Chemical Engineering at . . .
The University of Canterbury

Peter A. Gostomski
Conan J. Fee

Overhead view of part of The University of Canterbury with Engineering in the foreground.

While possibly most famous for hobbits, rugby, and sailing, New Zealand is a diverse country with a mixture of big city and rural life and a variety of climates including ocean beaches, mountains, dry plains, and temperate rain forests. It is roughly the same size as California but with only 4.4 million inhabitants. The University of Canterbury is located in the city of Christchurch on the Canterbury plains of New Zealand, which stretch from the east coast of the South Island to the Southern Alps, 60 km to the west. Christchurch is a city of 400,000 people with an eclectic mix of sights and activities. It was recently listed in the top 10 cities for travel by *Lonely Planet*, partially due to the excitement around the recovery from the 2010/2011 earthquakes (more about that later).

The flowering cherry trees on campus provide an annual spring display.

THE UNIVERSITY

The University of Canterbury, established in 1873, is a comprehensive university, similar to many state universities in the United States. It has approximately 16,000 students located in a suburb of Christchurch. The university is divided into five colleges (Engineering, Arts, Science, Education, and Business & Law) and the College of Engineering consists of four engineering departments (Chemical & Process, Civil & Natural Resources, Electrical & Computer, and Mechanical) and three closely aligned disciplines (Mathematics and Statistics, Computer Science, and Forestry). The college has about 2,500 engineering students across nine undergraduate engineering degrees and a variety of postgraduate options from diplomas through to Ph.D.s. Originally sited downtown in Gothic-style buildings reminiscent of Oxford University—upon which the city's founders based its design—the university was relocated to a spacious campus in the 1970s. The grounds have now matured into a lovely green and modern environment, but with easy access to the dynamic central city. The old university campus was gifted to the city and converted into a thriving Arts Centre.

The Chemical and Process Engineering department (CAPE) graduates approximately 50 – 60 chemical engineers per year from its 4-year degree program and has approximately 30 Ph.D. students. The demographic make-up of the undergraduates is typically one-third women and about one-quarter international. While historically most of the international students have come from Southeast Asia, in the last decade the profile has changed and become more global, with countries from the Middle East, Africa, South America, and Europe represented. The post-grad demographic is more international, from a similar variety of countries. In addition, we host approximately six exchange students per year either for one or two semesters, mainly from the United States and Europe. In addition to a quality education, students are attracted to the lifestyle options in Christchurch, with a variety of outdoor activities available, having both the ocean and mountains at our doorstep, along with the cultural activities associated with a medium-size city. Skiing, surfing, mountain biking, and hiking trails are all nearby, there is a superb symphony orchestra, and Christchurch is the gateway to the beautiful South Island, which is packed with some of the most beautiful scenery in the world.

EMPLOYMENT

Chemical engineering employers in New Zealand cover a diverse range of industries. Traditional industries such as pulp and paper, refining, fertilizer, energy, and environmental consulting are well represented, but there is less emphasis on fine chemicals and polymer production compared with other countries. Food-related industries are an important employer of chemical engineers and New Zealand is the world's largest exporter of dairy products, exporting more than 97% of the milk produced as milk powder, cheese, whey protein, etc. Key developments in the dairy industry have been driven by chemical engineers over the years, allowing the export market to grow despite our distance from most markets, through world-leading processing efficiency. Industries such as human therapeutics or advanced materials processing are relatively small but growing. Because of the focus on adding value to primary products, the degree program has remained focused on graduating chemical engineers with a strong focus on design and fundamental principles such as separations and safety, along with a good grounding in the professional skills such as communications and group work. Therefore, as in other countries, chemical engineering graduates in New Zealand are still the most flexible of the classic engineering programs with regard to the diversity of industries where they find employment outside traditional fields, including banking, electricity distribution, and insurance, to name a few. Like most chemical engineers, we can also appreciate how a chemical engineering degree prepared both the current Pope and the President of China well for leading their complex organizations!

