Chemical Engineering at

the University of Sherbrooke

J. Peter Jones, Bernard Marcos, and Gervais Soucy

The University of Sherbrooke is a French-language university in the city of Sherbrooke, Quebec. It is 100 miles east of Montreal, about 30 miles from the Vermont border, and approximately due north of Boston, Mass. The Main Campus, which houses the university administration and eight faculties, and the separate Health Campus—with the Faculty of Medicine and Health Sciences, and forming part of the Sherbrooke University Hospital Centre Complex—are all located in Sherbrooke, at the heart of the beautiful Eastern Townships region of southern Quebec. The area is well known for its many rivers, lakes, and mountains. Part of the Northern Appalachian chain of mountains, it is a favored cottage, skiing, and recreation area for Montrealers, among others.

THE UNIVERSITY

The university includes nine faculties and offers more than 260 study programs, at both the undergraduate and graduate levels.

The university has been experiencing unprecedented development: Since 2001, 650 people have been hired. In fact, more than 40% of its currently employed professionals joined the university within the last four years. In keeping with this growth, the university is presently investing some $310 million to renovate and make additions to existing buildings. Close to 35,000 students attend courses at the University of Sherbrooke, some 85% coming from outside the region; more than 1,300 international students are enrolled on a yearly basis.

A study, published annually for the past three years in *The Globe and Mail* national newspaper, reveals that the University of Sherbrooke has consistently been the most appreciated university in Quebec and is among the three top-ranked universities in Canada. According to *MacLean* magazine's annual study, the University of Sherbrooke enjoys the best overall reputation in Quebec. The university is first in Canada for the excellence of its cooperative system, which allows students to alternate between study terms and paid-work terms, and for the high quality of services offered to its students. The co-op education system provides a large number of students with paid-work terms, giving them an opportunity to combine the theoretical notions acquired in the formal classroom with their practical experiences as received in the workplace. Students

Known as The Agora, the campus fountain is a frequent fair-weather gathering spot of Sherbrooke students and visitors alike.

involved in Sherbrooke's cooperative education system earn more than $30 million in salaries annually, for more than 4,000 paid-work terms.

A LEADER IN RESEARCH AND CREATION

The University of Sherbrooke has identified the fields of expertise it intends to develop, in both teaching and research, to meet tomorrow's requirements both nationally and internationally. As well, the university is addressing increasing numbers of requests for "partnerships" from institutions in Europe, Latin America, North Africa, and Asia concerning its master's and doctoral degree programs, especially in the fields of education, administration, cooperative management, and applied ethics. It also receives the most royalties of any Canadian university from past inventions by professors and researchers. Thus, it has received more than $79 million royalties to date, including $14.3 million in the 2002-2003 academic year alone. In addition, some 22 spinoff companies have been created by the University of Sherbrooke over the past 20 years.

In fact, the university holds title to 300 patents (both established and pending)—51% having been transferred to businesses. Notable among these innovations is the ACELP technology, developed at the University of Sherbrooke, which has become the standard in mobile telephony (with more than a billion users) and on the Internet (with more than 500 million users).

RECENT EARLY HISTORY

Sherbrooke's Department of Chemical Engineering started its existence as a process engineering section in the Department of Mechanical Engineering. Originally, there were three professors: **Bernard Coupal, André Marsan**, and a French military co-operant, **Bernard Koehret**. They were later joined by **Maurice Ruel**, **Esteban Chornet**, and **Normand Thérien**. In December 1971, under the determined leadership of Coupal, the department was established as a full department in its own right, with a distinct program of studies in chemical engineering.

The battle to become a separate department was difficult as other departments were wary they would lose scarce resources, but Coupal advised them that the establishment of a Department of Chemical Engineering could be done at "zero cost." Some of the older professors from other departments long remembered his statement, and used it liberally when later the department was fighting for an increased share of resources.

The department continues to be the only one in a Quebec university to have a fully cooperative program.

