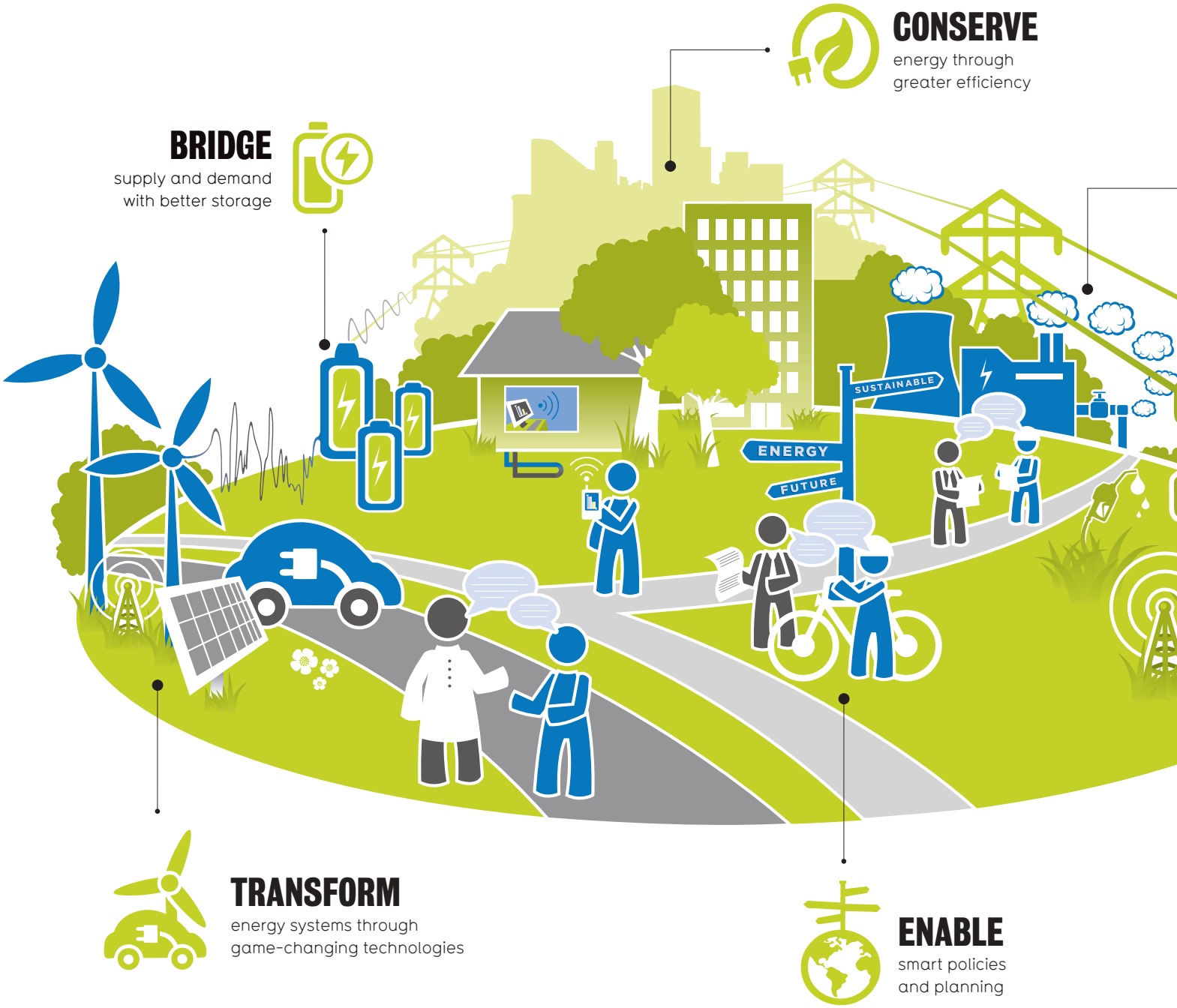
WISE annual report

Waterloo Institute for Sustainable Energy

2019–2020

UNIVERSITY OF WATERLOO | WISE WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY

Waterloo Institute for Sustainable Energy



IMPROVE
conventional
generation methods

DELIVER
energy more
intelligently

VISION

Energy challenges command our world's attention. A healthy energy system requires balance amongst energy resources we know and those we have yet to bring to fruition.

Building a globally sustainable energy future requires us to rethink and then re-fashion the way we produce and use energy. In this critical endeavor, we wish to engage emerging science and technologies to unlock the previously unimagined pathways for the evolution of the energy system. At WISE, we focus on integration of social, environmental and economic innovation that can enable rapid diffusion of transformative technologies.

OUR VISION: CLEAN ENERGY, ACCESSIBLE AND AFFORDABLE FOR ALL

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MISSION

Conduct original research and develop innovative solutions and policies to help transform the energy system for long-term sustainability.

STRATEGIC OBJECTIVES

COLLABORATE

Expand opportunities for multidisciplinary energy research at Waterloo, improve research productivity – share facilities and resources and develop highly qualified personnel (HQp) through research and education.

REACH OUT

Promote engagement of external partners and advance energy research through partnerships and greater access to research funding.

INFLUENCE

Establish WISE as the authoritative source of energy insights and analysis, and translate important scientific discoveries for a wide audience, informing energy policy both here and around the globe.

FROM THE EXECUTIVE DIRECTOR

It is with pleasure I submit the WISE Annual Report for the fiscal year 2019-2020. We continue to make significant societal impacts by advancing the national energy research agenda through contributions of our members. Our presence at the global level through effective collaborations at the institutional and individual levels remains strong and I applaud the commitment of WISE members to our strategic goals.

Although this report is a condensed and selective illustration of specific highlights and accomplishments, it points to the range and depth of expertise in energy research at University of Waterloo. Not resting on laurels, we remain fully engaged with stakeholders beyond our walls, to understand their issues and challenges and work co-operatively to shape and create new projects to address changing circumstances.

I remain proud of our members' contributions and look forward to meeting future challenges with optimism. I welcome you to review the highlights of the report and remain open to engaging with you in future developing new initiatives.

JATIN NATHWANI, Executive Director

FROM THE VICE PRESIDENT, RESEARCH

As I invite you to read the 2019-2020 annual report produced by the Waterloo Institute for Sustainable Energy (WISE), I pause to reflect on how different these two years have been.

Researchers at WISE continue their mission to develop innovative solutions to transform the energy system for long-term sustainability, but the current global situation reminds us of how vulnerable and dependent we are on the earth and how critical a long-term sustainability plan is.

Complex problems require interdisciplinary research, collaboration, and a global commitment to mitigating causes and seeking solutions. The pages ahead focus on smart and energy efficient buildings, solar energy, power to gas, bioenergy, and the global change initiative Affordable Energy for Humanity (AE-4H) but with every initiative, the overarching goal of long-term sustainability remains at the core.

CHARMAIN DEAN,
Vice-President, Research and International

RESEARCH LABS

From renewable energy technology to smarter demand management, economic modelling to carbon capture and storage, we're solving immediate problems in a timely way and providing leadership to shape the long-term evolution of sustainable energy systems.

BRIDGE:

SUPPLY AND DEMAND WITH BETTER STORAGE

Applied Nanomaterials and Clean Energy Lab

Carbon Nanomaterials Lab

Fuel Cell and Green Energy Lab

Giga-to-Nano Centre

Nazar Research Group

CONSERVE:

ENERGY THROUGH GREATER EFFICIENCY

Advanced Systems Glazing Lab

Information Systems and Science for Energy Lab (ISS4E)

Sustainable Energy Policy Group

DELIVER:

ENERGY MORE INTELLIGENTLY

Electricity Market Simulation and Optimization Lab

High Voltage Energy Lab

Information Systems and Science for Energy Lab (ISS4E)

Non-destructive Testing Lab

ENABLE:

SMART POLICIES AND PLANNING

Sustainable Energy Policy Group

IMPROVE:

CONVENTIONAL GENERATION METHODS

Center for Pavement and Transportation Technology Lab

Mechatronics Vehicle Lab

Non-destructive testing Lab

Qing-Bin Lu's Lab

Solar Thermal Research Center

TRANSFORM:

ENERGY SYSTEMS THROUGH GAME-CHANGING TECHNOLOGIES

Center for Advanced Photovoltaic Devices and Systems

Center for Advanced Materials Joining

Fluid Mechanics Research Lab

UW Live Fire Research Facility

Wind Energy Lab

Energy Harvesting Lab

Kleinke Research Centre

Fuel Cell and Green Energy Lab

Giga-to-Nano Centre

Mechatronics Vehicle Lab

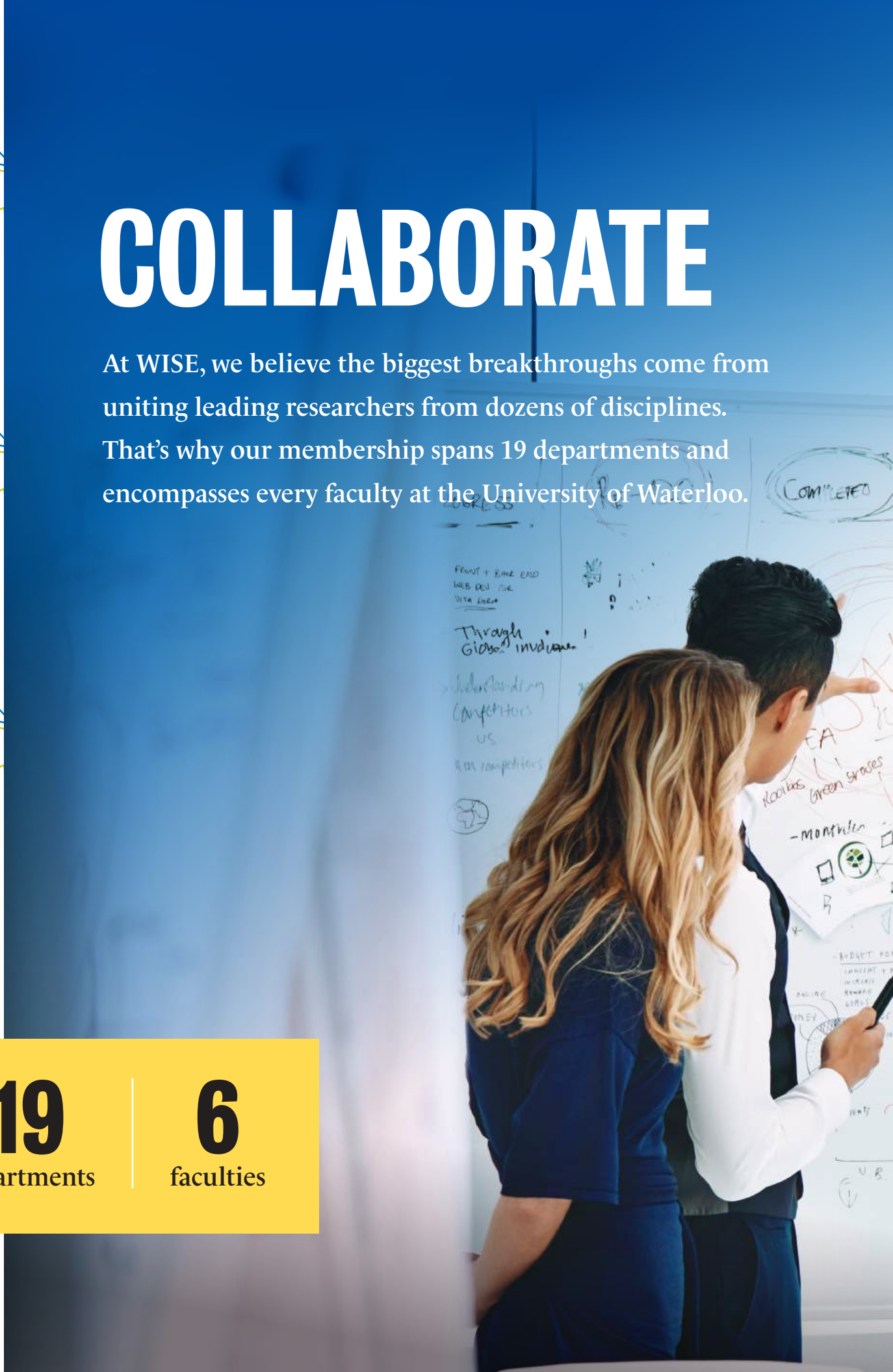
Solar Thermal Research Center

Advanced Glazing System Lab

Laboratory for Research in Thermochemical Process and Green Energy

COLLABORATE

At WISE, we believe the biggest breakthroughs come from uniting leading researchers from dozens of disciplines. That's why our membership spans 19 departments and encompasses every faculty at the University of Waterloo.



19 departments | **6** faculties


Planned
DIRECT
Increase
online subscriptions
Take action
risk → 2,5%
Output
Focus
on
Growth
Date of

FROM THE DEP
CHEMICAL ENG

Professor Eric Croiset (WISE Faculty Member and Department Chair, Chemical Engineering) is one of the lead investigators of the smart energy networks (SENs) program initiated by WISE ten years ago. A Smart Energy Network is a total energy network system consisting of an electricity grid, a natural gas infrastructure, a district heating network, and advanced information and communications technology. The aim of SEN is to improve reliability, security, and efficiency of energy systems by enabling an optimal combination of renewable energy, energy storage, and effective natural gas energy applications, coupled with conventional bulk supply of energy. The integration is achieved with advanced information and communication technologies. A SEN has the potential to address Ontario's challenges in energy security, global climate change, renewable energy integration, and growing energy demand.

Prof. Croiset's research interests include sustainable energy management, reaction engineering, the exploration of alternative energy and the optimization of carbon dioxide capture and utilization processes. He and his team have collaborated with CanmetENERGY, Natural Resources Canada, to understand, simulate and economically evaluate carbon dioxide capture processes: post-combustion, pre-combustion, and oxy-fuel combustion. Prof. Croiset's expertise in alternative energy sources has led him to pursue research in the development of solid oxide fuel cell (SOFC) and solid oxide electrolysis cell (SOEC), both experimentally through material development, and theoretically through charge transfer and reaction kinetics in SOFC and SOEC. In particular, his interest is in CO2 utilization via CO2 reduction in SOEC. Another area of Prof. Croiset's research work is in syngas/hydrogen production from natural gas, liquefied petroleum gas (LPG), ethanol and glycerol.

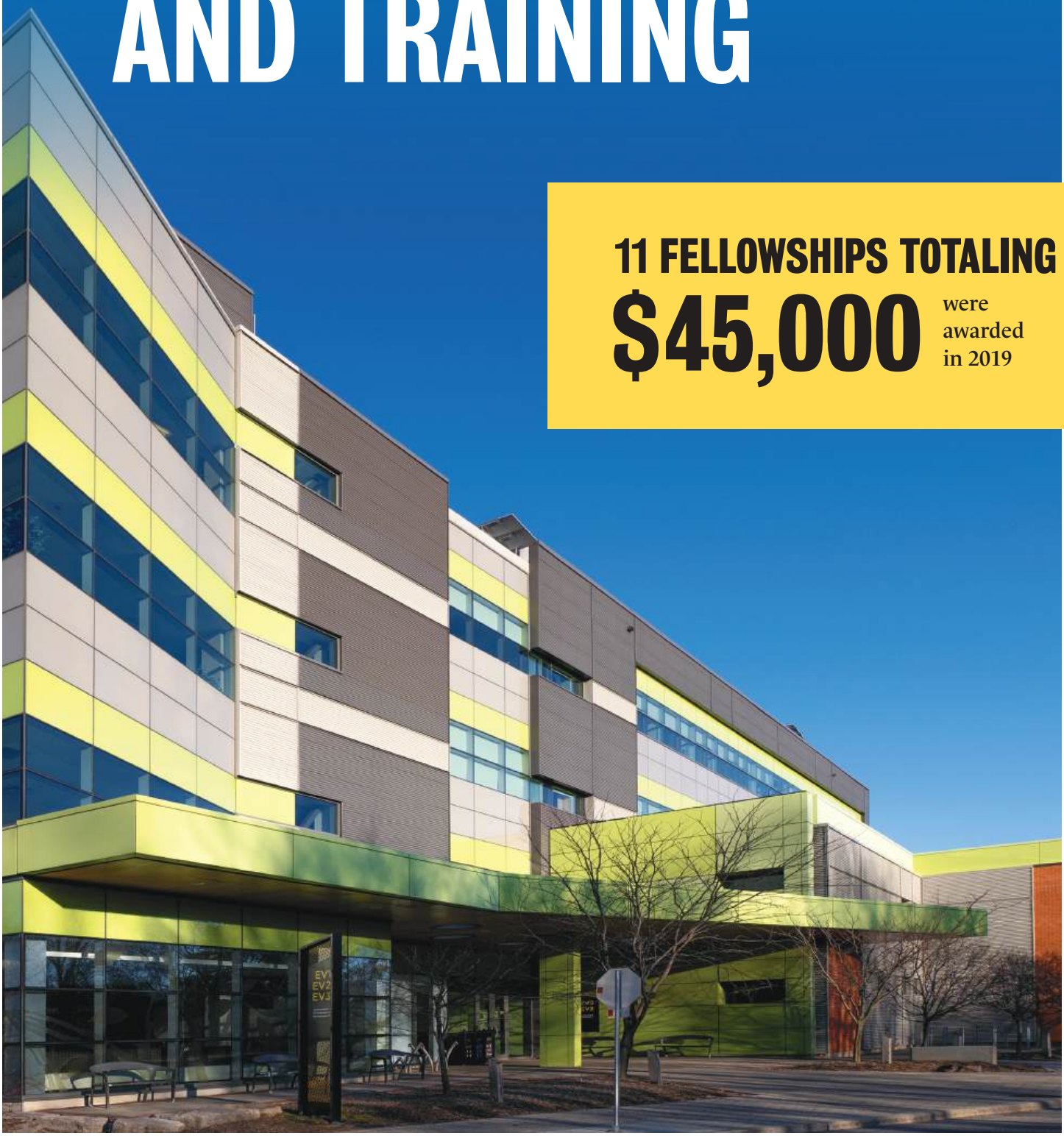
ARTMENT CHAIR, INEERING

The Department of Chemical Engineering has grown and thrived under the leadership of Prof. Croiset since 2012. The Department is home to more than 900 students, faculty and staff, and has thousands of alumni worldwide. The department's interdisciplinary research culture, engaging teaching practices and state-of-the-art facilities create a vibrant learning environment where students are empowered to solve problems related to energy at the global level. Profs. Anderson, Chen, Chou, Douglas, Elkamel, Feng, Fowler, Gostick, Li, Chen, Moresoli, Ng, Pritzker, Ricardez-Sandoval, Simakov, Yu, and Zhao (Chemical Engineering) are world-class leaders in the field of clean energy. Their contributions in the areas of bioenergy, biochemical engineering, pollution control, biofuel cells, thermodynamics, battery storage, fuel cell catalysis, carbon capture and sequestration/storage (CSS), syngas/hydrogen production, energy planning, energy and environmental engineering systems, combinatorial optimization, power to gas energy storage, electrochemical energy conversion, combustion based energy systems, organic and dye-sensitized solar cells, biogas, renewable synthetic fuels, and nanomaterials for energy technologies have proved to create positive socio-economic impacts.

For the past several decades, the Department of Chemical Engineering has an extensive network of industrial connections in the energy sector that has helped earn the department a global reputation for research initiatives in a wide variety of interdisciplinary subjects. Our goal is to make sure that our engineers will be at the forefront of the energy technologies and play a major role in modern society by creating social and economic value through innovation and entrepreneurial activities.

PROFESSOR ERIC CROISET,
Department Chair, Chemical Engineering

EDUCATION AND TRAINING



11 FELLOWSHIPS TOTALING

$45,000 were awarded in 2019

Energy Council of Canada
Conseil canadien de l'énergie

The Energy Council of Canada is a vehicle for strategic thinking, collaboration and action by senior energy executives in the private and public sectors with an interest in national, continental and global energy issues.

ENERGY POLICY RESEARCH FELLOWSHIPS

Annual fellowships are valued at up to $15,000 for Master's students and up to $25,000 for Doctoral students registered at the University of Waterloo.

With Energy Council of Canada support, researchers and students at WISE have been tackling today's complex energy issues. Since 2013, 28 students have received $389,500 to support their research in sustainable energy. 2019-2020 completes the Fellowship Program at the University of Waterloo.

