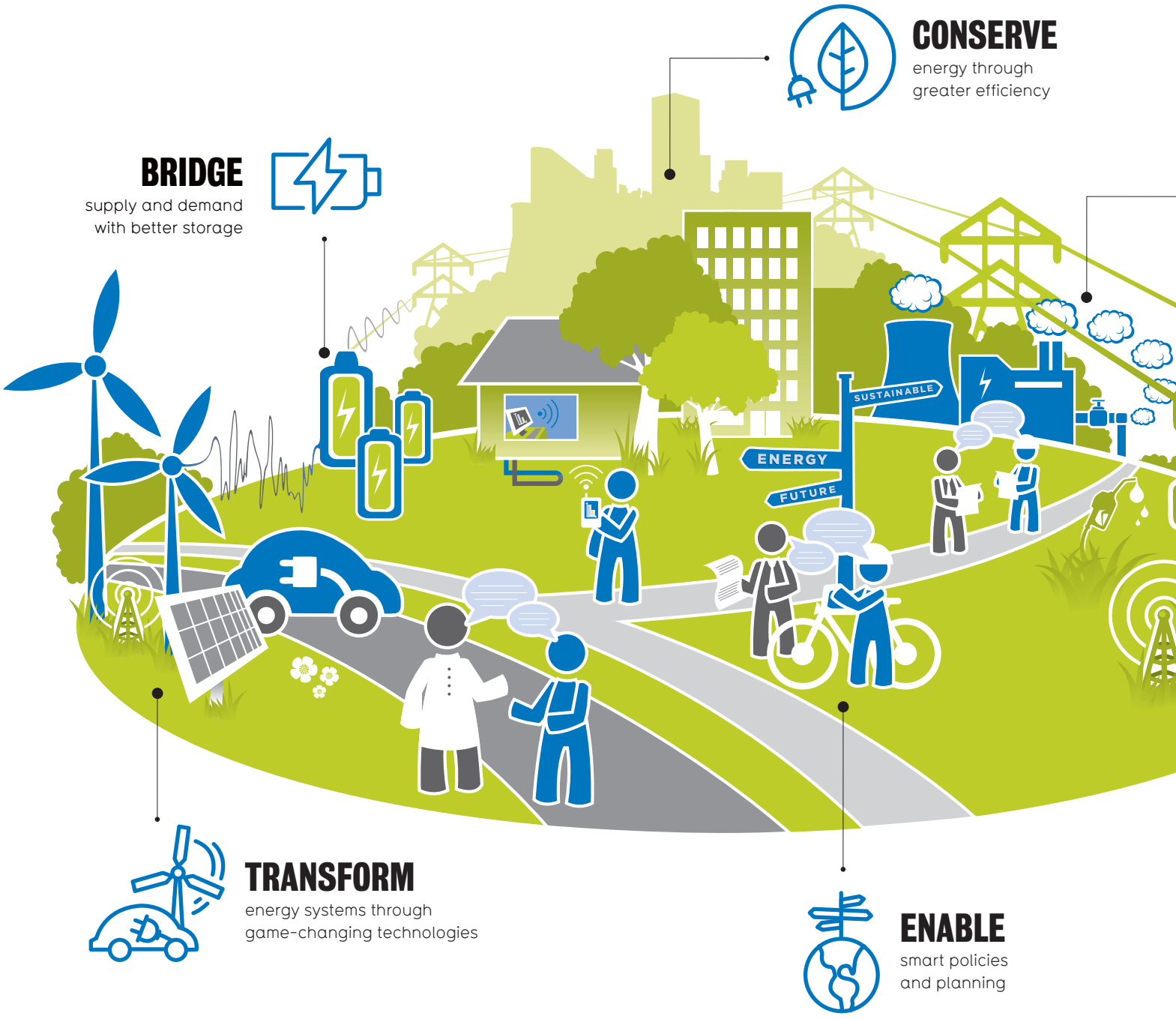
WISE annual report

Waterloo Institute for Sustainable Energy

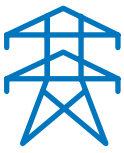
2017–2018

UNIVERSITY OF WATERLOO | WISE WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY

Waterloo Institute for Sustainable Energy



IMPROVE
conventional
generation methods



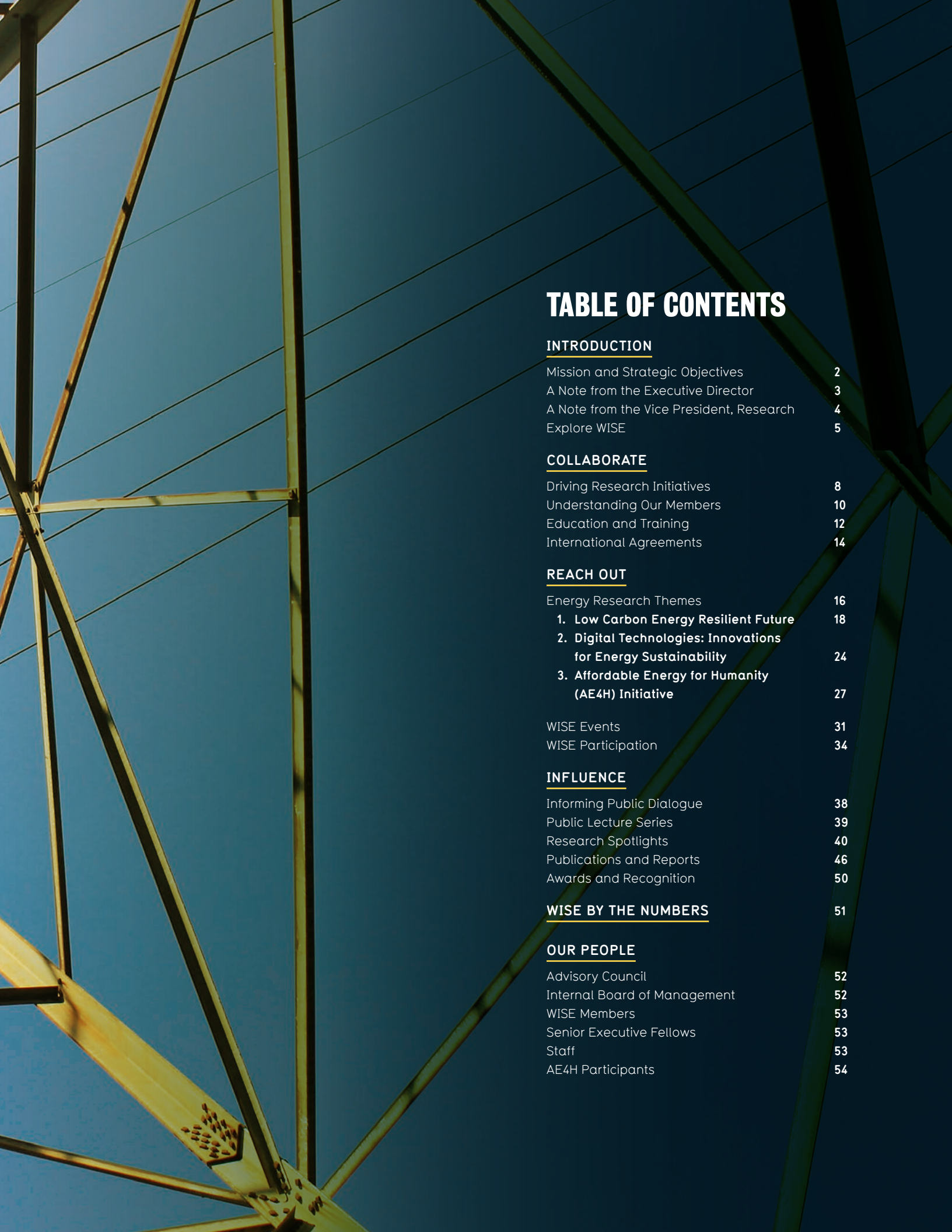
DELIVER
energy more
intelligently

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.

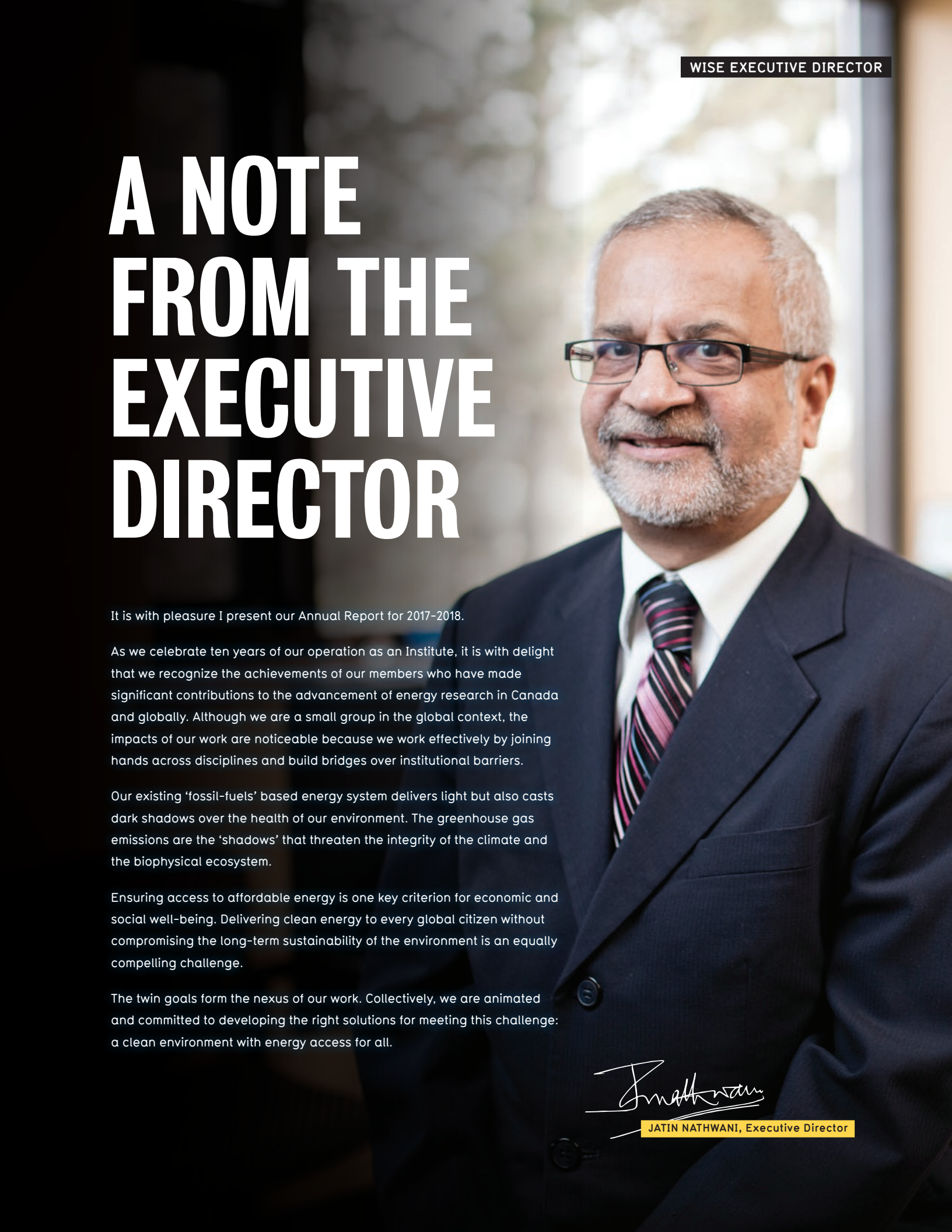
REACH OUT

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.

