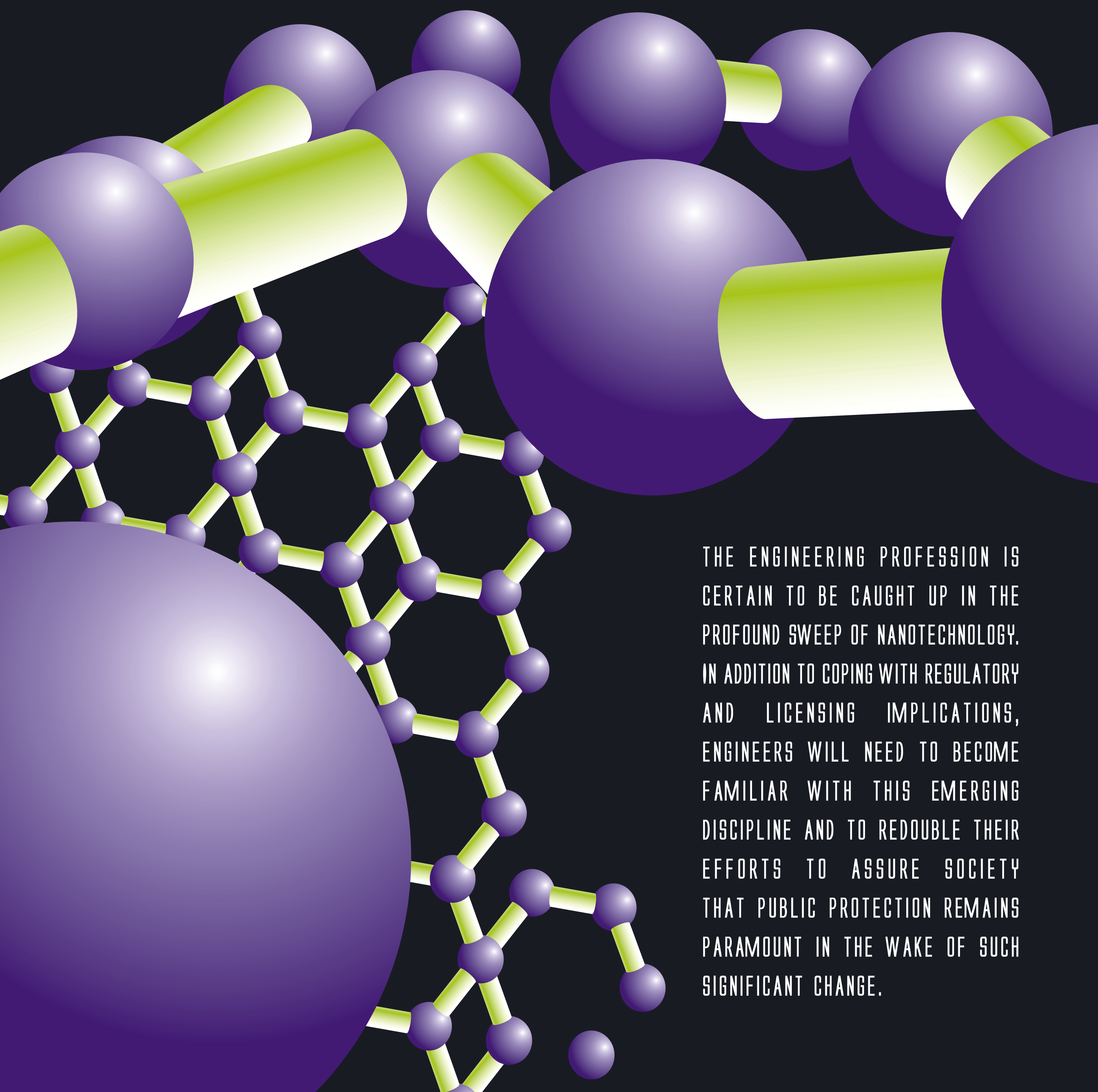
NANOTECHNOLOGY:

BRACING FOR A WHOLE NEW WAY



THE ENGINEERING PROFESSION IS CERTAIN TO BE CAUGHT UP IN THE PROFOUND SWEEP OF NANOTECHNOLOGY. IN ADDITION TO COPING WITH REGULATORY AND LICENSING IMPLICATIONS, ENGINEERS WILL NEED TO BECOME FAMILIAR WITH THIS EMERGING DISCIPLINE AND TO REDOUBLE THEIR EFFORTS TO ASSURE SOCIETY THAT PUBLIC PROTECTION REMAINS PARAMOUNT IN THE WAKE OF SUCH SIGNIFICANT CHANGE.