THE CURRICULUM

The undergraduate degree program at Canterbury is a classic chemical engineering degree, with a strong focus on design. The degree is accredited by both the Institution of Professional Engineers New Zealand (IPENZ)—a signatory to the Washington Accord—and the Institution of Chemical Engineers (IChemE). We also offer a bioprocess engineering minor that is becoming increasingly popular, with over one-third of the students pursuing it through a series of electives and having a bio-focus to their 4th year research and design projects. The degree program is based on the U.K. model, with a strong emphasis on technical papers and professional skills and no liberal arts requirement. With a 24-week lecturing calendar in New Zealand, however, capacity for a broader course requirement is constrained compared with the typical 29- to 30-week lecturing calendar in the United States. What is gained or lost from this approach is always an interesting debate. The Ph.D. program is also based on the U.K. model (thesis only), with most students finishing in three to four years.

The first year is a common curriculum shared by all engineering disciplines. This allows the students to explore the different engineering disciplines while at university. A key feature is the Foundations of Engineering course developed and coordinated by CAPE. This introduces all of Canterbury's 750 first-year engineering students to the ideas of design, problem solving, technical communication, and other professional skills common to all engineering disciplines. Upon successful completion of all eight courses in the first year, they are eligible to formally enter chemical engineering. Their second year introduces the basics of chemical engineering, with associated labs and some advanced science and mathematics courses, along with design. The third year builds on the core chemical engineering disciplines and also has a large laboratory component with a strong emphasis on data handling and engineering report writing. The program has a strong focus on separations during years 3 and 4 to underpin design and reflect the needs of New Zealand industry. The fourth and final year allows the students to explore the depth and breadth of the field through electives in the first semester. The students can choose from electives in advanced process control, advanced reaction engineering, and computational fluid dynamics, along with bioprocess, energy, and environmental engineering. The second semester is somewhat unique, with no lectures or exams so the students can focus on two major projects.

The first project is the traditional capstone design project, consisting of groups of 3 – 4 students developing their design skills as well as group work, presentation skills, and other professional skills. The other project, run in parallel, is an individual research project, in which students join the various research groups in the department or work at government or industry research labs on a variety of research topics. Each student is responsible for submitting an extensive research report, which in the best cases forms a basis for peer-reviewed journal articles or conference presentations. Both projects are due at the end of the university exam period. This structure is designed to help the students transition into the work environment, where they would typically start out with one or two projects and have to learn to manage their time over a longer horizon then the typical assignment-text-exam structure of a normal course. The other advantage is that they complete all of their technical courses before embarking on the capstone design and research projects.

The students complete a variety of non-lecture learning activities. Early in the degree, usually during the second year, the students complete workshop training where they get hands-on experience with machine tools, lathes, and welding. They must also complete a first-aid course before graduating. A key activity is the required 100 days of summer work, divided into 40 days of practical work (plant operator, maintenance, or mechanical workshop) and 40 days of professional work supervised by a chemical engineer; the remaining 20 days can fit either category. The students must submit two 3,000-word reports covering the two placements, discussing the company structure, staffing issues, health and safety, and the activities performed. We do not place the students in their jobs but we do maintain a database of former employers to help them with contacts. The summer work experience is a very important contribution that industry provides to engineering education at the University of Canterbury.

Health and safety has a high profile in the teaching program as it is required for successful accreditation by both IPENZ and IChemE. The students, through a series of lectures over three years, are exposed to the concepts of basic hazards (*e.g.*, flammable vapors, dust explosions, runaway reactions, toxicity), leaning heavily on the excellent material provided by both the U.S. Chemical Safety Board and IChemE. The students are also introduced to risk reduction techniques such as procedural, active, and passive techniques and inherent safety, followed by an introduction to the hazop technique, coupled with order-of-magnitude risk analysis. They apply this knowledge as part of their capstone design project through a preliminary hazard analysis.

Management of health and safety in the research environment is very comprehensive because universities in New Zealand are regulated in a similar fashion to industrial research facilities. All new researchers must go through a safety induction, complemented by periodic safety briefings for all research students and staff. Each new experiment is evaluated through a rigorous hazard and risk checksheet with input from both academic and technical staff, culminating in a permit-to-work, which is then reviewed annually. This is complemented by monthly safety inspections of the labs to identify and correct minor problems. Occasionally, for larger or particularly hazardous experiments, a more rigorous hazop is performed such as prior to commissioning our custom-built 100 kW gasifier. There are also systems for incident/near-miss reporting, a hazard register, and tracking of particular hazardous chemicals to meet compliance requirements.