A NOTE FROM THE EXECUTIVE DIRECTOR



It is with pleasure I present our Annual Report for 2017-2018.

As we celebrate ten years of our operation as an Institute, it is with delight that we recognize the achievements of our members who have made significant contributions to the advancement of energy research in Canada and globally. Although we are a small group in the global context, the impacts of our work are noticeable because we work effectively by joining hands across disciplines and build bridges over institutional barriers.

Our existing 'fossil-fuels' based energy system delivers light but also casts dark shadows over the health of our environment. The greenhouse gas emissions are the 'shadows' that threaten the integrity of the climate and the biophysical ecosystem.

Ensuring access to affordable energy is one key criterion for economic and social well-being. Delivering clean energy to every global citizen without compromising the long-term sustainability of the environment is an equally compelling challenge.

The twin goals form the nexus of our work. Collectively, we are animated and committed to developing the right solutions for meeting this challenge: a clean environment with energy access for all.

JATIN NATHWANI, Executive Director

A NOTE FROM THE VICE PRESIDENT, RESEARCH

I am pleased to briefly introduce WISE's 2017-2018 Annual Report. Over the past 10 years, WISE has grown into a unique institute within the Waterloo community that embodies many of the strengths of our institution. From being a leading proponent and driver of interdisciplinary research that brings together faculty from a broad range of departments and disciplines, to engaging with industry partners and government decision-makers at various levels, WISE works to bring the insights and innovations of our researchers into the wider world.

There are many ways to engage with WISE: through participation at their public events and lecture series that bring leading energy sector thinkers and doers to Waterloo, to working with their managers to secure funding for new research initiatives, or staying up to date with the fast pace of progress in the sustainable energy sector through reading WISE reports and the WISE website. I encourage all members of the UWaterloo community to take advantage of these opportunities, and commend the institute's members and its staff for their diligence in bringing the energy and sustainability issues of the 21st century here for the wider UWaterloo community to engage with.

CHARMAIN DEAN, VP, Research

RESEARCH LABS

BRIDGE:

SUPPLY AND DEMAND WITH BETTER STORAGE

Applied Nanomaterials and Clean Energy Lab

Carbon Nanomaterials Lab

Fuel Cell and Green Energy Lab

Giga-to-Nanoelectronics (G2N) Centre

Nazar Research Group

CONSERVE:

ENERGY THROUGH GREATER EFFICIENCY

Advanced Glazing System 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 Group

Power and Energy Systems Group

Smart Distribution Research Lab (SDRL)

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

Lab for Biomanufacturing

Sustainable Reaction Engineering Lab

Maglev Microbiotics Lab

Research Laboratory for Green Energy and Pollution Control

Printable Electronic Materials Lab

Laboratory for Emerging Energy Research Lab (LEER)

Geomechanics Lab

Student Design Centre

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-Nanoelectronics (G2N) Centre

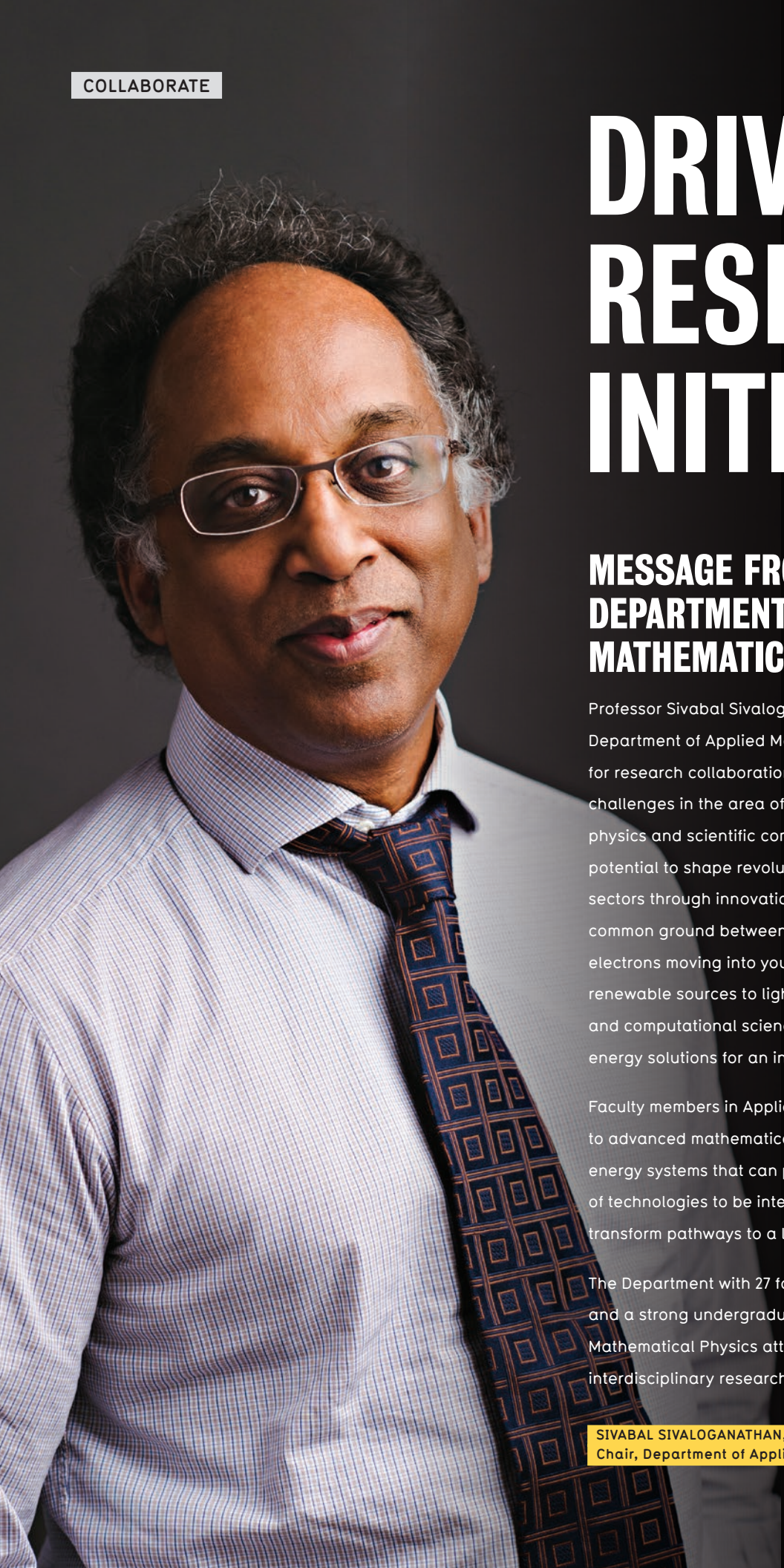
Mechatronics Vehicle Lab

Solar Thermal Research Center

Advanced Glazing System Lab

COLLABORATE

At WISE, we believe the biggest breakthroughs come from uniting leading researchers from dozens of disciplines. That's why our membership spans 21 departments and encompasses every faculty at the University of Waterloo.



DRIVING RESEARCH INITIATIVES

MESSAGE FROM THE CHAIR, DEPARTMENT OF APPLIED MATHEMATICS

Professor Sivabal Sivaloganathan (new WISE member and Chair, Department of Applied Mathematics) is exploring future opportunities for research collaboration with existing WISE members to tackle challenges in the area of smart energy networks, mathematical physics and scientific computing. Applied mathematics has the potential to shape revolutionary developments in traditional industry sectors through innovation. He observes that there is a significant common ground between engineering and mathematics to get the electrons moving into your electric vehicle, or the electricity from renewable sources to light up homes or power industry. Mathematics and computational sciences are integral to the development of new energy solutions for an increasingly, energy demanding world.

Faculty members in Applied Mathematics bring unique expertise to advanced mathematical models and simulation techniques for energy systems that can provide a solid platform for a network of technologies to be integrated to improve, deliver, enable and transform pathways to a low carbon energy future.

The Department with 27 faculty members, over 100 graduate students and a strong undergraduate program in Applied Mathematics and Mathematical Physics attracts outstanding students involved in interdisciplinary research.

SIVABAL SIVALOGANATHAN,
Chair, Department of Applied Mathematics

University of Waterloo Faculty Members

JOHN WEN

ASSOCIATE PROFESSOR, MECHANICAL AND MECHATRONICS ENGINEERING

"The Laboratory for Emerging Energy Research (LEER) of the University of Waterloo have greatly benefited from both funding and networking opportunities offered by this institute. A seeding grant provided by WISE is expected to help perform the scoping and sizing research for building an innovative smart energy network near Sanya, Guangdong, China. Multiple networking meetings and lab tours organized by WISE have undoubtedly enhance the profile of LEER in the global research stage where smart energy technologies are demonstrated."

MAURICE DUSSEAULT

PROFESSOR, EARTH AND ENVIRONMENTAL SCIENCES

"Several of us in the Science and Engineering Faculties who are working in Energy Geo-Storage and Geothermal Energy have been interacting steadily with WISE administrators for several years. We have received useful advice, assistance with our applications, organizational input, and generally valuable guidance and direction. WISE has been a great help to us in our pursuit of more environmentally friendly energy solutions."

BEHRAD KHAMESEE

PROFESSOR, MECHANICAL AND MECHATRONICS ENGINEERING

"WISE has a resourceful team helping in every aspect of research and development from networking to funding and administration."