BY MICHAEL MASTROMATTEO

As far as emerging disciplines are concerned, something frequently described as the "science of the small" portends very big things for the engineering profession. The imminent unfolding of nanotechnology will be a force to be reckoned with in the engineering profession in the coming years.

Despite the sense of "smallness" or miniaturization often used to describe this atomic-scale technology, there is nothing trivial about its anticipated impact on engineering practice and regulation in Ontario and far beyond.

Some have even been moved to describe nanotechnology as a second "Industrial Revolution" that will forever change the way science and technology combine to shape society, hopefully for the better and the more secure. Others have been moved to suggest nanotechnology is poised to become the dominant technology of the 21st century–outdistancing in scope the harnessing of electricity or the rise of computer-based information exchange. As for superlatives, there is another school of thought arguing that, if fully realized, nanotechnology could become humanity's greatest scientific achievement.

Engineering faculties, led in Canada by the University of Waterloo and the University of Toronto, have established nanotechnology education programs with a view to turning out "Renaissance engineers" who can best exploit the opportunities inherent in this emerging discipline.

No doubt engineering regulators, such as PEO, will be monitoring the emerging field in anticipation of licensing revisions to maintain a proper regulatory framework over this innovative and multi-disciplinary way of turning science and research into practical application. Working with other stakeholders, such as the Canadian Council of Professional Engineers (CCPE) and its Canadian Engineering Accreditation Board (CEAB), regulators will also be attuned to efforts to incorporate nanotechnology into universities' engineering teaching curricula.

Meanwhile, nanotechnology research is gaining strength, research funding, even its own vocabulary. The nano prefix is now readily attached to create new compound expressions (nanoengineering, nanomedicine, nanobiotechnology), illustrating in words the expected adaptability and reach of this trend. Nano (Greek for "dwarf") refers to things of a microscopic measure. The nanometer, for example, measures one billionth of a metre, or about 1/750,000th the diameter of a single human hair.

In its simplest terms, nanotechnology involves activities at the level of atoms and molecules. The benefits of nanotechnology come with greater precision in manufacturing, assembly, computer operation, medical diagnosis and treatment, and countless other applications. Rather than clumping together large masses of atoms, as is done with regular manufacturing and assembling processes, nanotechnology allows material to be assembled atom by atom or molecule by molecule. This, in turn, allows for the creation of lighter, stronger and more durable materials and, in some cases, the production of substances that can locate breakages and initiate a self-repair process. Researchers suggest some of nanotechnology's building materials uses are nearing commercialization. Among these are extra-strength, corrosion-resistant membranes, certain catalysts to trigger chemical processes, and low-cost devices to monitor heat, radiation, stress, vibration and physical movement. Nano research is also yielding new information about the laws of physics at the atomic level which, in turn, promises exciting possibilities in the area of energy, fuels and power generation.

Scanning tunneling microscope

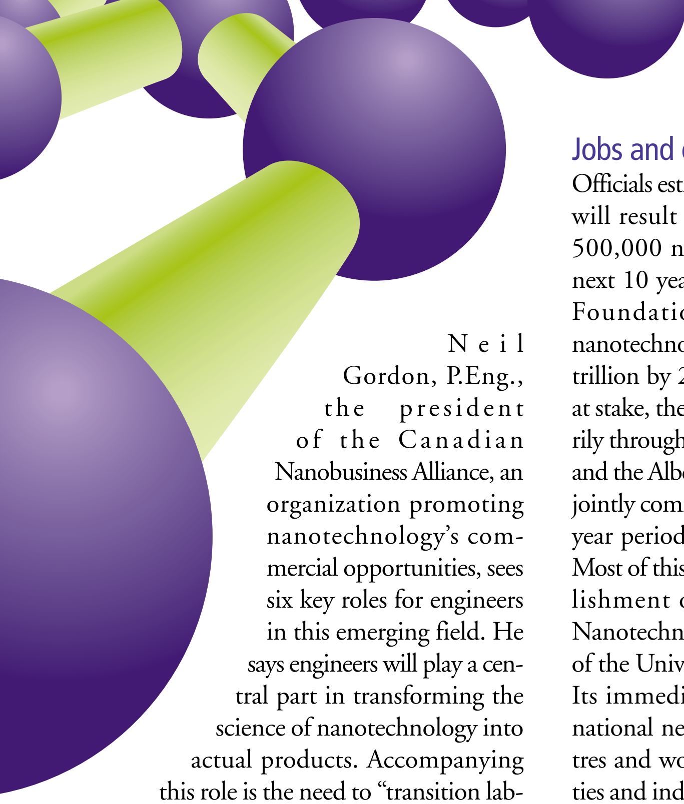
An important innovation in the entire nanotechnology area centres on developing instruments of ultra-fine measurement. A scanning tunneling microscope, for example, now allows researchers to identify and manipulate matter as small as a single atom. This ability to "see" activity at the atomic scale is a necessary prelude in moving from the research lab to the marketplace. And, at the risk of excessive metaphor, it becomes a way station at which nanotechnology becomes nanoengineering.

