3

Our community is defined by multidisciplinary collaboration, technical ingenuity and creative trailblazing, as well as leading in engineering innovation and entrepreneurship. The calibre and global impact of our research contributes to our reputation for excellence and as Canada's top-ranked engineering school and one of the world's best.

We continue to enhance pathways for our researchers to collaborate across disciplines, generating new knowledge and advancing innovation. Each year, we engage with more than 300 external partners from a variety of sectors, including information technology, biomedical devices, resource extraction and environmental engineering. Programs such as EMHSeed, created in partnership with the Faculty of Medicine, support collaborative research projects that are at the convergence of engineering and other disciplines.

Our researchers create innovative technologies and processes across a wide range of strategic areas – from sustainability to artificial intelligence to human health – that drive economic development, improve lives and protect the planet. Our commitment to research excellence is reflected in more than 25 leading-edge centres and institutes – nearly half of which were created in the last five years, including the Institute for Water Innovation (IWI). The IWI, which was established to develop novel solutions for domestic, commercial and industrial water management challenges, is one of several research centres that will have a home in the forthcoming Centre for Engineering Innovation & Entrepreneurship (CEIE).

Our research continues to earn strong support from both federal and provincial research funding agencies, as well as endowments from our alumni and funding from external partners. Our Faculty is home to 90 research chairs, a 30% increase over the last five years. Our success in obtaining collaborative grants, such as the prestigious NSERC Collaborative Research and Training Experience (CREATE), enables us to strengthen our industry partnerships while providing our graduate students with experiential learning opportunities relevant to their chosen areas of expertise.

Selected Research Highlights

Printable solar cells just got closer to reality

Postdoctoral researcher and Rubicon Fellow Hairen Tan (ECE) and his team cleared a critical manufacturing hurdle in the development of a new class of solar devices called perovskite solar cells. This alternative solar technology could lead to low-cost, printable solar panels capable of turning nearly any surface into a power generator. Perovskite solar cells depend on a layer of tiny crystals made of low-cost, light-sensitive materials, which can be mixed into a kind of liquid 'solar ink' that can then be printed onto glass, plastic or other materials using a simple inkjet process. To generate electricity, electrons excited by solar energy must be extracted from the crystals so they can flow through a circuit. That extraction happens in the electron-selective layer (ESL). Tan, who works under Professor Ted Sargent (ECE), and his colleagues have developed a new chemical reaction that enables them to grow an ESL made of nanoparticles in solution, directly on top of the electrode. The new nanoparticles are coated with a layer of chlorine atoms, which helps them bind to the perovskite layer on top, allowing for efficient extraction of electrons. In a paper published in *Science*, Tan and his colleagues report the efficiency of solar cells made using the new method at 20.1%, the best ever reported for low-temperature processing techniques. Tan's cells retained more than 90% of their efficiency even after 500 hours of use.

Diesel trains may expose passengers to exhaust

A new study by Professor Greg Evans (ChemE), director of the Southern Ontario Centre for Atmospheric Aerosol Research (SOCAAR), and Dr. Cheol-Heon Jeong, a senior research associate at SOCAAR, finds that diesel trains may expose passengers to elevated levels of pollutants, especially if they are sitting directly behind the locomotive. They measured the concentration of two kinds of airborne particles: black carbon (BC), which is essentially soot, and ultrafine particles (UFP), which are formed when gases in the exhaust condense into microscopic particles. Both measurements also act as proxies for the complex mixture of gases in diesel exhaust, which is an established carcinogen associated with respiratory, cardiovascular and reproductive health effects. In a paper appearing in the journal *Atmospheric Environment,* they report that cars being pulled by diesel trains and located directly behind the locomotive had an average of nine times the levels of BC and UFP compared to air next to a busy city street, and that cars in the middle of the trains had levels three times lower than the front-most cars. The average BC and UFP concentrations across all pulled cars was about five times higher than on city streets. Evans and his team are currently working with Metrolinx to test new filters for the air intake vents, and preliminary results show an 80% reduction in the levels of black carbon.

Skin cells "crawl" together to heal wounds treated with unique hydrogel layer

A team led by Professor Milica Radisic (IBBME, ChemE) has demonstrated for the first time that their peptide-hydrogel biomaterial prompts skin cells to "crawl" toward one another, closing chronic, non-healing wounds often associated with diabetes, such as bed sores and foot ulcers. The team tested their biomaterial on healthy cells from the surface of human skin, called keratinocytes, as well as on keratinocytes derived from elderly diabetic patients. They saw non-healing wounds close 200% faster than with no treatment, and 60% faster than treatment with a leading commercially used collagen-based product. Their work was published in the journal *Proceedings of the National Academy of Sciences*. Until now, most treatments for chronic wounds involved applying topical ointments that promote the growth of blood vessels to the area. But in diabetic patients, blood vessel growth is inhibited, making those treatments ineffective. Radisic and her team knew their special peptide — called QHREDGS, or Q-peptide for short — promoted survival of different cell types, including stem cells, heart cells and fibroblasts, but this was the first time they applied it to wound healing. Radisic and PhD candidates Yun Xiao (ChemE, IBBME) and Lewis Reis (IBBME) worked with Covalon Technologies Ltd., a company dedicated to the research, development and commercialization of novel healthcare technologies, on this project. Covalon's chief scientific officer, Dr. Val DiTizio (IBBME PhD 0T1), has been leading the partnership with Radisic's group for about three years, and contributed its collagen-based wound-healing dressing, ColActive, as one of the controls.

Data in this chapter are presented for the 2015–2016 grant year (April to March). This is the most recent year for which complete data are available. Highlights are from July 2016 to June 2017.

Reducing the risks of cycling

Professor Marianne Hatzopoulou (CivE) has created the Clean Ride Mapper, an online tool that leverages Google Maps to help cyclists find routes that have lower levels of airborne pollutants like ultra-fine particles or nitrogen oxides. In 2016, Hatzopoulou and her team collaborated with Health Canada on a study that aimed to map out how pollution affects human health in different areas of Toronto. Volunteers walked the streets of Toronto equipped with GPS devices and instruments to monitor their heart rates and blood pressure, as well as the level of noise and air pollution they were exposed to. By correlating location with pollution and physiological data, the team is finding the cleanest, safest routes. Employing an online survey, Hatzopoulou and postdoctoral researcher Sabreena Anowar (CivE) have determined that cyclists, on average, are willing to travel an additional 3.6 minutes (approximately one kilometre) to reduce their exposure to pollution.

Target practice on tumours

Professor Warren Chan (IBBME), a pioneer in the field of nanomedicine, is working to reduce the harmful side effects of cancer treatments by determining how to deliver chemotherapy drugs directly into tumours — and nowhere else. He and his group are engineering more effective nanoparticles for drug delivery. The group published a paper in *Nature Reviews Materials* in 2016 revealing that less than 1% of nanomedicines reach their intended tumour targets. Most of the nanoparticles get stuck in the liver, spleen and kidneys — organs responsible for filtering toxins and waste from blood. Chan's group is now examining how the liver takes up nanoparticles, in partnership with Dr. Ian McGilvray at Toronto General Hospital, Professor Anton Zilman in U of T's Department of Physics, and Professor Julie Audet (IBBME).

Ancient microbes offer insight on better mine wastewater strategies

A new research project led by Professor Lesley Warren (CivE) examines how microbes make their living in mine wastewater by studying their genes — an insight that could help further reduce the environmental footprint of the mining industry. All mining wastewater must be cleaned to strict federal guidelines before it can be discharged back into the environment. It is this sulphur-rich wastewater in which the microorganisms thrive. Warren is collaborating with Professor Jill Banfield, from the University of California, Berkeley, Professor Christian Baron, a microbial biochemist from the Université de Montréal, and Dr. Simon Apte, a research scientist in analytical chemistry and geochemical modeling from Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), to unravel the role played by these sulphur-loving microbes. Informed by genomic and geochemical insights, they plan to develop new tools that can help mine managers make better decisions about how to manage their wastewater, including ensuring conditions that encourage the growth of organisms that break down toxic compounds or prevent the growth of organisms that produce those toxic compounds in the first place. The team is partnering with three Canadian mining companies, as well as two engineering consulting firms, Advisian and Ecological and Regulatory Solutions. The $3.7-million endeavour is funded in part by Genome Canada through the Large Scale Applied Research Projects (LSARP) program, with additional support from the Mining Association of Canada, the Ontario Mining Association and CSIRO. The project also has the endorsement of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM).

