Creating Solutions to Address Global Challenges

Strategic Research Plan (SRP) Summary for the CRC Program

July 7, 2014

For almost 60 years, the University of Waterloo has been advancing knowledge through innovative research that addresses major challenges arising from the intersection of social, scientific, technological, health, and policy issues. Waterloo research has fuelled new ideas and technologies, and research excellence across all Faculties continues to foster a vigorous spirit of discovery and knowledge mobilization. The University's strategic research plan "*Creating Solutions to Address Global Challenges"* maps the path for continued discovery of new knowledge and its mobilization for the benefit of society at large.

Strategic Research Objectives

Create solutions to address global challenges in eight priority research areas *(1) Discovery and Design of Materials and Systems; (2) Environment and Energy; (3) Health and Well-Being; (4) Information and Communication Technology; (5) Manufacturing and Devices; (6) Mathematical Sciences and Computer Science; (7) Society, Culture, and Governance; and (8) Quantum Information and Nanotechnology* by:

- Emphasizing basic and applied research and facilitating the synergy between them;
- Stimulating high impact multi- and inter-disciplinary research on major societal problems;
- Committing resources for data management and knowledge mobilization;
- Continuing to attract high-quality graduate students and postdoctoral fellows into research that is deep, broad, and challenging;
- Accelerating a global presence through enhanced international collaborative research and increased international graduate student enrolment;
- Promoting timely and effective dissemination of research through presentation and peer-reviewed publication of results;
- Facilitating, as appropriate, commercialization of research results.

Priority Research Areas:

Discovery and Design of Materials and Systems

Waterloo research is redefining current understanding of the physical world and applying this knowledge to the creation of advanced materials and systems. The scope of activity ranges from the smallest scale manipulation of light and the properties of subatomic matter to the creation of projects that help shape the future of large-scale infrastructure installations. This entails:

- Developing new strategies for processing composite materials including cement and concrete, intermetallics, nanostructured materials, and thin films, as well as materials for hydrogen storage, superconductivity, and other energy conversion applications. Designing and constructing civil infrastructures, and determining their reliability.
- Using leading-edge nanofabrication and metrology facilities housed in the Mike & Ophelia Lazaridis Quantum-Nano Centre to discover new materials and design new systems. Modelling and predicting the behaviour of multi-material lightweight structural components for automobiles, ensuring safety standards continue to be met or exceeded.
- Promoting product development-driven research. From 10,000-frame per second camera images of crash impacts to complex powertrain simulation models, Waterloo's mechanical and mechatronics engineering competencies are widely recognized and in high demand.

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Environment and Energy

A healthy environment and energy equation requires balance amongst existing resources and those still to be discovered. To this end, Waterloo researchers are:

- Addressing issues such as climate change, the sustainability of food systems, ecological restoration, and urban planning, as well as how these issues impact sustainable energy.
- Finding ways to improve energy generation and incorporate new energy sources, convert and deliver energy more efficiently, and create smart energy grids, microgrids, and networks.
- Providing critical policy advice to stakeholders, including government and the private sector.
- Modelling the impact of urbanization and agricultural practices on wetland ecosystems, engaging in research on river-engineering, eco-hydraulics, and fluvial geomorphology, and engineering new water purification technologies for developing countries.
- Pursuing the development of third generation solar cells based on organic electronics and quantum dots.
- Developing new battery technologies with high energy capacity and energy density.
- Undertaking studies of mineral and energy resources, aquatic systems, earth surface and subsurface processes, and the cryosphere.
- Addressing the challenge of feeding a burgeoning world population utilizing strengths in plant biology, agricultural biotechnology, ecological agriculture, and soil science.
- Exploring the politics and governance of food, agriculture, and the environment.

Health and Well-Being

Research in health and well-being is leading to the development of life-changing technologies with significant impact on individuals and communities. Waterloo researchers are:

- Engaged in studies of chronic disease prevention and management, healthy active aging, youth health, public health policy and practice, nutrition, and human movement, all with a view to developing strategies that improve well-being.
- Conducting fundamental research into the genetic, molecular, and biophysical determinants of disease states.
- Improving medical diagnostic procedures and drug design.
- Using developments in artificial intelligence to deliver personalized care for medical conditions such as Alzheimer's disease.
- Developing new and improved technologies for the targeted release of therapeutic agents, including viral and non-viral drug and gene delivery systems.
- Creating lab-on-a-chip technologies, micro- and nano-biomedical sensors, and new processes for the development of biopharmaceuticals and vaccines.
- Using advances in sensor technology and information processing to develop highly accurate, non-invasive diagnostic and screening instruments.
- Improving the quality of health services for vulnerable populations, including the frail and elderly, through the development and implementation of innovative research and training programs.
- Integrating research and education programs to enhance dementia care practices in Canada.