Thanks to the support of the Energy Council of Canada, our students have been helping to shape public attitudes, inform energy policy and create transformative change for the future. Our students deeply appreciate the Council's generosity that has made a difference in their lives.

The Waterloo Institute for Sustainable Energy thanks the incredible generosity of the Energy Council of Canada for helping our students make new discoveries, create new innovations, and inform new policies that will improve our world.

MEET THE ENERGY POLI FELLOWSHIP RECIPIENT

BO LIN

MANAGEMENT SCIENCES

Bo's research is focused on optimizing electric vehicle (EV) routing and charging/discharging under dynamic electricity prices, which is of great value for EV fleet operators and energy policy makers.

YIXIN (CANDICE) CHEN

GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT

Yixin's objective is to examine the impact of "Vehicles-to-grid" on Urban resilience.

DAVID BILLEDEAU

POLITICAL SCIENCE

David's research topic explores Performance and Transparency of Carbon Reduction Strategies within Canadian Companies to advance carbon capture utilization and storage technologies.

FRANCISCO FELIX MARTIN DEL CAMPO,

SUSTAINABILITY MANAGEMENT, SEED

Francisco's research focuses on the dynamics of socioeconomic metabolism on islands, specifically, the material and energy flow of analysis of islands.

CY RESEARCH S FOR 2019–2020:

JANETTA MCKENZIE

GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT

Janetta is working on the role of regulatory governance in decarbonization by way of lessons from petroleum producers.

KAYLIA LITTLE

SUSTAINABILITY MANAGEMENT, SEED

Kaylia's research examines the energy-gender nexus in remote and isolated communities with a focus on gender dynamics of renewable energy in Southern Labrador Inuit communities as a pathway for gender equality.

NICHOLAS PALASCHUK

SUSTAINABILITY MANAGEMENT, SEED

Nick's objective is to understand increasing societal awareness about the impacts of anthropogenic climate change.

SHEIDA SHAHI

CIVIL AND ENVIRONMENTAL ENGINEERING

Sheida's research is focused on adaptive reuse of Residential towers in northern climates.

TRUZAAR DORDI

SOCIAL AND ECOLOGICAL SUSTAINABILITY

Truzaar's research seeks to gain a better understanding of mitigating the systemic consequences of stranded carbon assets along the path of decarbonization.

YING ZHOU

SUSTAINABILITY MANAGEMENT

Ying's research examines the transition to a low-carbon energy economy in Canadian municipalities.

YIPING ZHANG

SUSTAINABILITY MANAGEMENT

Yiping's objective is to determine what innovations are required to support an increasing share of non-carbon sources of energy in the supply system.

QUEEN ELIZABETH SCHOLARSHIPS

As an institute committed to growing clean energy development at home and abroad, we take pride in collaborating with the Queen Elizabeth Scholarship foundation. Within this partnership, WISE/AE4H has been able to assist with clean energy development in nations lacking adequate energy infrastructure, as well as continuing the cycle of new, innovative learning and opportunity for Waterloo students. As representatives of the University of Waterloo and WISE/AE4H, these students have done extraordinary work with some of our member organizations, helping to actualize clean energy development abroad. This year's students worked primarily in east Africa and India putting their technical and interdisciplinary skills to the test during in-field placements for their co-op semesters. These partnerships are an important way WISE/AE4H works to fulfil the United Nations Social Development Goals (SD7).

CO-OP STUDENT PROGRAMMING

In order to catalyze long-term action to promote sustainable and affordable energy for all, it is important to foster young global changemakers whose innovation and drive will promote sustainable development. Starting in 2017, WISE began partnering with AE4H partners and Co-operative and Experiential Education to create international co-op placements that gave University of Waterloo co-op students hands-on experience in energy and development.

In 2019-20, 14 undergraduate students participated in these international co-op opportunities, nine through the Queen Elizabeth Scholars program funded by the Rideau Hall Foundation and managed by Universities Canada.

WISE is grateful for the support of the following AE4H employers who hosted students at their organizations in 2019-2020.

STUDENTS

- Andrew MacMillan, Mechanical Engineering
- Jordan Lin, Mechanical Engineering
- Kyle Psuik, Civil Engineering
- Gabrielle McMullan, Environment and Resource Studies
- Nicole Howard, Chemical Engineering
- Jeffray Behr, Mechanical Engineering
- Laurel Pilon, Biomedical Engineering
- Meetika Kher, Environmental Engineering
- Mandy Coleman, Environmental Engineering
- Emma Wildeboer, Chemical Engineering
- Tuneer Mondal, Computational Mathematics
- Kevin Chan, Systems Design Engineering
- Eva Chen, Geography and Environmental Management
- Lukas Winter, Mechanical Engineering

ENVENTURE, UGANDA

72% of Ugandans lack access to electricity. Rural cooperatives and Community Based Organizations (CBOs) created by members of the community know this problem well. Solar energy, non-electric water filters, improved biomass cookstoves, and fuel briquettes are all modern low-cost technologies that can solve rural and refugee settlement energy problems.

The ENVenture program powered by New Energy Nexus empowers rural CBOs in Uganda to start clean energy enterprises. Through our Seed Incubator, we invest small amounts in a large number of CBOs. Over a 1-year period of monitoring their energy sales and loan repayments, the best performers are selected for our Growth Accelerator which offers larger debt, financial management support, and investment-readiness.

JAZA ENERGY, TANZANIA

Jaza is an off-grid solar energy company that was founded in 2015. This company provides solar energy services to rural communities in Tanzania based on a “battery-swapping” business model. In each community that Jaza operates in, a small “solar hub” is built. These solar hubs are equipped with solar panels on the roof, and a number of portable batteries that can then be charged with the solar panels. Customers can come to the hub to rent a charged battery that can be carried to their homes to power lights and other electronics. Once a battery has been depleted, customers bring it back to the hub in exchange for a small fee.

LAUREL PILON, CO-OP STUDENT WINTER AND SPRING 2019

MANDULIS ENERGY, UGANDA

Mandulis Energy develops both on-grid and off-grid renewable energy projects in emerging markets in Sub-Saharan Africa, starting in Uganda. They use innovative technology including biomass gasification and software-enabled renewable energy. Crucially, they are committed to creating and deploying new technologies and approaches, including proprietary software, to address the energy access "trilemma" by reconciling reliability, sustainability and affordability.

AVANI BIO ENERGY, INDIA

Avani-Kumaon is a non-profit social enterprise that develops sustainable livelihood solutions in the rural, developing region of Uttarakhand, India. In its energy sector, Avani has developed and implemented several biomass gasification power plants in villages across Uttarakhand. These plants, which are fueled by pine needles, produce electricity which is sold to the state power company, generating revenue for the villages. This initiative provides employment opportunities for men who operate the power plants, as well as women who collect and deliver pine needles for the biomass fuel. The power plant project also helps address forest fire problems in the region, as collecting the pine needles from the forests around the villages and power plants helps reduce the spread of fires.

ANDREW MACMILLAN, CO-OP STUDENT SPRING 2019

ACCESS TO ENERGY INSTITUTE, TANZANIA/GERMANY

The Access to Energy Institute (A2EI) is the first collaborative non-profit research and development institute for the off-grid industry. Founded at in early 2019 with the support of IKEA, DOEN, Good Energies Foundation and FMO, A2EI's focus is on delivering solar solutions for productive use and income generating appliances to improve livelihoods. Operating from two fronts, the Access to Energy Lab in Arusha combines customer centered development with engineering expertise in Berlin.

JORDAN LIN, CO-OP STUDENT SPRING 2019

INTERNSHIP PROFILES

ANDREW MACMILLAN, MECHANICAL ENGINEERING
AVANI BIO ENERGY

"At Avani, I was asked to investigate options for a biomass handling system that would lower the moisture content of the pine needles as well as to load the needles into the power plant. I focused on finding an appropriate means of drying the pine needles, which is essential to having the power plant run efficiently. A low energy method of drying was desired, as any electrically powered equipment would reduce the net output of electricity being sold by the power plant. Considering this, I looked for existing heat sources in the plant that could be redirected and used for drying. With the available tools and materials, I worked with Avani's technicians to construct a prototype dryer and connect it to a source of hot air from the engine. This method required no additional energy input and made use of the otherwise wasted exhaust heat. After preliminary testing, the plan was changed to instead use heat from the power plant's reactor tower. Recommendations were left with Avani on how to proceed with design changes and further testing for the future of the project. The drying system will be especially important during the rainy season, when frequent rains make it challenging to keep the pine needles dry."

JORDAN LIN, MECHANICAL ENGINEERING
ACCESS TO ENERGY INSTITUTE

"As a Research Associate at A2EI, I was involved in two major research projects and also lent support on different tasks. Across the two phases of the solar electric pressure cooker research, I assisted with the installation of solar systems, analysis of data retrieved, report writing and helped conduct lab tests with the pressure cookers. In another task, I worked with a team member to design and create computer aided design (CAD) models in Fusion 360 of a seed planter constructed by a local innovator in order to improve its replicability. As a 3D CAD design software, Fusion 360 facilitated the visualization of components and recording of dimensions for the innovator. I also co-led a research project to understand which specific agricultural equipment can be solar-powered and brought to market. A number of field visits were made to learn about machines such as oil presses, spice grinders, and rice mills. The technical specifications surrounding the function of the equipment as well as business model employed were also a part of the information gathered. With this data, I prepared a feasibility report that outlined the potential of solar powering these machines and what conditions may promote this possibility."

KYLE PSUIK, CIVIL ENGINEERING
JAZA ENERGY

"In Tanzania I was responsible for a number of tasks involved in the production and installation of the hub buildings from which Jaza sells their electrical products throughout Tanzania's Mtwara region. Shortly before my arrival in Tanzania, Jaza had established an in-house production facility within Mtwara Region. I spent the beginning of my employment with Jaza developing systems intended to monitor various parameters relating production at this facility, such as inventory, cost, and production rate trackers. Once these were established, I was part of the team responsible for using the information they collected to optimize production. My specific roles on this team included making weekly task lists and schedules, preparing material orders, and inspecting hub production and installation processes to ensure that the finished product met all of Jaza's standards."