Sherbrooke's Chemical Engineering Faculty

Nicolas Abatzoglou's activities are in the areas of thermo-catalytic chemical reactors and the behavior of particulate systems in reactive and nonreactive industrial processes. His work is being used by companies for the gasification process commercialization, for conditioning of industrial gases, and for pharmaceutical product formulation. He has extensive scientific and industrial R&D experience in fields at the "juncture" of energy and environment as well as in dry formulation of pharmaceutical products, and has initiated a substantial program on Process Analytical Technology for the pharmaceutical industry. He teaches various courses including the capstone design course, reaction engineering, pharmaceutical engineering processes, and separation and purification in biotechnology.

Maher Boulos is a leading figure in the thermal plasma field, along with colleagues in Minnesota, France, Switzerland, and Japan. His work through the Sherbrooke Plasma Research Center has been broadly based and includes many novel experimental studies, but it has also included industrial scale development studies, modeling, and—with collaborators—more "in depth" theoretical work.

Esteban Chornet is a leading international figure in research whose work has led to the production of chemicals and energy values from biomaterials and organic wastes. The first chemical engineer in Canada to obtain the prestigious Steacie Fellowship for research, he is the founder of the research center on the transformation of biological materials. Much of his recent work has been applied to environmental concerns (*e.g.*, "green" chemical engineering, biomaterials recycling, and environmental concerns). He has initiated a number of high-tech spinoffs in Quebec and has also developed spinoffs in his native Catalonia.

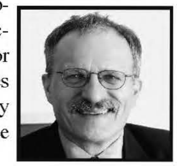
Nathalie Faucheux, a biochemist with a Ph.D. in biomedical engineering, plans to determine how biomaterials and cells can share information with one another. She is one of the few researchers in the world working to gain a deeper understanding of how biochemical signals, triggered by contact with a biomaterial, activate a cell's capacity to survive, multiply, and function. The cutting-edge materials she is using are based on grafts of small molecules called peptides, which, among other things, promote cell adhesion. She holds a Tier 2 Canada Research Chair.

François Gitzhofer was recruited for his expertise in materials engineering from the University of Limoges, France. He has become director of the department's Plasma Research Group, which is continuously evolving toward a broader role in fuel cell development and other energy-intensive applications. His focus is on creating new ways of making coatings on various substrates, using both established and newly emerging plasma technologies.

Denis Gravelle, one of the earliest professors to join the department, is an expert in the application of thermodynamics to thermal plasma systems and in the use of spectroscopic methods/techniques for a fuller understanding of plasma torch dynamics. A key teacher of thermodynamics at both the graduate and undergraduate levels, he is also involved in the lab courses, aiming at the integration of basic engineering concepts of thermodynamics, transport phenomena, and reaction kinetics.

Michèle Heitz, the associate dean for students (Engineering Faculty) and a full professor, teaches introduction to chemical engineering, thermodynamics, and chemical thermodynamics. She is also in charge of integrating projects for both the chemical and the biotechnological first-year students. Since 2002, she has also taught air pollution control and design, introduction to biochemical engineering, and chemical kinetics and reactor engineering. Her current research projects include air treatments by biofiltration as well as biodiesel production and biomass and whey valorization—both topics involving various chemical and biotechnological approaches.

Peter Jones arrived at the Sherbrooke shortly after the department was created. He has developed a research area in industrial water treatment and the application of statistical methods to environmental problems, and more generally, to experimental research. A past chairman of the department, he was director of the environmental engineering and science master's program and vice dean for research.



Jerzy Jurewicz is a specialist in the area of plasma generation, using either direct or high-frequency AC currents. He applies this expertise to the development of new reactors for the synthesis of new products, especially for nanometric powders. Jerzy is responsible for courses in safety in the first year and also in process safety courses in the fourth year, and is a key member of the design course team.

Bernard Marcos has done much work in the field of expert systems and neural networks as well as pursuing educational research such as the use of a system of intelligent tutorials. He was the first director of the new program in biotechnological engineering.

Pierre Proulx has been involved in mathematical modeling of thermal plasmas since his graduate studies under the supervision of Maher Boulos in the Plasma Research Center. His current projects entail mathematical modeling of complex reactors. He teaches transport phenomena and process control.