DIPANJAN BASU

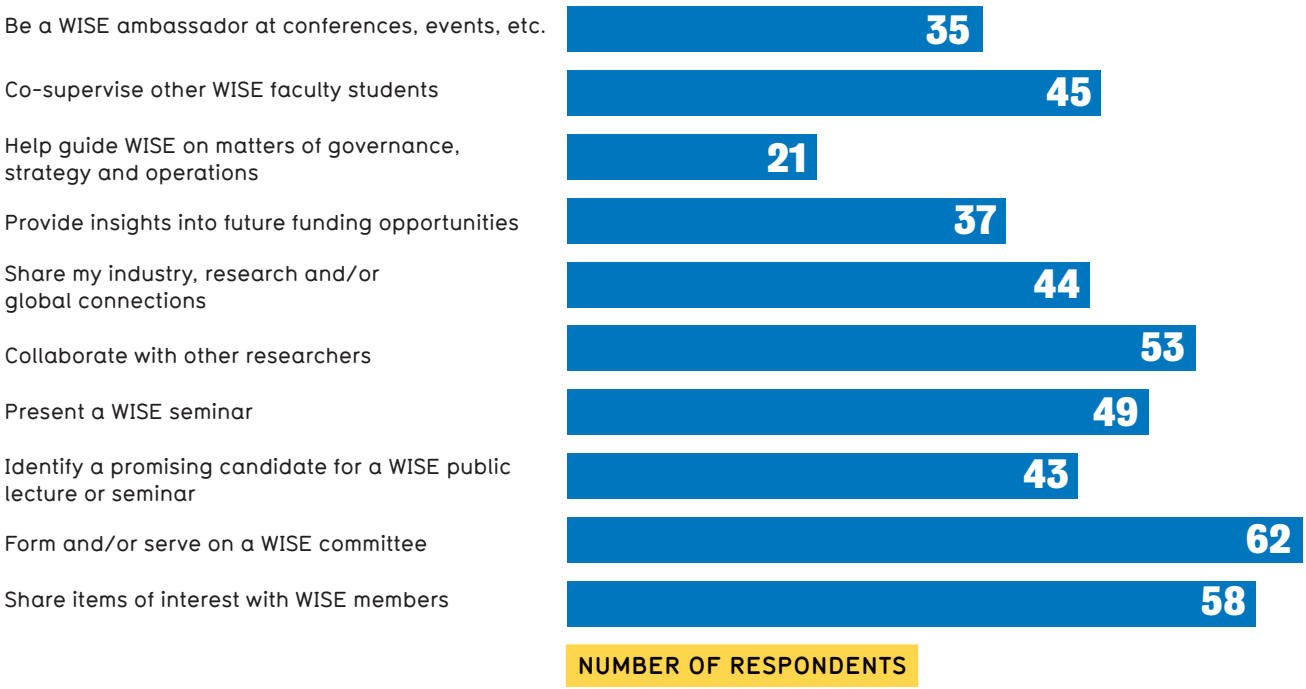
ASSOCIATE PROFESSOR,
CIVIL AND ENVIRONMENTAL ENGINEERING

"WISE has helped me significantly in finding new funding and research opportunities."

UNDERSTANDING OUR MEMBERS

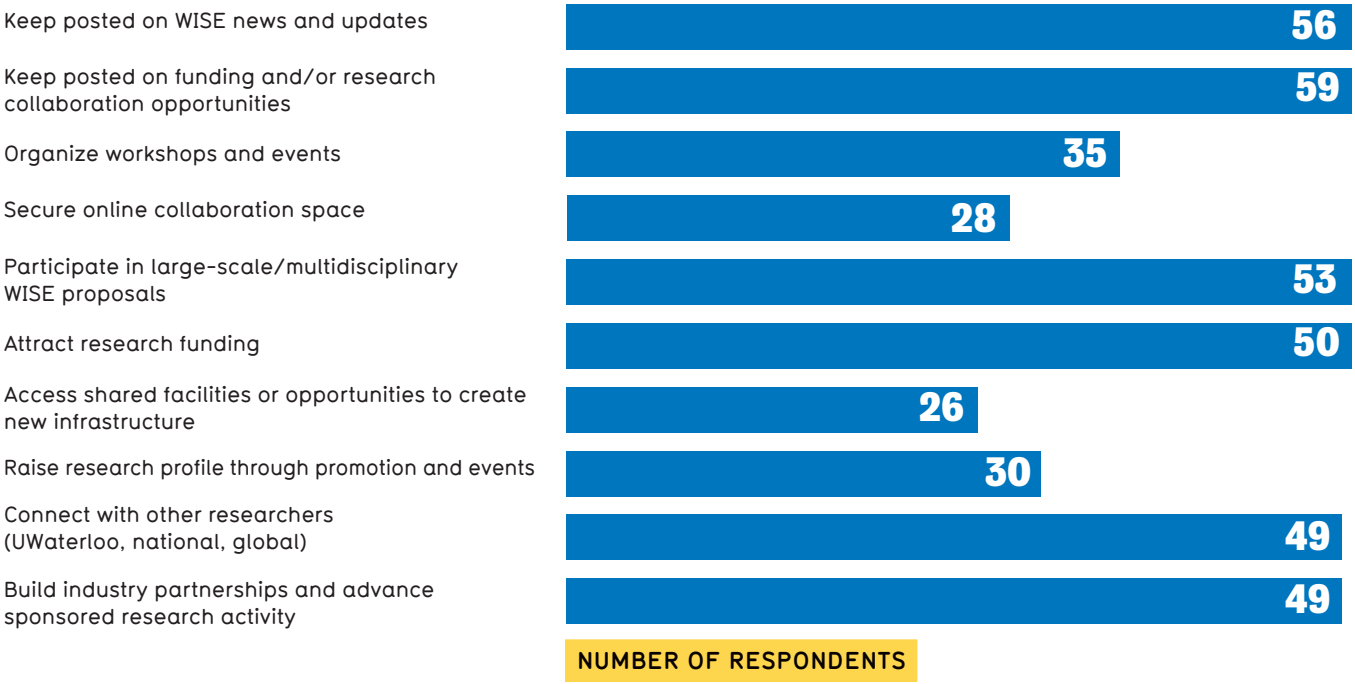
Serving our members starts by understanding their needs and priorities. We do this through one-on-one meetings throughout the year, as well as enabling large-scale multi-disciplinary initiatives.

HOW MEMBERS PLAN TO ENGAGE WITH WISE



$16M+
IN FUNDING
secured since 2010

WHAT FACULTY VALUE ABOUT THEIR WISE MEMBERSHIP



EDUCATION AND TRAINING

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.

3 FELLOWSHIPS TOTALING

$37,500

were awarded in 2017

Meet the Energy Policy Research Fellowship Recipients for 2017-2018:

BENJAMIN ANDRADE

CIVIL AND ENVIRONMENTAL ENGINEERING

Ben's research will explore the valuation and monetization of the environmental impacts of the residual life of building stock in North America. His research will add a Life Cycle Assessment (LCA) perspective to the decision-making methodology involved in adaptive reuse of buildings, in order to contribute to sustainability and climate change through mitigation of CO_2 emissions.

INES HAVET

GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT

Ines's research investigates the extent and ways in which residential energy use patterns are affected by the complex relationships between household members, including gender relationships, as household members interact with energy-using technologies. Her research explores whether these factors, often unaccounted for in impact assessments and policy design, play a role in encouraging or discouraging residential energy consumption.

NICHOLAS MERCER

SOCIAL AND ECOLOGICAL SUSTAINABILITY

Nick's research focuses on sustainability implications of renewable energy [RE] development in off-grid communities throughout Canada. In particular, the research project seeks to assess how RE projects create economically, environmentally, and socially vibrant communities. Furthermore, the project aims to identify policy factors which have facilitated off-grid sustainability via RE development in a global context – with particular attention given to Alaska and Canada's northern territories.

MENTOR PORTAL

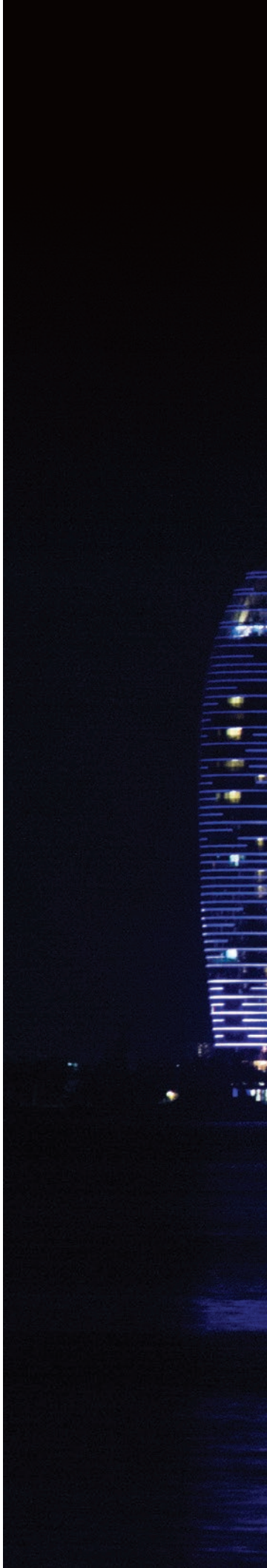
In 2017 WISE created a Mentor Portal program with input from the Energy Council. The confidential web portal provides each Fellow with a profile and space to upload material related to their research. The Energy Council members are able to connect directly with students looking for a mentor to establish a relationship.

INTERNATIONAL AGREEMENTS

MOU WITH CHANGFENG ENERGY

In December 2017, Changfeng Energy Inc. and the Waterloo Institute for Sustainable Energy at the University of Waterloo signed a ten-year collaboration MOU for smart grid energy solutions. Furthermore, Changfeng Energy and the University of Waterloo are exploring options to jointly develop an energy research center.

The research center will strengthen the Sino-Canadian collaboration on Smart Energy research and advance the field of integrated energy utilizing both renewable and traditional energy sources.



REACH OUT

Change requires many partners. That's 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.

OUR THREE ENERGY RESEARCH THEMES:

1. Low Carbon Energy Resilient Future
2. Digital Technologies: Innovations for Energy Sustainability
3. Affordable Energy for Humanity (AE4H) Initiative

1 LOW CARBON ENERGY RESILIENT FUTURE

i) NET POSITIVE ENERGY BUILDINGS

One effective pathway to a low-carbon energy future is the development of net positive energy buildings. This powerful concept is anchored not only in reduction of energy use but rests on a smart integration of a range of renewable energy technologies with sensors, devices and data analytics for superior economic performance. New construction projects present the best opportunities to achieve zero carbon performance and create a low carbon building stock for future generations. New buildings designed for optimal efficiency and resiliency also help to create new markets for renewable energy resources (solar, wind, geothermal, and bioenergy) and reduce combustion of fossil fuels.

JOHN STRAUBE
Professor, Civil and Environmental Engineering

Professor Straube (Civil and Environmental Engineering) leads forensic investigations and research projects in the areas of low energy building design, building enclosure performance, hygrothermal analysis and field monitoring of wall assemblies. His important contributions to advancements of standards and building codes (CSA A371, CAN/ULC S741-08, ASHRAE, and IBPSA) bridges the gap between practical implementation and research. Professor Straube's latest R&D projects involve maximizing the durability and resilience of multi-storey buildings with precast concrete enclosure systems. An important recent finding highlights the use of upgraded precast concrete wall systems: it quadruples the thermal resilience of the building leading to higher efficiency of energy use and cost-effective building operations.

Evolv1 Building

Cora Group will complete construction of the first net positive building on the University of Waterloo North campus. Evolv1 will be operational in Autumn, 2018 and will be home to WISE. This multi-tenant commercial office building is the first of its kind to meet the Canada Green Building Council's rigorous new zero carbon standard. Evovl1 building is one of 16 elite projects across Canada to be selected by the CaGBC to participate in a two-year pilot of its new Zero Carbon Building Standard. It is the first building in Canada to earn the Zero Carbon Building – Design certification.

