3

U of T Engineering research is defined by multidisciplinary excellence in innovation and collaboration. We produce high-impact publications and — through our rich entrepreneurial ecosystem and global network of collaborators, including many industry leaders — we ensure that new technologies are translated from the lab to the marketplace to improve the lives of people around the world.

Our faculty members and graduate students are world leaders in our strategic research foci: advanced materials and manufacturing; analytics and artificial intelligence; human health; robotics; sustainability; and water. U of T Engineering is home to 120 research chairs and professorships, as well as 29 multidisciplinary research institutes, the newest of which, the Centre for Analytics and Artificial Intelligence Engineering (CARTE), launched in July 2019. We have also evolved the structure of the University of Toronto Robotics Institute to focus on three pillars: autonomous vehicles and field robotics, health care robotics and robotics in advanced manufacturing.

In 2017–2018, the most recent year for which complete data is available, we attracted research operating funds of $77.0 million from a wide variety of sources. We have increased the proportion of our funding that comes from direct partnerships with industry to $12.7 million, a 41.1% increase over the previous year, and more than double the value from five years ago. Our more than 400 industry partners include local startups and major multinationals. The Fujitsu Co-Creation Research Laboratory, housed on the top floor of the Myhal Centre, is one example of our innovative collaborations.

We continue to make strategic investments to foster multidisciplinary collaboration initiatives. XSeed, a seed funding program that supports partnerships between professors at U of T Engineering and other Faculties across the University, was launched in January 2018. Eight projects were supported by XSeed, and 11 more were funded in the 2019 cohort, including partnerships with the Faculty of Arts & Science, University of Toronto Mississauga, University of Toronto Scarborough and the Faculty of Kinesiology & Physical Education.

In the past year, our faculty and students have developed innovations with applications in fields from medicine to energy — including miniature robots that can probe the inside of cancer cells, and low-cost catalysts for producing sustainable fuels. Companies founded on U of T Engineering research, such as AmacaThera, TARA Biosystems and Peraso Technologies, continue to generate significant investment and make powerful contributions to their respective sectors.

Selected Highlights Organized by Innovation Cluster

Advanced Manufacturing

Startup based on U of T Engineering research raises US$42 million to alleviate congested wireless networks

A Canadian semiconductor startup based on technology developed in the lab of Professor Sorin Voinigescu (ECE) has raised US$42 million to ease the strain on increasingly congested wireless networks. Founded in 2009, Toronto-based Peraso Technologies develops chips for the 60 gigahertz (GHz) band, enabling more data to be pushed through wireless hotspots for applications such as streamed 4K television or virtual reality. The technology could be used in 5G wireless data networks, as well as the emerging Wi-Gig standard, an ultra-fast type of Wi-Fi. While Voinigescu is no longer involved with the company, it was founded by his former graduate students, and his team fabricated and tested the initial prototypes.

Toward a future quantum Internet

U of T Engineering researchers have demonstrated proof-of-principle for a device that could serve as the backbone of a future quantum Internet. Professor Hoi-Kwong Lo (ECE, Physics) and his collaborators have developed a prototype for a key element for all-photonic quantum repeaters, a critical step in long-distance quantum communication. Existing repeaters for quantum information require storage of the quantum state at the repeater sites. They are error prone, difficult to build and, because they operate at cryogenic temperatures, energy-intensive. All-photonic quantum repeaters would eliminate or reduce many of these shortcomings. With collaborators at Osaka University, Toyama University and NTT Corporation in Japan, Lo and his team demonstrated proof-of-concept of their work in a paper published in *Nature Communications*.

Data Analytics and Artificial Intelligence

U of T Engineering launches new AI research centre

A new multidisciplinary research centre at U of T Engineering will leverage the power of AI to address challenges in a wide range of fields, including human health, sustainability and advanced manufacturing. The Centre for Analytics and Artificial Intelligence Engineering (CARTE), launched July 1, 2019, fosters collaborations between researchers who study analytics and AI directly and those in domains where AI could be a useful tool. It brings together more than 30 professors with expertise in optimization, analytics and AI, energy, transportation, and life sciences, among many others. Together, they will catalyze translation of analytics and AI techniques and algorithms to practical challenges, and provide boundless opportunities to prepare the next generation of AI leaders. CARTE has deep ties to the Engineering Science major in Machine Intelligence — the first undergraduate engineering program of its kind in Canada — as well as the undergraduate minor and certificate in Artificial Intelligence Engineering.

EngSci student holds companies accountable for biased AI facial recognition technology

A study by Engineering Science student Deb Raji (Year 4 + PEY) and researchers at the Massachusetts Institute of Technology (MIT) underscores the racial and gender biases found in facial-recognition services. Raji spent the summer of 2018 conducting research at MIT's Media Lab, where she audited commercial facial recognition technologies made by leading companies such as Microsoft, IBM and Amazon. The researchers discovered that all of them had a tendency to mistake darker-skinned women for men, but that one service in particular — Amazon's Rekognition — showed a higher level of bias than the rest. Rekognition was recently piloted by police in Orlando, Fla., using the service in policing scenarios such as scanning faces on cameras and matching them against those in criminal databases. The researchers suggest that the bias within the algorithm could lead to misidentification of suspects. The work was presented at the Association for the Advancement of Artificial Intelligence Conference on AI Ethics and Society, held January 27-28, 2019 in Honolulu, Hawaii.

Smarter cancer treatment: AI tool automates radiation therapy planning

MIE researchers have developed automation software that aims to greatly reduce the time required to generate radiation therapy plans. PhD candidates Aaron Babier and Justin Boutilier, along with their supervisor Timothy Chan (MIE), and Professor Andrea McNiven (Faculty of Medicine) looked at radiation therapy design as an intricate — but solvable — optimization problem. They created software that uses AI to mine historical radiation therapy data, then applies it to an optimization engine to develop individualized maps that help doctors determine where to blast tumours. They applied the tool in a study of 217 patients with throat cancer, who also received treatments developed using conventional methods. The therapies generated by the AI achieved comparable results to patients' conventionally planned treatments — and did so within 20 minutes, compared with days required using conventional methods. The researchers published their findings in *Medical Physics*.

Data in this chapter are presented for the 2017–2018 grant year (April to March). This is the most recent year for which complete data are available. Highlights are from July 2018 to June 2019.

Human Health

U of T Engineering startup raises $3.25 million to eliminate prescription opioids after surgery

A startup built on gel-based technology developed in the lab of Professor Molly Shoichet (ChemE, IBBME) has raised $3.25 million to develop a drug delivery system that could eliminate the need to give patients powerful painkillers following surgery — a key source of the current opioid crisis. AmacaThera uses Shoichet's gel technology to dramatically extend the duration of anesthetics injected at the site of a surgical incision, thus reducing the need for powerful, and potentially addictive, painkillers such as OxyContin. The biocompatible gel is similar to ones previously developed by Shoichet for stem cell injection. It can be easily stored and injected at room temperature, but firms up once it enters the body. It has been formulated to deliver commonly used anesthetic drugs to surgical sites and keep them there for two to three days.

A 'training gym' for lab-grown heart cells

A new device designed by Milica Radisic (IBBME, ChemE) and her team uses a rigorous training regimen to grow small amounts of cardiac tissue in the lab — and measure how strongly they beat. The device builds on the group's previous work, such as the Biowire, a platform in which heart cells grow around a silk suture. By pulsing electricity through the cells, the device causes them to elongate and become more like mature human heart cells. The Biowire II, described in a paper published in *Cell,* contains two wires made of elastic polymers and positioned three millimetres apart. The heart cells form a small band of tissue between the wires, and bend them each time they contract. By measuring the amount of deflection in the wires, the researchers can determine the force of the contraction. Biowire II is already finding commercial application through TARA Biosystems, a spinoff co-founded by Radisic. The company uses its lab-grown heart tissues to carry out cardiac drug testing studies for pharmaceutical companies. Ultimately, lab-grown tissues such as those incubated in the Biowire II may one day be implanted back into humans to repair damaged organs.

U of T Engineering researchers create nano-bot to probe inside human cells

U of T Engineering researchers have built a set of magnetic 'tweezers' that can position a nano-scale bead inside a human cell in three dimensions with unprecedented precision. The nano-bot has already been used to study the properties of cancer cells, and could point the way toward enhanced diagnosis and treatment. Professor Yu Sun (MIE, IBBME, ECE) and his team have been building robots that can manipulate individual cells for two decades. Their latest study, published in *Science Robotics,* describes a system of six magnetic coils placed in different planes around a microscope coverslip seeded with live cancer cells. A magnetic iron bead about 700 nanometres in diameter is placed on the coverslip, where the cancer cells easily take it up inside their membranes. Once the bead is inside, PhD candidate Xian Wang used a computer-controlled algorithm to vary the electrical current through each of the coils, shaping the magnetic field in three dimensions and coaxing the bead into any desired position within the cell. He tracked its position using real-time feedback from confocal microscopy imaging. In collaboration with researchers from Mount Sinai Hospital and The Hospital for Sick Children (SickKids), the team used their robotic system to study early-stage and later-stage bladder cancer cells, including the stiffness of their nuclei. In the future, Sun imagines using the technique to starve a tumour by blocking the blood vessels that feed it, or destroying it directly via mechanical ablation.

Robotics

What makes robots 'persuasive' to humans?

A new study at U of T Engineering is exploring how robots persuade and build trust with humans. This research could guide the development of AI in the next generation of socially assistive robots to aid in health care and other fields. Under the supervision of Goldie Nejat (MIE), Canada Research Chair in Robots for Society, PhD candidate Shane Saunderson conducted an exploratory study of persuasion strategies to observe which methods would most influence a human's decision. Two hundred human participants were asked to write down their best estimate of how many jelly beans were in a jar, taking into consideration the two differing suggestions provided by a pair of commercial robots, Luke and Leia. The robots attempted to influence the participants' guess using one of 10 randomly selected persuasion strategies. The top two strategies to emerge were an "emotional" approach and a "logical" one. The findings were published in *IEEE Robotics and Automation Letters* and presented at the IEEE International Conference on Robotics and Automation in May 2019.

National robotics consortium receives $5.5M NSERC Strategic Partnership Grant

Professors Angela Schoellig and Steven Waslander are representing the University of Toronto Institute for Aerospace Studies (UTIAS) in the NSERC Canadian Robotics Network (NCRN), a consortium of leading robotics researchers from across Canada that includes members from universities, industry and government. The NCRN earned $5.5-million in funding from NSERC's Strategic Partnership Grants for Networks competition. Its goal is to strengthen the growing robotics and AI communities in Canada through a wide range of collaborative research activities, including annual demonstrations and conferences, student exchanges between top Canadian labs and multi-university collaborative research programs.