Authorities anticipate vast potential applications for nanotechnology, ranging from the creation of molecule-sized robots, to fuel cells that do not need to be recharged, to molecular capsules able to convey precise quantities of medication directly to the site of infection and disease within a patient's body, thereby eliminating the need for invasive surgery.

A July 2004 research study by the Canadian Council of Professional Engineers breaks down nanotechnology into five major research areas:

- nanomaterials and processing (new approaches to materials development);
- nanoelectronics and nanoinstrumentation (development of "nanodots" to build more efficient lasers or memory devices in electronics);
- software/computing (shrinking size of transistors to create a new generation of components-data storage in the order of trillions of bytes of information);
- nanobiotechnology medical products (development of drinkable "nanorobot" medicines that seek out and destroy cancer cells or viruses in patients); and
- environment (development of alternative ways of water purification, bioremediation, ozone regeneration, renewable fuel sources).

Still in its infancy, nanotechnology has practical applications in telecommunications, manufacturing and other industries that will lead to an improved quality of life and generate enormous opportunities for engineers to commercialize and apply nanotechnical innovations on a broad scale. Also of importance to the engineering community is the multi-disciplinary nature of nanotechnology. One authority has observed that research at the nano scale is marked by a need to share knowledge on tools, techniques, and information on the physics governing atomic and molecular interactions. Materials scientists, mechanical and electronic engineers, and medical researchers are already working in teams with biologists, physicists and chemists. As such, engineers of the future will do well to be conversant with nanotechnology to maintain a preeminent role on these teams.



Neil Gordon, P.Eng., the president of the Canadian Nanobusiness Alliance, an organization promoting nanotechnology's commercial opportunities, sees six key roles for engineers in this emerging field. He says engineers will play a central part in transforming the science of nanotechnology into actual products. Accompanying this role is the need to "transition laboratory work" into a production mode, as well as the importance of educating potential customers and consumers about new products available via nanotechnology.

As well, engineers will be key in evaluating commercial viability and spearheading the creation of companies devoted entirely to nanotechnology. Finally, Gordon says, engineers can serve as a vital link between researchers and investors in bringing the benefits of nanotechnology to the marketplace.

While Gordon believes the federal government could be doing more to support research and commercialization of nanotechnology, he has no doubt about its opportunities for engineers. "Nanotechnology is the convergence of so many fundamental technologies and it includes material science, chemistry, physics, biology, and they are all coming together at the nano scale," Gordon told *Engineering Dimensions*. "What engineers are unique in doing is working together on a multidisciplinary team. For example, when you are building a bridge or a computer system or an airplane, you have the electrical engineer working with the mechanical [engineer], working in turn with the materials people. And now you have that mindset opening up for nanotechnology, where you have engineers working with physicists and biologists and medical doctors. Essentially it is the transition of science into products, and I think that domain is going to be owned by engineers."

Jobs and opportunities

Officials estimate that nanotechnology itself will result in the creation of more than 500,000 new jobs in the U.S. over the next 10 years. The U.S. National Science Foundation suggests the market for nanotechnology products will climb to $1 trillion by 2015. With all of this potential at stake, the Canadian government, primarily through the National Research Council and the Alberta provincial government, have jointly committed $120 million over a five-year period for nanotechnology research. Most of this funding is devoted to the establishment of the National Institute of Nanotechnology (NINT) on the campus of the University of Alberta in Edmonton. Its immediate goal is to participate in a national network of nanotechnology centres and work with government, universities and industry to set national innovation priorities in nanotechnology.