The CaGBC's Zero Carbon Building Standard is an innovative made-in-Canada solution supporting the building sector to reduce GHG emissions and grow the low-carbon economy. Evolv1 stands out as an innovator and a true leader for the industry setting an example for

Evolv1: Waterloo's IdeaQuarter

building owners and policymakers across the country. Zero carbon buildings are now technically feasible and economically viable. The building industry is in a position to lead the way in the fight against climate change. The Evolv1 building is not only a show-case but a living lab for UWaterloo researchers.

Architectural Engineering Program

The launch of Waterloo's Architectural Engineering program (Department of Civil and Environmental Engineering with the School of Architecture) is a design-driven, co-op program one-of-a-kind in North America. A cohort of 90 plus undergraduate students will engage in hands-on experience, coupled with peer learning in studio-based program that will provide students with both the technical knowledge, and requisite design skills necessary to become industry leaders.

TERRI BOAKE
Professor,
School of Architecture

WISE members Professor Straube (Civil and Environmental Engineering) and Terri Boake (School of Architecture) will play an active role in the program to foster joint ventures with academia and industry leaders and help shape the next generation housing infrastructure.

ii) WIND ENERGY

The role of wind power in the reduction of CO_2 emissions is well recognized. Wind power generation has shown remarkable growth worldwide and in Canada with generation capacity increasing dramatically over the past decade. One challenging issue for social and community acceptance of wind power development is noise and potential health impacts. To meet regulatory requirements for noise levels, new predictive tools are required in support of new wind farm development.

Professor Johnson (Mechanical and Mechatronics Engineering) has developed tools based on computational fluid dynamics studies such as Large Eddy Simulation (LES) in conjunction with the Ffowcs-Williams and Hawkings (FW-H) acoustic analogy to predict the far field sound. Validation of these predictive tools with experimental measurements of 2D airfoil self-noise measurements obtained at the University of Waterloo Wind Energy Research wind turbine field site shows good agreement with the measured experimental data.

Professor Lien (Mechanical and Mechatronics Engineering) and his team of graduate students have also investigated noise emission and the power output from a small horizontal axis wind turbine by using coarse-resolution computational fluid dynamics (CFD) simulations conducted with the commercial software STAR-CCM+®. The predicted A-weighted sound pressure level (SPL) spectra, as well as the apparent SPL, obtained from the permeable formulation of the FW-H equation agree well with the wind turbine acoustic field measurements. It is found that the presence of the tower slightly decreases the wind turbine power output at all simulated incident wind speeds. It is also found that the presence of the tower leads to modifications of the SPL spectra at frequencies between about 300 and 1,500 Hz. Professor Lien's team has shown that a computational modeling/simulation framework involving coupled aerodynamic and aeroacoustic components can be used to address a specific industrial challenge: namely, a physics-based prediction of the noise generated by a full scale wind turbine.

iii) SOLAR ENERGY

Low-cost alternative to the conventionally deposited devices include new promising materials and thin film deposition techniques for printable solar cell applications such as light-emitting diodes, thin film transistors, capacitors, coils, and resistors. Fabrication simplicity and the feasibility of using large-area flexible substrates and printable solar cell (PSC) is a prospective candidate in many application fields. Furthermore, light-absorbing layer of PSC is usually several orders of magnitude thinner than widely used conventional Si solar cells; thus production of PCS requires much less material, and in the case of printing deposition there is very little waste of material in comparison to other deposition methods. The possibility of using flexible large scale substrates opens the door to multiple advanced application opportunities such as smart textiles, photovoltaic window shades and options for building integrated solar techniques.

Professor Sivoththaman's (Electrical and Computer Engineering) project is focused on graphene-decorated nanocomposites for printable electrodes in thin wafer devices for future solar cells. The synthesis of nanocomposites by incorporating graphene nanopowders as well as silver nanowires into epoxy-based electrically conductive adhesives (ECA) is examined to improve electrical conductivity and to develop alternate printable electrode materials that induce less stress on the wafer. The observed parameters of low curing temperature, good thermal resistance, reasonably high conductivity, and low residual stress in the ECA/graphene nanocomposite makes this material a promising alternative in screen-printed electrode formation in thin substrates.

IRENE GOLDTHORPE
Professor, Electrical and Computer Engineering

Professor Goldthorpe (Electrical and Computer Engineering) has completed work on Al-doped ZnO/Ag-nanowire composite electrodes for flexible three-dimensional nanowire solar cells. The power conversion efficiency (PCE) of the three-dimensional solar cells improved by up to 60 per cent compared to using

AZO electrodes alone due to enhanced coverage of the top electrode over the 3-D structures, decreasing the series resistance of the device by five times. The composite layer also showed a 10 times reduction in sheet resistance compared to the AZO thin-film contact under applied mechanical strain.

MAURICE DUSSEAULT
Professor,
Earth and Environmental Science

iv) ENERGY STORAGE

Development of high performance, cost effective energy storage technologies is critical to future development and interpretation of low-carbon sources of energy such as wind and solar into the power grids. Practical energy storage solutions comprise a range of technologies: electrochemical (batteries and capacitors), compressed air, pumped hydro and indirect options such as power-to-gas and hydrogen.

ROYDON FRASER
Professor, Mechanical
and Mechatronics Engineering

Compressed Air Energy Storage (CAES) in Salt Caverns: First Commercial Project in Canada

Compressed Air Energy Storage (CAES) in Salt Caverns is a technically feasible technology for support to the electric grid. The CAES in Salt Caverns allows for several hours or even days of stored energy, which lets power producers to deliver electricity during peak hours when the demand for electricity, and price, is highest. By employing the CAES technology, energy can be used more broadly since electricity can be stored and dispatched as needed.

Professor Dusseault (Earth and Environmental Science), Professor Fraser (Mechanical and Mechatronics Engineering), and Professor Cascante (Civil and Environmental Engineering) has collaborated with NRStor and Hydrostor to initiate Canada's first CAES in Salt Caverns project in the city of Goderich, Ontario. This $7.2 million CAES facility has a planned installed capacity of 1.75 MW (7MWh) and will be operating under a contract with the Independent Electricity System Operator (IESO). In addition, NRStor Goderich intends to provide energy and operating reserve services to the IESO markets. This project is expected to be the world's first commercial fuel-free CAES facility when completed.

GIOVANNI CASCANTE
Professor,
Civil and Environmental Engineering

Electrochemical Storage

Currently, lithium-ion batteries are extensively employed in portable electronic devices with their expanded applications has expanded to the electric vehicle market. Battery technologies beyond Li-ion batteries, such as lithium-sulfur (Li-S), sodium-ion (Na-ion), and magnesium (Mg) batteries, have gained much attention from the research communities and industry as they offer advantages for sustainability, cost-effectiveness and high capacity performance. Recent focus on dual carbon battery comprises a dual carbon complex made from organic, carbon-based cotton restructured so fibres act as anodes and cathodes inside an organic electrolyte-conducting liquid. The Dual Carbon battery is so named for the fact that both the anode and cathode are made of carbon and provide a modern electric vehicle with a range of almost 500 kilometers (300 miles). Despite its impressive energy density, it can also charge up to 20 times faster than modern lithium-ion batteries.

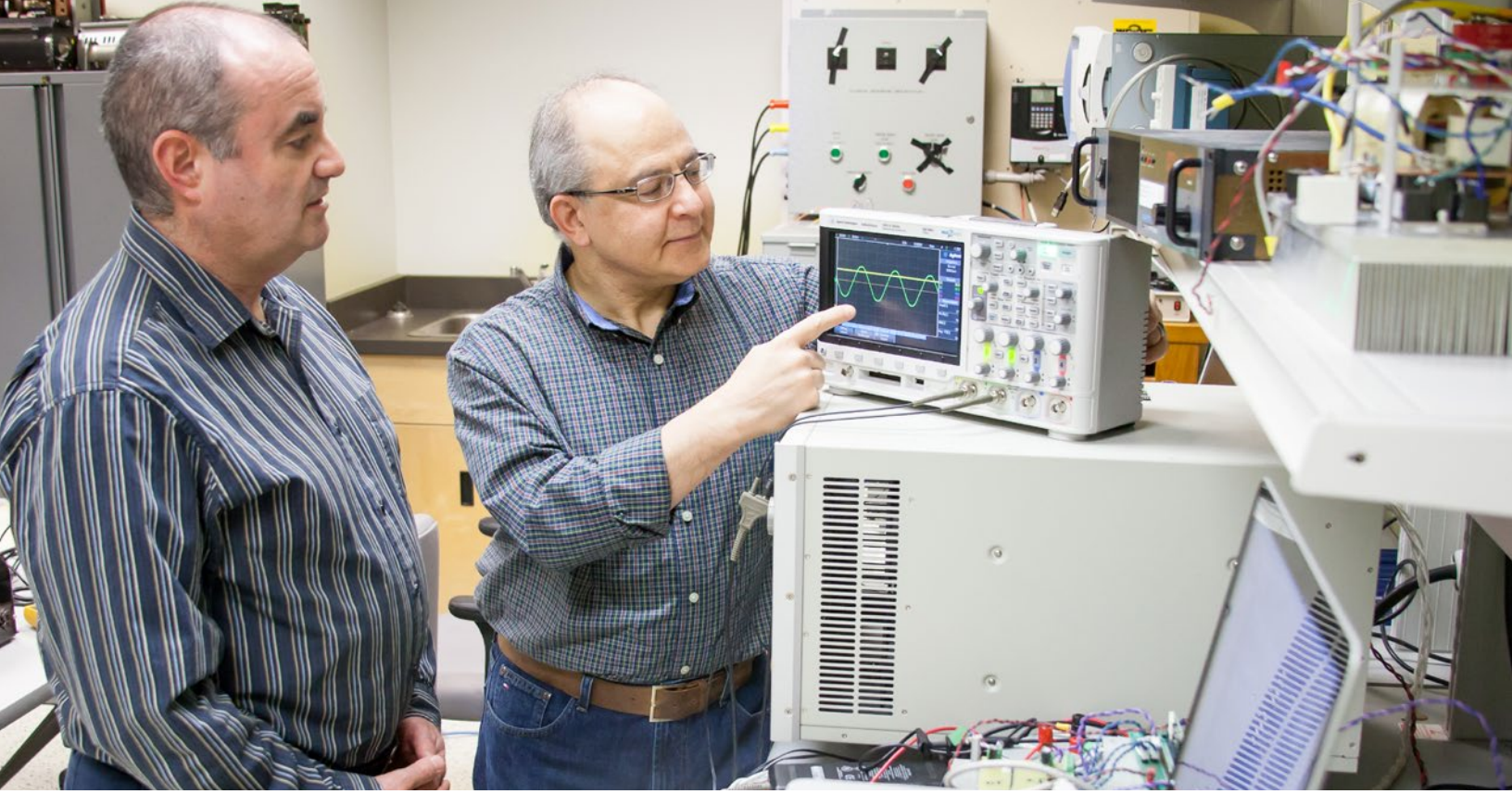
Professor Nazar's (Chemistry) team has made advances on the significant characterization techniques commonly employed for battery evaluation. The recent work is a study of methods and protocols for electrochemical energy storage materials. This project involves a comprehensive analysis of electrode preparation, coin cell assembly, electrochemical evaluation techniques, operando X-ray diffraction, operando pair distribution function analysis, operando X-ray absorption spectroscopy, and X-ray photoelectron spectroscopy techniques. Professor Nazar was named an Officer for the Order of Canada in recognition of her excellence in research. She holds the Canada Research Chair in Solid State Energy Materials, and is a Fellow of the Royal Society of Canada.

v) SUSTAINABLE MOBILITY

In April 2018, Waterloo became the first Canadian university to install a smart charging infrastructure for electric vehicles (EVs). Unlike regular chargers, these units optimize charging patterns based on demand levels and time-of-use electricity costs. The infrastructure provides a strong base for research studies and access to detailed data to shed light on critical issues of grid management and next generation EV design.