GABRIELLE MCMULLAN, ENVIRONMENT, RESOURCES AND SUSTAINABILITY
AVANI BIO ENERGY

"At Avani, I worked on the bio-energy project, an initiative that provides villages with pine-needle powered bio-energy gasifiers. The project provides clean energy for the community to use and sell back to the grid, is run by village entrepreneurs and employs community members to clear fallen pine needles from the forest floor. Additionally, clearing the fallen pine needles controls and prevents the rampant forest fires in the area. My position was as an impact assessment intern, researching and analysing the ecological impacts of removing pine needle litter from the forest floor, and the socioeconomic impacts of the gasifier project on communities. My primary responsibility was to deliver the two (ecological and socio-economic) impact assessment reports. This involved a lot of research, designing field studies, visiting villages and interviewing villagers, surveying forests, and collecting and analysing data. We surveyed several forest sites to collect ecological data and interviewed villagers to collect socio-economic data, their ecological insights and gage their interest in undertaking the project. Ultimately, this work will be the starting point of regular, iterative research to follow ongoing impacts of the project as they increase number of gasifiers in Uttarakhand."

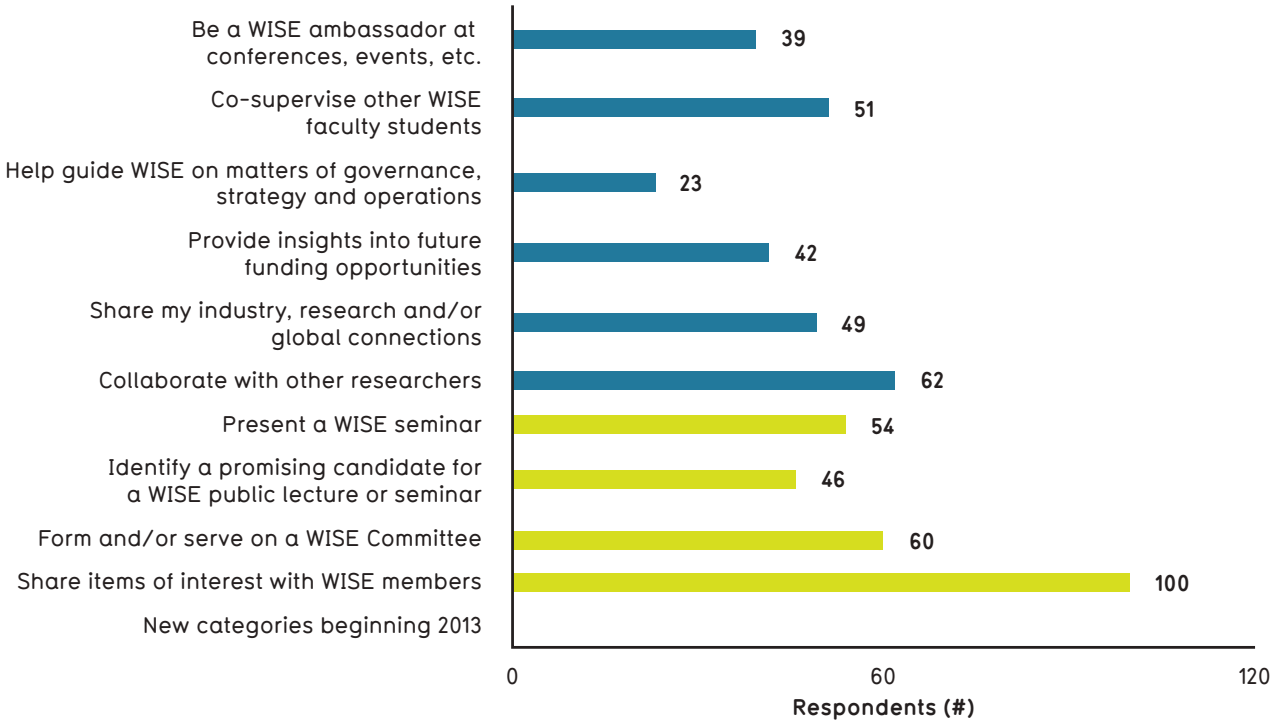
NICOLE HOWARD, CHEMICAL ENGINEERING
ACCESS TO ENERGY INSTITUTE

"The main goal of my internship was to learn about sustainable development with regards to engineering and small business applications. While I was able to work with my colleagues on a number of interesting projects, the main focus of my internship was the development of a sodium-oxygen battery for solar applications. Currently, the lithium ion battery and lead-carbon battery are the industry standards. The main purpose of my project was to develop a feasible alternative to current energy storage systems that would have a more favorable energy density value, longer life cycle, and be more environmentally friendly and sustainable than the leading lithium ion battery being utilized for solar applications. A sodium-oxygen battery would also allow solar systems to be more affordable for the people of East Africa. Validation of the sodium-oxygen design is currently being conducted at the University of Waterloo in partnership with the Waterloo Institute for Sustainability Energy (WISE) Organization, with the main objective of the project being to construct and build a working prototype battery cell and test and analyze its performance with respect to the theoretical mathematical calculations and simulations."

RESEARCH INTERESTS OF OUR MEMBERS

Serving our members starts by understanding their needs and priorities. We do this through one-on-one meetings throughout the year, as well as enabling large-scale multi-disciplinary initiatives.