In terms of research expenditure per capita, Canada's commitment to nanotechnology is significantly below such countries as the U.S., Japan, South Korea, Australia and Taiwan. Nonetheless, the emerging discipline remains something of a priority for those directing Canada's national science policy. Sara Filbee, acting director of the manufacturing industries branch, Industry Canada, agrees that nanotechnology is beginning to take on a life of its own.

"This is obviously an exciting time for us with respect to nanotechnology, not only in terms of engineering, but for all of the sciences," Filbee said. "One of the things we are seeing is that because it is an interdisciplinary field, there are partnerships and strong collaboration among our engineers and scientists, from all disciplines, in our universities. There are already a number of 'nanoproducts' in the stores, and our researchers are quite excited about what they see coming down the road. As a result, one of the things the government needs to do is to identify what the issues are going to be vis-à-vis government and the regulation side of things."

Certainly the regulatory and professional practice implications of nanotechnology form a central part of CCPE's investigation of new growth areas in engineering. In its research paper, CCPE suggests that regulation of engineers in such a vibrant emerging discipline will be aided as more and more practitioners take to the field. CCPE is also in the process of staking out a position on nanotechnology, in concert with the various provincial/territorial engineering licensing bodies across Canada. "It is imminent," CCPE says, "that the provincial/territorial engineering licensing bodies will be charged with granting professional status to bioengineers, chemical engineers (and others) who work in the area of nanotechnology. In the future, it may be important for the P.Eng. applicant to demonstrate appropriate experience in the area of nanotechnology to obtain status in the engineering profession."

Karen Martinson, P.Eng., CCPE manager, research and evaluation, suggested that a special classification of nanoengineer could be one of the most significant licensing issues relating to nanotechnology. "The engineering profession may need to license nanoengineers in the future as this exciting area of technology unfolds," she said.

PEO's method of dealing with emerging disciplines was established by the Engineering Disciplines Task Group, whose five-phase process to identify new areas of practice and license practitioners in them was approved by PEO Council in February 2002. The process involves: recognizing a new practice area and monitoring it; identifying the necessary knowledge for competent practice; using the body of knowledge to define the required and optional areas of study for a program to fulfill the academic requirements for licensing; reviewing the experience and education of current practitioners in the new area to determine if they have obtained the required body of knowledge for licensing; and identifying the facets of the new area that require licensing to protect the public and working with government to develop legislation to regulate practice in these areas. This is the process PEO used in relation to both software engineering and bioengineering.

Argyrios Margaritis, P.Eng., a professor of biochemical engineering at the University of Western Ontario, who was recently made an Officer of PEO's Order of Honour, suggests the need for a task force to study the full impact of nanotechnology on the profession. Margaritis co-chaired PEO's Bioengineering Task Group, which defined bioengineering for licensing purposes.

"I had the pleasure of chairing the PEO Bioengineering Task Group, and in collaboration with many distinguished engineering colleagues from across Canada, we were successful in recommending the establishment of a new discipline, bioengineering," Margaritis told *Engineering Dimensions*. "I would recommend a similar move by PEO to study the impact of nanotechnology on different engineering disciplines."

In addition to his experience on the Bioengineering Task Group, Margaritis could be considered a practising nanoengineer. "I am branching out into the new area of research called 'nanobiotechnology,' which combines basic principles of biotechnology with nanotechnology," he said. "One project I am considering is to produce nanoparticles made from a biodegradable biopolymer called polyglutamic acid for the controlled release of different pharmaceuticals to fight different diseases, including cancer."

already adjusting curricula in response to new realities. These changes reflect the CCPE's view that "it will be important to monitor universities in Canada in the future to ensure that if any undergraduate nanoengineering programs are developed, they conform to the standards and criteria set forth by the Canadian Engineering Accreditation Board."