Time required for charging is the key differentiator. This is important for consumers. Typically, a level II charger (max 7.2 KW capacity) can be used for overnight charging at home. The level III charger can deliver up to 50 kW for full charge between 20 minutes to an hour. The units come with PowerLimiting option, making it possible to remotely control how much power they deliver. At UWaterloo, researchers will also have access to 20 kW Tesla Wall Connector that can be enabled as a smart charger with additional metering.

This project complements our existing Drive4Date (D4D) program launched in 2012. The capability to collect a large amount of data through telematic devices provides a significant boost to UWaterloo researchers. The D4D program involves 10 EVs and the data collected reflect "real-life" usage: length of trip, drive cycles and status of battery charge under hot and cold conditions. The installation of the smart chargers enhances our capacity to allow a larger number of vehicles to be included in the D4D program. Data mining and analytics will support the next generation of modelling tools and algorithms.



Professor Cañizares and Kazerani (Electrical and Computer Engineering)

vi) VEHICLE TO GRID (V2G)

The term “vehicle-to-grid” describes the use of car batteries as a source of power that can be used for grid services, such as frequency regulation when the car is not in the drive mode. The idea has significant appeal because the battery capacity of electric vehicles is not in use for 95 per cent of the time. The goal is to “develop driver-centered business models” to support a rapid roll out of vehicle-to-grid (V2G) technologies, allowing millions of electric car batteries to become a vital part of the power grid.

Professor Kazerani and Cañizares (Electrical and Computer Engineering) completed a project on modeling and testing of a bidirectional smart charger for distribution system EV integration. A practical case study demonstrates and tests the proposed smart charger and model, investigating the provision of V2G for active and reactive power in a low voltage (LV) residential distribution network. The results confirm the advantages of the charger model for developing V2G strategies in distribution networks. This project developed a prototype and an average model of a single-phase, two-stage, level one bidirectional smart charger comprising of a full bridge ac/dc converter and a bidirectional buck-boost converter. The ac/dc converter used a dq frame controller with an additional loop to control reactive power, and the dc/dc converter employed a PI controller with an additional loop to control active power, thus giving the charger the capability of independent P and Q control.

The model has been validated using measurements from an actual smart charger prototype, verifying its steady-state response in all four quadrants of the P-Q plane, as well as the step response when P and Q references are changed. The model represents with fidelity the steady-state response and cycle-to-cycle dynamics of the chargers when interacting with a distribution system and provides a sound basis for the design of smart charging strategies and detailed real-time analysis of impacts on distribution feeders.

2 DIGITAL TECHNOLOGIES: INNOVATIONS FOR ENERGY SUSTAINABILITY

i) BLOCKCHAIN TECHNOLOGY: UNLOCKING AN ENERGY REVOLUTION

Blockchain applications have the potential to create substantial new value in the energy sector. The blockchain ledger is currently used to reduce transaction costs, pinpoint origins of energy, increase the efficiency of exchanges, and maintain more proficient records. This technology also gives consumers the opportunity of distinguishing where energy is coming from – renewables or traditional fossil fuel based power generating plants. In the past, electric grids used to measure electricity as net amounts and don't allow consumers to pick and choose. Now, the consumers are empowered to choose their preferred energy generation option and switch providers. The technology overcomes a process that is currently full of technical and financial constraints.

Professor Keshav (Cheriton School of Computer Science) and colleagues have developed a prototype blockchain solution called Canopus with capability of handling more than one million transactions per second in support of the Renewable Energy Certificates (REC) trading. The goal is to reduce the cost of certification, eliminate onerous auditing and avoid non-market price controls, so that even a small-scale green generator could de-risk investments. Today's blockchains cannot support the addition of more than a few hundred certificates or trades (we can call them both "transactions") per second. This is because blockchain servers require agreement on the contents of each block with endemic server and communication failures and the presence of malicious servers. This is known as the difficult "consensus problem."

Currently, BitCoin, the best-known blockchain, supports only about 10 transactions per second and HyperLedger, IBM's competing solution, under 1,000 transactions per second. Professor Keshav's Canopus prototype takes a server's location on the internet cloud into account, minimizing communication between geographically-distant servers.

By keeping most communications local and fast, blockchain servers can process far more transaction records each second than a traditional consensus protocol that doesn't take location into account. This improvement in scaling allows even mom-and-pop green generators to obtain certificates and participate in energy transactions. In long term, this work will encourage homeowners and small businesses to invest in renewable energy technologies to become green generators. It would also encourage Ontario's electricity consumers to become 100 per cent green.

ii) ARCHITECTURE OF 5G NETWORKS IN THE POWER SECTOR

5G Technology is the fifth Generation Mobile technology. From generation 1G to 2.5G and from 3G to 5G, telecommunication technologies have seen vast improvements with improved performance. 5G technology has the potential to unleash the next wave of smart grid or "intelligent" features to improve efficiency and cost performance. By allowing many unconnected, energy consuming devices to be integrated into the grid through low-cost connections, 5G enables these devices to be more accurately monitored to support better forecasting of energy needs. By connecting these devices using a smart grid, demand side management can be enhanced to support load balancing, helping reduce electricity peaks and ultimately reduce energy costs. Capturing this data through 5G connections will further enable large cities with high density urban growth to plan for energy infrastructure spending more efficiently and reduce downtime.

The business potential of introducing 5G in the energy domain is exceptionally high; it provides support not only to the critical machine type communication (MTC) applications of energy grid protection and control, but also to the massive volume of MTC type applications of the emerging smart metering. The ongoing evolution of the power grid into a grid supporting a much more distributed generation and storage of power as well as micro-grids would be a clear beneficiary of the high performance with a very flexible communication architecture provided by 5G.

CATHERINE ROSENBERG
Professor, Electrical and Computer Engineering

Professor Rosenberg (Electrical and Computer Engineering), Cisco Research Chair in 5G Systems, is leading a multidisciplinary team of experts to help the industry leaders to prepare for the introduction of 5G. She will be working on a family of 5G technologies related to new frequency bands, which will enable faster data transfer and reduced delays for greatly improved wireless service.

Over the last three decades, Professor Rosenberg's research has focused on understanding the structural properties and performance of networks, with a particular emphasis on: (1) modeling and analysis, and (2) system-level issues. In 2010, she expanded her research program to address the convergence of energy systems and the Internet with the same foci on modeling, analysis and system level issues and a new thread on data analysis. Her latest award winning project was on a multi-timescale electricity theft detection and localization in distribution systems based on state estimation and PMU (phasor measurement unit) measurements.

iii) SMART GRIDS

The electric grid is a complex web of interconnected physical systems that comprise the generation, transmission, and distribution infrastructure. It is an ecosystem of asset owners, manufacturers, service providers, consumers, prosumers and diverse stakeholders. The aging electric infrastructure is being pushed to do more than it was originally designed to do. To modernize the grid is to make it "smarter" and more resilient through the use of cutting-edge technologies, equipment, and controls that communicate and work together to deliver electricity more reliably and efficiently.

Smart grids are a key enabler for consumers and businesses to better manage their own energy consumption and costs through easier access to data. Utilities also benefit from a modernized grid, including improved security, reduced peak loads, increased integration of renewables, and lower operational costs. "Smart grid" technologies are made possible by two-way communication technologies, control systems, and computer processing. These advanced technologies include: advanced sensors known as Phasor Measurement Units (PMUs) that allow operators to assess grid stability, advanced digital meters that give consumers better information, automated feeder switches that re-route power around problems, and batteries that store excess energy to help the grid operator meet fluctuating customer demand.

Professor Salama's (Electrical and Computer Engineering) novel incentive-based distribution system expansion planning (IDSEP) model enables an LDC and distributed generation (DG) investors to work in a collaborative way for mutual benefit. Using the proposed model, the LDC would establish a bus-wise incentive program (BWIP) based on long-term contracts, which encourage DG investors to integrate their projects at specific system buses to benefit both parties. The model guarantees that the LDC will incur minimum expansion and operation costs while concurrently ensuring the feasibility of DG investors' projects. To derive appropriate incentives for each project, the model enforces several economic metrics. All investment plans committed to by the LDC and the DG investors for the full extent of the planning period are then coordinated accordingly. The intermittent nature of both system demand and wind- and PV-based DG output power is handled probabilistically, and a number of DG technologies are taken into account.

Professor Cañizares and Bhattacharya (Electrical and Computer Engineering) work on the development of a freeware Smart Residential Load Simulator facilitates the study of residential energy management systems in smart grids. The tool is based on Matlab-Simulink-GUIDE toolboxes and provides a complete set of user-friendly graphical interfaces to model and study smart thermostats, air conditioners, furnaces, household appliances, and appliance specific models are validated with actual measurements. Wind and solar power generation as well as battery sources are also modeled allowing impact of different variables such as ambient temperature and household activity levels to be quantified for optimal use of energy. The simulator allows modeling of the way appliances consume power to enhance our understanding of how these contribute to peak demand, providing individual and total energy consumption and costs. In addition, the value and impact of generated power by residential sources can be determined for a 24 h horizon. This freeware platform is a useful tool for researchers and educators to validate and demonstrate models for energy management and optimization, and can also be used by residential customers to model and understand energy consumption profiles in households.

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

In September 2015, WISE launched the Affordable Energy for Humanity (AE4H) initiative in partnership with the Karlsruhe Institute of Technology (KIT) and a global consortium of leading experts in the fields of sustainable energy and international development. The goal of this 'Global Change Initiative' is to accelerate large-scale deployment of effective solutions at the global level, with a strong focus on science and technology innovation, social science research and rapid transfer of knowledge and expertise to the field. The initiative advances Sustainable Development Goal 7: ensuring access to affordable, reliable, sustainable and modern energy for all by 2030.