New AI algorithm taught by humans learns beyond its training

U of T Engineering researchers Parham Aarabi (ECE) and Wenzhi Guo (ECE MASc 1T5) have designed a machine learning algorithm that learns directly from human instructions, rather than an existing set of examples, and which has outperformed conventional methods of training neural networks by 160%. The algorithm also outperformed its own training by 9%. Humans "teach" neural networks by providing a set of labeled data and asking the neural network to make decisions based on the samples it has seen. This algorithm is different: it learns directly from human trainers who provide instructions that are used to pre-classify training samples rather than a set of fixed examples. Their work is published in the journal *IEEE Transactions on Neural Networks and Learning Systems*. This heuristic training approach holds considerable promise for addressing one of the biggest challenges for neural networks: making correct classifications of previously unknown or unlabeled data. This is crucial for applying machine learning to new situations, such as correctly identifying cancerous tissues for medical diagnostics, or classifying all the objects surrounding and approaching a self-driving car.

Drone-delivered AEDs offer novel approach to saving lives at home

A group of U of T Engineering researchers aims to use drones to deliver life-saving automatic external defibrillators (AEDs) rapidly and directly to homes. Justin Boutilier (IndE PhD candidate) envisions a future in which a bystander or family member who witnesses a cardiac arrest can call 911, and within minutes, an AED is flown to their doorstep or balcony to be administered, even before the paramedics arrive. Boutilier is working under Professor Timothy Chan (MIE), Director of the Centre for Healthcare Engineering at U of T, in collaboration with Professor Angela Schoellig (UTIAS) and researchers from the St. Michael's Hospital Rescu Program, to turn this futuristic idea into a life-saving reality. This project builds on research by Chan's lab on cardiac arrests that occur outside of hospitals, and the lack of accessible AEDs in public locations during non-business hours. Boutilier is now focusing on reducing deaths from cardiac arrests that occur at home. To determine where drones should be stationed and how many are needed to serve a given population, Boutilier obtained historical cardiac arrest data from eight regions in Southern Ontario, including dense urban areas and sparse rural communities. He found that they were able to shave several minutes off the median ambulance response times in both rural and urban regions, and drones could arrive ahead of ambulances more than 90% of the time. Boutilier and Chan presented their research at the American Heart Association Resuscitation Science Symposium in New Orleans, and they plan to pilot the project in Muskoka, a region that has a high rate of bystander cardiopulmonary resuscitation (CPR), and the slowest ambulance response time of all the regions from which they have gathered data.

Can microwaves make mining more sustainable?

Professor Erin Bobicki (MSE, ChemE) is working to reduce the environmental impact of mining and mineral processing, and her secret weapon is a common household appliance – the microwave. Mineral processing is all about separating valuable metals such as nickel, copper and zinc from the low-value minerals — known as gangue — that make up most of the ore. Minerals have different dielectric properties, and in some cases different magnetic properties, and many high-value compounds respond differently to the electromagnetic radiation produced by microwaves than less valuable ones. By playing with those properties, researchers can encourage cracks at the boundaries between the valuable grains and the gangue. Bobicki is experimenting with microwaves to alter the surface chemistry and composition of mineral grains, making it easier to separate the valuables from the gangue in downstream processing.

Researchers reduce climate-warming carbon dioxide into building blocks for fuel

Researchers have long tried to find simple ways to convert greenhouse gases into fuels and other useful chemicals. Now, a group of researchers led by Professor Ted Sargent (ECE) has found a more efficient way to catalyse the reaction powered by renewable energies such as solar or wind. The team's catalyst takes climate-warming carbon-dioxide (CO_2) and converts it to carbon-monoxide (CO), a useful building block for carbon-based chemical fuels, such as methanol, ethanol and diesel. They start by fabricating extremely small gold "nanoneedles" — the tip of each needle is 10,000 times smaller than a human hair — which act like lightning rods for catalyzing the reaction. When they applied a small electrical bias to the array of nanoneedles, they produced a high electric field at the sharp tips of the needles that helps attract CO_2, speeding up the reduction to CO at a rate faster than any catalyst previously reported. This represents a breakthrough in selectivity and efficiency, which brings CO_2 reduction closer to the realm of commercial electrolysers. The team is now working on skipping the CO and producing more conventional fuels directly.

U of T Engineering collaborates with industry and government on drone navigation

A new research partnership between U of T Engineering, Drone Delivery Canada and Defence Research and Development Canada will enable unmanned aerial vehicles — UAVs, also known as drones — to safely find their way back to their launch point if their communication or GPS navigation systems fail. The technology could greatly expand the use of drones in applications from delivery of goods to military reconnaissance. Professor Angela Schoellig (UTIAS) is leading the team, which also includes Professor Tim Barfoot (UTIAS). Current GPS technology allows UAVs to navigate without the help of a ground crew. But if this system gets disrupted by bad weather or malfunctioning equipment, the drone could lose control and crash. Schoellig and her team are proposing to develop a navigation system that relies instead on digital photos taken by drones as they fly.

Research Funding and Partnerships

Our innovative and collaborative research, the strength of our industrial partnerships and our dedicated fundraising efforts enabled U of T Engineering to attract $74.6 million in research funding in 2015–2016, including $63.4 million in operating funds and $11.2 million in infrastructure funds. This funding came from a variety of sources, including federal and provincial granting councils, and corporate partners.

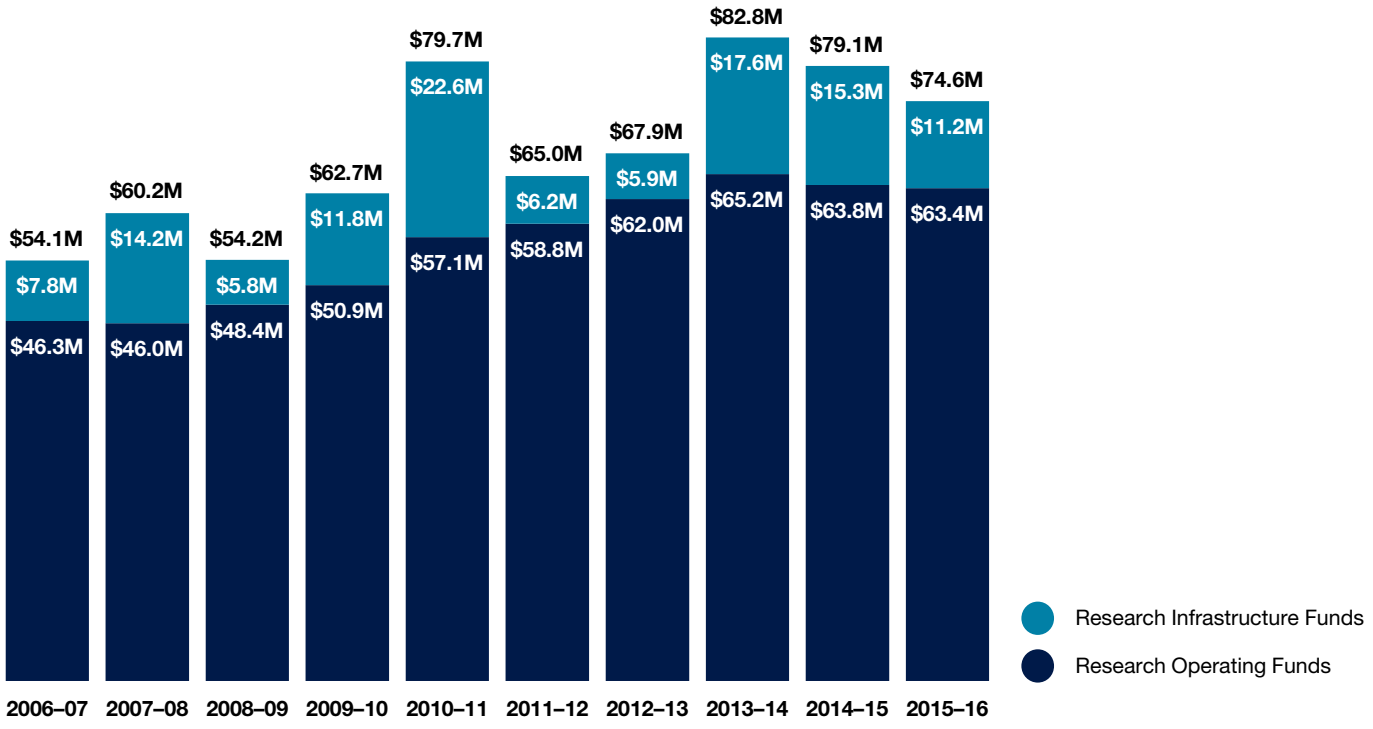
We generated $31.1 million of our research operating funds from the Tri-Agency, which include the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR) and the Social Sciences and Humanities Research Council (SSHRC), plus the Networks of Centres of Excellence (NCE). The majority of our Tri-Agency funding continues to come from NSERC, from which U of T Engineering researchers received $26.4 million in 2015–2016.