Information and Communication Technology

Through the discovery of new knowledge and its innovative deployment, Waterloo is poised to revolutionize information and communication technologies. This entails:

- Designing operating systems to ensure high-speed provision of new services such as streaming content delivery.
- Developing technology that enables vital processes such as information discovery, spam filtering, and multi-lingual speech based systems on mobile devices.
- Applying quantum theory to the transmission of information using devices that encode information as the superposition of states. Applications include advanced encryption for secure communication and the development of practical quantum computing. Using physical and computational tools, researchers are hoping to make unprecedented optical and microwave-based communication possible.

- Developing data management capabilities essential for the advancement of health informatics and health policy.
- Using biomechanics and mechatronics modelling together with advancements in robotics and artificial intelligence to develop new healthcare devices for treatment, rehabilitation, and training. Advances in communications, smart biosensor technologies, integrative data processing and interface design are being used to develop large-scale mobile health networks and management protocols for healthcare operations.
- Focusing on topics ranging from real-time embedded systems to cloud computing, ensuring connectivity throughout these systems.
- Investigating smart infrastructure, the Internet of Things, Mobile Internet, and Machine-to-Machine communications.
- Developing data security technology that integrates rigorous software protocols, deep algorithms from computational mathematics, performance guarantees in networking, and critical mobile privacy designs.

Manufacturing and Devices

Although traditional manufacturing has experienced a decline in North America, industry, government, and academic institutions are working together to foster a shift toward more competitive manufacturing through innovation and technology. Waterloo is contributing to this by:

- Pursuing design and development processes on-screen, in a virtual environment, with the objective of achieving more rapid and economical product development. This is proving to be of particular importance in the development and deployment of technologies such as fractal analysis of vehicle component structures and vehicle-to-vehicle communication.
- Creating cars that have fewer, more intelligent manufactured components, deeper integration of sensors to expand functionality of on-board devices, increased efficiency and stability, and are more crash-proof and recyclable.
- Improving assembly line designs to reduce repetitive strain injury and incorporate parts-movement within a just-in-time logistics integration system for enhanced efficiency. Building sophisticated models that map the impact of the manufacturing process on resulting material properties and, ultimately, product performance.
- Developing new technologies including transparent, flexible display screens, nano-enabled biodiagnostic medical devices, and nano-cellulose – and nano-fibre – modified plastics.
- Opening new doors in quantum computing for novel research on nano-bio-based quantum devices, furthering investigations that have spawned devices such as lab-on-a-chip.
- Driving innovations such as printed electronics in traditional industries using new materials such as graphene and carbon nanotubes.
- Developing nanowire/thin film structures for solar cell and sensor applications.
- Collaborating to build next generation telescope and satellite technologies that will provide unprecedented understanding of the earth and furthest points of the visible universe.
- Advancing additive manufacturing (3-D printing) to enable mass customization and rapid prototyping.

Mathematical Sciences and Computer Science

By integrating theoretical developments in mathematical and computer sciences with real applications, Waterloo is developing sophisticated methodologies and tools that increasingly provide valuable new insights for a diverse range of natural and technological processes. This is being achieved by:

- Fundamental contributions in foundational areas of mathematical sciences, such as combinatorics, algebra, logic, geometry, graph theory, analysis, and statistical theory.
- Developing efficient algorithms, data structures, computational methods, and software systems to address computational problems in many fields.
- Studying innovative approaches to modelling and associated statistical techniques, addressing challenges arising in environmental science, finance, chronic disease, and industrial processes.
- Developing advanced computational, mathematical, and statistical techniques and methods for big data management, analytics, and visualization in fields such as bioinformatics and medical informatics, online social networks, smart energy distribution systems, and text analytics.

- Foundational research in number theory, public-key cryptography, security, and privacy to protect cyber-physical systems.
- Pushing the boundaries of scientific discovery through advanced computer simulation and leading-edge laboratory experiments in areas such as fluid mechanics, control theory, and mathematical biology and medicine.