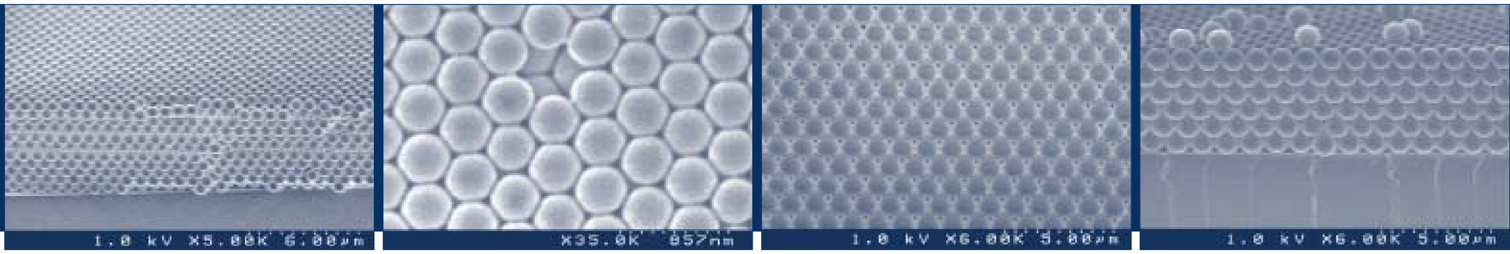
At present, the University of Toronto and the University of Waterloo are at the forefront in revising engineering curricula to cover aspects of nanotechnology. The University of Toronto has established a nanoengineering option in its engineering science program. Meanwhile, the University of Waterloo has launched a Bachelor of Science degree program in nanotechnology engineering, with the first batch of students to begin studies in the fall of 2005.

Siva Sivoththaman, director of the nanotechnology engineering program,

of terminology, metrology, characterization, calibration and certification."

Whatever curriculum revisions, licensing changes and regulatory implications may be in store, it seems certain that nanotechnology will continue to deliver big changes to the profession. For engineering regulators, this presents an opportunity to reaffirm the profession's commitment to upholding public safety.

"Nanotechnology is about being able to manipulate materials at the atomic or molecular level in such a way that beneficial properties of the materials are obtained, precisely due to the nano-scale manipulations," says Sivoththaman. "When these novel properties are used in advanced and new applications that are beneficial to society, that becomes the achievement of nanotechnology engineering. In terms of applications, nanoengineering has a wider and beneficial



These colloidal crystals, or "synthetic opals," consist of a layer of silica glass or polymer spherical particles arranged in a closely packed structure. Opal films are made by carefully growing the particles in suspension to be all the same size, then allowing them to assemble onto a flat substrate by sedimentation or evaporation-induced assembly. While the spheres pictured above are slightly larger at 200 to 800 nm than typical nanomaterials, they represent the self-assembly capability that is one of the key achievements of research into nanotechnology. Photos courtesy University of Toronto Innovations Foundation.

CCPE lead

Canadian engineering regulators appear to be taking their cue on nanotechnology from the CCPE. Anne Garrett, P.Eng., executive director and registrar, Association of Professional Engineers and Geoscientists of British Columbia (APEGBC), agrees that nanotechnology is a fascinating area that clearly cuts across a number of current disciplines, similar to–but more extensive than–the software development issue. "We [APEGBC] are just setting up an emerging disciplines task force to start dealing with this one," she said. "The first telephone call will be to the CCPE to get up to speed on their work to date."

But while regulators cope with the imminent impact of nanotechnology on the profession, engineering faculties are

University of Waterloo, says this is the first undergraduate program entirely dedicated to nanotechnology. "The overall idea is to create engineers capable of meeting the practical needs of nanoengineering, which is already finding its way, in a multidisciplinary fashion, into several areas of engineering and science,"Sivoththaman said. Despite its relative novelty among Canadian engineering faculties, the Waterloo program was specially designed to meet the accreditation requirements of the CEAB.

"One other area where I think the nanoengineering program will have an impact on engineering practice is in standardization," Sivoththaman added. "Because the technology involves novel techniques and applications, standardization would become necessary in terms

impact in the area of communications, pharmaceuticals, medicine, new and safe materials, the environment and instrumentation. Therefore, the area of public safety and protection will definitely benefit from most of these applications."

Indeed, CCPE is concerned that the rate of research and development in this little-understood discipline requires the engineering profession to educate policymakers, the public–and its own members–about the wider implications of this radical new way of doing things. As CCPE's Karen Martinson has noted, "It will be important for the engineering profession to remain proactive in its communications and education of government and the public in the area of nanotechnology and specifically, nanoengineering."