Automated microrobotic assembly

U of T Engineering researchers have developed a method of assembling robots the size of a pin more quickly and easily than previous methods. These robots are small enough to travel through fluid-filled vessels and organs within the human body, and can be controlled wirelessly using magnetic fields. Some can travel with worm-like motion through fluid channels, while others can close tiny mechanical 'jaws' to take a tissue sample. Assembling these microrobots is currently done by hand and can take more than eight hours per device. By using a 3D printer to precisely arrange microscopic sections of magnetic needles atop a flat, flexible material, Professor Eric Diller and his team have reduced the assembly time to only about 20 minutes. The new method enables the team to iterate much more quickly on robot designs. In the future, they plan to develop more complex microrobots for applications such as targeted drug delivery, assisted fertilization, or biopsies. The research is published in *Science Robotics*.

Sustainability

Smart Freight Centre aims to deliver the goods — faster and greener

Leading experts from U of T Engineering, McMaster University and York University are working together to improve — and future-proof — how goods are delivered across the Greater Toronto Hamilton Area (GTHA) through the newly established Smart Freight Centre (SFC). Professor Matt Roorda (CivMin), of the U of T Transportation Research Institute, is the centre's inaugural chair. SFC will study ways to improve the transportation of goods throughout the region, taking into account issues such as traffic, population growth and the environment. One project will involve industry partners including Walmart, Loblaws and LCBO stores shifting key deliveries from distribution centres to retail locations to the late evening, from 7 to 11 p.m. Roorda and his research group will examine how the time shift affects emission levels, as well as examining cost mitigation for companies, and considering the issue of late-evening noise levels for residents along freight delivery routes. SFC's five-year plan will include research projects on automated trucks and innovative alternatives to last-mile deliveries.

Low-cost catalyst boosts hydrogen production from water

A new catalyst developed at U of T Engineering gives a boost to a number of clean energy technologies that depend on producing hydrogen from water. In a paper published in *Nature Energy,* Professor Ted Sargent (ECE) and his team describe a catalyst that can lower the amount of electricity needed to split water into hydrogen and oxygen. Currently, the best-performing catalysts for this reaction rely on platinum, a high-cost material, and operate under acidic conditions. The new catalyst is made of low-cost copper, nickel and chromium, and is able to perform under pH-neutral conditions. This could enable the use of seawater as a feedstock for hydrogen, as well as the use of microorganisms to make chemicals such as methanol and ethanol from hydrogen and waste CO_2. A team from Sargent's lab is among the five finalists in the international NRG COSIA Carbon XPrize, a $7.5-million competition to use renewable energy to convert waste CO_2 into fuels or other value-added products.

Large trucks are biggest culprits of near-road air pollution: U of T Engineering study

A two-year U of T Engineering study has revealed large trucks to be the greatest contributors to black carbon emissions close to major roadways. The study also indicated that for the 30% of Canadians who live within 500 metres of a major roadway, the type of vehicles rolling past their homes can matter more than total traffic volume in determining the amount of air pollution they breathe. The comprehensive study — led by Professor Greg Evans (ChemE) and collaborators at Environment and Climate Change Canada, and the Ontario Ministry of the Environment, Conservation and Parks, as well as the Metro Vancouver Regional District — involved measuring vehicle emissions near roads in Vancouver and Toronto, including the 401, North America's busiest highway. The difference between emission levels across the sites was more closely correlated with the number of large trucks on the road rather than the number of cars. The data also revealed a significant drop in emissions on the 401 on the weekends, when personal vehicle traffic is still very high, but the volume of large truck traffic is low. The study was published in the journal *Environmental Science & Technology*.

Water

Reinventing the toilet: U of T Engineering team presents sustainable prototype in Beijing

A team led by Professor Yu-Ling Cheng (ChemE) was one of a select group invited to present in Beijing to prospective industry partners, government officials, international agencies, and leadership from the Bill & Melinda Gates Foundation as part of the 2018 Reinvented Toilet Expo. They showcased their prototype for a sustainable toilet designed for the billions of people worldwide who lack access to effective sanitation or waste management systems. Cheng, who was the founding director of the Centre for Global Engineering, has been working on the challenge since 2011, and placed third at the first World Toilet Expo in 2012. Through a spinoff company, Sankoya Technologies, Cheng is actively looking for partners who can help adapt the device for mass production and to reach target markets.

Multidisciplinary collaboration to analyze microplastics in drinking water

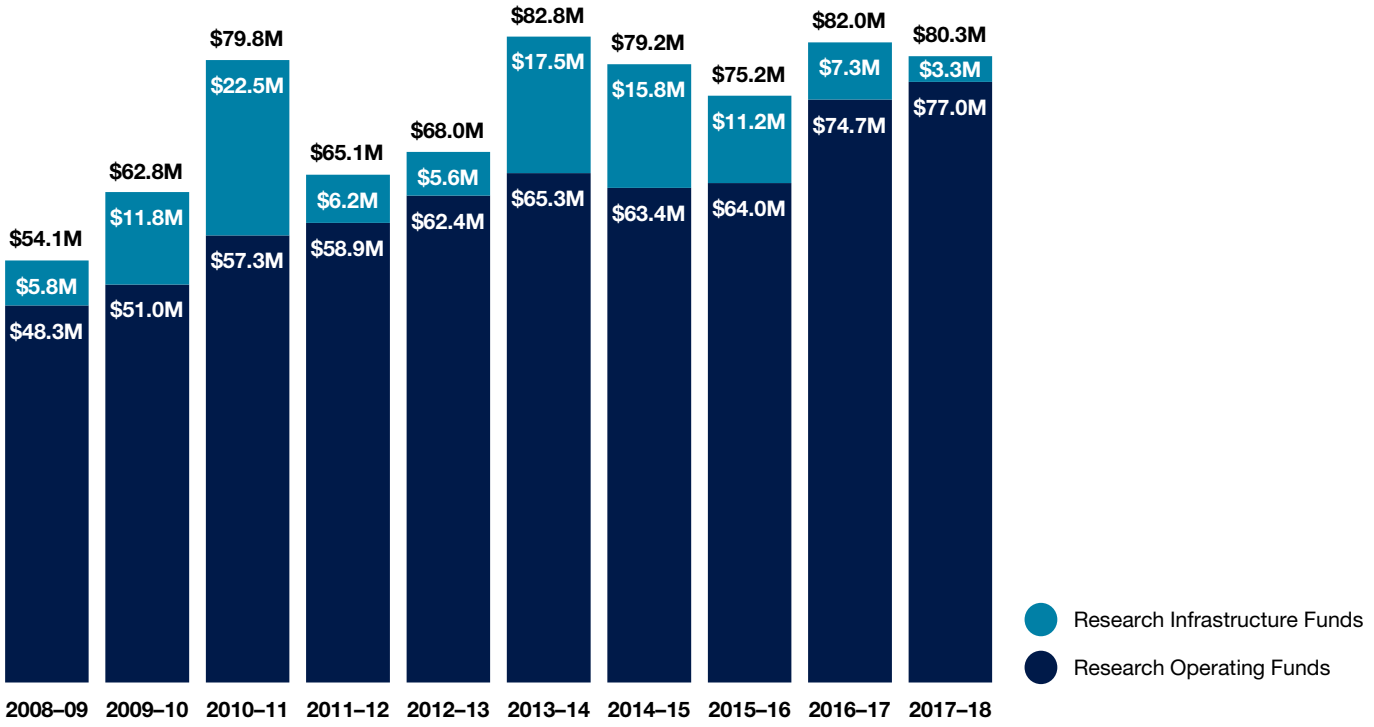
Microplastics — particles anywhere from a few millimetres to a few micrometres in size — have been found in drinking water around the world, but little is known about their effects on human health. One of the challenges is that there are currently no standardized methods for testing levels of microplastics in drinking water, making it hard to compare scientific studies conducted by different groups. Professor Bob Andrews (CivMin) is collaborating with Professor Chelsea Rochman (Ecology and Evolutionary Biology) to develop such methods. One strategy the team is considering is pyrolysis-gas chromatography-mass spectrometry, in which microplastics would be filtered from water, volatilized with heat, and then analyzed at the molecular level to determine which varieties of plastic are the biggest sources. The collaboration is funded in part by XSeed, an interdivisional funding program designed to promote multidisciplinary research.

Research Funding and Tri-Agency Grants

Our collaborative, multidisciplinary approach to research leverages our strong international reputation and our network of partnerships with companies, hospitals and peer institutions around the world. In 2017–2018, the most recent year for which complete data is available, we earned research operating funds of $77.0 million. This is our highest level to date, equivalent to $328,912 per faculty member, representing a 59.1% increase since 2008–2009.

Research infrastructure funding was lower in 2017–2018 than in previous years, due to fewer grants from organizations such as the Canada Foundation for Innovation. However, this total does not include multidisciplinary research facilities funded by private donations, such as those located in the Myhal Centre.

Figure 3.1a **Research Infrastructure Funding and Research Operating Funding, 2008–2009 to 2017–2018**



Our Tri-Agency funding total was the highest yet, and we continue to grow the proportion of funding from agencies other than NSERC. Funding from CIHR was $4.2 million in 2017–2018, a 23.5% increase over the previous year. CIHR now accounts for 11.7% of Tri-Agency funding. In 2017–2018 we also received the Faculty's first sole-PI grant from the Social Sciences and Humanities Research Council. Professor Li Shu (MIE) will lead a project on combining social psychology and engineering interventions to reduce automobile idling.