Data for 2016–2017 indicate that we already exceeded our Academic Plan goal of $32 million in Tri-Agency funding by 2016. We had revised this goal after achieving our original target of $25 million three years early.

From 2011–2012 to 2015–2016, U of T's five-year cumulative share of NSERC funding was 9.5%, which is the largest of any Canadian university. The allocation of Canada Research Chairs to U of T and its divisions is updated every two years and is based on its portion of national Tri-Agency funding, including NCE funding.

We also attracted $3.6 million from CIHR for research in biomedical engineering and health systems. The funding represents a 12.5% increase over the previous year.

Figure 3.1a **Breakdown of Research Infrastructure Funding vs. Research Operating Funding, 2006–2007 to 2015–2016**



Note 3.1: The figures in this chapter report research funding the Faculty received in 2015–2016. 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 **Canadian Institutes of Health Research (CIHR), Natural Sciences and Engineering Research Council of Canada (NSERC) and Networks of Centres of Excellence (NCE) Funding, 2006–2007 to 2015–2016**

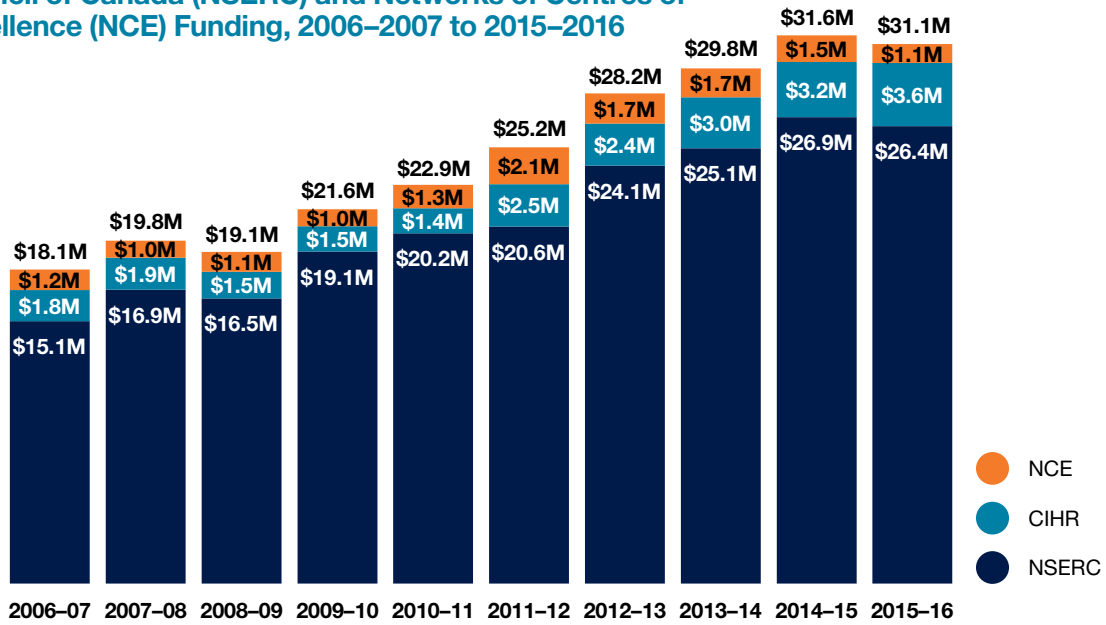
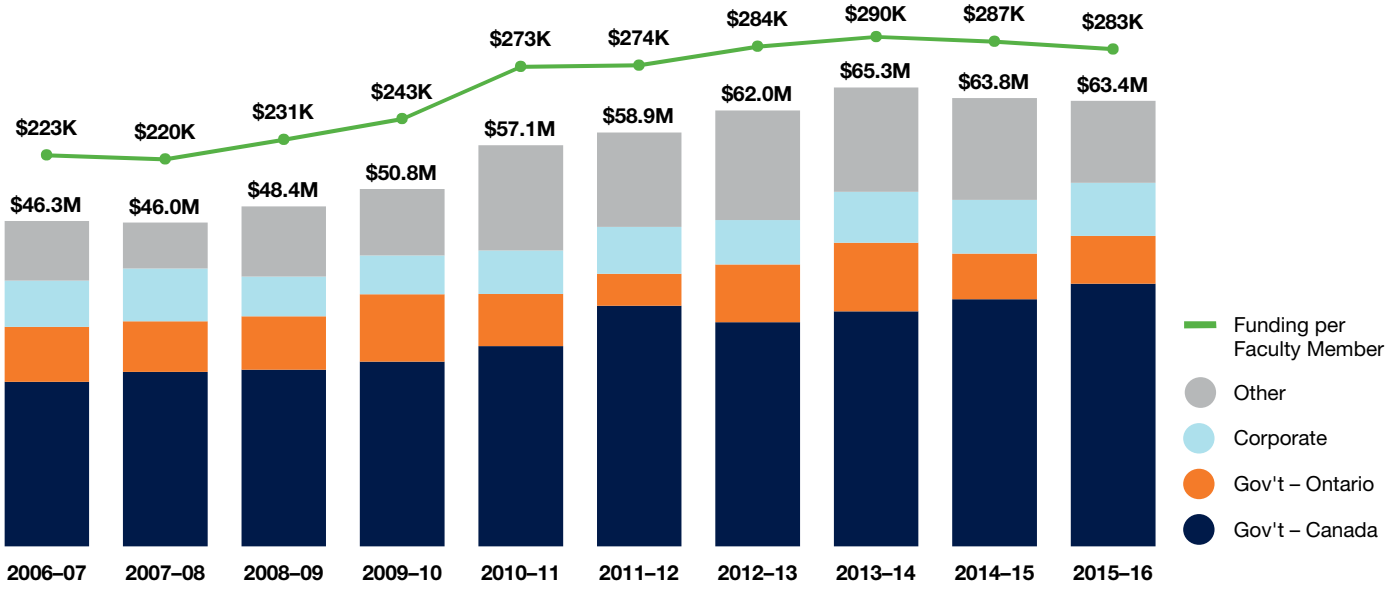


Figure 3.1c **Research Operating Funding by Year, Source and Funding per Faculty Member, 2006–2007 to 2015–2016**