Joël Sirois, the most recently hired professor, comes with a very strong background in biotechnology and was recently the chief technology officer at a start-up company in this field. His focus is in the areas of characterization, modeling, and optimization of cell metabolism and the design and scale-up of bioreactors.

Gervais Soucy is current chair of the department. His teaching is concentrated in unit operations. His research field is in the application of new technologies for various processes in the aluminium industry. He has also developed expertise in thermal plasma technology to produce carbon nanostructures.

Normand Thérien, recently retired from the department, is an expert in the application of mathematical techniques to environmental problems. His most important work has been in the area of modeling of hydroelectric reservoirs, where he has been an important figure in determining how mercury can accumulate in reservoirs and render fish unfit for human consumption.

Patrick Vermette is a researcher at the Research Centre on Aging and is an engineer and professor in the department, with a joint appointment in the Service of Orthopaedics. He has built a state-of-the-art laboratory for surface science and tissue engineering studies. He and co-workers are involved in fields including biomaterials, angiogenesis, colloids and interface science, drug delivery systems, bioreactors, tissue engineering, and haematopoietic stem cells.

THE COOPERATIVE PROGRAM

The Faculty of Engineering at the University of Sherbrooke was a very early adopter of the cooperative system of engineering in North America. The University of Waterloo had initially adopted the cooperative system in 1956, and the University of Sherbrooke followed in 1966, before the Department of Chemical Engineering was formed. The co-op system seeks to prepare students for their future career(s) by providing the practical experience that meets employer requirements in the workplace. Thus, the work term offers students the opportunity to acquire practical experience and to develop competencies (knowledge, skills, attitudes, values, etc.) relevant to their future careers. Cooperative education, a pedagogical approach whereby students spend alternate trimesters studying in the classroom and earning wages in the workplace, also offers many valuable features to potential employers. As a pioneer of cooperative education in Quebec, the University of Sherbrooke is proud to be a leader in this expanding field. A result is that the University of Sherbrooke now ranks second in Canada—and is among the top five advanced learning institutions in North America—for the importance given to its cooperative education system. In the Department of Chemical Engineering, students are able to achieve this gradual integration by switching alternate trimesters between their paid terms in the workplace and their study terms at the university. When students graduate, they will have served five work terms (15 weeks / term) in an industrial company (90%) or in a research laboratory (10%). Since there are eight academic sessions, the student obtains his B.Ing. degree after a period of 52 months.

THE UNDERGRADUATE PROGRAMS

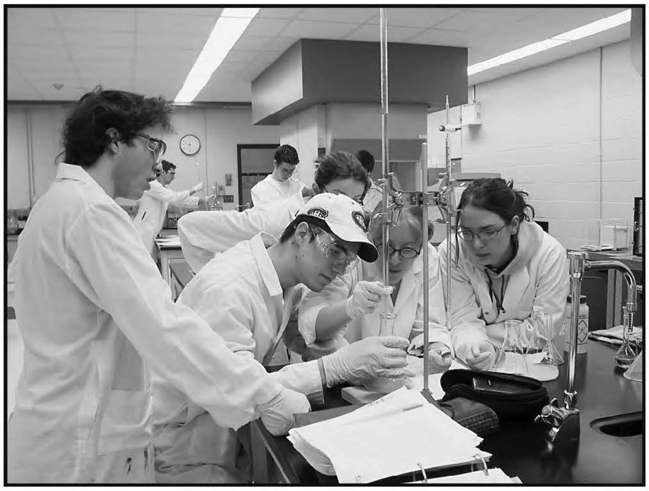
Chemical Engineering

The Department of Chemical Engineering has always kept up to date with the needs of employers in Quebec and the rest of Canada.