A key teaching resource for the department is the university's Erskine Fellowship program. This endowment funds two world-class educators to visit CAPE annually for periods of 1 – 3 months to lecture to our undergraduate students (Table 1). The endowment also funds CAPE staff members to make similar outgoing trips to learn about the best teaching practices being used around the world. This combination helps keep the teaching in CAPE modern and refreshed through exposure to teaching and learning styles implemented internationally. (Further information on the Erskine Fellowship program is available at <*http://www.canterbury.ac.nz/erskine/*>).

TABLE 1
Recent Erskine Visitors to Chemical & Process Engineering

Phil Wankat	Purdue University
Al Center	Cornell University
Matthias Kind	Karlsruhe
David Silverstein	University of Kentucky
Giorgio Carta	University of Virginia*
Mike Bird	Bath
Laurence Weatherley	University of Kansas
Todd Przybycien	Carnegie Mellon
Oluwafemi Taiwo	Obafemi Awolowo Univ.
Don Green	University of Kansas

* BIC International Fellow

CULTURE AND HISTORY

The student culture within the department is quite cohesive. The academic year starts out in late February with a Year 2 mixer for new chemical engineering students to meet each other and the staff. This is followed by the annual departmental barbeque organized by the 4th-year students. There are also a scattering of field trips to local industry and sporting competitions between professional years and with staff. The staff have trouble beating the students in soccer or cricket but are long undefeated in volleyball, due to regular lunch-time staff volleyball organized by the university. There is also the multi-day, 4th-year field trip where students visit process industry in different parts of the country. The social events culminate with the 4th-year student dinner, which is usually a lively affair at a local restaurant, with various "awards" given to students and staff alike. CAPE students are also very active in the Engineering Society (ENSOC) and Women in Engineering (WIE), which organize various industrial speakers, employer events, and social events.

Attendees enjoy the department's typically lively 4th-year end-of-year student dinner.

Chemical engineering at Canterbury got its start in industrial chemistry in the 2nd quarter of the 1900s under the guidance of Henry Denham. Stan Siemon was appointed the first chair in chemical engineering at Canterbury in 1957 and he later went on to establish the chemical engineering department at the University of Melbourne. Following Professor Siemon's move in 1964, the chair was filled by one of the department's early graduates, Miles Kennedy. Under Professor Kennedy's leadership between 1965 and 1981, the department grew from an annual intake of 18 students to 44 and the staff increased from five academics and four technicians to 13 academics, 11 technicians, and two administrators. About 1,500 m^2 of laboratories and well-equipped mechanical and electrical/electronic workshops were added during this period. In the 1980s, the department officially added Process Engineering to its name to better reflect the breadth of the industry supported by the graduates and research. The department also moved to a shorter term for the head position, with Roger Keey, Arthur Williamson, Brian Earl, and Laurence Weatherley all filling the role. The department has been headed by Peter Gostomski since 2005 with 20 staff plus additional research personnel.

The academic year finishes in early November but the main graduation ceremony takes place in April. This is a vestige of when the final exams were sent back to the U.K. for marking, the 4-month delay being the typical turnaround time for ships to sail back and forth and allow for marking. While that practice ended prior to World War II due to the unfortunate loss of a ship full of unmarked exams (!), the graduation date remains the same. This does allow for a mini-reunion, as most employers are happy to give their new engineering employees a bit of time off as it is "tradition." We do, however, wish that we could convince our colleagues in the U.K. to re-establish the tradition of marking our exams!

Academic, research, and technical staff from the Department of Chemical and Process Engineering at the University of Canterbury.