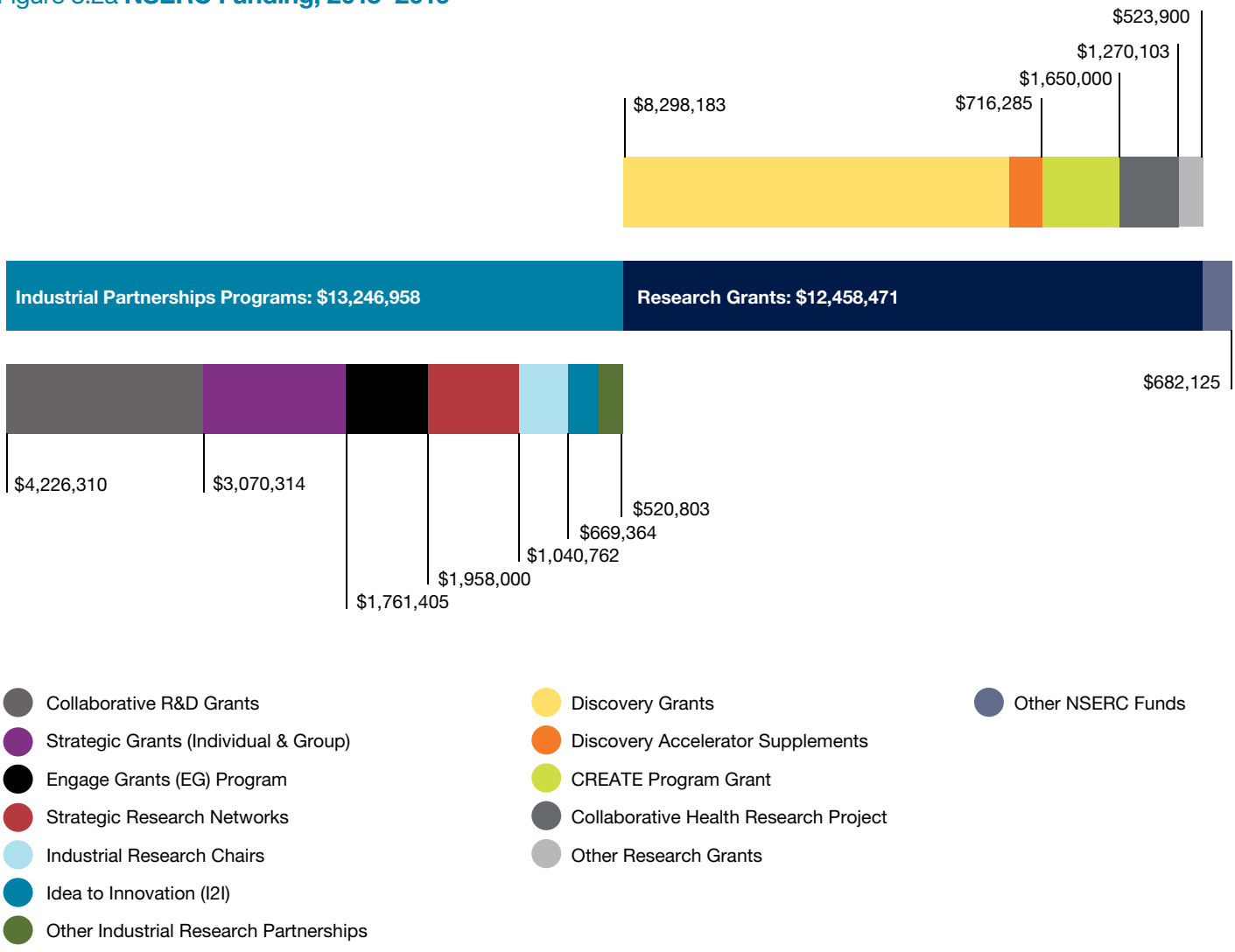
	Funding per Faculty Member	Gov't – Canada	Gov't – Ontario	Corporate	Other	Total
2006–07	$222,608	$23,421,386	$7,817,967	$6,583,699	$8,479,398	**$46,302,450**
2007–08	$220,305	$24,828,188	$7,168,950	$7,520,781	$6,525,854	**$46,043,773**
2008–09	$231,470	$25,122,618	$7,618,346	$5,640,631	$9,995,737	**$48,377,332**
2009–10	$243,266	$26,276,883	$9,562,402	$5,540,382	$9,462,900	**$50,842,567**
2010–11	$272,982	$28,504,020	$7,395,585	$6,180,621	$14,972,995	**$57,053,221**
2011–12	$273,772	$34,218,893	$4,538,965	$6,702,822	$13,400,263	**$58,860,943**
2012–13	$284,491	$31,876,929	$8,240,162	$6,315,707	$15,586,318	**$62,019,116**
2013–14	$290,006	$33,424,711	$9,773,183	$7,256,554	$14,796,883	**$65,251,331**
2014–15	$287,311	$35,146,451	$6,487,530	$7,634,736	$14,514,221	**$63,782,938**
2015–16	$282,920	$37,371,283	$6,787,653	$7,562,726	$11,652,375	**$63,374,037**

Research chairs and major grants generate recognition that enhances our reputation as the top engineering school in Canada. U of T Engineering earned three new Canada Research Chairs in 2016–2017: one in Endogenous Repair, one in Transportation and Air Quality, and one in Quantitative Cell Biology and Morphogenesis. This brings our total of Canada Research Chairs to 31. The Faculty's inaugural NSERC Chair in Multidisciplinary Engineering Design was renewed for five years. This brings our total number of research chairs, including Canada Research Chairs, endowed chairs, NSERC Industrial Research Chairs, U of T Distinguished Professors and University Professors, to 90 held by 84 individual chairholders. *(For the full list, see Appendix D.)*

In addition to research chairs, our faculty members currently hold six prestigious NSERC Collaborative Research and Training Experience (CREATE) grants, aimed at training and mentoring highly qualified students in collaborative and integrative approaches. Each of these NSERC grants provides $1.65 million in support over six years.

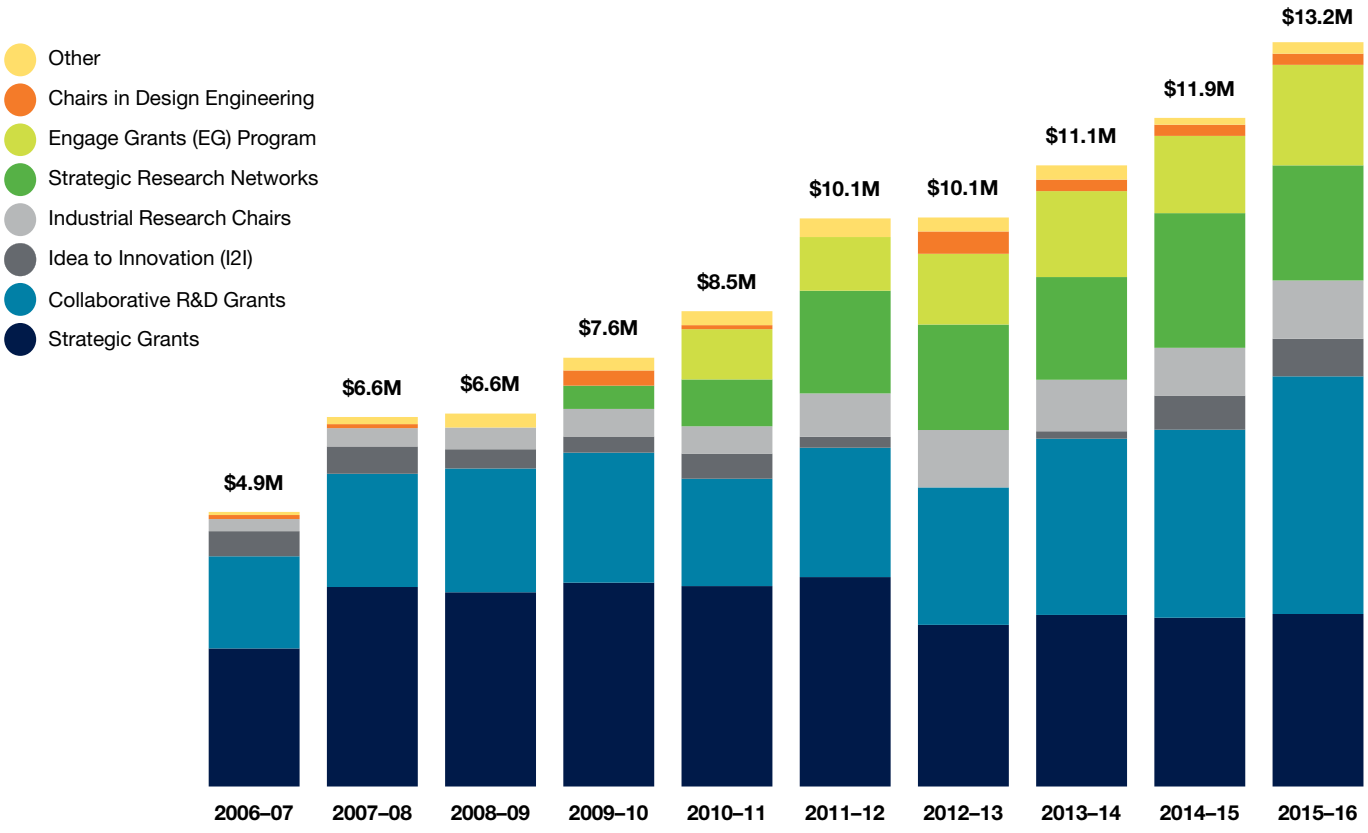
We continue to leverage industrial partnerships, which have played a key role in the growth in our NSERC funding over the past decade. Grants based on industrial partnerships made up 50.3% of our NSERC funding in 2015–2016, a significant increase over the previous year when industrial partnership grants made up 44.3% of NSERC funding. The Faculty attracted three 2016 NSERC Strategic Partnership Grants (SPG) worth a total of $1.05 million. We also launched a workshop series on maximizing success in each stage of the NSERC Discovery Grant program process to strengthen our competitiveness of our NSERC applications.

