected to this subject matter. He had direct experience with these new linkages during his tenure as vice-president of research at uOttawa, when he oversaw the introduction of a biopharmaceutical program that broke new interdisciplinary ground on campus and became extremely popular among students seeking to work in this field. "Here was something not only fundamentally important but also attuned to the times and the needs of industry," he recalls. Looking ahead, Alper suggests that this kind of initiative will not be exceptional but altogether typical of how chemistry education faces the future. It is also why he is equally pleased to recall another milestone from his time in that office, when he launched the Excellence in Education prize. "It's one thing to do excellent research but the foundation of an institution is its education; its curriculum must be appropriate for the time and forward-looking."

Suzanne Fortier

From understanding to action

Suzanne Fortier's academic roots as a chemist lie in areas such as the use of complex numerical modalities to determine protein structure and mine crystallographic data. Fortier has also maintained a high-level perspective on how this scientific discipline affects society and the economy. The principal and vice-chancellor of McGill University since 2013, Fortier, a former NSERC president, is also a member of the Minister of Finance's Advisory Council on Economic Growth Council, the World Economic Forum's Global University Leaders Forum (GULF) as well as a member of the International Jury of France's Investissements d'Avenir and Canada's Business - Higher Education Roundtable. "Chemists, to me, have always been practical people," she says. "They are driven by a purpose, they want to do something with their science."

Fortier suggests that the past century has seen chemistry move into ever-more practical activities, progressing from a desire to understand to an ability to act. "We were trying to understand what molecules looked like and what they did," she says. "But now people are designing and constructing all sorts of things, for example, architectures of molecules that build on that understanding."

According to Fortier, this understanding has grown with the technological ability to model complex systems, which makes it possible to explore topics such as atmospheric chemistry or nanoscale interactions. Among the unifying themes of this work has been the concept of sustainable chemistry — replacing expensive, environmentally harmful chemical processes of the past with alternatives that can be carried on well into the future. "Sustainability comes naturally to chemists," Fortier says, pointing to such game-changing concepts as green chemistry and yield optimization.

Mario Pinto

As to what the future holds for the upcoming generation of chemists, Fortier remarks that, "students today are very interested in innovation. Some of them may want a career like their professors but many more want to do something else, to work with people in many different disciplines. We already see chemists working in fields such as biology or medicine and we'll see even more of that. As we enter the Fourth Industrial Revolution, we'll start seeing the fusion of the biological, the physical and the digital. These networks will be much more diversified and we can't yet imagine what they'll be able to do."

Above all, Fortier says, chemists serve as the intermediaries between various branches of science. She sees students eager to embrace this role, even if they do not find it in any kind of regular curriculum. "They will not wait for you to create the program for them. They are creating their own opportunities, whether it is through a campus club, a business or some other initiative." As for where these efforts will arrive, Fortier is content to be surprised. "We will have a big wow factor," she says. "One thing I'm sure of is that I'll be amazed."

Guarding the centre

As a chemical biologist at Simon Fraser University, Mario Pinto spent much of his career examining disease processes. In addition to serving in senior research and administrative positions at the university, Pinto has also been active in a number of chemistry organizations, serving as Canada's representative to the International Carbohydrate Organization, vice-chair of the Chemical Institute of Canada and president of the Canadian Society for Chemistry. In 2014 he became president of the Natural Sciences and Engineering Research Council of Canada (NSERC). With a front-row seat looking at changes in the laboratory as well as government policy, Pinto argues that chemistry must take care not to become a victim of its own success.

"The past 100 years have positioned chemistry as a central science," Pinto says. "But the evolution of science has also blurred the boundaries between disciplines, so that chemistry has been subsumed into a number of diverse fields, from chemical biology to materials science."

Pinto says that it has been easy for outside observers to blame chemistry for problems, such as how the ubiquitous use of plastics in consumer products has led to this material becoming an equally ubiquitous pollutant. The good and the bad are reflections of just how significant the impact chemistry has had on civilization. Moreover, seemingly unrelated innovations such as photovoltaic cells, new battery materials, vaccines or smart phones would be unthinkable without the chemical innovations that made this technology possible. "There's a lot of chemistry there," he says, "but we don't think of these inventions in those terms. In this sense the discipline has lost its identity."