THE STAFF

Research in chemical engineering has a strong profile at Canterbury. The New Zealand government assesses university research quality every six years through the submission of individual academic research portfolios. In the 2012 round, CAPE received the top departmental score for chemical engineering in New Zealand and regularly features as a top department at Canterbury. Research in CAPE is grouped into various themes with a strong emphasis on energy, catalysis, biochemical engineering, and natural product processing. Most of the work is interdisciplinary, with strong collaborations with other departments, government research labs, and industry. The research ranges from pilot-scale gasification and full-scale bag filtration down to molecular science supported by surface plasmon resonance, circular dichroism, and quartz crystal microbalances. There are currently nine research-active academics, whose interests are described below.

• **Conan Fee** is interested in biomolecular processes, looking both at bioseparations and molecular interactions relevant to life sciences and biopharmaceuticals. He was one of the founders of the Biomolecular Interaction Center (<www.bic.canterbury.ac.nz>), a multi-disciplinary research institute based at Canterbury comprising 40 investigators and 50 Ph.D. students, and collaborating with 11 other research organizations. He has a long-standing interest in the production and properties of PEGlyated proteins. Current work is on protein chromatography, surface plasmon resonance for influenza-anti-viral drug and insulin-insulin receptor interactions, peptide-modified membranes, and quartz crystal microbalance investigations of stainless steel fouling. He teaches chemical reaction and bioprocessing engineering and is currently deputy pro-vice-chancellor and dean of Engineering and Forestry and a fellow of IPENZ.

• **Peter Gostomski** is a bioprocess engineer with an interest in microbial processes. His research is split between environmental applications including work in biofiltration for air pollution control and algae-bacterial systems for waste water treatment. He is also working on reactor systems for microbial cellulose production and he collaborates with Marshall on microbial fuel cell applications using gaseous feed streams. On a separate vein, he has worked with both Fee and Morison on developing immersive learning tools to complement field trips and introduce the complexity of real-world design.[1] He teaches process safety and bioprocessing and as noted before is currently head of the department. He is a fellow of IChemE.

• **Aaron Marshall** is interested in hydrogen energy and catalysis as well as materials characterization using synchrotron-based techniques. This includes activities on fuel cells, water electrolysis, and conversion of biomass to hydrogen. Much of this research combines electrochemical engineering and surface science to better understand and ultimately improve processes involving catalysis. He is working on applications such as hydrogen generation by water electrolysis, and methanol from carbon dioxide, and collaborates with Gostomski on microbial fuel cells. He teaches thermodynamics, chemical reaction engineering, and energy.

• **Ken Morison** focuses on dairy process design methodologies and modeling, including physical property measurements. Recent projects have looked at falling-film minimum wetting rates, surface tension, contact angle, and viscosity of dairy products. Models of ultrafiltration, cheese production, and evaporator flows have been developed to show which parts of a design are most important. He also has an interest in non-Newtonian fluid flow to understand how these fluids will behave in different processes. He teaches the first-year Foundations of Engineering course, fluid mechanics, and process dynamics and modeling and is a fellow of IChemE.

• **Justin Nijdam** is active in experimental investigations and CFD modeling of multi-component, multiphase processes such as bioreactors and spray dryers. Recent projects include air-lift reactors, adsorption processes for fouling in the dairy industry, functional particles from spray drying, and improved bag house filter operation. He also is active in the drying technologies for New Zealand's difficult-to-dry indigenous beech timbers. He teaches fluid mechanics and heat transfer and coordinates the undergraduate laboratory classes.

• **Shusheng Pang** is actively researching in a number of areas including biomass energy, wood-based composites, and drying of wood. In addition, he is interested in drying of particulate materials, evaporation, and heat and mass transfer processes. He directs a large research program on thermal gasification of woody biomass for energy and liquid fuels, including the construction of a 100 kW dual fluidized bed steam gasifier. Other areas include pyrolysis of waste plastics and woody biomass for liquid fuels and product development and processing technologies for wood-plastic composites. He is presently the director of the Wood Technology Research Center. He teaches in the areas of heat and mass transfer, separations, and energy.

• **Gabriel Visnovsky** focuses on the development of industrial processes for the production of large-scale, high-cell-density cultures of bacteria and fungi for their use as biological control agents or for their valuable secondary metabolites. He also has a strong interest in animal cell culture area, and particularly with shear-sensitive cells such as fish and insect cells for their use in human therapeutics, veterinary, and agriculture. He teaches mass and energy balances and environmental and bioprocess engineering.