Figure 3.2a **NSERC Funding, 2015–2016**



Note 3.2a: Data current as of May 2017 and based on grant year (April to March).

Figure 3.2b **NSERC Industrial Partnership Funding by Program, 2006–2007 to 2015–2016**



	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
Other	$55,267	$130,000	$247,392	$230,000	$251,770	$328,780	$246,790	$258,882	$119,531	$203,803
Chairs in Design Engineering	$69,076	$69,076		$267,173	$69,076		$400,000	$200,000	$200,000	$200,000
Engage Grants (EG) Program					$897,114	$960,531	$1,254,468	$1,533,924	$1,375,371	$1,786,405
Strategic Research Networks				$417,293	$832,697	$1,826,000	$1,879,000	$1,824,940	$2,400,000	$2,050,000
Industrial Research Chairs	$216,000	$329,834	$390,667	$493,197	$485,711	$773,964	$1,025,031	$918,349	$847,278	$1,040,762
Idea to Innovation (I2I)	$449,032	$483,200	$339,200	$287,417	$448,612	$195,000		$133,750	$608,417	$669,364
Collaborative R&D Grants	$1,637,132	$2,015,904	$2,203,103	$2,313,127	$1,909,431	$2,301,643	$2,445,232	$3,137,628	$3,347,888	$4,226,310
Strategic Grants	$2,457,079	$3,549,374	$3,457,330	$3,625,317	$3,567,277	$3,725,049	$2,875,127	$3,050,467	$3,001,610	$3,070,314
Total	**$4,883,586**	**$6,577,388**	**$6,637,692**	**$7,633,524**	**$8,461,688**	**$10,110,967**	**$10,125,648**	**$11,057,940**	**$11,900,095**	**$13,246,958**

U of T Engineering continues to generate and strengthen our research collaborations with more than 300 industry partners, from large multinationals such as Intel, Fujitsu Labs and Huawei to U of T spinoffs such as ModiFace and Deep Genomics. These partnerships provide our Faculty with commercialization expertise and employment opportunities for students, while our partners gain access to our world-class researchers, students and facilities.

In 2016–2017, leading industry partners signed two strategic partnership agreements with U of T Engineering. Global information and communications technology provider Huawei signed a three-year, $3-million agreement to provide collaborative research and outreach funding. Havelaar EV signed a five-year, $10-million partnership agreement with U of T Engineering to establish the U of T Havelaar Electric Vehicle Research Centre. The agreement includes $7.5 million in collaborative research project funding and $2.5 million in seed funding for lab space, equipment and administrative needs.

Figure 3.2c **Industrial Partnerships as a Proportion of Total NSERC Funding, 2006–2007 to 2015–2016**