AE4H puts WISE at the center of a global movement that aims to leverage the potential of cutting edge sustainable energy technologies to improve the quality of life of the third if humanity that lives without reliable access to electricity.

i) AE4H INNOVATION LAB

In June 2017 AE4H hosted a 2.5-day workshop at the Institute for Advanced Sustainability Studies (IASS) in Potsdam Germany. The event brought together leading thinkers and innovators from the AE4H consortium to advance new research areas to sustain emerging needs of the energy access sector.

The 'innovation lab' – a non-traditional format to help participants focus on what they want to do new and how they might work together, rather than on sharing past results – was attended by an invited group of 53 experts from 31 institutions and 16 different countries, including academic researchers, entrepreneurs, energy policy-makers and civil society leaders.

The AE4H Innovation Lab featured working sessions on a diverse set of themes including:

- Scaling micro-grid development
- Capacity-building at the last mile
- Supporting energy access entrepreneurs
- Establishing effective research to impact labs
- Working with local partners: private vs. public
- Inclusive business models for the 'Bottom-of-Pyramid' (BOP)
- Data, IoT and smart infrastructure deployment
- Global talent pool development and training
- End-uses and users of electricity

New collaborations and activities emerging from the event include:

- The establishment of a core scientific advisory group for AE4H that will shape the development of future 'Innovation Labs.' The core scientific group comprises leading experts from University of Waterloo, KIT, the University of Oxford, UC Berkeley, MIT and Arizona State University.
- A special issue of IEEE Proceedings entitled 'Electricity for All: Solutions for Energy Disadvantaged Communities', with guest editors Professor Jatin Nathwani (WISE), Professor Claudio Cañizares (WISE) and Professor Dan Kammen (UC Berkeley).
- A follow-up innovation lab to be held at the 'International Conference on Solar Technologies and Hybrid Mini-grids to Improve Energy Access' in Palma de Mallorca, Spain. The event a partnership between WISE, The Siemens Foundation, Trama TecnoAmbiental (a Spanish off-grid technology consultancy) GIZ (the German International Development Agency), SNV (the Dutch International Development Agency), EnDev (an energy access initiative financed by six donor countries: the Netherlands, Germany, Norway, United Kingdom, Switzerland and Sweden), and REPIC (An interdepartmental platform of the Swiss government for renewable energy promotion). The event will cover a range of topics from policy to finance, advanced technologies, and capacity-building related to energy access initiatives all over the world. Professor Nathwani and AE4H Manager Nigel Moore are members of the scientific and organizing committees, respectively.
- A WISE report that outlines practical steps for planning, organizing and executing 'innovation labs', which is now available through the University of Waterloo's Office of Research, and distributed to researchers engaged in international partnership building and workshop organization activities.

ii) QUEEN ELIZABETH SCHOLARS FOR ENERGY ACCESS

In partnership with Waterloo Co-op, the School of Environment, Enterprise and Development, and St. Paul's Greenhouse Social Impact Incubator, AE4H has been awarded $300,000 from the Queen Elizabeth II Diamond Jubilee Scholarship Program to prepare UWaterloo students for leadership in the emerging off-grid renewable energy sector, with a focus on the developing world. Between 2018 and 2021, approximately 40 UW students will undertake international internships at sustainable energy social enterprises with in the AE4H network.

Participation of the AE4H global network of partners and St. Paul's Greenhouse allows opportunities for students to engage with global knowledge networks and develop their own social ventures related to energy access. On campus programming will include social innovation competitions, design jams, guest speaker events, and other activities related to this critical and growing development sector that crosses disciplinary boundaries.

Beginning May 2018, the first cohort of student interns will be deployed to the following social enterprises:

- Steama.co (Manchester, UK): a start-up that provides remote operation and control software for the mini-grid sector in East Africa
- Burro (Koforidua, Ghana): a social enterprise that develops sustainable technologies for rural Ghanaians.
- HITCH (Lagos, Nigeria): A UWaterloo-based start-up that has launched an off-grid internet hardware product for Nigerian schools that face frequent blackouts

iii) COLLABORATION WITH ARIZONA STATE UNIVERSITY ON THE 'SOCIAL VALUE OF ENERGY'

AE4H is collaborating with ASU's Grassroots Energy Innovation Lab, led by Professor Clark Miller, to develop a framework for understanding the broader social impacts of energy access initiatives. The goal of this work is to contribute to ongoing policy developments at national, international and sub-national levels which aim to use energy access as a lever advance economic and social development.

AE4H manager Nigel Moore, alongside Professor Miller and his students, jointly published a working paper on the topic: 'Poverty Eradication through Energy Innovation: A Multi-Layer Framework for Social Value Creation', which was published jointly by both institutions. This working paper has also been submitted to UN in support of the 2019 Global Development Progress Report.

AE4H collaborated with ASU to host a session at an ASU workshop on energy access, held in February 2018. Participation at this workshop has resulted in a number of follow-up activities including a field research project that utilizes the social value of energy framework. This project will be carried out jointly by ASU's Grassroots Energy Innovation Lab and AE4H members from KIT and University of Waterloo.

iv) MENTORING UWATERLOO STUDENT TEAMS FOR THE HULT PRIZE SOCIAL INNOVATION COMPETITION

The Hult Prize is the world's largest student Social Enterprise competition. Teams from all over the world compete annually for a $1 Million grand prize to put their social enterprise idea into action. In 2017, the Hult Prize theme is 'Harnessing the Power of Energy to Transform the Lives of 10 Million People'.

AE4H has actively mentored Hult Prize teams from the University of Waterloo, a number of which are pursuing other social innovation competitions both on campus and off.

AE4H Manager Nigel Moore and Uche Onuora, the Founder of partner enterprise HITCH, spoke at the University of Waterloo Hult Prize Launch event.

HULT PRIZE
UNIVERSITY OF WATERLOO

AE4H also helped to organize a speed mentoring event for UWaterloo Hult Prize teams. AE4H members Srinivasan Keshav (Waterloo), Malcolm McCulloch (Oxford), Uche Onuora (HITCH), Michael Sinclair (Ecobee) and Nigel Moore (WISE) served as mentors at the event.

v) INCUBATING OFF-GRID INTERNET START-UP 'HITCH'

HITCH is a Smart Wireless Mesh Router and Predictive Content Caching Software Platform that pre-downloads relevant online content once, so many users can access the same information quickly without an Internet connection. Globally, over 4 billion people don't have sustainable (available, affordable and accessible) broadband. Most of these users live in rural and urban emerging markets. HITCH enables communities to automatically build, operate, and sustain self-contained Internet platforms; accelerating sustainable broadband in emerging markets.

HITCH

HITCH was founded by ICT expert Uche Onuora. After completing his Master of Business, Entrepreneurship and Technology at University of Waterloo's Conrad Centre, Uche joined Velocity to continue to develop HITCH technology and prepare it for deployment in his native Nigeria. One of the key challenges facing HITCH is lack of consistent access to electricity to run its devices. AE4H has provided support to HITCH in developing a solar and battery system to run its devices and to refine their prototype technology. Initial field tests in Nigeria in 2017-2018 have seen HITCH working closely with 10 schools for a three-month trial period to intelligently deliver affordable educational video content straight to classrooms.

vi) EARN WHILE YOU COOK

AE4H is collaborating with Dr. Sankaran Ramalingam, President of the Energy and Fuel Users Association of India, to refine a concept for economic development in rural India driven by application of 'Top-Lit/Up-Draft' (TLUD) cookstoves. This technology is cleaner and more efficient than traditional stoves, and produces a valuable by-product (charcoal) that can be sold by users for income generation. This sustainable use of bioenergy shows promise in creating real economic value for fuel users at the bottom of the economic pyramid and in particular to help empower women to become entrepreneurs through using the stoves for cooking and charcoal production.

AE4H is developing a working paper to advance and refine the 'earn while you cook' concept while Dr. Ramalingam visits WISE as a visiting scholar in 2018.

WISE EVENTS

CIRCULAR ECONOMY INTERNATIONAL WORKSHOP

› "Green Growth, Sustainable Communities and the Circular Economy" with Dalian University (China) held at the University of Waterloo | **29-30 May 2017**

The goal of the workshop was to explore strategies for green growth through providing a platform for researchers from the four institutes to share case studies that illustrate widely applicable strategies for furthering economic and environmental stewardship aims simultaneously.

Keynote Speaker: Richard Blundell, University of Toronto

This workshop was the second of a series and part of an international collaboration between Dalian University in China, The University of Waterloo in Canada, Imperial College London in the UK and the International Academy of Ecology and Life Protection Science in Russia. The event featured presentations and panel discussion and break-out sessions on the topics of: business strategies for green growth; cities, infrastructure and planning for sustainability; and the circular economy.

RESOURCE RECOVERY PARTNERSHIP WORKSHOP 2017

› University of Waterloo | **6 June 2017**

The purpose is to advance our understanding of the role of circular economy and carbon reduction initiatives to identify opportunities to build fiscal capital through re-designing of ecosystem services infrastructure while respecting environmental limits. The workshop brings together an executive forum designed to encourage the exchange of ideas that will help create a roadmap to guide the future of waste management and resource recovery (including energy demand reduction) research in Canada.

Keynote Speaker: John Coyne, Vice-President and General Counsel, Unilever Canada

Panel discussions, student poster presentations and an innovation showcase were the highlights of the day-long workshop. Discussion themes were: Circular economy and sustainable materials management; carbon capture, reduction and preservation; and moving forward – how to advance the resource recovery agenda towards acceptance.

AE4H INNOVATION LAB

› "Accelerating Energy Access Solutions" held at the Institute for Advanced Sustainability Studies in Germany | **15-17 June 2017**

This 2.5 day workshop, held at the Institute for Advanced Sustainability Studies in Potsdam, Germany, brought together a collection of leading thinkers and innovators from the AE4H consortium to share ideas, synthesize key areas of inquiry and scope future collaboration.

Keynote Speaker(s): Dan Kammen, Founding Director of the Renewable and Appropriate Energy Laboratory, University of California, Berkeley, and Thomas Gottschalk, CEO of Mobisol Group, Berlin, Germany.

The 2018 workshop is tentatively scheduled to be held in Oxford, England hosted by Dr. Malcolm McCulloch, Co-Director of the Oxford Martin Programme on Integrating Renewable Energy, University of Oxford.

GEOTHERMAL SYMPOSIUM

› University of Waterloo | **26 September 2017**

The purpose of the event was to advance our understanding of the role of geothermal technologies in providing decarbonized energy to Canadian communities, particularly those in remote and cooler climates. The Symposium brought together technology developers and innovators, leading researchers and entrepreneurs, industry thought leaders, and policy

Workshop held jointly with the University of Strathclyde, Scotland at the University of Waterloo

makers to help shape a vision of geothermal energy integration into Canada's energy future.