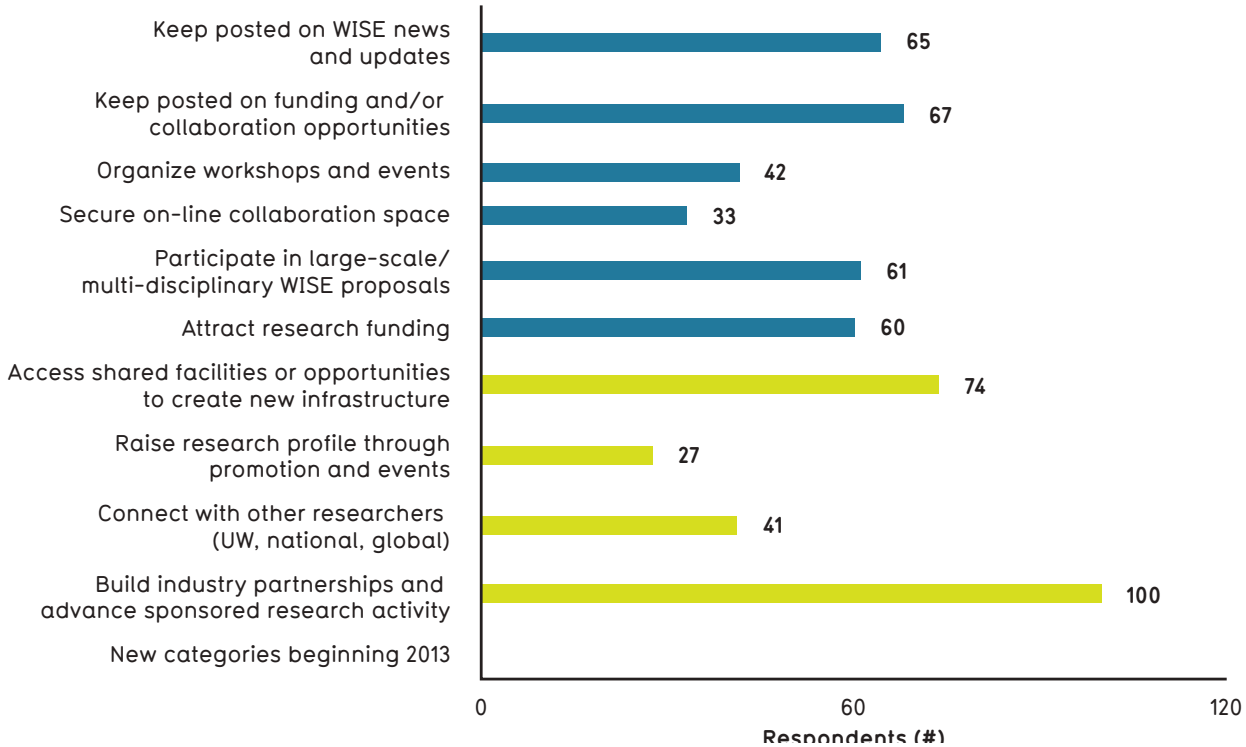
HOW MEMBERS PLAN TO ENGAGE WITH WISE



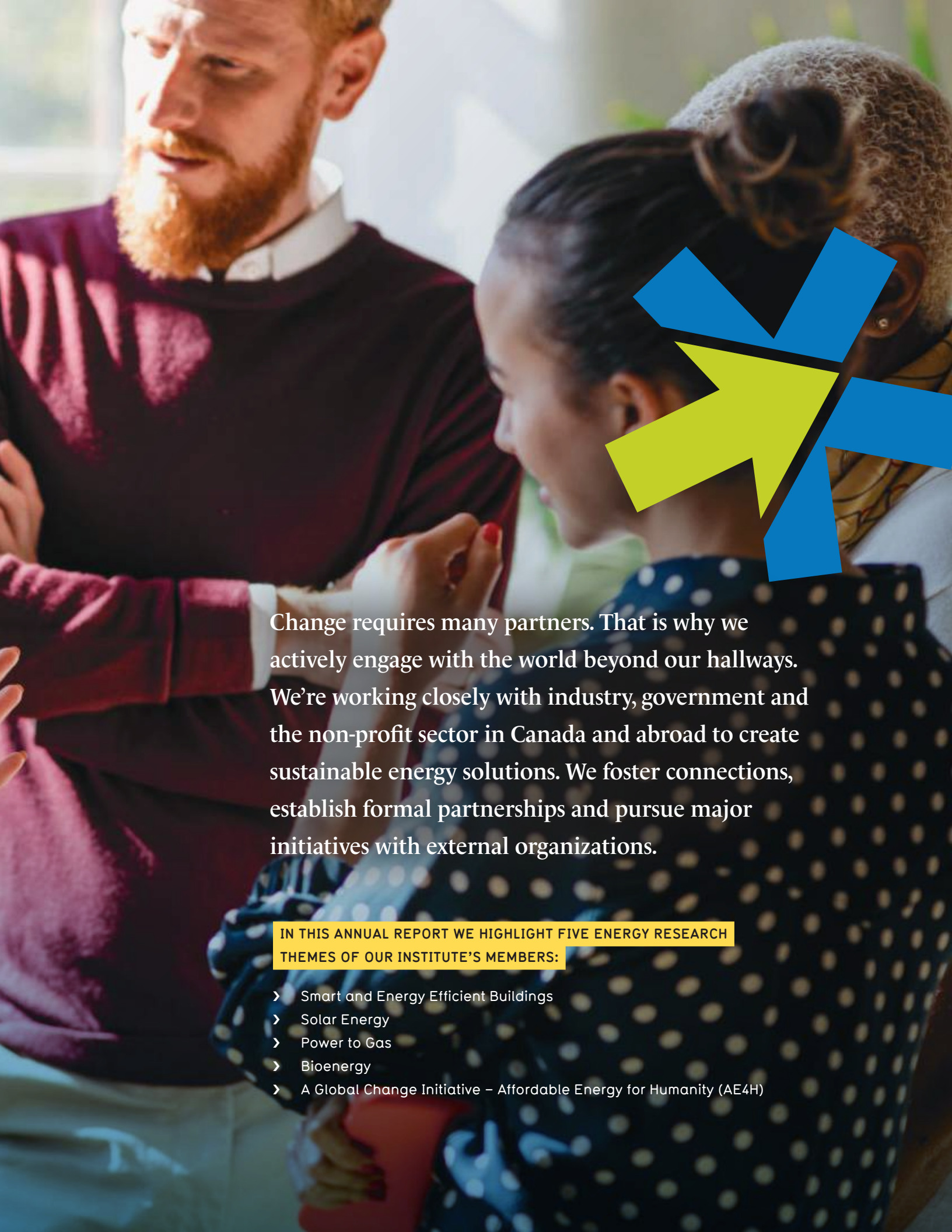
IN FUNDING SECURED SINCE 2010

$23,000,000 +

WHAT FACULTY VALUE ABOUT THEIR WISE MEMBERSHIP



REACH OUT



Change requires many partners. That is why we actively engage with the world beyond our hallways. We're working closely with industry, government and the non-profit sector in Canada and abroad to create sustainable energy solutions. We foster connections, establish formal partnerships and pursue major initiatives with external organizations.

IN THIS ANNUAL REPORT WE HIGHLIGHT FIVE ENERGY RESEARCH THEMES OF OUR INSTITUTE'S MEMBERS:

- Smart and Energy Efficient Buildings
- Solar Energy
- Power to Gas
- Bioenergy
- A Global Change Initiative – Affordable Energy for Humanity (AE4H)

1 SMART AND ENERGY EFFICIENT BUILDINGS

Low carbon energy systems and use of information and communication technologies (ICT) in the building sector plays a vital role to address the challenges of climate change. The residential, commercial, and industrial buildings are a significant source of energy consumption and greenhouse gas (GHG) emissions in Canada. An emission-free and energy efficient building needs to be structured in such a way that it retained an optimized environment. This can be achieved through the integration of renewable energy HVAC technologies, smart sensors and climate-adaptive or smart building envelope. The use of data science and intelligent algorithms to help operate a building that is connected to multiple subsystems is a prerequisite to increase comfort productivity, cost minimization, and reduce environmental impact over its entire lifecycle.

CATHERINE ROSENBERG
Professor, Electrical and Computer Engineering

Professor Rosenberg (Electrical and Computer Engineering) and **Professor Srinivasan Keshav** (Cheriton School of Computer Science) found out that majority of the contemporary HVAC systems in office buildings are not capable to meet the various comfort requirements of the occupants and are not energy efficient. Therefore, their research team have proposed to mitigate both issues by using personal comfort systems (PCS). Energy use could be minimized during periods of sparse occupancy by choosing appropriate thermal set points, with each PCS providing the additional offset in thermal comfort required by each occupant. They presented the design of a PCS-aware HVAC control strategy based on Model Predictive Control (MPC) that employs a bi-linear thermal model. The research team use extensive simulations to compare the energy use and comfort offered by their PCS-aware HVAC system with that of a state-of-the-art MPC-based central HVAC system. They studied several room layouts and scenarios with full or partial deployment of PCSs. Numerical evaluations showed that their system yields substantial savings in energy use in both summer and winter, compared both with a state-of-the-art system that does not deploy PCSs and with a similar system that deploys PCSs, but is not aware of them.

Climate change has led to governments mandating greater energy efficiency in building codes throughout Canada and the US. Increased energy efficiency requires a high level of insulation of the building envelopes, which may introduce unintended durability concerns. To investigate potential durability issues, six types of high thermal resistance (High RSI) wall assemblies were tested at a building envelope test facility by **Professor Straube** (Civil and Environmental Engineering) and his colleagues. This study compared the hygrothermal performance of conventional 38 x 140 mm framing (i.e. baseline wall) with three types of deep cavity walls and three types of exterior insulated walls. The

wall assemblies tested have an average installed thermal resistance of RSI 6.8 and they were installed at both north and south-facing orientations of the building envelope test facility to observe their relative performance. The hygrothermal conditions of test walls were monitored under three consecutive periods: baseline period without air leakage in fall/winter time, air leakage period with air injection in winter/spring time, and drying period without air leakage in spring time. The hygrothermal performance in terms of moisture content profile of OSB sheathing and mold growth risk at the interior surface of OSB sheathing was analyzed with respect to wall types and orientation. The exterior insulated walls had lower moisture content than deep cavity walls and the baseline wall throughout the whole monitoring period, and there was no condensation or mold growth risk under simulated air leakage. Although the deep cavity walls had higher moisture content levels than the baseline wall, they were less responsive to air leakage than the baseline wall due to the hygroscopic characteristics of cellulose fiber insulation installed in the stud cavity. The deep cavity walls had higher risk of moisture problems than the baseline wall and the exterior insulated walls.

Professor Parker (School of Environment, Enterprise and Development) is leading a study as a co-investigator on the role of smart sensors in energy efficient buildings. Evolv1 (net positive building) in the North Campus of University of Waterloo was selected for this project. Smart sensors are installed on the ground floor that tracks anonymous movements. This will help to document the relative usage of private office spaces, open office spaces and meeting spaces as well as meetings between people from the different partners in evolvGREEN. The sensors achieve this by tracking devices connected to Wi-Fi such as cellphones and laptops. evolvGREEN is a program that exists in Evolv1. It consists of Accelerator Centre, Sustainable Waterloo Region, University of Waterloo and Wilfrid Laurier University. It is also the region's foremost collaborative workspace for business ventures/start-ups, social entrepreneurs, academic researchers and green energy supporters. The goal of evolvGREEN program is to develop ideas and commercialize them to decrease environmental impact and improve well-being at the community, national and international level.

SRINIVASAN KESHAV
Professor, Cheriton School of Computer Science

JOHN STRAUBE
Professor. Civil and Environmental Engineering

PAUL PARKER
Professor. School of Environment, Enterprise and Development

2 SOLAR ENERGY

Solar energy has a vast potential to contribute towards decarbonizing the global energy systems and mitigation of climate change via carbon emissions reductions. The driving force behind the successful deployment of solar electric energy is increased efficiencies and reduced production costs. The installation of solar energy in Canada has increased in recent years but it is still quite small in terms of market penetration. The first generation solar cell technology (monocrystalline and polycrystalline solar PV) has majority of the market share followed by the second generation (thin film solar). The third generation (quantum dot solar cells and organic photovoltaics) is less commercially advanced but shows a lot of promise in the near future due to its minimal cost and easier fabrication process.

SIVA SIVOTHTHAMAN
Professor, Electrical and Computer Engineering

Professor Sivoththaman (Electrical and Computer Engineering) with his research group is working on quantum dots (QD) to analyze its technical and financial viability in the photovoltaic devices by studying various research components such as tunable bandgaps, adjustable optical and electronic properties, ability for multiple exciton generation, good photostability, and high absorption coefficients.

Organic solar cells (OSCs) have been extensively studied recently as a promising technology to convert sunlight to electrical power since they are more advantageous in terms of mechanical robustness, lightweight, large area fabrication capability, and low cost compared to silicon based and other solar cell technologies. **Professor Li** (Chemical Engineering) along with his collaborators have suggested the design, synthesis, and properties of a novel type of donor (D)-acceptor (A) polymer, poly(3-(([2,2':5',2"-terthiophen]-3-yl-5,5"-diyl)methylene)-1-(2-octyldodecyl)indolin-2-one) (PTIBT), with a donor backbone and acceptor side chains (Type II D-A polymer) as donor for organic solar cells (OSCs) as opposed to the conventional D-A polymers having both donor and acceptor units on backbone (Type I D-A polymers). This polymer has a high dielectric constant of 7.70, which is beneficial for the exciton diffusion and dissociation in the active blend layer in an OSC. In addition, PTIBT was found to have a low-lying HOMO energy level of -5.41 eV and a wide band gap of 1.80 eV in comparison to its counterpart Type I D-A polymer. In organic thin film transistors (OTFTs), PTIBT showed typical p-type semiconductor performance with hole mobilities of up to 1.81×10^{-2} $cm^2 V^{-1} s^{-1}$. When PTIBT and ITIC were used as donor and acceptor to form a blend active layer, the best OSC device showed a JSC of 15.19 $mAcm^{-2}$, a VOC of 0.66 V,

and a fill factor of 0.57, resulting in a power conversion efficiency (PCE) of up to 5.72%. Their research clearly demonstrated that the Type II D-A polymers are a promising new family of polymer donors for high performance and low-cost organic solar cells.

YUNING LI
Professor, Chemical Engineering

Professors Pritzker and Li (Chemical Engineering) worked on the concept of electrodeposited p-type Cu_2O thin films at high pH for all-oxide solar cells with improved performance. They reported the electrodeposition of cuprous oxide (Cu_2O) films from cupric sulfate-lactate electrolytes at high pH 13.5 and their performance in all-oxide fluorine-doped tin oxide/Cu_2O/aluminium-doped zinc oxide solar cells. The deposit grains were found to grow with rather randomly distributed <111> and <100> crystal orientations and have a poorly-defined morphology with evidence of chemical dissolution that takes place during the deposition process. Significant improvements in the solar cell performance with high power conversion efficiencies of up to 1.55% was achieved, which is much better that those (<0.2%) of solar cells with Cu_2O layer electrodeposited at lower pH. The performance enhancement is primarily attributed to the improved electron transport in the Cu_2O thin film due to partial merging of grains.