The studies program in chemical engineering was completely overhauled for students set to begin in September 2001 and graduate in December 2005. Table 1 presents the curriculum of the reformed chemical engineering program. We have since initiated five cohorts, or graduating classes, to this new

TABLE 1
Chemical Engineering

Session	Description
S-1	**Introduction to chemical engineering** The role of the engineer, safety and risks, chemistry, communications
S-2	**Measurement techniques for use in the laboratory and the factory/plant** Instrumentation, chemistry, chemical analysis techniques, reports, controls
T-1	**Work term #1**
At the end of the first year, the student should be capable of describing the chemical engineer's role and of undertaking control actions and performing analyses, both in the laboratory and at the plant; thereby displaying, at an early stage, a satisfactory competence level in performing the necessary tasks.	
S-3	**Transport and exchange in fluids** Fundamentals of chemical transport/transfers in processes
T-2	**Work term #2**
S-4	**Design of the basic units employed for a chemical process** Advanced chemical transfer/transport, chemical reactor and associated units calculations
At the end of the second year, the student should be capable of modeling the operations of several parts of a functioning chemical process plant.	
T-3	**Work term #3**
S-5	**Industrial scale plant operations** Control methods, techno-economics, process control laboratories
S-6	**Design basics of industrial-scale chemical processes** Types of processes, process simulation, environmental and safety aspects
At the end of the third year, the student should be capable of designing the unit parts and creating the basic overall process concept for an industrial-scale process.	
T-4	**Work term #4**
S-7	**Combining process design skills and experiences – I** Integration of all aspects required to establish, modify, and operate a chemical industry installation at an important scale
T-5	**Work term #5**
S-8	**Combining process design skills and experiences – II** Integration of all aspects required to establish, modify, and operate a chemical industry installation at an important scale
At the end of the fourth year, the student should be capable of designing the unit parts and creating the basic overall process, taking into account relevant aspects of process economics as well as social and environmental issues.	



Sherbrooke students pitch in on a project in one of the university's well-equipped labs.

regime. This overhaul was dictated by our knowledge of the companies that hire our graduates. We were also influenced by the tradition of innovation in pedagogical methods used in the university's Faculty of Engineering. We have aligned our developments with the goal that engineering graduates of our programs will be responsible for the development of new products and processes. Most of these new products and processes are not even mentioned in traditional course materials for aspiring chemical engineers, yet our students must now develop ability to work creatively in these areas. We have therefore developed three distinct avenues for going forward:

- *Students are responsible for their own development, which is central to the educational process. They must combine their technical development with the simultaneous improvement of their leadership skills, their entrepreneurship, their teamwork skills, and their respect for their profession.*
- *Students must now take full and early advantage of the new computing and information technologies at their disposal, especially the software products specific to their profession and their technical competence as chemical engineers.*
- *Courses cannot be approached separately. We and the students must find the commonalities through the sessional projects program, activated during each of the first, third, and fourth years.*

The result has been an immersion in the practice of chemical engineering from the very first session. Students were often ill-prepared for some of the challenges they faced, but through their initiative and determination they were able, nevertheless, to produce very interesting results. The projects performed in those early sessions required a lot of "digging" to find pertinent information. This information was then applied to experimental setups, which they also had to design. They did, however, have considerable help from professors leading the course(s) for each session, along with assistance from departmental technicians. The project is a capstone design project, with which we have now had considerable success for a number of years. These projects are presented at the CSChE competitions. We have won the SNC–Lavalin prize a number of times.

The 40 courses offered in the program are distributed in the following manner:

- *11 courses as general engineering courses in mathematics, thermodynamics, and materials*
- *17 courses in chemical engineering, transport phenomena, unit operations, and reactor design*
- *six courses in humanities and social science, law, ethics, and engineering economics*
- *six courses in the students' chosen major*

Students are mentored by their more-senior peers, who help them become accustomed to the range of department operations and also provide them with professional contacts at the very beginning of their professional careers. The unifying projects chosen for each session are an excellent initiation to the later work terms, following two sessions spent in the department. Through the projects students also learn about the human and societal aspects of their chosen profession.