Keynote Speaker: Murat Basarir, Manager, Business Development, CoPower

Welcoming Remarks delivered by Charmaine Dean, Vice President Research, and Professor, Statistics and Actuarial Science, University of Waterloo

WISE hosted the first of its kind Geothermal Symposium and featured distinguished speakers and experts in geothermal energy from across the globe. Participants also included innovators from academia, industry, funding and international agencies with student poster presentations.

WORKSHOP HELD JOINTLY WITH THE UNIVERSITY OF STRATHCLYDE, SCOTLAND

› University of Waterloo | **23-24 October 2017**

This two day workshop was organized to explore various options of collaboration between University of Waterloo and University of Strathclyde to advance the low carbon energy initiatives.

University of Waterloo Participants: Bissan Ghaddar (Assistant Professor, Management Sciences), Claudio Cañizares (Professor and Hydro One Chair, Electrical and Computer Engineering), Olaf Weber (Professor, School of Environment, Enterprise and Development), Roydon Fraser (Professor, Mechanical and Mechatronics Engineering), Eric Croiset (Professor and Chair, Chemical Engineering), Mahesh Pandey (Professor and UNENE Chair, Civil and Environmental Engineering).

University of Strathclyde Participants: John Quigley (Dept Head, Management Sciences), David Comerford (Research Associate in Economics and Environmental Modelling, Fraser of Allander Institute, Grant Allan (Senior Lecturer, Economics, and Deputy Director, Fraser of Allander Institute, Kerem Akartunali (Associate Professor, Management Science), Stuart McIntyre (Lecturer, Economics, and course co-Director of the MSc in Global Energy Management), Alex Dickson (Senior Lecturer, Economics), and Matthew Revie (Principal Knowledge Exchange Fellow, Management Sciences).

Major research themes (Day 1): Renewable Energy Grid System Integration, Electrical Vehicle Charging, Environmental Planning, Data Mining/Analytics, and Environmental Sustainability

Major research themes (Day 2): Reliability, Availability and Maintainability (RAM), Non-Destructive Testing (NDT), and Carbon Capture Storage (CCS) and Sequestration

ANNUAL TECHNOLOGY INNOVATION AND POLICY FORUM

› University of Waterloo | **9 November 2017**

In partnership with the Council for Clean & Reliable Energy.

Our goal was to shape the pathways of development for emerging disruptive technologies and to understand the impacts of microgrids embedded on a large scale within the existing distribution networks.

Keynote Speaker: Pamela D. Jones, Director of Transmission and Distribution Policy Canadian Electricity Association

Annual Technology Innovation and Policy Forum at the University of Waterloo

The forum addressed an urgent need to accelerate impactful integration of cost effective solutions to decarbonize our energy system and brought together technology developers and innovators, leading researchers and entrepreneurs, industry thought leaders, and policy makers to help shape next generation smart energy solutions.

The forum focused on establishing a common basis for accommodating divergent interests. Special features of the day's events included poster presentations by students, an innovation showcase, a tour of the solar lab – Center for Advanced Photovoltaic Devices and Systems – as well as an electric vehicle showcase held outdoors

WISE ENERGY DAY 2018

› University of Waterloo | **27 March 2018**

To share emerging knowledge from cutting-edge research to advance our understanding of the role of clean technologies for a low carbon energy future for Canada. The event brings together technology developers and innovators, leading researchers and entrepreneurs, industry thought leaders, and policy makers to help shape a vision of a decarbonized economy.

Keynote Speaker: Linda Nazar, Professor, Chemistry; Canada Research Chair in Solid State Materials, University of Waterloo

The forum identified key technical issues that must be addressed. We hope to focus on establishing a common technical and social vision that can accommodate both community and industrial interests.

NATIONAL AND INTERNATIONAL OUTREACH ACTIVITIES BY WISE EXECUTIVE DIRECTOR

› **Frontier Science Roundtable** held at Perimeter Institute (Waterloo, Canada) | Sep 25, 2017

› **Distinguished Lecture: 'Driving a Revolution: Affordable Energy for Humanity'** held at Technology Center for Sustainable Development, Monterrey Institute of Technology and Higher Education (Mexico) | Oct 6, 2017

› **Frontier Science Roundtable** held at Perimeter Institute (Waterloo, Canada) | Sep 25, 2017

› **Sanya International Energy Forum** held in Sanya (China) | Dec 6-8, 2017

› **Arizona State University (ASU) Conference** held in Phoenix, Arizona (U.S.A) | Feb 12-16, 2018

› **Energy and Fuel Users Association of India (ENFUSE) Visit** held in Chennai (India) | Feb 19-28, 2018

› **Anna University** (Chennai, Tamil Nadu)

› **Chennai Petroleum Corporation Limited** (Chennai, Tamil Nadu)

› **IIT Madras** (Chennai, Tamil Nadu)

› **Vellore Institute of Technology** (Vellore, Tamil Nadu)

WISE PARTICIPATION

JOHN STRAUBE

Associate Professor, Civil and Environmental Engineering

John Straube was invited as a presenter to the Learning About Building Science (LAB) event, titled: Not So Elementary: Towards Net-Zero Schools held at the RDH Building Science Laboratories on August 8, 2017. The focus was on, Can net-zero energy schools be achieved at a reasonable cost? Yes, with the right approach. Designing or retrofitting a school building is a complex process with many stakeholders and budgetary constraints. But as with any net-zero project, understanding the science behind low-energy buildings can help guide the design process and ensure that project requirements are met. This session will focus on balancing requirements for the building enclosure, HVAC, and renewable energy systems, as taking a whole-building perspective is critical.

IAN ROWLANDS

Professor and Associate Vice-President, International, School of Environment, Resources and Sustainability

Ian Rowlands participated at the event of the Ideation Night: Utilizing Alternative Energy for Better Living (in collaboration with UW Energy Network and GreenHouse) held at University of Waterloo on March 8, 2018. The focus was on greener future in transportation, food production, agriculture and social aspects with the power of renewable energy.

NEIL CRAIK

Associate Professor, School of Environment, Enterprise and Development (SEED)

Neil Craik explored the international legal and ethical dimensions of the important but controversial technology pathways with respect to carbon emission technologies and considers how Canada might approach the governance challenges connected to these technologies. The event *Saving the Planet: Overcoming Challenges of Emissions Monitoring and Climate Engineering* took place at the CIGI campus auditorium in Waterloo on March 21, 2018.

WISE members and their research team participated at the Ontario Centres of Excellence (OCE) Discovery 2018 event on April 30 and May 1 at the Metro Toronto Convention Centre to showcase their research.

ELENA ZAIKOVA

Postdoctoral Fellow, Biology

Elena Zaikova talked about her research on microbiome optimization. The current leading area of commercialization is the microbiome of hydroponic systems of controlled environment agriculture, such as greenhouses and vertical farms.

CRISTOBAL LARA

MASc, Civil and Environmental Engineering

Cristobal Lara showcased a new, non-destructive methodology for detecting early decay of distribution wood poles and concrete columns using ultrasonic waves.

FLORA NG

Professor, Chemical Engineering

Flora Ng talked about Cleantech and the innovative sustainable production of clean fuels and high value chemicals from renewables, wastes, and light hydrocarbon.

KHOSROW MODARRESSI

Technology Transfer Manager

SURAMYA MIHINDUKULASURIYA

Postdoctoral Fellow, Electrical and Computer Engineering

Khosrow and Suramya showed a new way of keeping food fresh and safe with a Pulsed Electric Field (PEF) Treatment Chamber for Liquid Food.


VELO
SCIEN
VORTEX GENIE 2

INFLUENCE

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

PUBLIC LECTURE SERIES

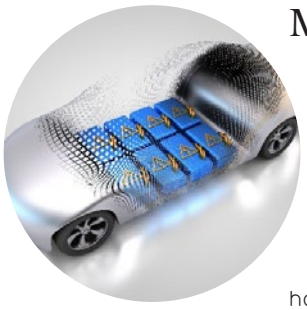
Our series of lectures brought leading energy experts to WISE, giving our members and our wider community insights into key issues.

MAY		
Dr. Matthew Peloso	CEO, Sun Electric Pte. Ltd., Singapore	Post-Net Metering for a Sustainable City
JUNE		
Dr. Paul Parker	Professor & Associate Dean, Strategic Initiatives, School of Environment, Enterprise and Development (SEED)	Sustainable Community Energy Planning
Dr. Robert Shorten	Professor & Chair, Control Engineering and Decisions Science, University College, Dublin	Smarter Cities: New Services, New Applications for Control
Dr. Hélène Debéda	Associate Professor, University of Bordeaux, IMS Laboratory, PRIMS Team	Printed MEMS: Sensors, Actuators or Energy Harvesters Processing with Standard or Modified Screen-Printing Technology
JULY		
Dr. Mohammad Reza Jalali	Lecturer & Researcher, Swiss Federal Institute of Technology (ETH)	Hydraulic Fracture Field Experiments for Geothermal Energy
Clinton Moss	President, Marksman Ranging Technologies, Scientific Drilling	Directional Drilling and Magnetic Ranging Services for Geothermal Energy Development
Benjamin Canning	Co-Founder & Co-Project Manager, Growing North	Self-Dependency in Remote Communities: Food, Energy, Future
AUGUST		
Dr. Mahdi Shahbakhti	Associate Professor, Mechanical Engineering, Engineering Mechanics, Michigan Tech	Physics-Based Control of Energy Systems Ranging from Smart Buildings and Power Grid to Smart Hybrid Electric Vehicles
SEPTEMBER		
Nirupa Balendran	Conservation Energy Manager, Newmarket-Tay Power Distribution Inc.	Navigating Ontario's Evolving Energy Landscape – A Utility's Experience
OCTOBER		
Marc Brouillette	Principal Consultant, Strategic Policy Economics	Ontario's Emissions and Long-Term Energy Planning
Martin Vroegh	Senior Director, Greenhouse Gas Reduction Technologies, Ontario Centres of Excellence	Greenhouse Gas Reduction Technologies in Energy Intensive Sectors of Ontario
NOVEMBER		
Erik Veneman	Vice President, Innovation and Growth, Guelph Hydro Electric Systems Inc.	Changing Perspectives in Ontario's Electricity Industry
JANUARY		
Dr. Adonis Yatchew	Professor, Economics, University of Toronto	Energy: Ten Big Ideas on Energy (What Everyone Needs to Know)
FEBRUARY		
Mehmet Ferdiner	Manager, Energy Modelling Services, Building Knowledge Canada	The Future of Net Zero Homes in Canada
Chandra Ramadurai	CEO, Efficiency Capital	Reducing Carbon Emissions Through Energy Efficiency: A Canadian Perspective
APRIL		
Alex Berruti	Senior Product Engineer, Enhanced Oil Recovery, Innovative Steam Technologies (IST)	Once Through Steam Generators (OTSG) in Power Generation and Energy in Canada

Note: 9 Industry, 6 Academic, and 1 Governmental (WISE Public Lecture Series)

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.