MARK PRITZKER
Professor, Chemical Engineering

Professor Kapsis (Civil and Environmental Engineering) is currently co-leading a group of 36 researchers from 16 countries under the IEA PVPS Task 15 Subtask C for the development of Building-Integrated Photovoltaic (BIPV) technical guidelines (photos: IEA PVPS Task 15 meeting during pre-covid and covid era). He also serves as an associated editor of the ASCE Architectural Engineering journal and as the vice-chair of ASHRAE TC6.7 on solar energy.

COSTA KAPSIS
Professor. Civil and Environmental Engineering

3 POWER TO GAS

The power-to-gas technology involves transformation of excess renewable energy into hydrogen gas with the help of polymer electrolyte membrane (PEM) electrolysis technology. The hydrogen is then added into the natural gas grid. This way hydrogen is able to replace natural gas that decreases the carbon emissions and dependence on fossil fuels. The method of P2G is a useful way of shifting to a low carbon natural gas mix.

In addition, this technology has the capability to integrate with the anaerobic digestion process. In this process, various microorganisms are converted to organic matter to produce fuel. The addition of hydrogen to this process aka as methanation significantly increases the conversion rates of CO_2 to biomethane. The hydrogen created through the PEM electrolysis technology plays a vital role to convert additional electricity produced from renewables into storable methane. This is then applied to the traditional natural gas grid.

MICHAEL FOWLER
Professor, Chemical Engineering

Power-to-gas is an energy storage and vector technology which can utilize off-peak power, assist in the integration of renewable power and provide needed fuel for industry and transportation. Further, power-to-gas is a useful technology for balancing surplus baseload and renewable energy generation with demand. There are numerous applications of power-to-gas, where renewable power is used to generate hydrogen for numerous applications. Examining each of these power-to-gas pathways across quantitative and qualitative criteria, **Professors Michael Fowler** and **Ali Elkamel** (Chemical Engineering) carried a study that utilizes the stochastic fuzzy analytic hierarchy process to determine criteria weights. These weights are then fed to a multiple criteria decision analysis tool to determine the viability of each pathway for investors and policy makers. A sensitivity analysis is carried out by reprioritizing the criteria and re-evaluating the multiple criteria analysis. The two pathways that score highest under multiple criteria rankings are power-to-gas to mobility-fuel and power-to-gas-to-power, due to their established technologies, lower costs and environmental performance. By extension, both of these power-to-gas pathways are the most appropriate ways for this technology to be implemented, due to their combination of public familiarity, emissions reductions, and developed, available technologies.

The maximum concentration of hydrogen that can be commingled with or blended in natural gas has been a topic of discussion for many years. The reasons for blending hydrogen with natural gas are mainly twofold: To improve the renewable content of natural gas and to utilize the existing natural gas pipeline infrastructure for hydrogen distribution. **Professors Michael Fowler** and **Ali Elkamel** (Chemical Engineering) aims at addressing these issues by proposing an optimization

model that considers blending hydrogen generated through a “power-to-gas” (PtG) technology pathway with natural gas. This paper develops a deterministic mixed-integer nonlinear programming network pressure-flowrate optimization model that captures the interaction between natural gas pipeline systems and the impact of hydrogen injections across multiple pipeline connections in the natural gas grid. A stochastic model is subsequently developed. The optimal quality/concentration of hydrogen in the natural gas pipelines and the optimal location of PtG units are realized while minimizing system-wide capital and operating costs.

ALI ELKAMEL
Professor, Chemical Engineering

The global destructive effects of carbon dioxide emissions and the importance of energy storage for grid stability and peak shaving applications are in deep concern. In this regard, **Professor Nathwani** (Management Sciences) and his team investigated the recycling of carbon dioxide from gas-fired power plant emissions into synthetic natural gas based on a novel power-to-gas process with the aim of chemical energy storage and emission reduction. The hybrid power-to-gas process proposed in this study integrated the power generated from the gas plant and renewable energies. To make a precise evaluation of system performance, the referenced system is analyzed from technical, economic, and environmental points of view. The process is optimized through the reaction operation conditions and the energy utilization of the process. The results demonstrated that the power-to-gas process achieves a reaction synthetic natural gas production yield of over 97% at the optimal operation conditions. Regarding energy and environmental outlook, the power plant provides 15.4% of the power-to-gas total energy consumption, with the remaining 84.6% supplied from renewable energy resources. From the synthetic natural gas produced, the power-to-gas process provides total annual energy storage of 2.9 x 107 GJ and recycles 1.6 Mton of carbon dioxide for the power plant flues, resulting in a reduction of the plant emissions by around 66%. According to the economic data, with the consideration of the selling price of oxygen, the cost of the synthetic natural gas produced results in 1738 $/ton. The obtained results indicated that the system designed can reduce production costs due to hybrid electricity and offers two unique attributes: energy storage capability and drastic reduction of carbon dioxide emissions.

JATIN NATHWANI
Professor. Management Sciences

4 BIOENERGY

Bioenergy provides considerable prospect to minimize GHG emissions and energy independence from fossil fuels. The conventional use of biomass has always supported the heating and cooking market for an extended period of time. Conventional bioenergy depends on the agricultural by-products, fuelwood, and charcoal at the local and regional scale. The contemporary use of biomass for electricity production and heat generation and provision of high temperature heat for industry and biofuels creation has laid the foundation towards a more efficient option of providing a low carbon energy future. The new bioenergy processes count on energy carriers i.e. bioethanol, biodiesel, wood pellets, and wood chips. The market penetration of the bioenergy technology both at the Canadian and global level is still at the early stage and encounter complex interactions among agriculture science, forestry division, and power sector.

FLORA NG
Professor, Chemical Engineering

Production of biodiesel from yellow grease (waste cooking oil and waste animal fats) is fast emerging as a promising alternative to address the twin challenges before the biodiesel industry today-fluctuation in prices of vegetable oil and the food versus fuel debate. Yellow grease has a high percentage of free fatty acids (FFA) and proves to be an unsuitable feedstock for biodiesel production from commercially viable alkali-catalyzed production systems due to saponification problems. "Green" methodologies based on heterogeneous solid acid catalyzed reactions have the potential to simultaneously promote esterification and transesterification reactions of yellow grease to produce biodiesel without soap formation and offer easy catalyst separation without generation of toxic streams. **Professor Flora Ng** (Chemical Engineering) and her research team investigated kinetic studies for the conversion of model yellow grease feeds to biodiesel using a heteropolyacid supported on alumina ($HSiW/Al_2O_3$) using a batch autoclave. Three model yellow grease feeds were prepared using canola oil with added FFA such as palmitic, oleic and linoleic acid. A pseudo homogeneous kinetic model for the parallel esterification and transesterification was developed. The rate constants and activation parameters for esterification and transesterification reactions for the model yellow grease feeds were determined. The rate constants for esterification are higher than the transesterification rate constants. The kinetic model was validated using the experimental biodiesel data obtained from processing a commercial yellow grease feed. The kinetic model could be used to design novel processes to convert various low-value waste oils, fats and non-food grade oils to sustainable biodiesel.

Professor Parker (Civil and Environmental Engineering) assessed the use of mainstream iron addition for phosphorous control on H_2S content of biogas from anaerobic digestion of sludges. A

material flux analysis on sulfur (S), phosphorus (P), aluminum (Al), and iron (Fe) was conducted for two WWTPs (Galt and Kitchener) to evaluate the potential of coagulants that are employed for phosphorus control to reduce hydrogen sulfide (H_2S) emissions in the biogas from anaerobic digestion. It was found that while the Galt WWTP receives higher concentrations of S in the raw wastewater than the Kitchener WWTP, this had only a modest impact on the speciation of S entering anaerobic digestion. At both plants, only 2%–4% of influent S entered the digesters. The presence of Fe in the sludge stream was found to cause S, that is released by volatile solid destruction and sulfate (Formula presented.) reduction, to become particulate-bound.

WAYNE PARKER
Professor. Civil and Environmental Engineering

A dosage of 1.1 mg/L of Fe into the raw wastewater (11% of the Fe dosed for P control) was sufficient for sulfide (S^{2-}) control. Transitioning the Galt WWTP from Al to Fe dosing for P control had no significant impact on effluent P concentrations and resulted in a substantial reduction in the biogas H_2S concentration. An additional secondary benefit was an increase in the solid content of the dewatered cake. Practitioner points: Material flux analyses can be employed to gain insight into the fate of key elements contributing to biogas quality. The use of iron for phosphorous control can effectively control H_2S in anaerobic biogas. Conversion from $Al_2(SO_4)_3$ to $FeSO_4$ dosing for P control resulted in increased solid content of centrifuged biosolids.

5 A GLOBAL CHANGE INITIATIVE – AFFORDABLE ENERGY FOR HUMANITY (AE4H)

AE4H
Global Change Initiative

Access to energy is a powerful catalyst of sustainable development. Energy access has large impacts on 13 of the 17 Sustainable Development Goals, ranging from alleviating poverty through the creation of micro-enterprises, to improving health by limiting indoor air pollution created by traditional cooking fuels, to strong climate action by creating decarbonized energy systems. Approximately one third of humanity (2.5 billion) does not have access to affordable, reliable, and sustainable sources of energy and a billion of this population has no access to electricity. In order to meet this basic need at the core of human sustainable development, innovative solutions that address the technical, political, and economic challenges of energy access must be carefully developed and implemented.

150 members | **32** countries

It is with this understanding that in 2015, the Affordable Energy for Humanity (AE4H) global change initiative was created by Dr. Jatin Nathwani and Dr. Joachim Knebel from the Waterloo Institute for Sustainable Energy (WISE) and the Karlsruhe Institute for Technology (KIT) respectively. The goal of AE4H is to build a committed network of energy access researchers and practitioners from around the world to develop innovation solutions to energy poverty.

In 2019-20, there were over 150 AE4H members from 32 countries, representing a broad array of expert researchers and practitioners in the area of energy access. AE4H members collaborated in co-op student programming, the AE4H Innovation Lab, and an application to the MacArthur Foundation's '100&Change' competition.

2019 AE4H INNOVATION LAB

From June 19-21 2019, 52 members of the AE4H consortium representing 18 countries attended the 2019 AE4H Innovation Lab in Waterloo, Canada, to meet and discuss solutions to energy access. This Innovation Lab was a forum for true innovation – instead of being passive listeners, participants were challenged to

actively contribute to new ideas to scale and improve the provision of global energy access. The purpose of the Innovation Lab was to leverage the expertise of the dynamic and diverse experts in the room to create tangible energy access solutions.