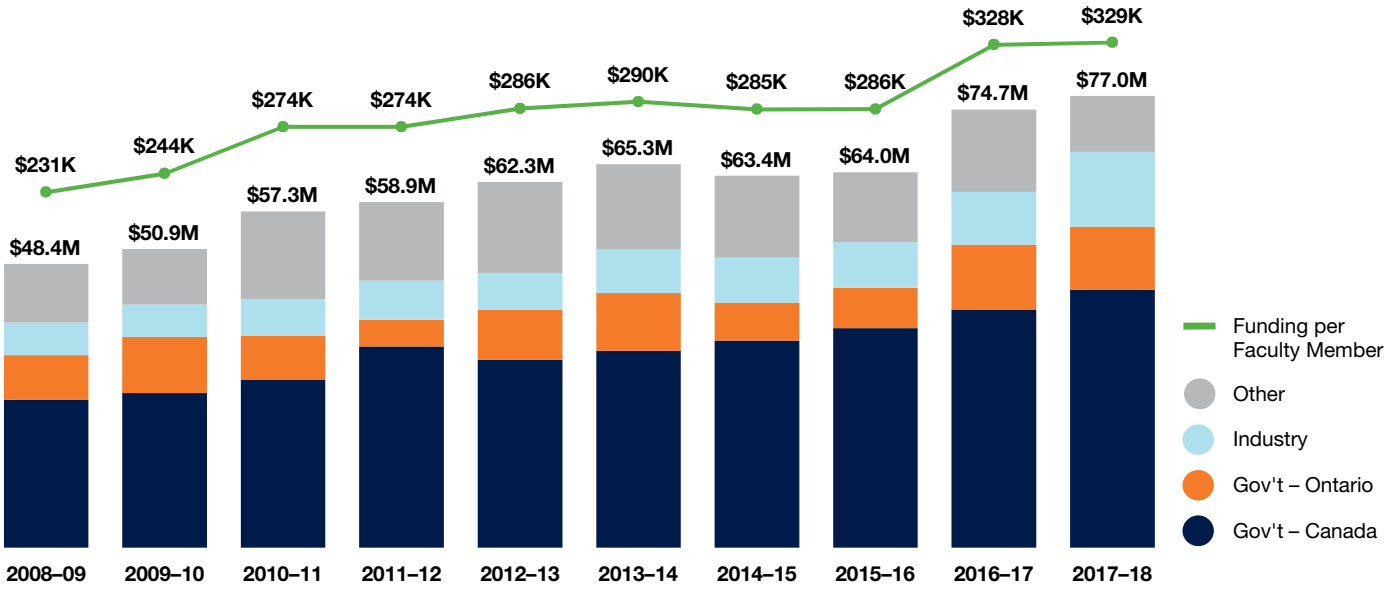
In 2018–2019 we received $4.4 million in NSERC Discovery Grants for 45 researchers across U of T Engineering, and $11.5 million in Strategic Partnership Grants. These funds will be reflected in the 2020 Annual Report.

All three of our applications for funding under the NSERC CREATE program were granted in 2019. This 100% success rate resulted in the largest number of NSERC CREATE grants ever received in a single round by a single institution, and brings the total number of active NSERC CREATE programs across U of T Engineering to eight. The three newest recipients are:

- **Emma Master (ChemE)** — NSERC CREATE for BioZone: An open science collaborative centre for industrial biotechnology in the context of the circular economy
- **Yu Sun (MIE)** — NSERC CREATE in Healthcare Robotics: Training Program
- **Jennifer Drake (CivMin)** — NSERC CREATE for Design of Living Infrastructure for Ecosystem Services (DesignLIFES)

Note 3.1: The figures in this chapter report research funding the Faculty received in 2017–2018. Because it takes some time after the completion of a fiscal year for research funding data to become final, this is the most recent year for which data are available.

Figure 3.1b **Research Operating Funding by Year, Source and Funding per Faculty Member, 2008–2009 to 2017–2018**



	Funding per Faculty Member	Gov't – Canada	Gov't – Ontario	Industry	Other	Total
2008–09	$231,450	$25,184,612	$7,618,345	$5,574,261	$9,995,735	**$48,372,953**
2009–10	$243,595	$26,342,234	$9,562,400	$5,540,382	$9,466,322	**$50,911,338**
2010–11	$274,046	$28,567,718	$7,520,797	$6,212,252	$14,974,772	**$57,275,540**
2011–12	$274,002	$34,287,390	$4,535,363	$6,702,708	$13,384,957	**$58,910,418**
2012–13	$286,008	$32,025,900	$8,511,021	$6,284,318	$15,528,448	**$62,349,687**
2013–14	$290,365	$33,545,785	$9,814,984	$7,449,403	$14,521,924	**$65,332,097**
2014–15	$285,428	$35,266,448	$6,486,482	$7,658,866	$13,953,120	**$63,364,916**
2015–16	$285,585	$37,411,421	$6,883,331	$7,770,092	$11,906,204	**$63,971,048**
2016–17	$327,540	$40,588,828	$11,038,645	$9,028,158	$14,023,425	**$74,679,056**
2017–18	$328,912	$43,969,492	$10,738,023	$12,743,136	$9,514,682	**$76,965,334**

Figure 3.1c **Tri-Agency and NCE Support: CIHR, NSERC and NCE Funding, 2008–2009 to 2017–2018**

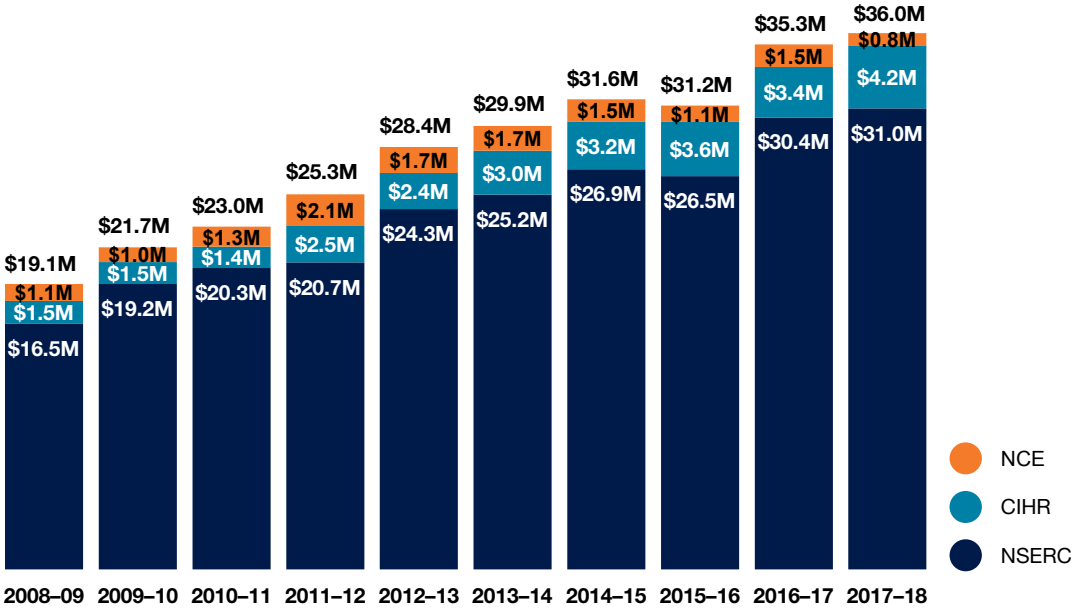
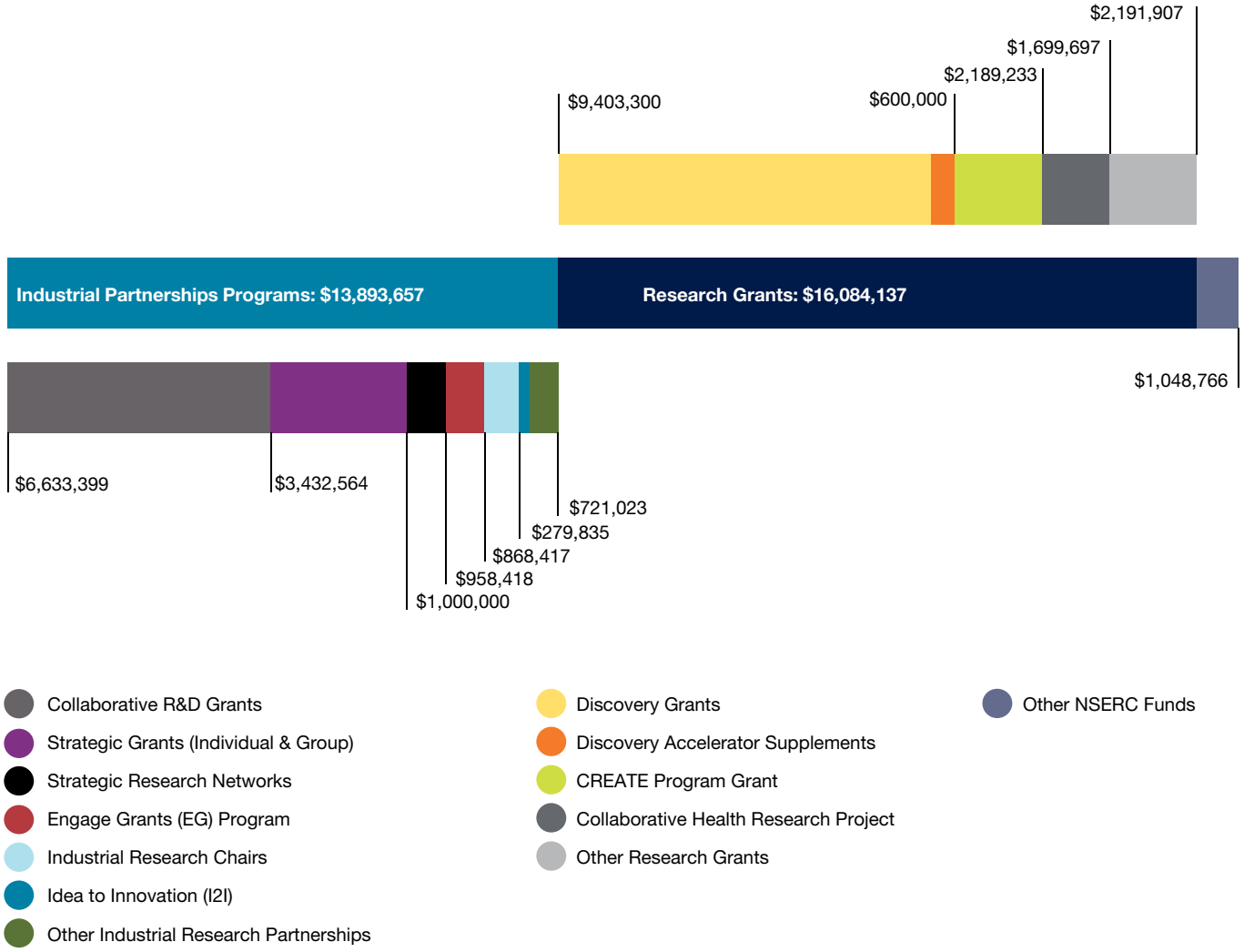


Figure 3.2a **NSERC Funding, 2017–2018**



We have 32 Canada Research Chairs at U of T Engineering, including the following who were added in 2018–2019:

- **Angela Schoellig (UTIAS)** — Canada Research Chair in Machine Learning for Robotics and Control
- **Natalie Enright Jerger (ECE)** — Canada Research Chair in Computer Architecture
- **Jonathan Kelly (UTIAS)** — Canada Research Chair in Collaborative Robotics
- Another faculty member, **Michael Garton (IBBME)**, holds the Canada Research Chair in Synthetic Biology through his cross-appointment to the Faculty of Medicine