• **Chris Williamson** contributes to the biomass energy team and has interests in design and control. Specific projects include wood gasification for combined heat and power systems, and the production of liquid biofuels via the Fischer-Tropsch process. In addition, he has interests in process control of a chemical engineering plant, especially in the pulp and papermaking process and neural networks for the prediction of atmospheric pollution levels. He teaches process dynamics and control and design in 3rd and 4th year.

Professor Conan Fee and Dr. Simone Dimartino display a new concept for porous media for chromatography using 3D printed prototypes.

• **Alex Yip** is interested in the design of advanced nanomaterials, from their structural determination to the application of new catalysts that are both environmentally benign and economically feasible. Specifically, he is interested in the synthesis of heterogeneous catalysts, photocatalysis, and conversion of biomass to transportation fuels using acid catalysis. He teaches separations and reaction engineering.

A key staffing approach we have taken at Canterbury is to maintain a highly skilled, department-funded technical support team including mechanical, electronic, analytical, computer, and biological technicians. They enable us to maintain pilot-scale, undergraduate teaching labs such as an 18" gas-liquid contactor and a 9" distillation column. They also make key contributions to research, through custom-built research gear. Examples include a 100 kW dual fluidized bed gasifier supporting the biomass energy research program, a full-scale bag filter used for fines collection in spray drying applications, and a number of smaller apparatus requiring detailed machining and electronics integration. Apparatus such as this would be much more difficult to obtain by contracting out fabrication because of the iterative nature of the development process. This also improves the safety in the laboratories because the technical staff provide continuity and knowledge about the practical operation of the equipment. The department also has the expertise to operate a specialized facility for recombinant organism and other biological work, which is strictly regulated to protect the New Zealand environment. Both the academics and the technical staff are supported by a strong administrative team in the department and in the College of Engineering.

CURRENT EVENTS

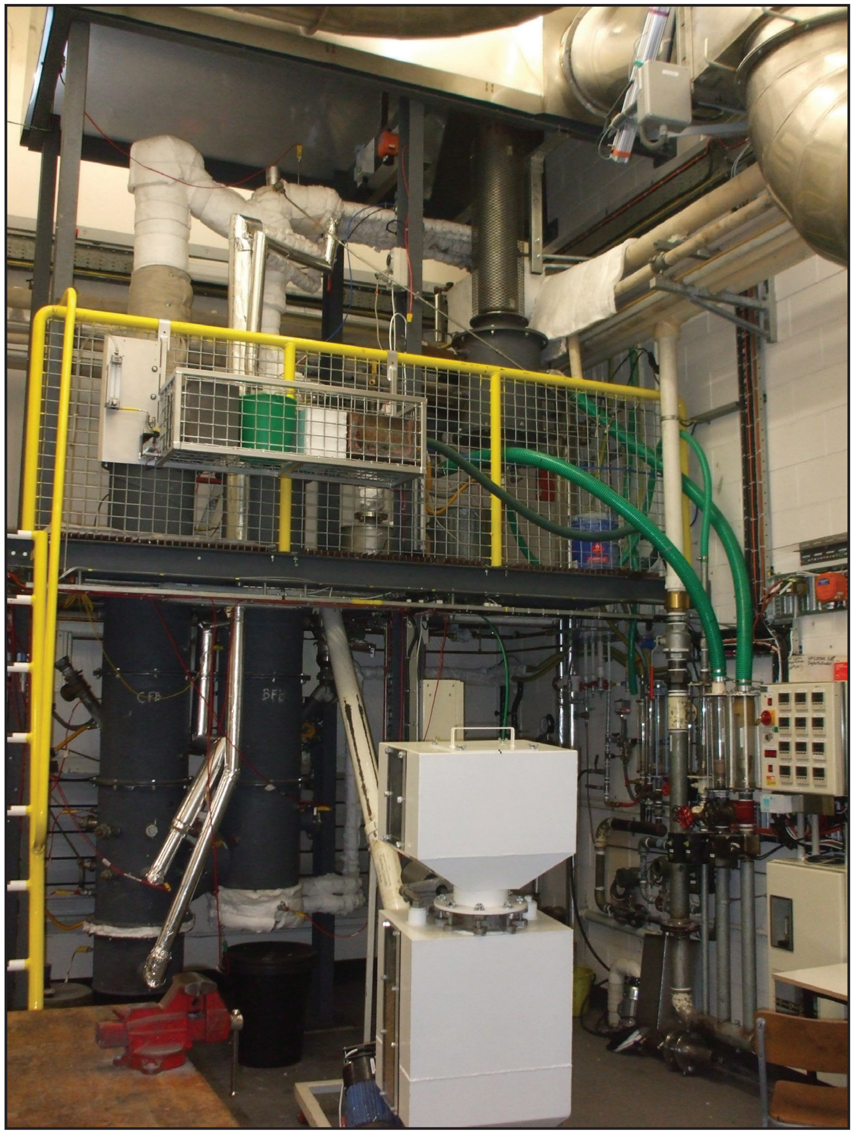
The recent experiences in the department have been dominated by the impact of the 2010/2011 earthquakes in Christchurch. The February 2011 earthquake was the most serious, with tremendous damage to the downtown area and 185 fatalities. The effects on the university were less dramatic but a number of buildings were damaged and the campus was closed for 5 weeks as the multi-story buildings were inspected. CAPE continued to deliver the lecture program at a local high school and temporary research facilities were arranged off-site for some research groups. Our six-story building, while not significantly damaged, was deemed below the building code and not easily remediated, so we never reoccupied the building and it was demolished in late 2011. This represented a loss of 40% of our space and was a mixture of offices, labs, and storage.