Through the Innovation Lab, participants first went through a series of brainstorming exercises to ascertain the most pressing energy access challenges of the day. They then self-arranged into diverse groups and developed the basis for a solution to one of the brainstormed challenges. These solutions were then developed further for several months after the end of the Innovation Lab, into a series of Innovation Briefs that outline the structure and merit of the proposed solutions. The Briefs outline current problems and solutions regarding energy access, and represent the strong global collaboration and commitment from AE4H members to ensure affordable, reliable, and sustainable energy for all.

MACARTHUR FOUNDATION 100&CHANGE

An outcome of the 2019 AE4H innovation lab was a deep desire to collaborate with partners to create energy solutions for some of the world's most vulnerable. Dr. Jatin Nathwani, in partnership with many key AE4H members, created a proposal for the MacArthur Foundation's 100&Change competition, which provides one project with $100 million USD to fund a project for global benefit.

AE4H's proposal, titled 'Mending Broken Lives through Clean Energy Solutions', proposed to provide electricity and energy services for basic necessities in refugee settlements in northern Uganda. The installed systems and mechanisms would be used as a foundation for global scalability of energy access systems and building human capacity for positive change.

Although it was not selected as the recipient of the $100 million, Mending Broken Lives through Clean Energy Solutions was ranked as one of the top 100 proposals in the 100&Change competition, adding WISE and its partners to the Lever for Change network with great potential for further partnerships and projects.

PARTNERS

- Arizona State University
- Massachusetts Institute of Technology
- University of Oxford
- University of California – Berkeley
- Karlsruhe Institute of Technology
- Institute for Advanced Sustainability Studies
- iiDevelopment GmbH
- African Minigrid Developer's Association
- Kenya Power and Lighting Company
- Mandulis Energy
- Trama TecnoAmbiental
- USAID
- TESFA-iig
- Energy and Fuel Users Association of India
- Clean Tech Hub Nigeria
- Energy Action Partners Malaysia
- NPC South Africa
- Waterloo Global Science Initiative

WISE EVENTS

ENERGY DAY 2019

September 26, 2019

This year's event was co-hosted by the Waterloo Institute for Nanotechnology (WIN) and the Centre for Bioengineering and Biotechnology (CBB)

- Panel 1: Energy Services Delivery: Is there a changing of the guard?
- Panel 2: Nano-based Energy Innovations: Breakthroughs or Bust?
- Panel 3: Bioenergy Solutions: Can it shape the transition to a low carbon future?

RESOURCE RECOVERY PARTNERSHIPS WORKSHOP, TORONTO

September 19, 2019

Armughan Al-Haq, WISE Manager of Program Development, Partnerships and Finance moderated Panel 1, "An Insiders Report on Advancing Technology and Innovation Supporting Resource Recovery". In order to grow resource recovery technology, we need to create a stable, supportive processing system with a reliable supply of feedstock, a reliable supply of finished product (energy too!) and all of the legislative competitive policies that are essential to its success.

INTERNATIONAL WORKSHOP ON ACCESS TO AFFORDABLE CLEAN ENERGY TO HUMANITY (IWSAACEH)

December 5-7, 2019

WISE has co-hosted and sponsored an event in the city of Chennai (India) with the Energy and Fuel Users' Association of India (ENFUSE), and SRM Institute of Science and Technology (SRMIST) on clean energy access. The workshop themes consisted of:

- Carbon Dioxide Capture – Storage – Conversion,
- Electric Mobility – Technology – Infrastructure,
- Hydrogen Energy – Commercialization in Industrial Applications,
- Smart Energy Networks,
- Internet of Things (IOT),
- Solid Waste Management and Disposal – Recyclable,
- State Space Controller,
- Battery Technologies,
- Renewable Energy Integration.

WISE PARTICIPATION

85TH ANNIVERSARY OF JACK EDMONDS, PANTHÉON-SORBONNE UNIVERSITY

Paris, France | May 3, 2019

Prof. Ghaddar (Management Sciences) has attended the event. She has given a talk on the global optimization approach for binary polynomial programs. In this talk, she presented branch-and-dig, an algorithm to find global solutions for binary polynomial programming problems. She discussed the inequality generating techniques based on lift-and-project relaxations that are developed to speed up the branch-and-bound process and reduce the number of nodes of the tree. Computational results for problems of degree two and degree three were presented to assess the impact of the proposed approach.

AE4H INNOVATION LAB, BALSILLIE SCHOOL OF INTERNATIONAL AFFAIRS

Waterloo, Canada | June 19-21, 2019

On Wednesday June 19th a public event was held, featuring innovation lab participants discussing cleantech entrepreneurship in Africa. This event was a part of the TrueNorth Festival, the largest annual gathering of tech leaders in Canada's technology triangle.

The 'innovation lab' is a non-traditional workshop format wherein participants focus more on what they want to do next and how they might work together rather than on sharing past results. Deep discussions in small groups were a feature. The invitation-only event featured a highly diverse set of participants (expertise, nationality, age, gender, etc.) was our second full-scale innovation lab.

STS FORUM 16TH ANNUAL MEETING

Kyoto,Japan | October 6-8, 2019

Prof. Nathwani (Executive Director, WISE) chaired the Session, "Renewable Energy and Management Systems"

The session examined the challenges of climate change and universal energy access, requiring radical scientific and social innovation. To ensure a cost-effective transition to a low-carbon energy economy, critical factors include a creative approach to new distributed energy technologies, energy storage and battery technology advances, SMEs and entrepreneurs, digitalization and smart energy networks, and the role of electrification including hydrogen.

GUEST LECTURE – TURNING OVER A NEW ARTIFICIAL LEAF, INSTITUTE FOR COMPUTING, INFORMATION AND COGNITIVE SYSTEMS (ICICS)

University of British Columbia, Vancouver Campus | December 9, 2019

Prof. Wu (Mechanical and Mechatronics Engineering) described novel techniques pioneered in his lab that combine X-ray and Transmission Electron Microscopy (TEM) to understand 2-dimensional materials such as graphene at the atomic level, then modify them for practical uses. One such use is an artifical leaf that mimics photosynthesis, converting carbon dioxide into methanol and oxygen, rather than glucose and oxygen as occurs in nature. This "leaf" could be used to capture carbon dioxide from high-yield sources such as thermal power plants, and convert it into methanol as an alternative fuel source.

GEOTHERMAL TECHNOLOGIES IN CANADA: FUTURE PATHWAYS,

Evolv1 Building, University of Waterloo | January 23-24, 2020

This 1.5 day workshop explored current activity in all geothermal technologies being used or considered in Canada, and generated a short synthesis outlining future pathways to greater adoption of this green energy source.

UN CLIMATE CHANGE CONFERENCE, COP25

Madrid, Spain | December 2019

Prof. Rowlands (School of Environment, Resources and Sustainability) attended COP25. About 27,000 delegates participated at the conference under the Presidency of the Government of Chile and was held with logistical support from the Government of Spain.

THE CONFERENCE BOARD OF CANADA'S LEADERSHIP ROUND TABLE ON NUCLEAR ENERGY

Ottawa, Canada | September 10, 2019

Prof. Nathwani (Executive Director, WISE) was invited to this by-invitation-only roundtable, governed under Chatham House Rules, which involved a broad spectrum of energy and environment stakeholders in Canada. The event was specifically structured to foster discussion, which will inform (in non-attributable form) an upcoming Conference Board research briefing.

The dialogue at the event was based on three key themes that guided the sessions of the day: Bankability and Finance, International Competitiveness, and Climate Legitimacy. Each session had a thematic speaker who gave an overview of the topic and the key issues, a panel that discussed the topic and offered diverse perspectives and a pathways to an outcomes piece where roundtable participants discussed the topic in a workshop format and provided recommendations.

THE 2019 IEOM NORTH AMERICAN TORONTO CONFERENCE

October 23, 2019

Prof. Nathwani (Executive Director, WISE) was invited to be a keynote speaker at the 4th IEOM NA Conference with participation from more than 50 countries.

4TH WATERLOO SYMPOSIUM ON TECHNOLOGY AND SOCIETY, BALSILLIE SCHOOL OF INTERNATIONAL AFFAIRS

Waterloo, Canada | December 10, 2019

Prof. Nathwani (Executive Director, WISE) was invited to attend The Waterloo Symposium on Technology and Society seeks to promote public discourse in Canada and beyond on the societal challenges and opportunities created by innovations in four primary areas: artificial intelligence, robotics, big data and social media.z

INFLUENCE

HYDROGEN/FUEL CELL TECHNOLOGY
RESEARCH AT WATERLOO

Our research shapes public attitudes, informs energy policies and improves quality of life at home and around the globe. By publicizing our work, organizing events and participating in important forums, we give governments, businesses and non-governmental organizations the information they need to advance new ideas and implement innovative concepts that benefit society as a whole.

INFORMING PUBLIC DIALOGUE

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PUBLIC LECTURE SERIES

JUNE		
Mohamed Elkadragy	PEng, Renewable Energy Scientist (Expertise in Energy Storage and Off-Grid Systems), Technical Trainer, Electrical Engineer	The Road to Reliable and Economically Feasible Electricity for Remote Communities in Developing and Developed Economies
JULY		
Dr. Ofelia A. Jianu	Assistant Professor, Department of Mechanical, Automotive and Materials Engineering, University of Windsor	Hydrogen as a Sustainable Fuel: Its Role Globally and in Ontario
Mohamed Elkadragy	PEng, Renewable Energy Scientist (Expertise in Energy Storage and Off-Grid Systems), Technical Trainer, Electrical Engineer	Li-ion and Hybrid Battery Storage Systems – Using Case studies within Africa and North America
SEPTEMBER		
Tom Rand	Venture capitalist, entrepreneur, engineer, and philosopher	Waking the Frog: Building a Renewed Climate Capitalism.
NOVEMBER		
Maurice B. Dusseault	Professor, Petroleum Geomechanics, Earth and Environmental Sciences, University of Waterloo	Compressed Air Energy Storage: a MegaWatt or a GigaWatt?
JANUARY		
Dr. Denis J. Gendron	Technical Director, Claire Lasers Corporation	Quantum Oil Refinery: A Viable Path to the Meet the Paris Target

RESEARCH SPOTLIGHTS

WISE research spotlights showcase the advances our members are making to **deliver** energy more intelligently, **enable** smart policies and planning and **conserve** energy through greater efficiency. As a result, we've helped WISE researchers gain prominence with a wider audience in government, business and industry.