Biotechnological Engineering

The numerous recent developments in biotechnology and in the medical sciences have led the Engineering Faculty to readapt its curricula under the belief that the most precious asset of a profession is its intellectual core. In an era of rapid evolution in biotechnology-based industry, it is imperative that the biotechnological engineering discipline define its own core. It must strengthen its core through scholarly activities and diverse applications. Considering that biotechnology constitutes a broad field, biotechnological engineers need to integrate skills in engineering principles, process engineering, and biological sciences, without being restricted to particular applications. Biotechnological engineering programs must take into account the complexity of living systems with their discrete and nonlinear relationships. The integration of complex engineering principles is not a simple task, and the biology-engineering barrier is an obstacle that has to be overcome. It is not sufficient to incorporate biological science courses into a chemical engineering curriculum hoping that students will be capable of integrating both concepts. Biotechnological engineers must eliminate the present gap and correct misunderstandings between traditional engineers and biologists. They must accept the fact that living organisms are not entirely predictable. Consequently, they must master basic knowledge of living organisms and bioproducts, and of the fundamental unit operations and simulation tools used by engineers. They must understand the physiology of prokaryotes and eukaryotes as well as the engineering concepts used in bioprocesses. Biotechnological engineers must also be able to operate and control small- and large-scale culture systems of cells and micro-organisms for the production of products of commercial potential (*e.g.*, proteins, antibiotics) as well as the downstream processing, including separation and purification of biomacromolecules. Finally, they must be skilled in project management and quality control. Broadly speaking, biotechnological engineers will be called upon to solve problems through the development of bioproducts and bioprocesses that use living organisms or the products they synthesize.

The biotechnological engineering program at the University of Sherbrooke was originated by the departments of biology and chemical engineering. It took four years to build the program, which now offers an integrated training in biotechnological engineering. Table 2 presents the curriculum of the new Biotechnological Engineering program at Sherbrooke. The program is divided into eight terms that include laboratory studies, applied projects, and lectures.

Creating a new discipline may present some drawbacks for the employment of new graduates. Industry will need to learn what a biotechnological engineer is—just as it understands what chemical engineers and biologists are. That is why the biotechnological engineering program was developed with industrial partners. These industrial partners are regularly updated on the curriculum's development. Another area of concern is that biotechnological engineers may be too narrowly trained and too application-oriented. As explained previously, the biotechnological engineering program is a science-based program that should ultimately alleviate a too-narrow perspective.

The goal of the training is to prepare a generalist engineer who is able to manage the evolution of the biotechnology industry. The wide breadth of knowledge of tomorrow's biotechnological engineers will be an important advantage to them.

Several segments of the bio-industry are relevant to the employment of future biotechnological engineers: biopharmaceutical and drug companies; agribusiness and food companies; environmental biotechnology companies; biomedical instrumentation companies; biomaterials; and the tissue-engineering sector.

TABLE 2
Biotechnological Engineering

Session	Description
S-1	**Introduction to Biotechnological Engineering** Role of the engineer, safety and risks, biochemistry, information technology
S-2	**Introduction to Biology** Biology, cell biology, functional biology, microbiology, laboratory techniques
At the end of the first year, the student should be able to describe the role of the engineer and to make measurements and perform laboratory analysis.	
S-3	**Genetics and transport phenomena** The fundamentals of genetics and chemical transport
T-1	**Work term #1**
S-4	**Design of basic units** Advanced transport, unit operations, experimental protocols
At the end of the second year, the student should be able to model the behavior of a number of the units that make up a biotechnological process.	
T-2	**Work term #2**
S-5	**Operation of industrial unit processes** Bioreactors, process control, engineering economics, biological polymers
T-3	**Work term #3**
At the end of the third year, the student should be able to design a process and the functional units to make it operate.	
S-6	**Downstream operations** Separation and purification, materials and biomaterials, biomolecular engineering
T-4	**Work term #4**
S-7	**Design of biotechnological processes** GMP-GLP standards, process simulation, design
S-8	**Integration of the abilities required to design a chemical process** Integrate all the aspects related to the building, the modification, and the operation of a large biotechnological industrial installation
At the end of the fourth year, the student should be able to design a process to include all of the economic, environmental, safety, and societal aspects for functioning in today's marketplace.	

Double Degree Program with Bishop's University

Sherbrooke students may choose to earn a double degree in engineering and liberal arts in a joint program with Bishop's University. The engineering program includes four, four-month, paid-work internships. The remainder of the liberal arts program is undertaken by taking selected courses at Bishop's University, located a few kilometers away from the University of Sherbrooke.