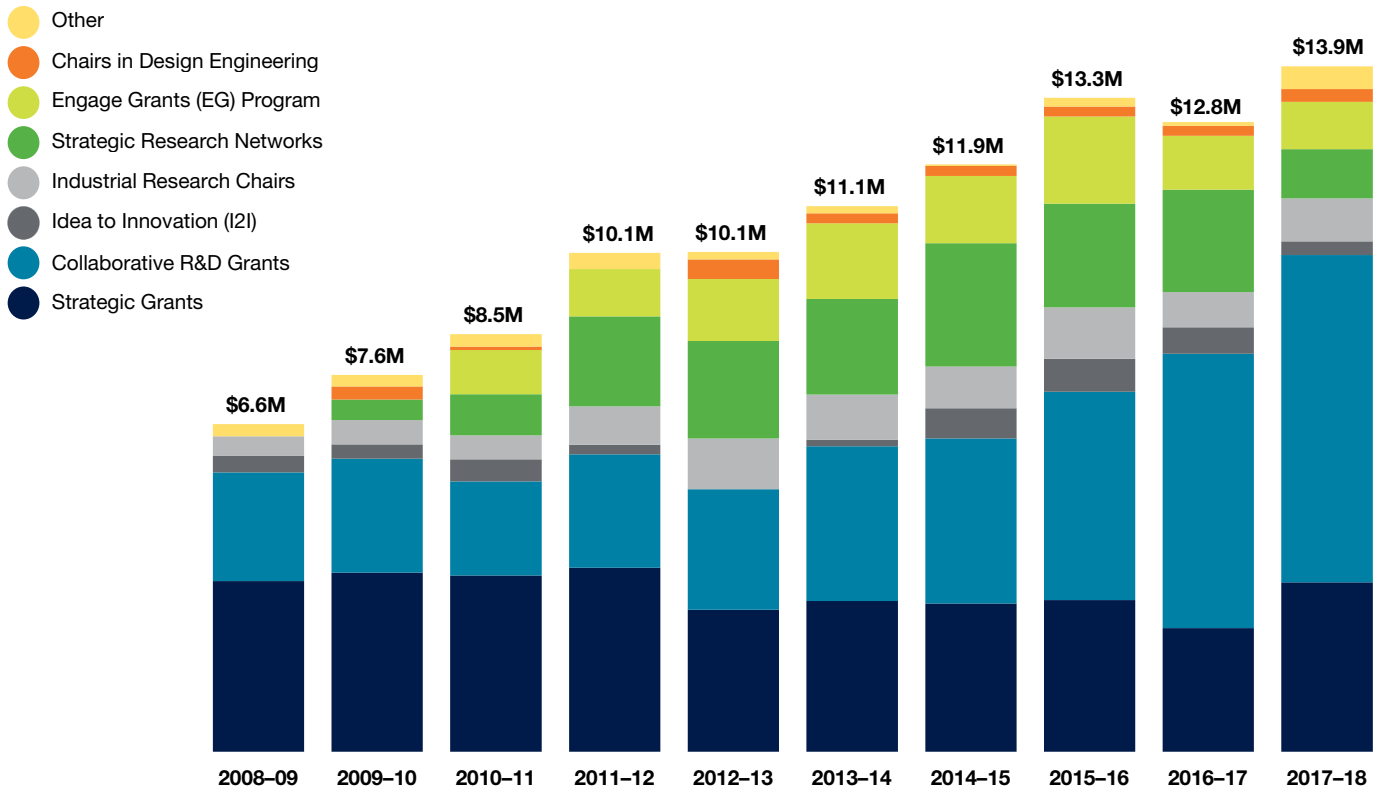
Six more CRCs were renewed in 2018–2019:

- **Aimy Bazylak (MIE)** — Canada Research Chair in Thermofluidics for Clean Energy
- **Timothy Chan (MIE)** — Canada Research Chair in Novel Optimization and Analytics in Health
- **Brendan Frey (ECE)** — Canada Research Chair in Biological Computation
- **Goldie Nejat (MIE)** — Canada Research Chair in Robots for Society
- **Piero Triverio (ECE)** — Canada Research Chair in Computational Electromagnetics
- **Wei Yu (ECE)** — Canada Research Chair in Information Theory and Wireless Communications

For a complete listing of chairholders and professorships, please see Appendix C.

Note 3.2a: Data as of May 2019 and based on grant year (April to March).

Figure 3.2b **NSERC Industrial Partnership Funding by Program, 2008–2009 to 2017–2018**

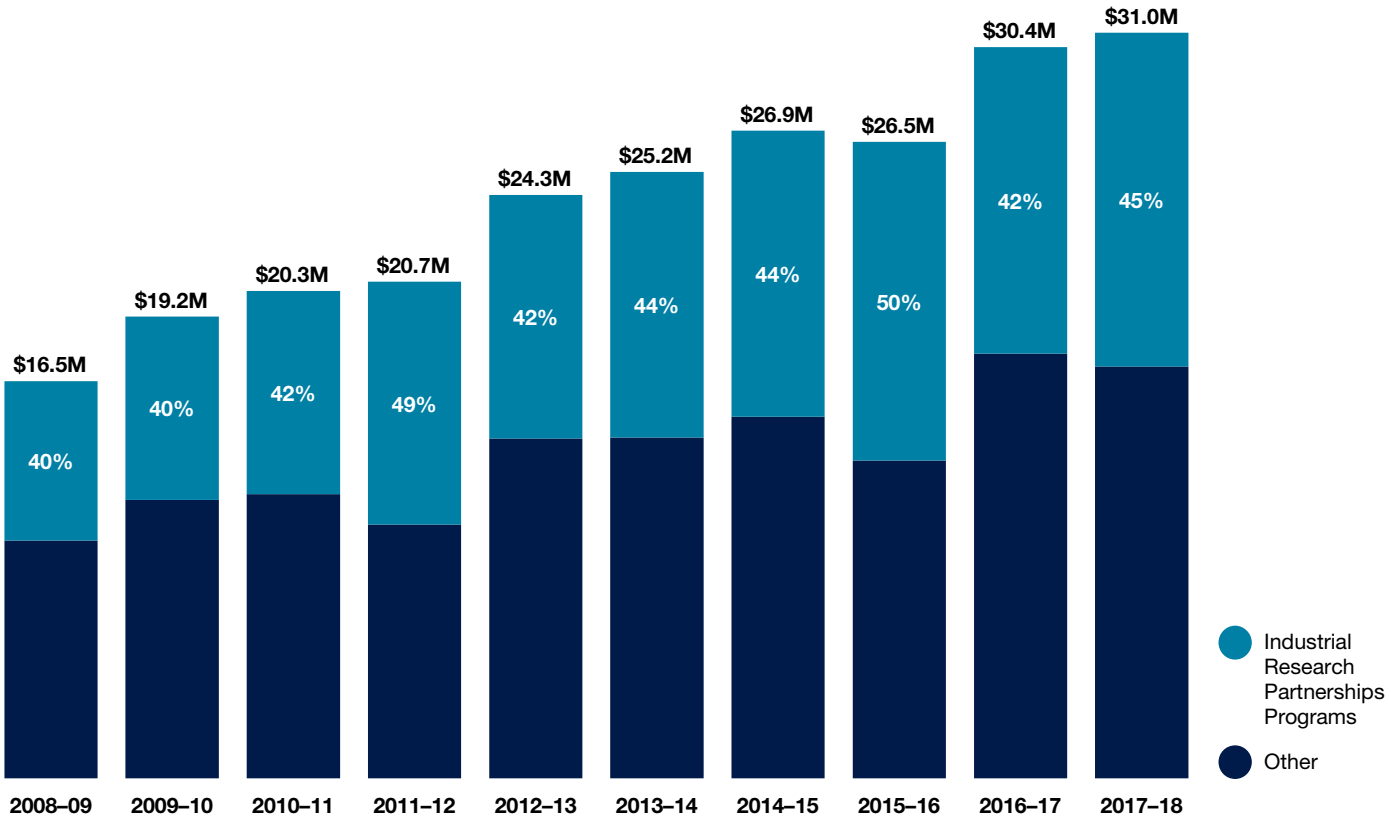


	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
Other	$247,392	$230,000	$251,770	$328,780	$146,905	$148,381	$32,031	$178,803	$72,536	$461,023
Chairs in Design Engineering		$267,173	$69,076		$400,000	$200,000	$200,000	$200,000	$200,000	$260,000
Engage Grants (EG) Program			$897,115	$960,531	$1,254,468	$1,533,923	$1,362,871	$1,767,890	$1,095,326	$958,418
Strategic Research Networks		$417,293	$832,697	$1,826,000	$1,978,886	$1,935,440	$2,500,000	$2,100,000	$2,075,000	$1,000,000
Industrial Research Chairs	$390,667	$493,197	$485,711	$773,964	$1,025,031	$918,349	$847,278	$1,040,762	$713,023	$868,417
Idea to Innovation (I2I)	$339,200	$287,417	$448,612	$195,000		$133,750	$608,417	$669,364	$535,951	$279,835
Collaborative R&D Grants	$2,203,103	$2,313,127	$1,909,431	$2,301,643	$2,445,210	$3,137,628	$3,347,888	$4,226,332	$5,564,099	$6,633,399
Strategic Grants	$3,457,330	$3,625,316	$3,567,278	$3,725,048	$2,875,127	$3,050,468	$3,001,609	$3,070,315	$2,503,150	$3,432,564
Total	**$6,637,692**	**$7,633,523**	**$8,461,689**	**$10,110,965**	**$10,125,627**	**$11,057,939**	**$11,900,094**	**$13,253,466**	**$12,759,084**	**$13,893,657**

Several professors launched new collaborations funded by NSERC Strategic Partnership Grants in 2018–2019, including:

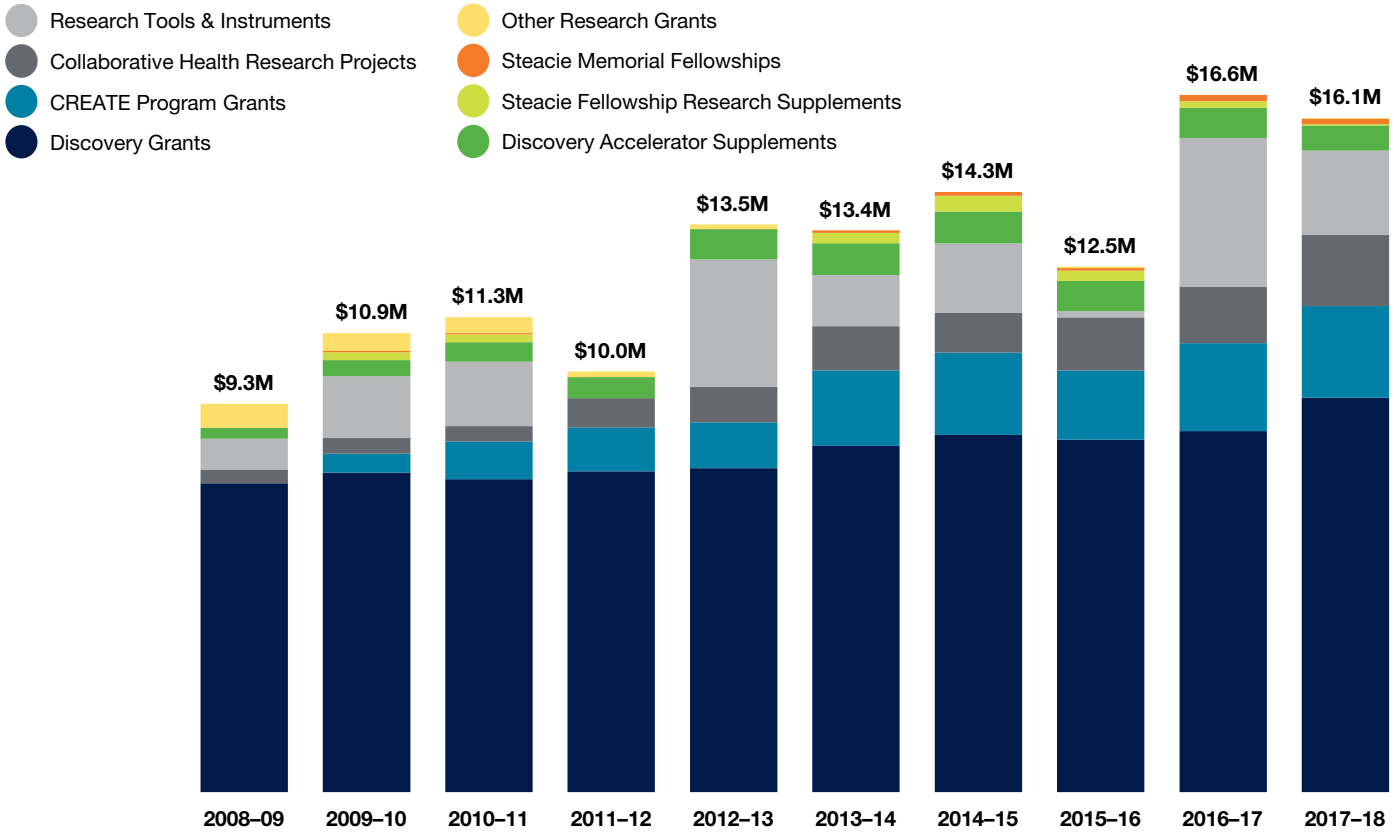
- **Erin Bobicki (MSE, ChemE)** — Novel strategies for CO2 utilization and storage in mineral processing
- **Peter Herman (ECE)** — 3D Additive/subtractive laser manufacturing of photonic circuit and sensor micro-systems
- **Sean Hum (ECE)** — Innovative Satellite Antennas for Emerging M2M/IoT applications
- **Andreas Moshovos (ECE)** — The Computing Hardware for Emerging Intelligent Sensing Applications (COHESA)
- **Wai Tung Ng (ECE)** and **James K. Mills (MIE)** — MOST - Manufacturing and applications of GaN power semiconductor devices/modules
- **Angela Schoellig (UTIAS)** and **Steven Waslander (UTIAS)** — The NSERC Canadian Robotics Network (NCRN)
- **Yu Sun (MIE)** — Development of new techniques for high-speed and high-accuracy industrial part metrology

Figure 3.2c **Industrial Partnerships as a Percentage of Total NSERC Funding, 2008–2009 to 2017–2018**



We continue to earn a larger five-year cumulative share of NSERC funding than any other engineering school in Canada. This proportion is significant as it is the metric used to determine our complement of Canada Research Chairs. In 2017–2018, we surpassed our own record for the highest-ever proportion of all NSERC funding in Engineering at 10.1%.

Figure 3.2d **NSERC Research Grant Funding by Program, 2008–2009 to 2017–2018**



	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
Other Research Grants	$567,950	$422,319	$382,583	$132,000	$111,000			$40,000		$25,000
Steacie Memorial Fellowships		$30,000	$30,000			$60,000	$90,000	$60,000	$155,000	$125,000
Steacie Fellowship Research Supplements		$187,500	$187,500			$250,000	$375,000	$250,000	$155,000	$30,000
Discovery Accelerator Supplements	$264,000	$383,999	$464,000	$504,000	$720,000	$760,000	$760,000	$716,285	$719,970	$600,000
Research Tools & Instruments	$734,572	$1,477,017	$1,533,781		$3,043,029	$1,218,076	$1,654,682	$146,900	$3,553,549	$2,011,907
Collaborative Health Research Projects	$326,169	$378,774	$366,899	$696,536	$846,731	$1,060,212	$950,376	$1,270,103	$1,338,873	$1,699,697
CREATE Program Grants		$450,000	$900,000	$1,050,000	$1,096,000	$1,797,084	$1,969,779	$1,650,000	$2,100,000	$2,189,233
Discovery Grants	$7,366,144	$7,617,106	$7,464,405	$7,650,892	$7,726,942	$8,256,362	$8,516,417	$8,406,314	$8,611,937	$9,403,300
Total	**$9,258,835**	**$10,946,715**	**$11,329,168**	**$10,033,428**	**$13,543,702**	**$13,401,734**	**$14,316,254**	**$12,539,603**	**$16,634,328**	**$16,084,137**

Figure 3.3a **Canadian Peer Universities vs. University of Toronto Share of NSERC Funding for Engineering Cumulative Five-Year Share, 2013–2014 to 2017–2018**

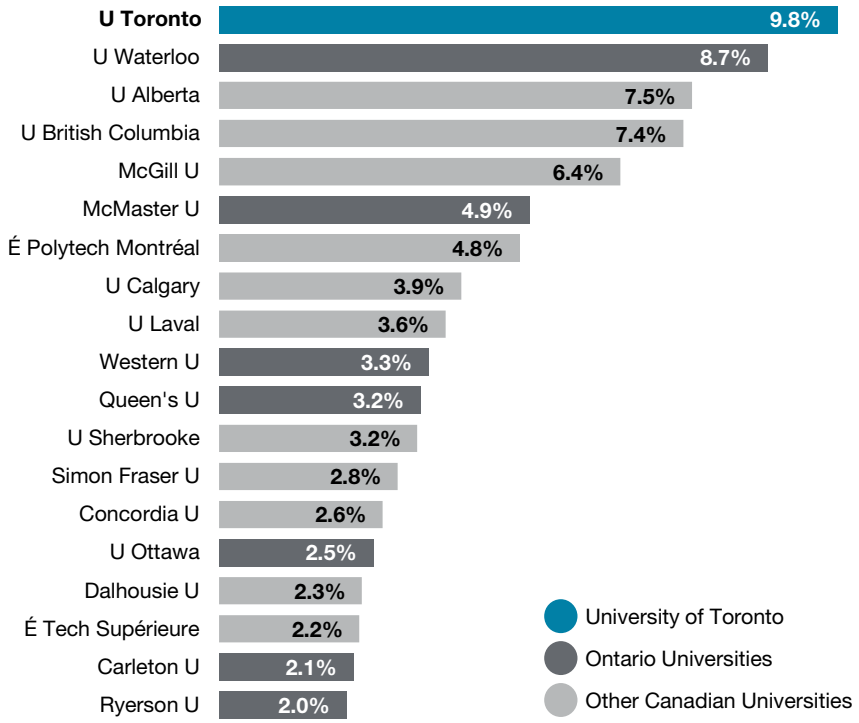
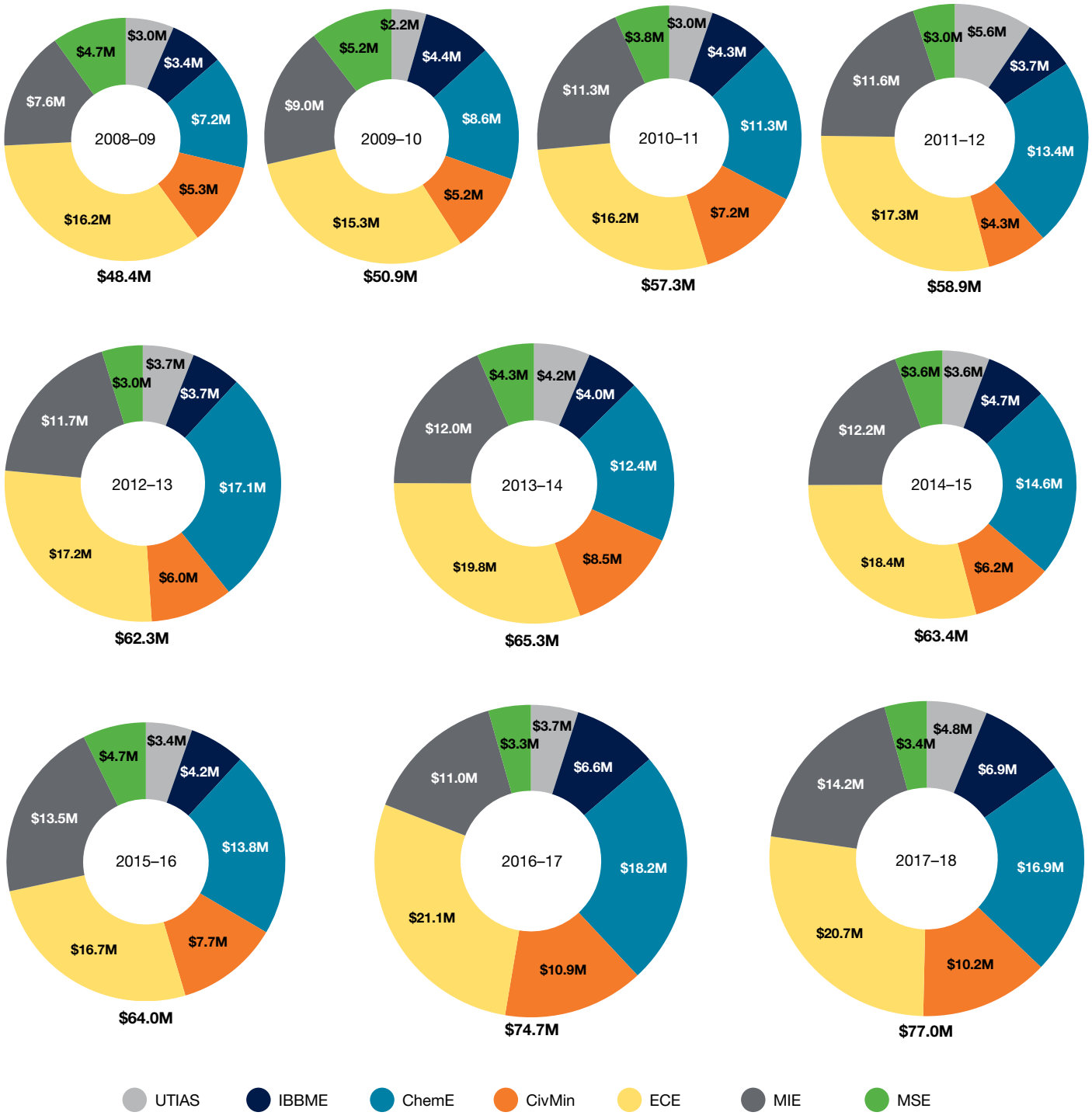