ASSESSING ENERGY EFFICIENCY ON THE FARM

RESEARCHERS: Keith W. Hipel, Byomkesh Talukder and Gary W. vanLoon

May 2019

Producing food consumes a lot of energy – and, as a result, creates a significant proportion of the world's greenhouse gases. As the global population grows and the planet continues to heat up, it becomes more important than ever to produce food efficiently.

That's why WISE member Keith Hipel, along with colleagues at York University and Queen's University, recently scrutinized five different agricultural systems in coastal Bangladesh to compare energy efficiency and greenhouse gas emissions.

TRANSFORMING FOOD WASTE INTO FUEL

RESEARCHERS: Hyung-Sool Lee, Ziyi Xiong, and Abid Hussain

JUNE 2019

In North America, we throw out roughly 400 kilograms of food waste per person each year. The bulk of those potato peels and chicken bones ends up in landfills, where it creates methane, a potent greenhouse gas.

Some municipalities take a greener approach. Some burn the methane to produce electricity, but that's an expensive process. Others use anaerobic digestion to break down food waste, but the value of the resulting compost isn't high.

Hyung-Sool Lee, director of the Waterloo Environmental Biotechnology Lab, offers another option. Lee and his team have developed a bioreactor that engineers natural fermentation to extract useful chemicals and fuel out of rotting food.

GIVING RETIRED ELECTRIC VEHICLE BATTERIES NEW LIFE

RESEARCHERS: Talal Alharbi, Kankar Bhattacharya, and Mehrdad Kazerani

September 2019

The battery in an electric vehicle (EV) faces serious performance demands every time the driver steps on the accelerator or the brake. So after a number of years, when its capacity has dropped 20 to 30 per cent, it gets replaced. But that retired battery can still function well in less demanding applications – like stationary energy storage systems of microgrids – where the fluctuations in power/energy and charge are much smaller.

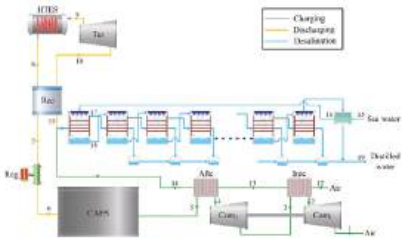
Because the sun doesn't always shine and the wind doesn't always blow, renewable energy microgrids need to incorporate either a way to store surplus energy or a back-up generator to fill the gaps. Repurposed EV batteries offer an attractive alternative to expensive new batteries or polluting diesel generators.

Now, a new tool developed by WISE researchers makes that choice easier.

Electrical engineering doctoral candidate Talal Alharbi, and professors Kankar Bhattacharya and Mehrdad Kazerani began by assessing how different classes of EV batteries degrade during their first life powering vehicles.

RESEARCH SPOTLIGHTS

GREENER ENERGY, DRINKABLE WATER



RESEARCHERS: Amirreza Razmi, Madjid Soltani, Mohammed Tayefeh, Mohammad Torabi, and Maurice.B. Dusseault

October 2019

Call it a double win. WISE researcher Maurice Dusseault and his Iranian collaborators have proposed a system that tackles two global imperatives: cutting carbon emissions and addressing water shortages at the same time.

Renewables like wind and solar offer green sources of electricity. But to be viable on a large scale, we need a way to store excess energy when production is high and demand is low. To achieve this, Dusseault's colleagues in Iran (Dr. Madjid Soltani, the second author, is a WISE Member and an Adjunct Professor at Waterloo) suggest using compressed air energy storage (CAES). This grid-scale solution uses surplus energy to compress air. When energy demand exceeds supply, the air can be used to drive electricity turbines.

VALUING THE KNOWLEDGE OF INUIT IN DIESEL-DEPENDENT COMMUNITIES

RESEARCHERS: Nicholas Mercer, Paul Parker, Amy Hudson, Debbie Martin

JANUARY 2020

Of 259 off-grid communities in Canada, 190 depend almost exclusively on diesel to generate electricity. And although the majority of these communities identify as First Nations, Inuit or Métis, little work has been done to understand Indigenous views on energy sustainability.

To help change that, the NunatuKavut Community Council partnered with WISE member Nick Mercer to undertake research in southeast Labrador into local perspectives on energy. Mercer teamed up with fellow WISE member Paul Parker, and Inuit researchers Amy Hudson and Debbie Martin to interview residents from the Inuit diesel-dependent communities of Black Tickle, St. Lewis and Norman Bay.

COMPRESSED AIR CALCULATIONS OFFER ENERGY STORAGE INSIGHTS

RESEARCHERS: Claudio Cañizares, Kankar Bhattacharya and Ivan Calero

FEBRUARY 2020

Some days are windier than others. So when you're relying on wind farms for electricity, you need a way to store unused energy, creating a buffer between supply and demand.

Compressed air energy storage (CAES) offers a solution. This approach uses excess energy to pressurize and cool air, storing it in underground caverns. When energy is needed, that stored potential can be released by heating and expanding the air.

The promise is strong. What has been lacking, however, are comprehensive models that help operators understand how the system will perform under different conditions and affect the broader energy grid.

Now, WISE researchers Kankvar Bhattacharya and Claudio Cañizares, together with PhD student Ivan Calero, have developed new, unified mathematical models that incorporate every key CAES variable – from caverns to compressors to control systems.

TACKLING ELECTRICAL TRAFFIC JAMS IN MICROGRIDS

RESEARCHERS: Jacqueline Llanos, Daniel E. Olivares, John W. Simpson-Porco, Mehrdad Kazerani and Doris Sáez

March 2020

Microgrid managers face a big challenge: ensuring the smooth flow of electricity between intermittent energy sources (such as wind, solar and hydro), storage systems and energy users. WISE researchers want to help. John Simpson-Porco, Mehrdad Kazerani and their Chilean colleagues have developed a distributed control system that overcomes many of the weaknesses of existing models.

Distributed control systems serve as automated checkpoints and traffic police that help regulate frequency, manage power flow and more. However, that's more difficult in isolated microgrids, where there are fewer interconnected components to share control functions. This can lead to voltage and overloading problems, causing power outages and damaging distribution lines and transformers.

To address those issues, the researchers proposed a new distributed inverter-control formula that helps control frequency, optimize operations and prevent grid congestion caused by too much electricity flowing into a transmission line.

PUBLICATIONS

SELECTED MEMBER PUBLICATIONS

Larkin, P., Leiss, W., Arvai, J., **Dusseault, M.**, Fall, M., **Gracie, R.**, Heyes, A., & Krewski, D. (2019). An integrated risk assessment and management framework for carbon capture and storage: A canadian perspective. International Journal of Risk Assessment and Management, 22 (3-4), 464-508.

Razmi, A., Soltani, M., Tayefeh, M., Torabi, M., & **Dusseault, M. B.** (2019). Thermodynamic analysis of compressed air energy storage (CAES) hybridized with a multi-effect desalination (MED) system. Energy Conversion and Management, 199, 112047, 1-11.

Ge, H., **Straube, J.**, Wang, L., & Fox, M. J. (2019). Field study of hygrothermal performance of highly insulated wood-frame walls under simulated air leakage. Building and Environment, 160, 106202, 1-14.

Alrumayh, O., & **Bhattacharya, K.** (2019). Flexibility of residential loads for demand response provisions in smart grid. IEEE Transactions on Smart Grid, 10 (6), 6284-6297.

Calero, I., **Cañizares, C. A.**, & **Bhattacharya, K.** (2019). Compressed air energy storage system modeling for power system studies. IEEE Transactions on Power Systems, 34 (5), 3359-3371.

Alharbi, W., & **Bhattacharya, K.** (2019). Flexibility provisions from a fast charging facility equipped with DERs for wind integrated grids. IEEE Transactions on Sustainable Energy, 10 (3), 1006-1014.

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AWARDS AND RECOGNITION

CANADA RESEARCH CHAIRS (TIER 1)

Professor Michael Fowler (Chemical Engineering)

Prof. Michael Fowler (Chemical Engineering) was awarded the Canada Research Chair in Zero-Emission Vehicles and Hydrogen Energy Systems. He is trying to demonstrate how power generation systems can operate more effectively while also providing hydrogen energy storage through power-to-gas and hydrogen for fuel cell vehicles (FCVs).

Prof. Fowler has already developed models for electrochemical energy storage, distributed energy (such as wind and solar), and large-scale systems. These models consider the unique impact of providing energy to ZEVs, battery electric vehicles (BEVs) and hydrogen for FCVs as well as the convergence of natural gas distribution and electrical transmission systems.

Prof. Fowler and his research team are now developing battery and FCV powertrain "adaptive" control systems and maintenance strategies. They are also studying battery and fuel cell reliability. This will support optimum vehicle power train configuration, which is now hampering market development of ZEVs.

Ultimately, Fowler's research program will yield key insights into how to integrate zero-emission vehicles into a cleaner energy generation system that can accommodate multiple energy vectors and technologies, including renewables, hydrogen and electricity. This will help provide the technology Canada needs to transition to a green "hydrogen economy" with fewer emissions.

EARLY RESEARCHER AWARD

The Ontario government's Early Researcher Award goes to the province's most promising researchers in the first five years of their academic careers. The Early Researcher Award program is a successor to the Premier's Research Excellence Award program.

Prof. Lan Wei (Electrical and Computer Engineering) received her Early Researcher Award in 2019. Her research focuses on device-circuit interactive design and optimization, integrated nanoelectronic systems with low-dimensional materials, as well as GaN-based technology. Prof. Wei is also actively doing research in Cryogenic CMOS technology – Enabling low-cost, compact control of large-scale quantum computers.

Prof. Wei's research will put Canada in a globally competitive position in the strategic area of next generation high-speed computer and RF communication platforms. Canadian semiconductor, IC design and wireless communication industries will greatly benefit from both the research outcomes and the highly qualified personnel getting trained under her supervision.

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31 labs

21 areas of expertise

14 research chairs

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