The liberal arts degree provides for a broad education in the social and human sciences, allowing students to develop fully as individuals in a chosen humanities specialty: history, literature, philosophy, fine arts, or theater.

This exclusive program is the result of close cooperation between the University of Sherbrooke and Bishop's University. It allows students to study in both of Canada's official languages while also experiencing the two unique and distinct university cultures.

Project-Based Learning Approach

The project-based learning approach is used to integrate coursework within an academic session in first-year projects and the third-year and final-year design project. Project-based learning is a new approach in the educational field. It was chosen by the department to fill new professional and industrial requirements. The main features of our approach are:

- *The project involves solution of a problem taken from a "real world" case. For instance, the last-year design project was an oil sands exploitation situation; the first-year project was the design of a process for the valorization of lactoserum.*
- *The student is responsible for this "on the job" learning and the initiative is to be taken by the students. The class is divided into small teams and collaborative learning principles are used to find and share new knowledge. At the end of these projects, teachers have often noted that their students have improved appreciably in the application of self-learning skills.*
- *The project results in a "deliverable" (i.e., a process, product, flow sheet, report). In the last year, the deliverable (for the last-year project) was the design and specifications for the oil sands plant; the end product (for the first-year project) was the design and monitoring of a pilot plant for lactoserum valorization.*
- *The work lasts for a realistic amount of time. Each project is spread over two sessions.*
- *Professors involved are considered an advisory committee and the approach is student-centered. The teacher team performs the "follow-up" each week and provides advice, if necessary. The team realizes the assessment of the project. The project is also evaluated by other students.*

Students subsequently present the project at public conferences and the annual Canadian Chemical Engineering Congress. During the last 10 years, Sherbrooke students have won many awards at the Congress of the Canadian Society for Chemical Engineering for the quality of their first-year and final-year project presentations. These projects enable students to substantially improve their mastery of both oral and written communications.

RESEARCH

Research has been a very significant part of the department's activities from its beginning. The department received funding of more than 4,000,000 CAD last year. This funding is primarily in the form of grants, so there are fewer overhead charges than American schools are likely to bear. This funding has been principally used to support graduate students and researchers, as well as to build and maintain very well-equipped laboratories.

Research in the department is conducted in a number of areas, including aluminium production technology, biomass conversion, biotechnology, environmental engineering, fuel cell technology, flow modeling, and plasma technology.

The research has evolved over the years as a result of recruitment of professors and substantial research funding. In 1973, Bernard Coupal obtained a very substantial grant to develop applications for peat moss during the first year of the department's existence as an independent entity. This grant provided a very important impetus to work in the department and led to a very substantial and lasting work program on biomass transformation.

Environmental engineering developed because we started a master's degree program in environmental engineering and science. Biotechnology research was developed as we recognized the need for specialists in our new biotechnological engineering program. The interest in this research has progressed hand in hand with the hiring of new professors working in the field.

Thermal plasma technology was not common in chemical engineering departments before the 1970s but the arrival of Maher Boulos led to very substantial growth in this area at Sherbrooke. The need to model gas/plasma flows in plasma torches led to general interest in the modeling of flow, heat transfer and kinetics, and particle behavior in a variety of systems.

Fuel cell research evolved because of our specialized knowledge, which already existed in the plasma research center for materials, especially deposition on surfaces using thermal plasmas.

Other research "specialities" were taken up because of their importance to certain industrial sectors existing in the Quebec economy, notably in aluminium production. The pharmaceutical industry is very developed in Quebec, and we are consequently developing very active research in this area, including PAT (Process Analytical Technology).

> ***Testimonial of a doctoral student's experience in a joint program with a university in Europe***
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> *"The Department of Chemical Engineering at the University of Sherbrooke provided me with an opportunity to do my doctoral research in collaboration with a Belgian laboratory at the Catholic University of Louvain (UCL). This collaboration lies within the scope of an agreement of joint direction established between the two universities.*
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> *"This European collaboration enabled me to work for some two-and-a-half years within the Bioengineering Unit at UCL. I discovered innovative enzymatic methods for the elimination of recalcitrant phenolic compounds. This experiment also allowed me to establish a network with other European laboratories working in fields related to my research task."*

GRADUATE EDUCATION

The department has provided a strong graduate program from its earliest days. Professors who were in the process section of the mechanical engineering department had large contingents of graduate students. Upon creation of the chemical engineering department, we were accorded, in addition to our existing undergraduate programs, the master's and doctoral programs.