Accommodating this loss in space was difficult for staff and students, but we have since been allocated sufficient office and lab space in nearby buildings due to the collegiality and creativity of our colleagues, especially in Mechanical Engineering and Biological Sciences, and our teaching and research program is now back to normal. We are busy working with the university on a 3,000 m^2 building with state-of-the-art teaching and research facilities. Work is expected to start in late 2014. This building program will be in parallel to the excitement of the re-build of downtown Christchurch as the city and the central government start from scratch through big swaths of the central business district—planning entertainment, sporting, and health precincts, combined with

The 18" gas-liquid contactor used in the teaching lab.

new parks surrounding the Avon River that meanders through the city. On a per capita basis, at NZ$40bn, this will be the largest economic rebuild project ever undertaken and represents significant opportunities. After the past couple of years of setbacks, we are looking forward to seeing one of the most livable cities in the world develop over the next few years.

Continuing on a positive note, the department received two unexpected investments recently that will significantly strengthen our program. The first was a $2M endowment received in 2011 from the estate of John Sutherland, who graduated from the department in 1971. He requested that the endowment be invested in chemical engineering teaching and research. This has allowed CAPE to start a prestige seminar series in 2012, including such speakers as Andrew Livingstone from Imperial, Phil Wankat from Purdue, and Ian Cameron and Max Lu from Queensland. It will also fund Ph.D. scholarships and further growth initiatives. A second investment in the department happened in 2012 when the university divested its holdings in ArcActive, a spin-off company developed by retired staff member John Abrahamson based on his work with carbon nanotubes. Abrahamson is now widely acknowledged as one of the first researchers to describe carbon nanotubes in work he did in CAPE during the mid-1970s. The university has generously invested all the funds from this sale back into departmental research.



The 100 kW dual fluidized bed gasifier.

SUMMARY

Chemical and Process Engineering has thrived at The University of Canterbury for more than 60 years. We look forward to continuing to provide outstanding graduates to New Zealand and many other countries while fostering a dynamic research climate. The near future will be especially dynamic as Christchurch renews itself as a modern, sustainable, livable city in parallel to revitalized teaching and research facilities at the university.

ACKNOWLEDGMENTS

Thanks to Duncan Shaw-Brown for the photos on page 2 and the bottom of page 5.

REFERENCES

1. Herritsch, A., E. Abdul Rahim, C.J. Fee, K.R. Morison, and P.A. Gostomski, "An Interactive Virtual Tour of a Milk Powder Plant," *Chem. Eng. Ed.*, **47**(2), 107 (2013) ❒