Figure 3.3b **U of T Annual Share of NSERC Funding in Engineering, 2008–2009 to 2017–2018**

2008–09	8.5%
2009–10	9.4%
2010–11	9.0%
2011–12	9.5%
2012–13	9.0%
2013–14	9.6%
2014–15	9.5%
2015–16	10.0%
2016–17	9.9%
2017–18	10.1%

Note 3.3a and 3.3b: Data are from the NSERC advanced search website and are shown by NSERC's fiscal year (April to March).

Figure 3.4 **Distribution of Research Operating Funding by Academic Area, 2008–2009 to 2017–2018**



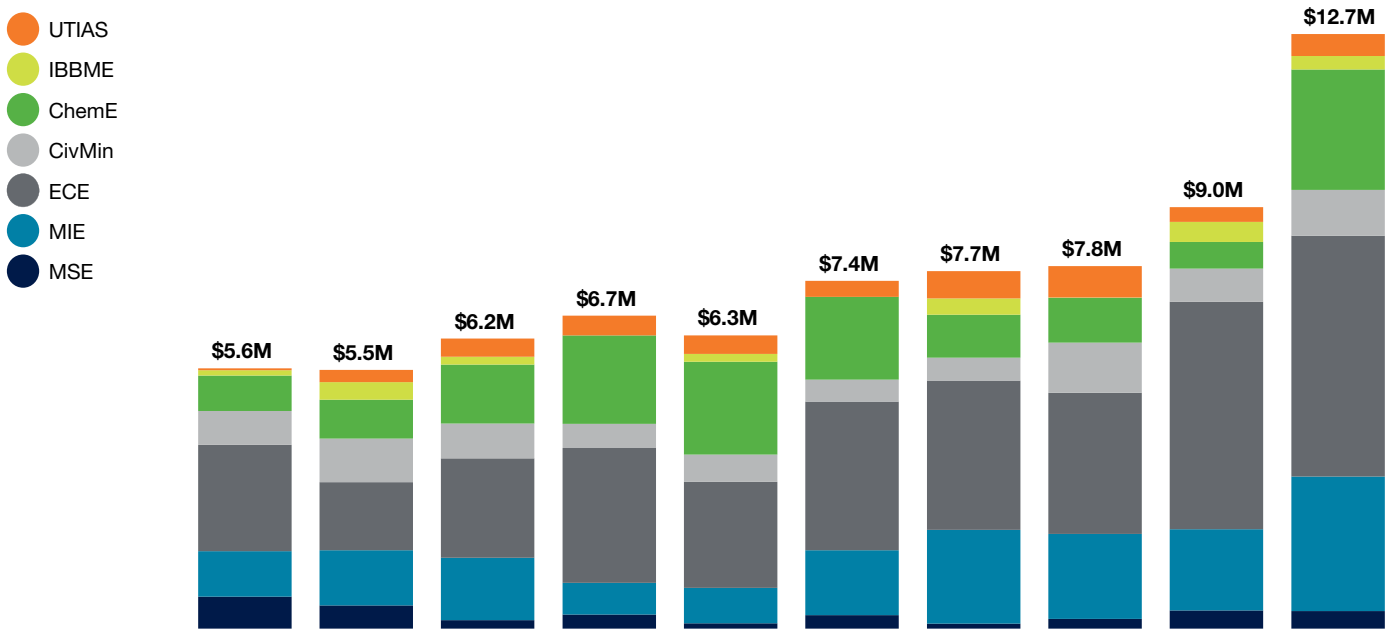
Note 3.4: Totals include a small amount of additional funding not shown in the breakdown by academic areas. The research funding attributed to IBBME for 2017–18 represents 83% of the total funding received by faculty members in the Institute. Because of IBBME's cross-disciplinary structure, some professors have their research funding processed through the Faculty of Medicine. The figure above shows only the funding that comes through U of T Engineering and is presented by grant year (April to March).

Industry Partnerships

We have significantly increased the proportion of our funding that comes from direct partnerships with industry. The most current available figure is $12.7 million, a 41.1% increase over the previous year and a 102.8% increase over the past five years. When additional sources of corporate funding are included, such as corporate philanthropy, foundation sponsored research, and foundation philanthropy, the total reaches $18.0 million. This reflects the increasing emphasis and resources that the Faculty has dedicated to fostering and strengthening industry partnerships, including through the Corporate & Foundation Partnerships Office.

One thriving partnership is the **Fujitsu Co-Creation Research Laboratory.** Situated on the eighth floor of the Myhal Centre, the research facility grew out of collaborations between Fujitsu Laboratories Ltd. and Professor Ali Sheikholeslami (ECE) which have flourished over more than two decades. As part of the centre, Fujitsu has also signed research partnership agreements with Professors Alberto Leon-Garcia (ECE), Shahrokh Valaee (ECE), Taufik Valiante (Department of Surgery, ECE) and Yuri Lawryshyn (ChemE).

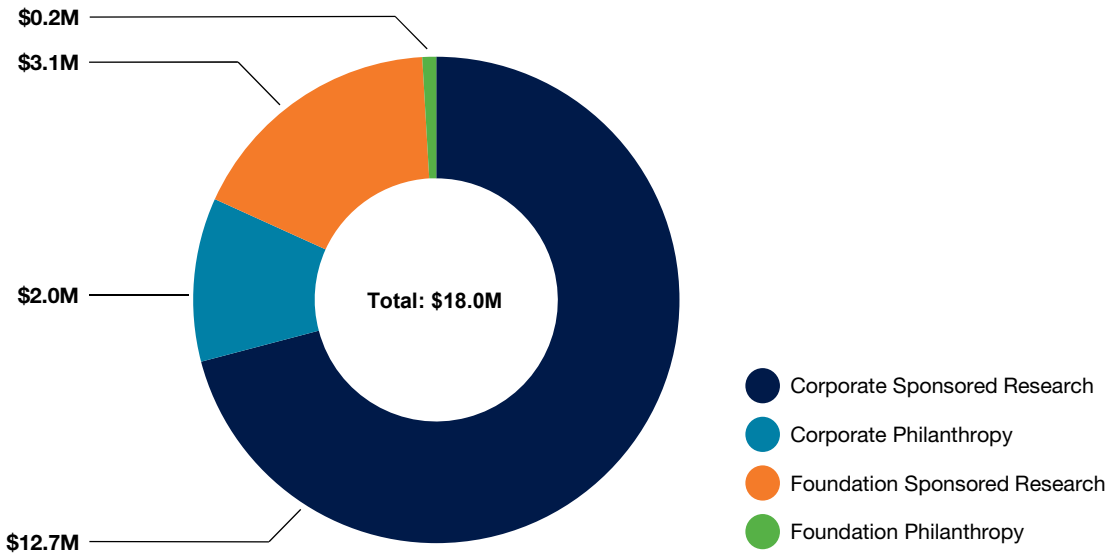
Figure 3.5a **Industry Research Funding by Academic Area, 2008–2009 to 2017–2018**



	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
UTIAS	$35,500	$259,200	$390,200	$420,400	$397,115	$342,396	$584,609	$674,557	$313,998	$474,246
IBBME	$117,411	$375,037	$165,534		$167,789	$1,301	$346,061	$4,802	$427,108	$285,487
ChemE	$757,256	$835,642	$1,261,227	$1,897,761	$1,990,738	$1,770,656	$920,026	$962,888	$570,070	$2,584,168
CivMin	$730,460	$931,988	$747,127	$515,246	$585,360	$470,776	$491,188	$1,072,331	$715,923	$981,529
ECE	$2,275,934	$1,460,500	$2,134,524	$2,891,234	$2,275,124	$3,184,516	$3,203,168	$3,025,580	$4,870,089	$5,160,598
MIE	$976,457	$1,180,330	$1,337,641	$679,470	$757,191	$1,393,542	$2,007,844	$1,824,219	$1,740,732	$2,883,537
MSE	$681,243	$497,685	$176,000	$298,597	$111,000	$286,216	$105,970	$205,715	$390,239	$373,571
Total	**$5,574,261**	**$5,540,382**	**$6,212,252**	**$6,702,708**	**$6,284,318**	**$7,449,403**	**$7,658,866**	**$7,770,092**	**$9,028,158**	**$12,743,136**

We also created the **Centre for Research and Applications in Fluidic Technologies (CRAFT)** in collaboration with the National Research Council. The first institute of its kind, CRAFT will bring together researchers from government and academia to advance microfluidic technologies and catalyze the commercialization of devices. Applications include point-of-care devices for rapid diagnosis of diseases, growing organ tissues on devices outside the body to test drugs or do research related to personalized medicine, and printing biological tissues that can be used to repair organs of the human body. CRAFT includes 200 researchers, 45 labs and 25 technology companies, and will be jointly funded by both partners with a $22 million investment over five years. The lead researchers from U of T Engineering are Axel Guenther (MIE), Milica Radisic (IBBME, ChemE) and Aaron Wheeler (Chemistry, IBBME).

Figure 3.5b **Industry Research Funding Sources, 2018**



Last year, our Faculty collaborated with more than 400 external research partners. In addition to these, many more companies hire our undergraduates through the Professional Experience Year Co-op Program, work with students on multidisciplinary capstone projects or provide philanthropic support.