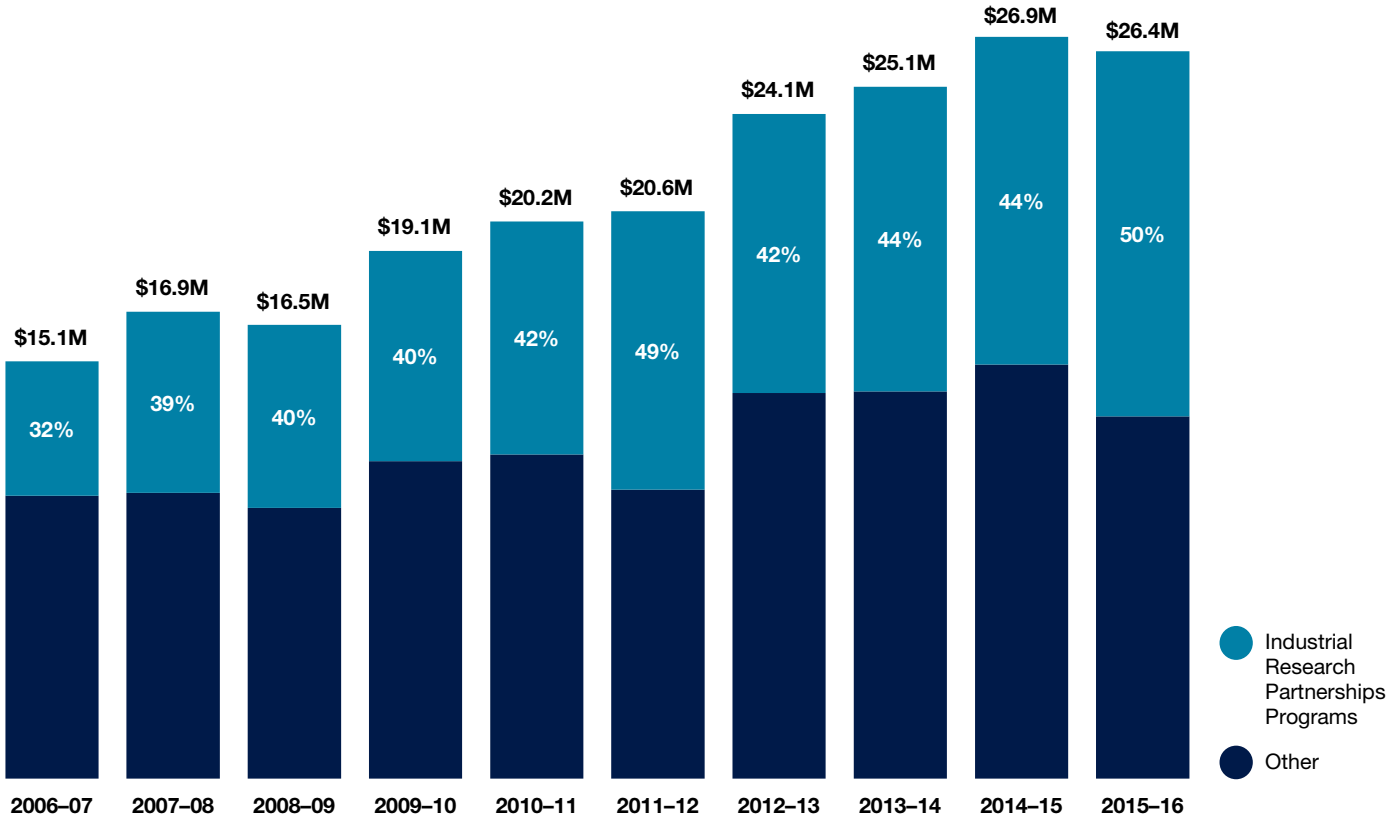


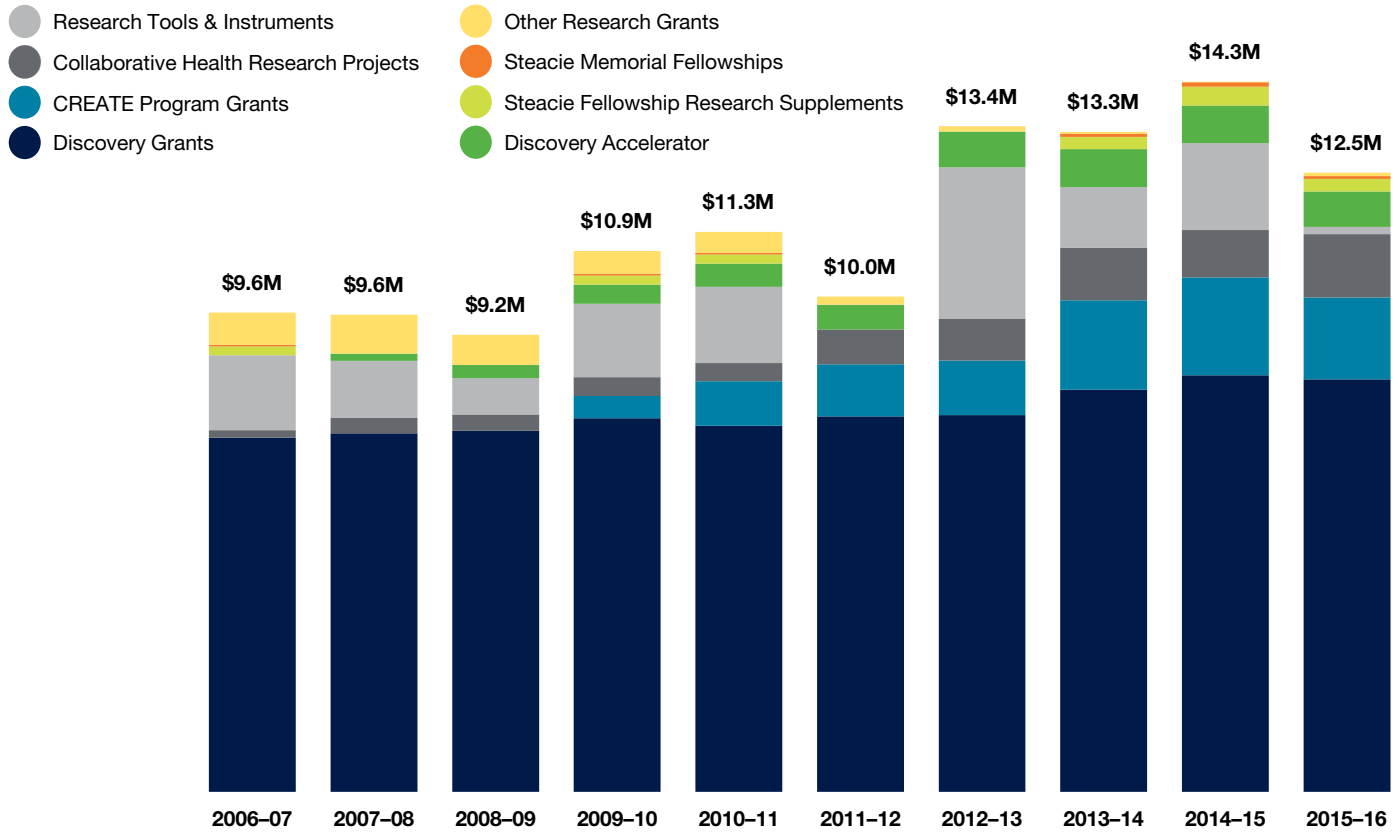
Figure 3.2d **Industry Partners, 2016–2017**

- 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
- AISC
- 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
- Arup Canada Inc.
- Astronauts4Hire
- Atomic Energy of Canada Ltd.
- AUG Signals Ltd.
- Autodesk
- AV Nackawic Group
- Avalon Rare Metals
- Avertus Epilepsy Technologies Inc.
- Babcock & Wilcox Ltd.
- 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
- Broadcom Corp.
- CAE
- CalEnergy Generation
- Calgon Carbon Corp.
- Cameco
- Canadian Automobile Association
- Canadian Institute of Steel Construction
- Canadian Nuclear Laboratories
- Canadian Nuclear Safety Commission
- Candu Energy Inc.
- Candu Owners Group
- Candura Instruments
- CanSyn Chem Corp.
- Carbon Cure Technologies
- Cardinal Health
- Carter Holt Harvey Ltd.
- Cascades
- CD Nova
- Celestica
- CellScale Biomaterials Testing
- Celulose Nipo-Brasileira
- Cement Association of Canada
- Center for Automotive Materials & Manufacturing
- Centre Line Ltd.
- 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
- Connaught Foundation
- Cook Medical
- Coraltec Inc.
- Crosswing Inc.
- Crowdmark
- Curiousitate
- Cyberworks Robotics
- Cyclone Manufacturing
- Daishowa-Marubeni International (DMI) Ltd. – Peace River Pulp Division
- Dana Canada Corp.
- Daniels Group
- Datatrends Research Corp.
- DCL International
- Defence Science & Techology Lab (UK)
- Dell
- Detour Gold Corp.
- Deveron
- Dionex
- Diros Technology Inc.
- Dongwon Technology Co. Ltd.
- Dr. Robot Inc.
- Drone Delivery Canada
- Droplet Measurement Technologies
- DSO National Laboratories
- DuPont Canada
- E. I. du Pont Canada Company
- Eclipse Scientific Inc.
- Ecosynthetix
- Eco-Tec Inc.
- Eldorado Brasil
- Electrovaya Inc.
- Eli Lilly Research Laboratories
- Enbridge Gas Distribution Inc.
- Energent Inc.
- Engineering Services Inc.
- ENMAX Power Corporation
- Ensyn Technologies Inc.
- ERCO Worldwide
- Ericsson Canada Inc.
- ESG Solutions
- exactEarth Inc.
- Exigence Technologies
- Explora Foundation
- FedEx
- Fibria Celulose
- Finisar Corporation
- Flight Safety International
- Ford Motor Company (USA)
- Ford Motor Company of Canada
- FPInnovations
- Fuji Electric Co. Ltd.
- Fujitsu Laboratories Ltd.
- Fujitsu Labs of America Inc.
- Futurebound Corp.
- G. Cinelli – Esperia Corporation
- G. S. Dunn Dry Mustard Millers
- 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
- GlaxoSmithKline Inc.
- Goodrich Corp.
- Goodrich Landing Gear
- Grafoid Inc.
- Greencore Composites
- Groupe Mequaltech Inc.
- GTAA Toronto Pearson
- GVA Lighting
- Hamilton Professional Fire Fighters Association
- Hanwha Solar Canada
- Hard Rock Innovations Inc.
- Hatch Ltd.
- Havelaar Canada
- Hawker Siddeley Canada
- HDR Corp.
- Hitachi High-Technologies
- Holcim Inc.
- Honeywell
- Huawei Technologies Co. Ltd.
- Hunch Manifest Inc.
- Huron Digital Pathology
- Hydro One Networks
- Hydro-Québec
- Hyundai Motor Company
- IBI Group
- IBM Canada Ltd.
- IBM T. J. Watson Research Center
- iGEN Technologies Inc.
- Imperial Oil Ltd.
- Indian Oil Company
- Industrial Thermo Polymers Ltd.
- Ingenia Polymers Corp.
- Inphi Corporation
- Institute for Energy Technology (Norway)

Note 3.2d: 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, work with them on Multidisciplinary Capstone Projects, or provide philanthropic support.