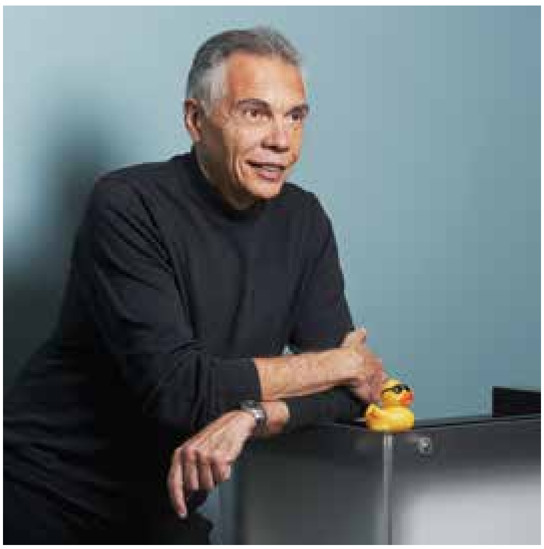
This could be a problem as we head into the next century of scientific and technological progress, Pinto argues. "Traditional sub-disciplines of chemistry will have to be dissolved and new ones forged. Chemistry must draw attention to its role in these new sub-disciplines, otherwise one will not be able to recruit the next generation of students. This requires a major modification of curricula, which are extremely traditional. In fact, if done correctly, it will completely transform chemistry departments on campuses."

Pinto says that the power and the opportunity to effect these changes are already in the hands of university faculty members but if they fail to do so they may consign the entire discipline to the history books. "So how does one get back to that place where chemistry is a central science?" he asks. "Students are looking forward to a Fourth Industrial Revolution — a confluence of digital, biological and engineering worlds. Chemistry is an integral component but, he adds, "if it continues to be taught in the same old-fashioned way" students may miss out on its importance. accn

NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA

The Canadian discovery that sparked a global industry

By Joe Schwarcz



On May 4, 1892 Thomas Willson, a Canadian inventor, placed some calcium oxide (lime), coal tar and aluminum oxide in a container and heated the mix to a high temperature. Willson was hoping to produce metallic aluminum, an expensive commodity at the time. The thinking was sound. Coal tar — basically carbon — was known to convert lime to metallic calcium. Willson knew that calcium was a more active metal than aluminum and he hoped that it would strip oxygen away from the aluminum oxide. After heating it he opened the furnace, hoping to see shiny metallic aluminum. Instead he saw a dark residue. Frustrated, he threw the residue into the stream running outside his lab. This, of course, was long before the existence of any environmental laws. It turned out to be a lucky thing.

As soon as the stuff hit the water, huge bubbles began to form and a plume of water shot up into the air. In an instant, disappointment changed into elation. Whatever Willson had made seemed more interesting than the aluminum he had sought. He repeated his experiment and, to his relief, produced the same residue, which once again produced gas when it reacted with water. Furthermore, the gas burned with a bright, sooty flame. It didn't take long before chemical analysis showed that Willson's residue was calcium carbide and the gas liberated on reaction with water was acetylene. The highly combustible acetylene was not a new discovery. Thirty years earlier, Friedrich Wohler, a chemistry professor from the University of Gottingen in Germany, had made calcium carbide by heating calcium with charcoal to a high temperature and observing that it formed acetylene when reacted with water. But Wohler's method wasn't an efficient way of making the carbide and hence not as useful for creating the gas on an industrial scale. Willson's method yielded large amounts of calcium carbide and afforded a ready method for making acetylene.

So, why was this important? The 1890s was the era of the gaslight. The world's first gaslight company had been established in London in 1813 and subsequently an elaborate network of gas lines had ensured that British city streets and homes could be well lit. But mobile lighting was still restricted to candles and kerosene lamps. Willson realized his acetylene, which burned with a more brilliant flame than kerosene, had great market potential. By 1895 he had founded a company that eventually became Union Carbide, one of globe's biggest chemical companies. Soon, calcium carbide-based lamps appeared. They were clever devices in which water dripped into a container of carbide and generated acetylene gas. This in turn was channeled to a nozzle where it could be ignited. A mirrored surface behind the flame increased the intensity of the light.

Car manufacturers jumped on the idea, using carbide lamps for headlights. Miners also used the lamps, although not without risk. Combustible gases are often present in mines and in some cases were ignited by carbide lamps — with tragic results.

Today, carbide lamps have been relegated to the history books but acetylene is still one of the most important industrial chemicals in existence. In fact, modern life would not be possible without it. In 1895, the same year that Willson established his company, the French chemist Henry Louis Le Châtelier, a professor of chemistry at the College de France, discovered that when acetylene is burned with an equal volume of oxygen, the temperature of the flame — more than 3,000 C — was higher than that achievable by any other gas and hot enough to melt steel. The concept of welding was born. Without oxy-acetylene welding torches, construction, as we know it, would not be possible.

Acetylene has other uses as well. About half of all acetylene produced today goes towards the production of other organic chemicals. The addition of hydrogen cyanide to acetylene, for example, yields acrylonitrile, which is used in the production of acrylic fibres. Acetylene can also be converted into vinyl acetylene, the raw material needed to manufacture the synthetic rubber neoprene, a discovery credited to DuPont chemist Wallace Carothers of the United States.

And all of these inventions came about thanks to Canadian chemist Willson capitalizing upon a chance discovery. accn

Joe Schwarcz is the director of McGill University's Office for Science and Society. Read his blog at www.mcgill.ca/oss.

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