Figure 3.5c **Industrial Partners, 2018–2019**

- 3E Nano Inc.
- ABB Group
- Advanced Measurement and Analysis Group Inc.
- Advanced Micro Devices Inc.
- Advanis
- Aerodyne
- Afsan Engineering Co.
- AGFA
- Agnico-Eagle Mines Ltd.
- Agrium Inc.
- Airbus SAS
- Alcan Aluminum International
- Alcohol Countermeasure Systems
- Altera Corp.
- AMAG Ltd.
- AMEC Foster Wheeler
- Americas Styrenics LLC
- Analog Devices Inc.
- Andec Manufacturing Ltd.
- Andritz Group
- Anemoi Technologies Inc.
- Angstrom Engineering Inc.
- Antex Western
- Apotex Inc.
- Applanix
- Apple
- Aquafor Beech
- ArcelorMittal Dofasco
- Armacell
- Artium Technologies
- Atomic Energy of Canada Ltd.
- AUG Signals Ltd.
- Autodesk
- AV Nackawic Group
- Avalon Rare Metals
- Avertus Epilepsy Technologies Inc.
- Babcock & Wilcox Ltd.
- BaoWu Steel Group Corp.
- Barrick Gold Corp.
- Bell Helicopter Textron Inc.
- Bickell Foundation (J. P. Bickell)
- BiomeRenewables
- Bio-Rad Laboratories Canada Ltd.
- Blackberry
- BMW
- Boeing
- Boise Cascade
- Bombardier Aerospace
- Bombardier Inc.
- Braskem

- BresoTec Inc.
- Brican Automated Systems Inc.
- Brigham & Women's Hospital
- CAE
- Calera
- CalEnergy Generation
- Calgon Carbon Corp.
- Canadian Institute of Steel Construction
- Canadian Nuclear Safety Commission
- Canadian Precast/Prestressed Concrete Institute
- Canadian Urban Transit Research & Innovation Consortium
- Candu Energy Inc.
- Candu Owners Group
- Candura Instruments
- CanSyn Chem Corp.
- Carbon Cure Technologies
- Cardinal Health
- Carter Holt Harvey Ltd.
- Cascades
- Cast Connex Corp.
- CD Nova
- Celestica
- CellScale Biomaterials Testing
- Celulose Nipo-Brasileira
- Cement Association of Canada
- Center for Automotive Materials and Manufacturing
- Centre Line Ltd.
- Chemetry
- Christie Digital Systems Canada Inc.
- Chrysler Canada Inc.
- Ciena Canada Inc.
- CIMA Canada Inc.
- Clearpath Robotics
- Clyde-Bergemann Inc.
- CMC Electronics
- Colibri Technologies
- COM DEV International Ltd.
- Commissariat à l'energie atomique
- ConCast Pipe
- Concretec Ltd.
- Connaught Foundation
- Cook Medical
- Coraltec Inc.
- CPCI
- Createx Technology (Suzhou) Co., Ltd.
- Crosswing Inc.
- Curiousitate
- Cyberworks Robotics
- Daishowa-Marubeni International (DMI) Ltd.
- Dana Canada Corp.
- Daniels Group
- Dasaerospace Inc.
- Datatrends Research Corp.
- DCL International
- Defence Science & Techology Lab (UK)
- Dell
- Detour Gold Corp.
- Deveron
- Dionex
- Dongwon Technology Co. Ltd.
- Domtar Inc.
- Dr. Robot Inc.
- Drone Delivery Canada
- Droplet Measurement Technologies
- DSO National Laboratories
- DuPont Canada Inc.
- Eavor Technologies Inc.
- eCamion Incorporated
- Eclipse Scientific Inc.
- Ecobee Inc.
- Ecosynthetix
- Eco-Tec Inc.
- Eldorado Brasil
- Electrovaya Inc.
- Eli Lilly Research Laboratories
- EllisDon
- Enbridge Gas Distribution Inc.
- Energent Inc.
- Engineering Services Inc.
- ENMAX Power Corp.
- Ensyn Technologies Inc.
- ERCO Worldwide
- Ericsson Canada Inc.
- ESG Solutions
- exactEarth Inc.
- Exigence Technologies
- Expert Process Solutions (XPS)
- Explora Foundation
- Exxon Mobil Corp.
- Facca Inc.
- Fibria Celulose
- Fidelity Canada
- Finisar Corp.
- Flight Safety International
- Food BioTek Corp.
- Ford Motor Company (USA)
- Ford Motor Company of Canada
- FP Innovations
- Fuji Electric Co. Ltd.
- Fujitsu Laboratories Ltd.
- Fujitsu Labs of America Inc.
- Futurebound Corp.
- Futurewei Technologies Inc.
- G. Cinelli – Esperia Corp.
- GE Energy
- GE Global Research
- GE Zenon
- Gedex Inc.
- Gener8 Inc.
- General Dynamics Canada
- General Electric Canada
- General Electric Inc.
- General Motors of Canada Ltd.
- Genpak
- Geosyntec Consultants
- Gerdau Long Steel North America
- GHGSat Inc.
- GlaxoSmithKline Inc.
- Glencore Canada Corp.
- Goodrich Landing Gear
- Grafoid Inc.
- Greencore Composites
- Groupe Mequaltech Inc.
- GTAA Toronto Pearson
- GVA Lighting
- Hanwha Solar Canada
- Hard Rock Innovations Inc.
- Hatch Ltd.
- Havelaar Canada
- Hawker Siddeley Canada
- HDR Corp.
- Hedgefog Research Inc.
- Hitachi High-Technologies
- Holcim Inc.
- Honeywell
- Huawei Technologies Co. Ltd.
- Hunch Manifest Inc.
- Huron Digital Pathology
- Hydro One Networks
- Hydro Quebec
- Hydrogenics
- Hyundai Motor Company
- IBI Group
- IBM Canada Ltd.
- IBM T. J. Watson Research Center
- IMAX Corp.
- Imperial Oil Ltd.
- Independent Electricity System Operator (IESO)
- Indian Oil Company
- Industrial Thermo Polymers Ltd.
- Ingenia Polymers Corp.
- Inphi Corp.
- Institute for Energy Technology (Norway)
- Integran Technologies Inc.
- Intel Corp.
- Interface Biologics Inc.
- International Business Machines (IBM)
- International Paper Company
- Ionicon
- Ionics Mass Spectrometry Group Inc.
- IRISNDT Corp.
- Irving Pulp & Paper Ltd.
- JDS Uniphase Inc.
- JITRI Micro and Nano Automation
- JNE Chemicals
- Johnson Matthey
- Kapik Integration
- Kasai Kogyo Co. Ltd.
- Kevin Quan Studios
- Keysight Technologies Canada Inc.
- Kiln Flame Systems Ltd.
- Kimberly-Clark Corp.
- Kinetica Dynamics
- Kinross Gold Corp.
- Klabin
- KQS Inc.
- Krauss Maffei Corp.
- Kumho Petrochemical R & D Center
- Laboratoire d'essai Mequaltech
- LaFarge Canada
- Lallemand Inc.
- Lattice Semiconductor Ltd.
- Leader's Circle
- LG Chem
- LightMachinery Inc.
- Lisgar Construction Company
- Litens Automotove Group

- Lubrizol
- Lumentra Inc.
- MacDonald, Dettwiler and Associates (MDA) Ltd.
- Magellan Aerospace
- Magna Closures
- Magna Exteriors and Interiors
- Magna International Inc.
- Magna Powertrain
- Manitoba Hydro
- Mantech Inc.
- Marmak Information Technologies
- Materials & Manufacturing Ontario
- Maxim Integrated Products Inc.
- McEwen Mining Inc.
- MeadWestvaco (MWV) Corp.
- Mercedes-Benz Canada Inc.
- Messier-Bugatti-Dowty
- Messier-Dowty Inc.
- Metso Pulp, Paper and Power
- Microbonds Inc.
- Micropilot
- Millipore
- Mine Environment Neutral Drainage
- Mitsubishi Rayon Co. Ltd.
- Moldflow Corp.
- Monaghan Biosciences Ltd.
- Nanowave
- NanoXplore Inc.
- National Aeronautical Establishment (USA)
- NatureWorks LLC
- NCK Engineering
- Nestle Canada
- New World Laboratories
- Newterra
- Nike Inc.
- Northern Yashi Engineering Construction, Ltd.
- NUCAP Global
- Nuclear Waste Management Organization
- NXP Semiconductors Netherlands BV
- OCMR
- Olympus Canada
- Olympus NDT Canada
- Ontario Clean Water Agency
- Ontario Power Generation Inc.
- Ontario Renal Network
- Opal-RT Technologies Inc.
- ORNGE Medical Transport
- Ossur Canada Inc.
- OtoSim
- OZ Optics Ltd
- Pall Corp.
- Perkin Elmer Canada
- Petronas Canada
- Philips Electronics North America Corp.
- Plasco Energy Group
- Platinum Unlimited Inc.
- Polumiros Inc.
- Polycon Industries
- Porewater Solutions
- Potent Group Inc.
- Pratt & Whitney Canada Inc.
- PrecisionHawk
- Process Research Ortech Inc.
- Procter & Gamble
- Prothena Biosciences Inc.
- Purolator
- QD Solar Inc.
- Qualcomm Canada Inc.
- Qualcomm Technologies Inc.
- Quanser Inc.
- Quantum Dental Technologies (QDT) Inc.
- Questor Technologies Inc.
- Quorum Technologies Inc.
- RBC – Royal Bank of Canada
- Regeneron Pharmaceuticals
- RESCON
- Resertrac Inc.
- Resonance Ltd.
- Resource Systems Group Inc.
- Rio Tinto Alcan Inc.
- Robert Bosch Corp.
- Rockwell International
- Rocscience Inc.
- Rolls Royce Canada Ltd.
- Rubikloud Technologies Inc.
- RWDI
- Safety Power Inc.
- Safran Electronics Canada
- Samsung Advanced Institute of Technology
- Samsung Display
- Samsung Electronics
- Sanofi Pasteur
- Saudi Basic Industries Corp. (SABIC)
- Sceye Inc.
- Schlumberger Canada Ltd.
- Sealed Air Corp.
- Semiconductor Research Corp.
- Sensor Technology Ltd.
- S-FRAME Software Inc.
- ShawCor
- Shinil Chemical Industry Co. Ltd.
- Side Effects Software
- Sidewalk Toronto Employees Ltd.
- Siemens ADGT
- Sinclair Interplanetary
- Sinclair Technologies Inc.
- Solantro Semiconductor Corp.
- Solar Ship Inc.
- Solvay Specialty Polymers
- Sony Corp.
- SPP Canada Aircraft Inc.
- St Mary's Cement Group
- Stackpole International
- Stantec Inc.
- Steel Structures Education Foundation
- StemCell Tecnologies Inc.
- StoraEnso
- Sulzer Metco
- Suncor Energy Inc.
- Sunnybrook Health Sciences Centre
- Sunwell Technologies
- Suzano Papel e Celulose
- Synbra
- Syncrude Canada Ltd.
- Teck Resources Ltd.
- Teledyne ISCO
- TELUS
- Telus Mobility
- Tembec Industries Inc.
- Tenova GoodFellow Inc.
- Tessonics Inc.
- Thales Canada Inc.
- The Iron Ore Company of Canada (IOC)
- The Miller Group
- Theralase Inc.
- ThermoFisher Scientific
- Tolko Industries Ltd.
- Toronto Hydro
- Total American Services Inc.
- Tower Automotive
- Tower Solutions
- Toyota Collaborative Safety Research Center (CSRC)
- Toyota Technical Center USA Inc.
- TransCanada
- Trapeze Software ULC
- TSI
- Ultrasonix
- Uncharted Software Inc.
- Unisearch Associates
- US Steel Canada
- VAC Aero International Inc. Vale Canada Ltd.
- Valmet Ltd.
- Vicicog
- VisImage Systems Inc.
- Visual8 Corp.
- Volkswagen Canada Inc.
- VTT Technical Research Centre of Finland
- Waterloo Instruments Inc.
- Westport Innovations
- Whitemud Resources
- WSP Canada Inc.
- Wugang Canada Resources Invest. Ltd.
- Wurth Elektronik eiSos GmbH & Co. KG
- Wuzhong Instrument Company
- Xilinx Inc.
- Xiphos Technologies Inc.
- XOR-Labs Toronto
- Zotefoams PLC