- Integran Technologies Inc.
- Intel Corp.
- Interface Biologics Inc.
- International Paper Company
- Ionicon
- Ionics Mass Spectrometry Group Inc.
- IRISNDT Corporation
- Irving Pulp & Paper Ltd.
- JDS Uniphase Inc.
- 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 Corporation
- Klabin
- KQS Inc.
- Krauss Maffei Corp.
- Kumho Petrochemical R & D Center
- Laboratoire d'essai Mequaltech
- LaFarge Canada
- Lallemand Inc.
- Lattice Semiconductor Ltd.
- LG Chem
- 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.
- Manulife Financial
- Marmak Information Technologies
- Materials & Manufacturing Ontario
- Maxim Integrated Products 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.
- Mr. Robot Inc.
- Nanowave
- National Aeronautical Establishment (USA)
- NatureWorks LLC
- NCK Engineering
- Nestle Canada
- New World Laboratories
- Newterra
- Nike Inc.
- Northern Yashi Engin, Const 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
- Ontario Teachers Pension Plan
- Opal-RT Technologies Inc.
- ORNGE Medical Transport
- Ossur Canada Inc.
- OtoSim
- Pall Corporation
- Perkin Elmer Canada
- Pfizer Inc. (New York)
- Philips Electronics North America Corp.
- Plasco Energy Group
- Platinum Unlimited Inc.
- Polaris Industries
- Polumiros Inc.
- Polycon Industries
- Porewater Solutions
- 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
- RBC Capital Markets
- RBC Global Asset Management
- Regeneron Pharmaceuticals
- RESCON
- Resertrac Inc.
- Resonance Ltd.
- Resource Systems Group Inc.
- Robert Bosch Corp.
- Rockwell International
- Rocscience Inc.
- Rolls Royce Canada Ltd.
- Rosellini Scientific LLC
- RWDI
- Safety Power Inc.
- Safran Electronics Canada
- Samsung Advanced Institute of Technology
- 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
- Siemens ADGT
- Sinclair Interplanetary
- Sinclair Technologies Inc.
- Solantro Semiconductor Corp.
- Solar Ship Inc.
- Solvay Specialty Polymers
- Sony Corporation
- 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.
- Sunwell Technologies
- Suzano Papel e Celulose
- Synbra
- Syncrude Canada Ltd.
- Teck Resources Ltd.
- Teknion
- 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.
- Thermodyne Engineering
- ThermoFisher Scientific
- TMS Robotics & Academics
- Tolko Industries Ltd.
- Toronto Hydro
- Toshiba Corporation
- Total American Services Inc.
- Tower Automotive
- Tower Solutions
- Toyota Collaborative Safety Research Center (CSRC)
- Toyota Technical Center USA Inc.
- TransCanada
- Trapeze Software ULC
- Tridel
- TSI
- Ultrasonix
- Uncharted Software Inc.
- Unisearch Associates
- US Steel Canada
- UTC Aerospace Systems
- VAC Aero International Inc.
- Vale Canada Ltd.
- Valmet Ltd.
- Van-Rob Kirchhoff Automotove
- Vicicog
- VisImage Systems Inc.
- Volkswagen Canada Inc.
- VTT Technical Research Centre of Finland
- Westport Innovations
- Whitemud Resources
- Wugang Canada Resources Invest. Ltd.
- Wurth Elektronik eiSos GmbH & Co. KG
- Wuzhong Instrument Company
- Xilinx Inc.
- Xiphos Technologies Inc.
- XOR-Labs Toronto
- Xstrata Nickel
- Zotefoams PLC

Figure 3.2e **NSERC Research Grant Funding by Program, 2006–2007 to 2015–2016**



	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
Other Research Grants	$653,000	$781,400	$607,950	$462,319	$422,583	$162,000	$111,000	$40,000	$15,000	$67,000
Steacie Memorial Fellowships	$30,000			$30,000	$30,000			$60,000	$90,000	$60,000
Steacie Fellowship Research Supplements	$179,250			$187,500	$187,500			$250,000	$375,000	$250,000
Discovery Accelerator Supplements		$144,000	$264,000	$383,999	$464,000	$504,000	$720,000	$760,000	$760,000	$716,285
Research Tools & Instruments	$1,510,468	$1,150,928	$734,572	$1,477,018	$1,533,781		$3,043,030	$1,218,077	$1,750,224	$146,900
Collaborative Health Research Projects	$151,355	$311,245	$326,169	$378,774	$366,899	$696,536	$846,731	$1,064,880	$950,376	$1,270,103
CREATE Program Grants				$450,000	$900,000	$1,050,000	$1,096,000	$1,797,084	$1,969,779	$1,650,000
Discovery Grants	$7,121,674	$7,209,862	$7,262,441	$7,513,403	$7,360,703	$7,552,389	$7,577,942	$8,090,620	$8,381,417	$8,298,183
Total	**$9,645,747**	**$9,597,435**	**$9,195,132**	**$10,883,013**	**$11,265,466**	**$9,964,925**	**$13,394,703**	**$13,280,661**	**$14,291,796**	**$12,458,471**

Figure 3.3a **Canadian Peer Universities vs. University of Toronto Share of NSERC Funding for Engineering Cumulative Five-Year Share, 2011–2012 to 2015–2016**

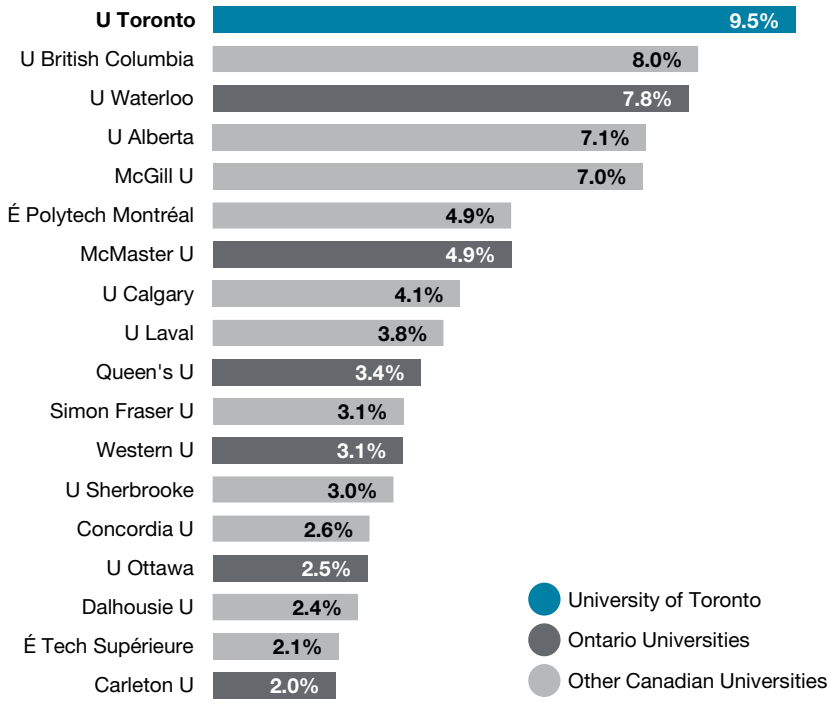


Figure 3.3b **U of T Annual Share of NSERC Funding in Engineering, 2006–2007 to 2015–2016**

2006–07	9.0%
2007–08	9.2%
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%

Figure 3.4a **Engineering Invention Disclosures by Academic Area, 2012–2013 to 2016–2017**

	2012–13	2013–14	2014–15	2015–16	2016–17	5-Yr Total
UTIAS	1.0	1.0		1.0	0.3	**3.3**
IBBME	8.2	5.9	6.5	7.8	5.9	**34.3**
ChemE	12.4	10.3	9.0	7.0	13.2	**51.9**
CivE	1.8	5.0	5.0	5.0	1.7	**18.5**
ECE	38.1	16.5	41.6	23.5	35.4	**155.1**
EngSci	0.5	1.2		1.1	0.3	**3.1**
MIE	13.1	9.5	18.8	17.0	19.8	**78.2**
MSE	4.0	2.5	1.5	0.3	2.3	**10.6**
Annual Total	**79.1**	**51.9**	**82.4**	**62.7**	**78.9**	**355.0**
University Annual Total	**166.1**	**147.1**	**174.0**	**162.7**	**210.0**	**859.9**
Engineering Percentage	**48%**	**35%**	**47%**	**39%**	**38%**	**41%**

U of T Engineering researchers applied for 39 patents in 2016–2017, representing more than 68% of all patent applications across the entire University. Our Faculty also led the way in invention disclosures, accounting for 38% of those made at U of T in 2016–2017 and 43% of those made in the last five years. Within our Faculty, ECE accounted for more than 40% of invention disclosures in the last five years, and MIE accounted for 22%.