There are presently approximately 50 post-graduate students working in the department. We graduate about eight master's degrees and five Ph.D. degrees per year.

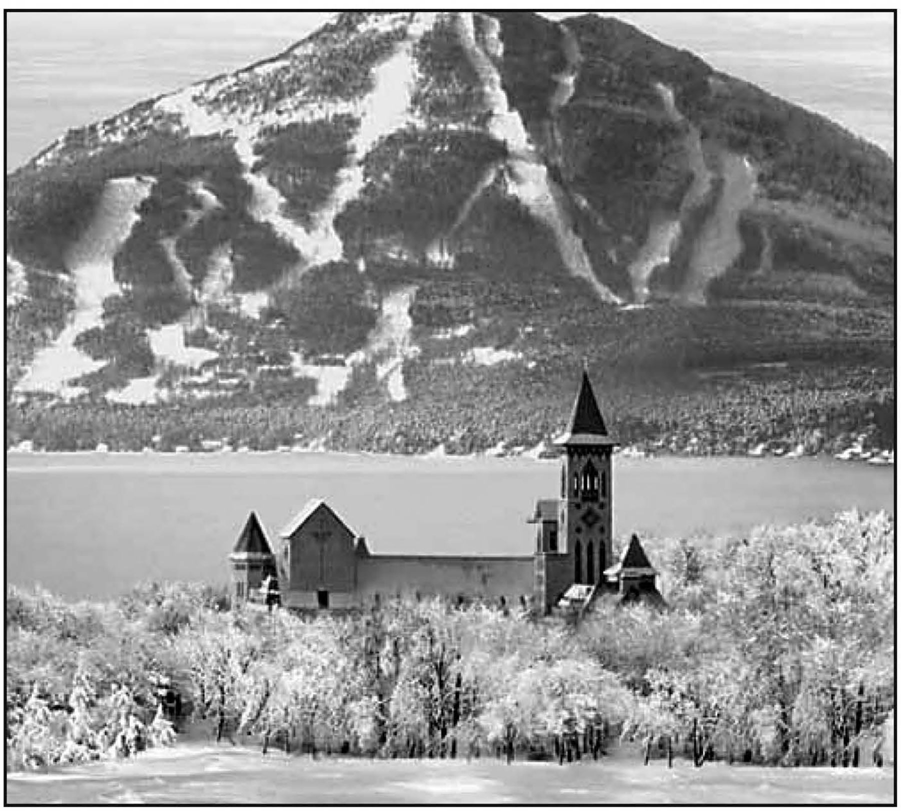
INFLUENCE OF OUR PROFESSORS IN CREATING HIGH-TECH SPINOFFS

The University of Sherbrooke generally and the Department of Chemical Engineering in particular have been very successful in obtaining licensing fees and creating spinoff companies. Esteban Chornet, with the contribution of Nicolas Abatzoglou, has created a number of companies, many very successful in the tasks of coproducing useful products and energy from biomass and organic wastes. Maher Boulos has created a company, based in Sherbrooke (Tekna), with more than 40 full-time employees, specializing in the area of thermal plasma technologies. This company exports its products all over the world, achieving particularly strong results in Japan.

THE FUTURE

The future is bright. We are recruiting large numbers of students into the biotechnological engineering program. The incoming class recruitment in chemical engineering is stable, with approximately 35 new admissions per year. We are in the process of recruiting additional professors for both chemical and biotechnological engineering.

The University of Sherbrooke provides a distinctive educational experience because of its "French" character. We encourage those predominantly English-speaking students who also have knowledge of "basic French" to come to Sherbrooke to simultaneously "perfect" both their chemical engineering and their French language skills for use in their future careers—in Canada, and beyond! ❒



Winter visitors to Sherbrooke will see some of the prettiest scenery snowy climes have to offer, such as this view of nearby St. Benoit-du-Lac Monastery.