Note 3.5c: The list above includes companies from U of T's Research Information System, along with collaborators that fund research through a number of industrial research consortia, including those associated with many of our Industrial Research Chairs. It does not include companies that hire our students through the Professional Experience Year Co-op program, work with them on Multidisciplinary Capstone Projects, or provide philanthropic support.

Catalyzing Multidisciplinary Collaboration

U of T Engineering is home to 29 multidisciplinary research centres and institutes, nearly half of which have been created in the last decade. By bringing together leading researchers from across our Faculty and beyond, we are catalyzing unexpected collaborations that drive innovation and spark new ventures in areas from sustainable energy and water to robotics and artificial intelligence.

In 2018–2019 we evolved the structure of the **University of Toronto Robotics Institute** to strengthen our brand in this rapidly evolving field and ensure that our leading-edge research cluster is well recognized both in Canada and internationally. The Robotics Institute includes more than 50 principal investigators from across the Faculty and beyond, bringing together expertise in various areas of robotics technology such as sensing, control and human-machine interfaces. The institute is now focused around three pillars:

- **Autonomous vehicles and field robotics** – This area includes both land-based and airborne vehicles which can greatly enhance monitoring of remote sites, including mines or power stations. In the future, such field robots may also be able to deliver goods to remote communities such as those in northern Canada.
- **Health care robotics** — Robotics Institute researchers and their collaborators are designing robots to enhance the diagnosis and treatment of diseases. These include robots that can automate surgical procedures to enhance accuracy and safety, assistive robotics that can aid physiotherapy, and nanoscale robots that can probe structures within human organs or even individual cells.
- **Advanced manufacturing** — The manufacturing industry was one of the first to implement robotics on a wide scale. Our researchers and their collaborators are leveraging new technologies, such as smart sensing and wearable electronics, to enhance human-robot interaction and further improve efficiency across the industry.

Our newest multidisciplinary research institute is the **Centre for Analytics and Artificial Intelligence Engineering (CARTE),** which fosters collaborations between researchers who study analytics and AI directly and those in domains where AI could be a useful tool. The goal is to catalyze translation of analytics and AI techniques and algorithms to practical challenges in areas including human health, sustainability and advanced manufacturing.

Our EMHSeed and XSeed initiatives are strengthening multidisciplinary collaborations across U of T. By providing seed funding for research projects that include professors both at U of T Engineering and in other Faculties, they encourage the development of new partnerships while enhancing creativity and innovation.

EMHSeed was created in 2016 as a partnership between U of T Engineering, the Faculty of Medicine and the Toronto Academic Health Sciences Network. It is well-aligned with other multidisciplinary initiatives such as Medicine by Design and the Translational Biology Engineering Program. Over the last four years, 29 projects have received funding through EMHSeed.

XSeed builds on the success of EMHSeed and expands the list of collaborators to include researchers in the Faculty of Arts & Science, University of Toronto Mississauga (UTM) and University of Toronto Scarborough (UTSC). Eight projects were funded through the program in 2018: four with co-investigators from the Faculty of Arts & Science, two from UTM and two from UTSC. For the 2019 cycle, the Faculty of Kinesiology & Physical Education has joined the partnership, and we expanded the total number of funded projects to 11. Examples include:

- A project to investigate the fate of nanoplastics in the environment (collaboration between Professors Bob Andrews (CivMin) and Chelsea Rochman (Ecology and Evolutionary Biology))
- A new strategy for asthma drug discovery through organ-on-a-chip enabled protein engineering (collaboration between Professors Edmond Young (MIE) and Jumi Shin (Chemistry, UTM))
- An evaluation of the environmental impact of alternative fuel vehicles under a diverse and changing climate (collaboration between Professors Daniel Posen (CivMin) and Paul Kushner (Physics))

Invention & Commercialization

Figure 3.6a **Engineering Invention Disclosure by Academic Area, 2014–2015 to 2018–2019**

	2014–15	2015–16	2016–17	2017–18	2018–19	5-Yr Total
UTIAS		1.0	0.3	2.0		**3.3**
IBBME	6.5	7.8	5.9	4.4	8.8	**33.4**
ChemE	9.0	7.0	13.2	6.1	10.3	**45.5**
CivE	5.0	5.0	1.7	4.0	2.0	**17.7**
ECE	41.6	23.5	34.8	46.0	39.5	**185.3**
EngSci		0.1	0.3	0.4	0.5	**1.4**
MIE	18.8	17.0	19.8	15.6	15.9	**87.1**
MSE	1.5	0.3	2.3	3.3	6.6	**14.0**
Annual Total	**82.4**	**61.7**	**78.3**	**81.8**	**83.7**	**387.8**
University Annual Total	**174.0**	**162.7**	**209.0**	**165.0**	**183.1**	**893.8**
Engineering Percentage	**47%**	**38%**	**37%**	**50%**	**46%**	**43%**

U of T Engineering continues to lead our institution in invention disclosures, as recorded by the Innovations and Partnerships Office. Our researchers accounted for 46% of these disclosures in 2018–2019 and 43% over the past five years. We also led the way in patent applications with 33 in 2018–2019, representing 50.8% of the University's total.

Figure 3.6b **U of T Invention Disclosures by Faculty, 2018–2019**

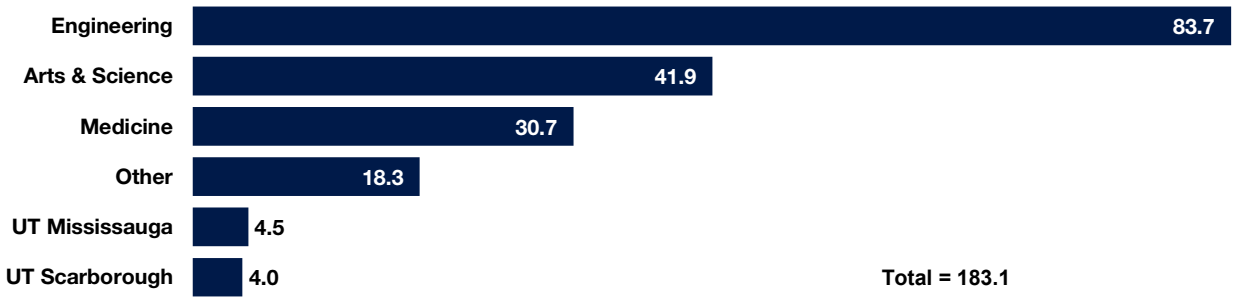
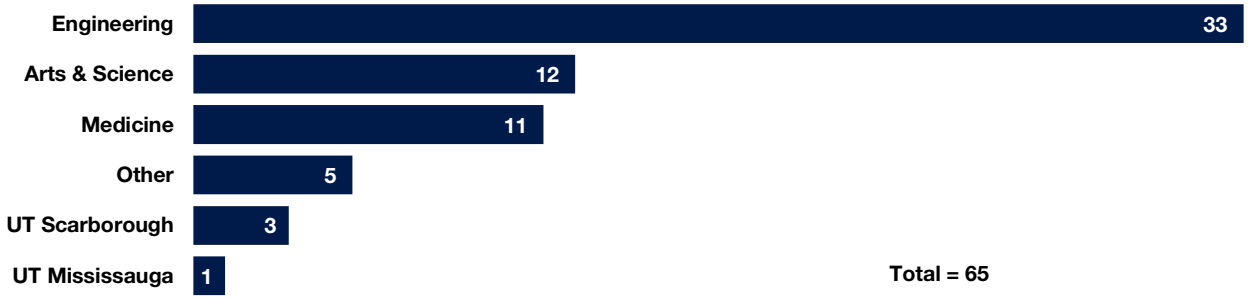


Figure 3.6c **U of T Patent Applications by Faculty, 2018–2019**



Several U of T Engineering startups and spinoffs achieved significant milestones this year:

- **AmacaThera,** built on gel-based technology developed in the lab of Professor Molly Shoichet (ChemE, IBBME) raised $3.25 million to develop a drug delivery system that could eliminate the need to give patients powerful painkillers following surgery – a key source of the current opioid crisis.
- **Peraso Technologies,** a Canadian semiconductor startup based on technology developed in the lab of Professor Sorin Voinigescu (ECE), reached a new funding milestone of US$110 million. The support will enable the company to further develop its chips for the 60 gigahertz (GHz) wireless band, enabling more data to be pushed through wireless hotspots for applications like streamed 4K television or virtual reality.
- **TARA Biosystems,** co-founded by Professor Milica Radisic (IBBME, ChemE), worked with Radisic's lab to develop the Biowire II, a platform that enables testing of potential drug molecules on realistic lab-grown heart tissues. The technique can prevent harmful drugs from reaching the commercial market and bring personalized medicine closer to reality.

For more details about entrepreneurship and commercialization, see the Student Entrepreneurship section of Chapter 4 – Cross-Faculty Education and Experiential learning.