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 3.4b **U of T Invention Disclosures by Faculty, 2016–2017**

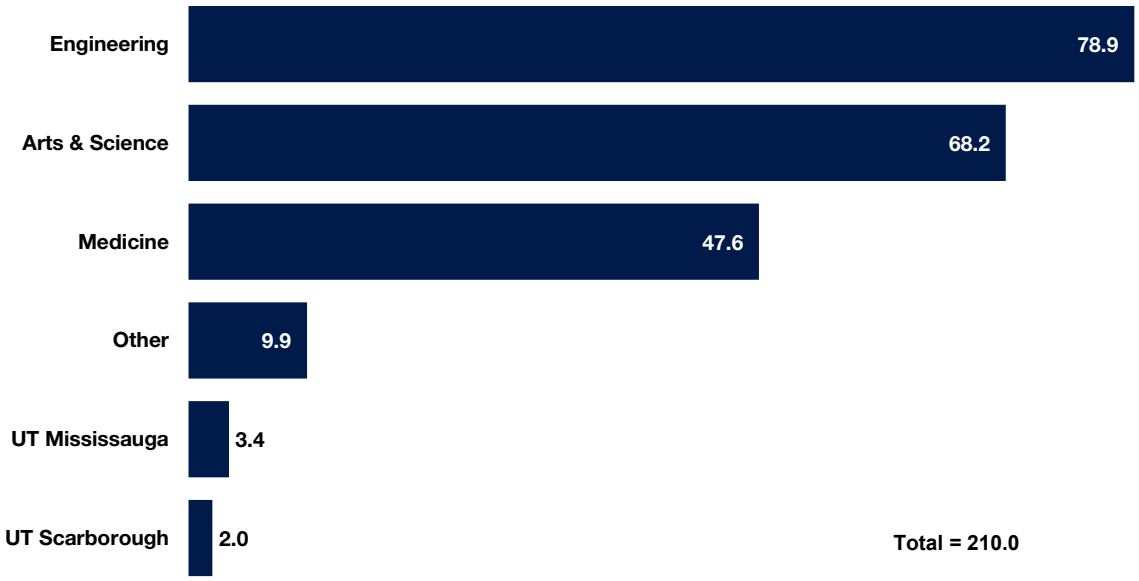


Figure 3.4c **U of T Patent Applications by Faculty, 2016–2017**

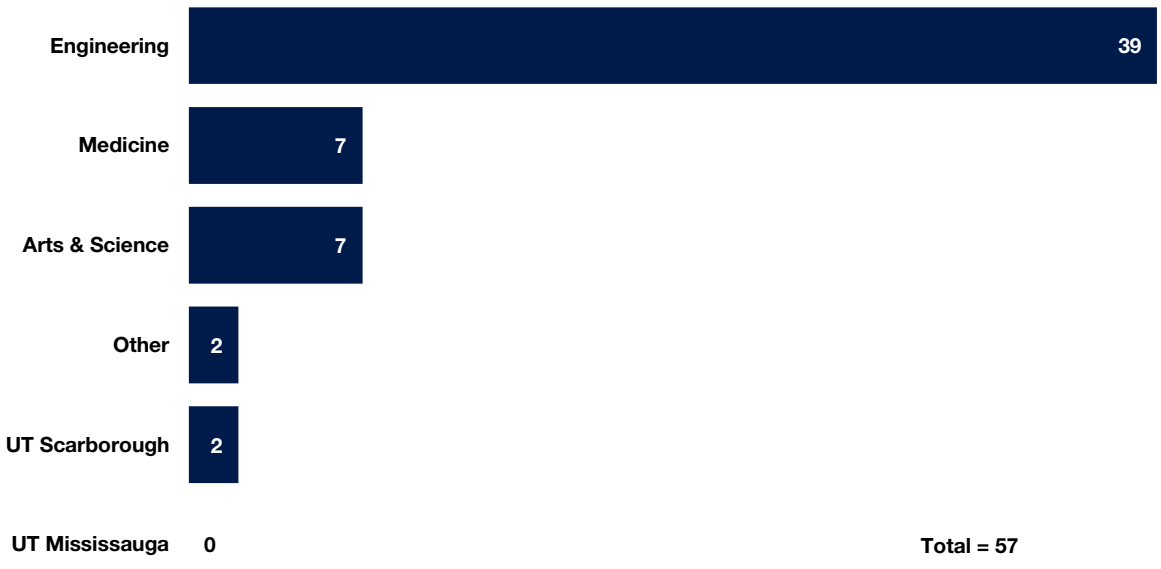
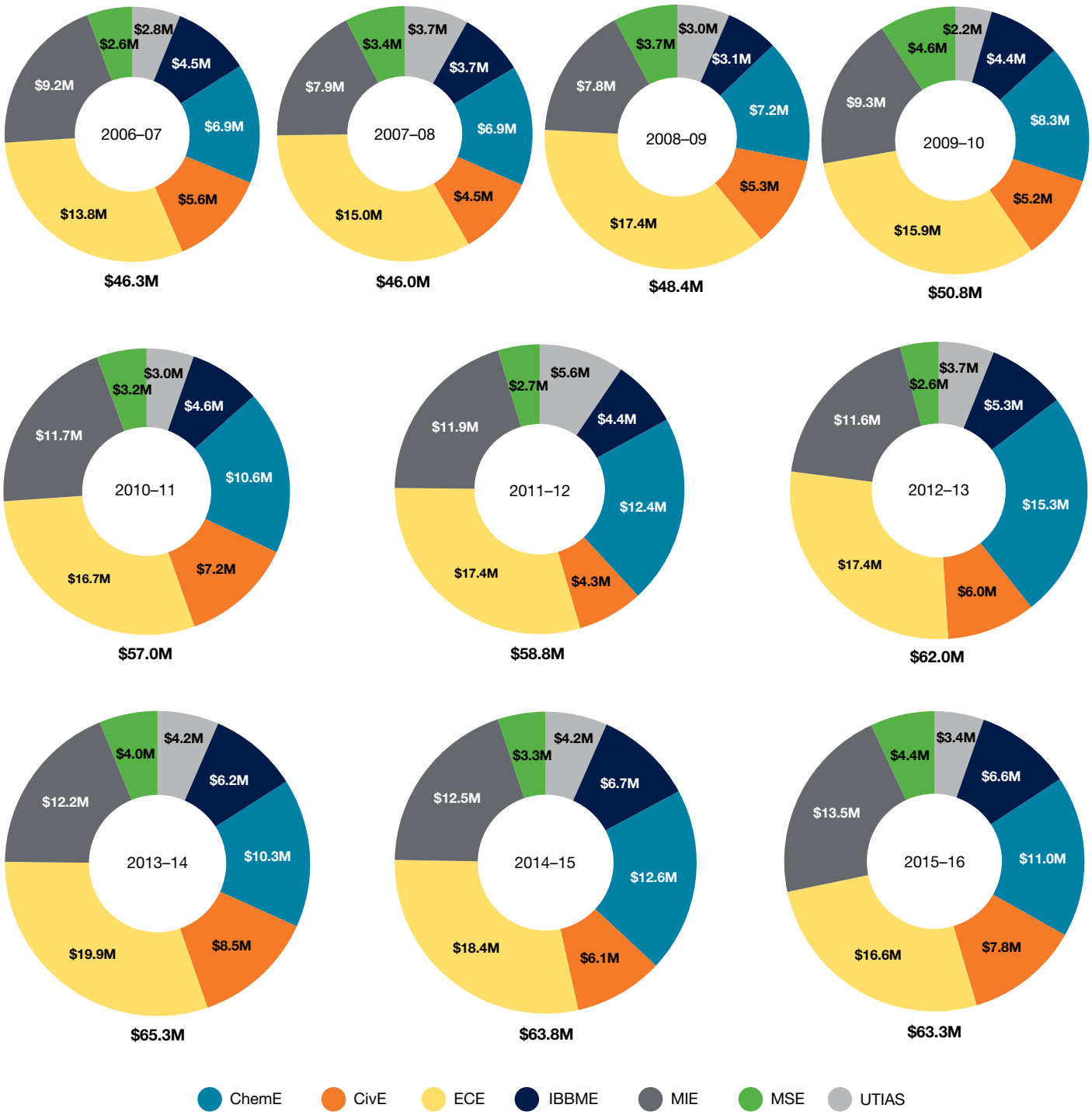


Figure 3.5 **Distribution of Research Operating Funding by Academic Area, 2006–2007 to 2015–2016**



Note 3.5: Totals include a small amount of additional funding not shown in the breakdown by academic areas. The research funding attributed to IBBME for 2015–16 represents 71% of the total funding received by core professors in the Institute. Because of IBBME's cross-disciplinary structure, many of its faculty have their research funding processed through the Medicine or Dentistry Faculties. The figure above shows only the funding that comes through U of T Engineering and is presented by grant year (April to March).