Society, Culture, and Governance

In a rapidly evolving world, the impact of change on people opens new doors for understanding society, culture, and governance. Waterloo is transforming the landscape of social sciences and humanities research by:

- Harnessing new technologies and methodologies to generate novel insights into the human condition in areas such as finance and accounting, clinical and social psychology, digital media, languages, literature and culture, international governance, and public policy.
- Advancing the understanding of governance at levels ranging from regional to global through a focus on contemporary processes and contextualizing social and historical factors.
- Fostering research in the neurological, cognitive, and social bases of thought and behaviour.
- Exploring the impact of technology on politics, art, trade, commerce, scholarship, education, as well as friendship and romance.
- Gaining an increased understanding of how health and well-being are enhanced through the effective use of leisure, including its social, psychological, economic, and environmental dimensions. This research encompasses outdoor recreation, park planning and governance, urban recreation leisure, tourism and sport policy, non-profit management, marketing, gender and sexuality, and the social nature of leisure and consumer behaviour.
- Examining quality of life using the Canadian Index of WellBeing, which develops statistical measures of progress toward the achievement of quality of life goals and outcomes.

Quantum Information and Nanotechnology

New developments in quantum information and nanotechnology at Waterloo are transforming the next generation of information technologies. The application of discoveries borne out of fundamental research in advanced fields of mathematics, quantum physics, and chemistry promises to deliver novel technologies with revolutionary impact in a number of fields. For example, quantum research at Waterloo has already led to commercialization of quantum technologies for oil exploration and scientific devices. Currently, Waterloo researchers are:

- Investigating quantum aspects of photonics, optical information processing, superconducting devices, circuit cavity electrodynamics, and fault-tolerant computation.
- Exploring nanomaterials critical to novel nanometre-sized devices such as field-effect transistors, self-assembled drug delivery systems, energy storage/generation materials, and molecular recognition elements.
- Creating nano-sized sensors to monitor and regulate engine combustion temperature.
- Utilizing nanotechnology to address issues such as watershed management, climate change, emerging contaminants, and water treatment.

Institutional support and collaboration

Waterloo will continue to pursue funding for research from a broad spectrum of sources, both nationally and internationally. The University will maintain, and strengthen anew, research partnerships with industry. The Institution will also actively pursue government and granting council opportunities for research funding, paying particular attention to basic research and areas in humanities and social sciences that typically do not attract private sector support. The Office of Research, which includes technology transfer expertise, industry liaison personnel, and contract and grant specialists, supports and facilitates high-quality research initiatives, including the preparation of internationally competitive applications for funding. High priorities include sourcing matching funds for federal and provincial initiatives, and funds for endowed research chairs and professorships.

Special attention is paid to the research needs of junior faculty members. This includes provision of mentoring, special financial support, and reduced teaching and service workloads. Central financial support is also provided to research centres and institutes that co-ordinate cross-disciplinary research in specified areas. In addition, Waterloo continuously looks for opportunities to complement

its own areas of research expertise through collaboration with other universities as well as government and industry.

Planning and approval process
Waterloo's strategic research plan "*Creating Solutions to Address Global Challenges"* identifies current research priorities for the University and provides a framework and direction for addressing these priorities. Its genesis included extensive consultation with the broader research community, and this engendered strong support for its implementation.

The planning and approval process for applications for CFI funding is summarized below:

- Central planning ensures alignment with University strategic research priorities.
- The Office of Research determines internal envelopes for each CFI program based on Faculty pro-rated shares of the overall university research portfolio and taking into account Institution-wide priorities.
- All CFI proposals originate at the Faculty level.
- Small proposals move forward automatically; large proposals require approval by a University-wide committee.
- Once their proposals have been approved internally, CFI applicants participate in kick-off meetings to review requirements.
- For small proposals, two early drafts are extensively reviewed; for large proposals, three early drafts are extensively reviewed.
- Depending on project needs, procurement and plant operations are brought into the planning at an early stage.

Measuring research achievements
Waterloo employs various measures to evaluate success in meeting the objectives of the strategic research plan. Some of the measurements are:

- **Scholarly output** – The number and quality of peer-reviewed journal articles, books, papers in conference proceedings, and other research publications generated by increased research activity in priority areas identified in the strategic research plan; growth in research funding, including industrial research funding; commercialization of research including patents, technology licences and startup companies; prestigious national and international research awards; prestigious invited talks at conferences.
- **Growth in research capacity** – Increases in university faculty and research staff, as well as infrastructure.
- **Training of highly qualified personnel** – Incremental numbers of post-graduate degrees granted, post-doctoral fellows supervised and visiting scholars attracted; acceptance and retention of graduates in positions in Canadian companies, institutions, and agencies.
- **Knowledge and technology transfer** –The extent and rate of knowledge uptake to create new products, processes, and policies, and to foster commercialization within the Canadian receptor community.
- **Original contributions** – The incorporation of intellectual property into teaching at all levels of study and the degree to which this has pushed back the limits to understanding.