Maintenance Planning to Extend the Life of Modern Battery Packs

Researchers: MICHAEL FOWLER, MANOJ MATHEW, Q.H. KONG,JAKE MCGRORY (MAY 2017)

Even rechargeable batteries eventually die. Month after month of using a battery, topping it up and repeating the cycle gradually reduces its ability to hold a charge and the amount power it can supply. That's why electric vehicle (EV) manufacturers suggest replacing the battery pack when its storage capacity drops below 80 per cent of maximum, and have eight year warranties.

WISE researchers envisioned a different approach. A battery is only as strong as its weakest cells, proposed by researchers in Chemical Engineering. That means if a single cell fails or degrades below the 80 per cent threshold it impacts the battery pack as a whole. But rather than throwing away the entire pack, why not replace just the low-performing cells?

Dr. Fowler and his team set about testing the feasibility of this idea. First, they collected data on how cells degrade over time, subjecting two different types of lithium ion batteries to a variety of accelerated test conditions. Next, they developed a computer simulation of a reconfigurable battery pack and fed in the experimental data.

Power-to-gas Systems: The Economics of Green Energy Storage

Researchers: MICHAEL FOWLER AND ALI ELKAMEL, U. MUKHERJEE, S. WALKER, A. MAROUFMASHAT, A. ALSUBAIE, D. VAN LANEN (JUNE 2017)

Power-to-gas systems may offer the energy storage solution the green energy sector has been searching for, allowing grid managers to match supply and demand. The process uses surplus electricity produced by wind and solar power to split water into oxygen and hydrogen.

That hydrogen then can be injected into existing natural gas distribution lines — providing customers with cleaner, hydrogen-enriched natural gas — or converted back to electricity when the grid needs it hours, weeks or months. The hydrogen can also be used to supply refuelling stations for fuel cell vehicles.

Chemical engineering professor Michael Fowler and his research group have been conducting studies into the potential application pathway for Power-to-gas in Ontario.

The Weather Wild Card: Assessing Time-of-Use Electricity Pricing

Researchers: LUCKASZ GOLAB, CATHERINE ROSENBERG AND R. MILLER (JUL 2017)

The theory behind time-of-use electricity pricing is simple. Charge more for electricity when demand is highest and consumers will either reduce the amount they use or shift their consumption to a lower-cost time of day. However, quantifying that impact isn't so simple.

Yes, you can compare electricity consumption before and after time-of-use pricing is introduced. However, weather changes from year to year, affecting how much people use fans, air conditioners, furnaces and space heaters. To date, researchers haven't agreed on the best way to account for those confounding variables.

Lukasz Golab and his colleagues at the University of Waterloo aimed to address that question by creating a methodology for modelling how weather affects residential electricity demand.

Putting The Pressure on Solar Road Panels

Researchers: SUSAN TIGHE AND A. NORTHMORE (AUGUST 2017)

Energy-generating highways are far from science fiction. Waterloo's Centre for Pavement and Transportation Technology (CPATT) and other groups have already developed prototypes of modular road panels that can produce electricity thanks to embedded solar cells.

But can panels made of sensitive photovoltaic material and tempered glass withstand the impact of 18-wheelers or Toronto's rush hour traffic?

Modelling software confirmed in all testing cases that the transparent and base layers of the panels fell well below their endurance limits, demonstrating that the prototype is road-worthy, and more.

Building the Case for Flexible Carbon Capture

Researchers: ALI ELKAMEL, COLIN ALIE, PETER L. DOUGLAS, ERIC CROISET (SEPTEMBER 2017)

Carbon capture and storage (CCS) is an important tool for reducing greenhouse gas emissions from coal-fired generating stations. CO_2-scrubbing systems, for example, use solvents to pull carbon dioxide from the flue gas before it's released into the atmosphere.

However, because it takes energy to regenerate the solvents used in the process, capturing carbon this way either reduces the power plant's generating capacity or its efficiency, or both.

That's why WISE faculty members Ali Elkamel, Peter Douglas, Eric Croiset and their colleague in Waterloo's Chemical Engineering department are fans of flexible CCS. This approach lets managers adjust the rate of CO_2 recovery based on factors like electricity demand and carbon pricing.

Converting Peat Into Power

Researchers: ALI ELKAMEL, WILLIAM ANDERSON AND M. ELSHOLKAMI, M. WARREN, C. HUANG, S. PETERS, Z. TU (OCTOBER 2017)

Each year, a noxious haze blankets much of Indonesia. It's the result of burning peatlands, the boggy land that covers more than ten per cent of the country. Farmers have traditionally used slash-and-burn techniques to prepare land for planting but the level of burning has increased dramatically as large areas are converted to industrial-scale palm oil plantations.

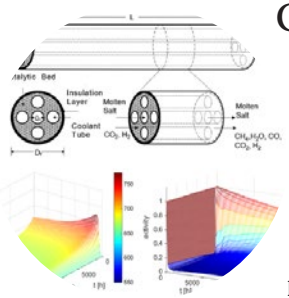
WISE researchers hate to see a valuable resource go up in smoke so they've proposed a better idea: gasification. Chemical engineers Ali Elkamel and Bill Anderson and their team have developed a conceptual design to convert peat into electricity and methanol, creating valuable commodities while cutting pollution.

Modelling Greener Microgrids

Researchers: KANKAR BHATTACHARYA, CLAUDIO CAÑIZARES AND B. SOLANKI (DECEMBER 2017)

More than half of Canada's 280 remote communities are cut off from centralized electricity grids, relying instead on high-polluting diesel generators. But as the need to reduce greenhouse gas emissions grows, more and more of these isolated communities are searching for greener microgrid options that add renewable energy to the mix.

Waterloo engineering professors Kankar Bhattacharya and Claudio Cañizares are helping guide that search.



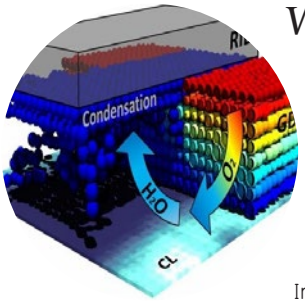
Catalyzing a lower-carbon world

Researchers: DAVID S. A. SIMAKOV, DUO SUN, FAISAL M. KHAN (DECEMBER 2017)

The more carbon dioxide (CO_2) we pump into the atmosphere, the hotter the planet will get. That's why researchers around the world are looking for ways to transform those emissions into useful resources. One promising approach is to convert them into methane fuel, using a hydrogenation process called the Sabatier reaction.

In theory, it's simple: just add hydrogen gas to CO_2 in the presence of a catalyst. However, there are technical challenges. Because the process generates a lot of heat, the reactor must be constantly cooled. It's also crucial to limit the creation of carbon deposits that can deactivate the catalyst.

WISE researcher David Simakov is addressing those issues. He and his chemical engineering team have developed a mathematical model of an actively cooled Sabatier reactor.



Watery insights could improve fuel cell performance

Researchers: JEFF GOSTICK AND MAHMOUDREZA AGHIGHI (JANUARY 2018)

ISE researcher Jeff Gostick can envision a day when clean, efficient fuel cells replace today's internal combustion engines. These eco-friendly energy generators run on hydrogen and air. They're quick to refuel. Best of all, they produce no greenhouse gases — only water.

In particular, Gostick is focusing his attention on polymer electrolyte membrane (PEM) fuel cells, where the hydrogen ions generated at the anode pass through a membrane to reach the cathode.

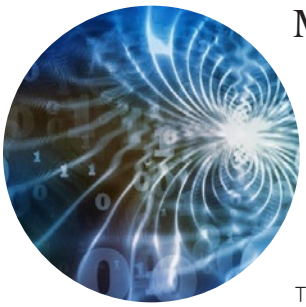
Foundational research into energy-efficient buildings

Researcher: POONEH MAGHOUL (MARCH 2018)

Canadians burn a lot of fuel to keep our buildings warm in winter. WISE researcher Pooneh Maghoul believes a key way to cut heating bills and reduce our carbon emissions lies beneath our feet.

The geotechnical engineer set out to better understand the heating, cooling, freezing and thawing that occurs in the soil surrounding building foundations. These are processes that depend not only on air temperature and heat loss from the building but also on the level of moisture in the soil.

Maghoul created a numerical model of coupled heat and mass transfer and validated it by comparing her results with experimental data published by other researchers. She then applied her model to a case study of soil around an insulated basement, creating a detailed picture of how soil temperature and ice distribution vary during the year.



Modelling Greener Microgrids

Researchers: OMAR M. RAMAHI, FARUK ERKMEN AND THAMER S. ALONEEF (APRIL 2018)

All around us, energy currently goes to waste. At any given moment, billions of Wi-Fi antennas and TV and radio stations are filling the atmosphere with electromagnetic waves. By harvesting these waves and converting them into electricity, we could tap into a vast source of "free" energy.

The question is how.

WISE member Omar Ramahi, a professor in Waterloo's Department of Electrical and Computer Engineering, is exploring the potential of frequency-selective surfaces (FSSs). Essentially, these are surfaces deliberately contoured to absorb and channel electromagnetic waves of a specific frequency, extracting as much usable energy as possible.

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AWARDS AND RECOGNITION

ORDER OF CANADA RECIPIENT

A longtime professor at Waterloo Engineering has added an appointment to the Order of Canada to his distinguished list of awards and accomplishments.

Keith Hipel, a systems design engineering professor who also earned three degrees at Waterloo as a student, was recently cited for one of the country's highest civilian honours by Governor General Julie Payette. During a career spanning decades, much of it dedicated to solving challenging problems related to conflict resolution in engineering, Hipel has taught thousands of students and supervised dozens of candidates for graduate degrees. He has a global reputation for pioneering contributions to environmental systems engineering and holds the title of University Professor, the highest academic honour at Waterloo. In addition to recognition by organizations including the Royal Society of Canada and the National Academy of Engineering, Hipel has won both the Distinguished Teacher Award and the Award of Excellence in Graduate Supervision at Waterloo.

For entry into the Order, which was created in 1967 and includes almost 7,000 members from all sectors of society, he was specifically cited for "his extensive contributions to the field of environmental engineering and for his leadership within multiple academic and professional institutions."

ROYAL SOCIETY OF CANADA FELLOWS

Weihua Zhuang of Waterloo's electrical and computer engineering department is a new fellow of the prestigious Royal Society of Canada's (RSC) Academy of Science.

Zhuang, the Tier I Canada Research Chair in wireless communication networks, has made significant research contributions to resource allocation, distributed network control, and mobile user positioning. Her achievements have led to impressive advances in engineering solutions, and generated high impacts in the research community.

WISE BY THE NUMBERS

OUR PEOPLE

113 University of Waterloo members

21 Non-University of Waterloo members

16 distinguished awards and honours

30 labs

21 areas of expertise

11 research chairs

4 University research chairs

SCHOLARLY OUTPUT

WISE hosted **31** visiting researchers, industry executives and government delegations

560+ member publications

21 Energy Council of Canada Fellowships since 2013 totaling **$284,500**

13 Cisco System Smart Grid Research Awards over five years totaling **$160,000**

OUR PEOPLE

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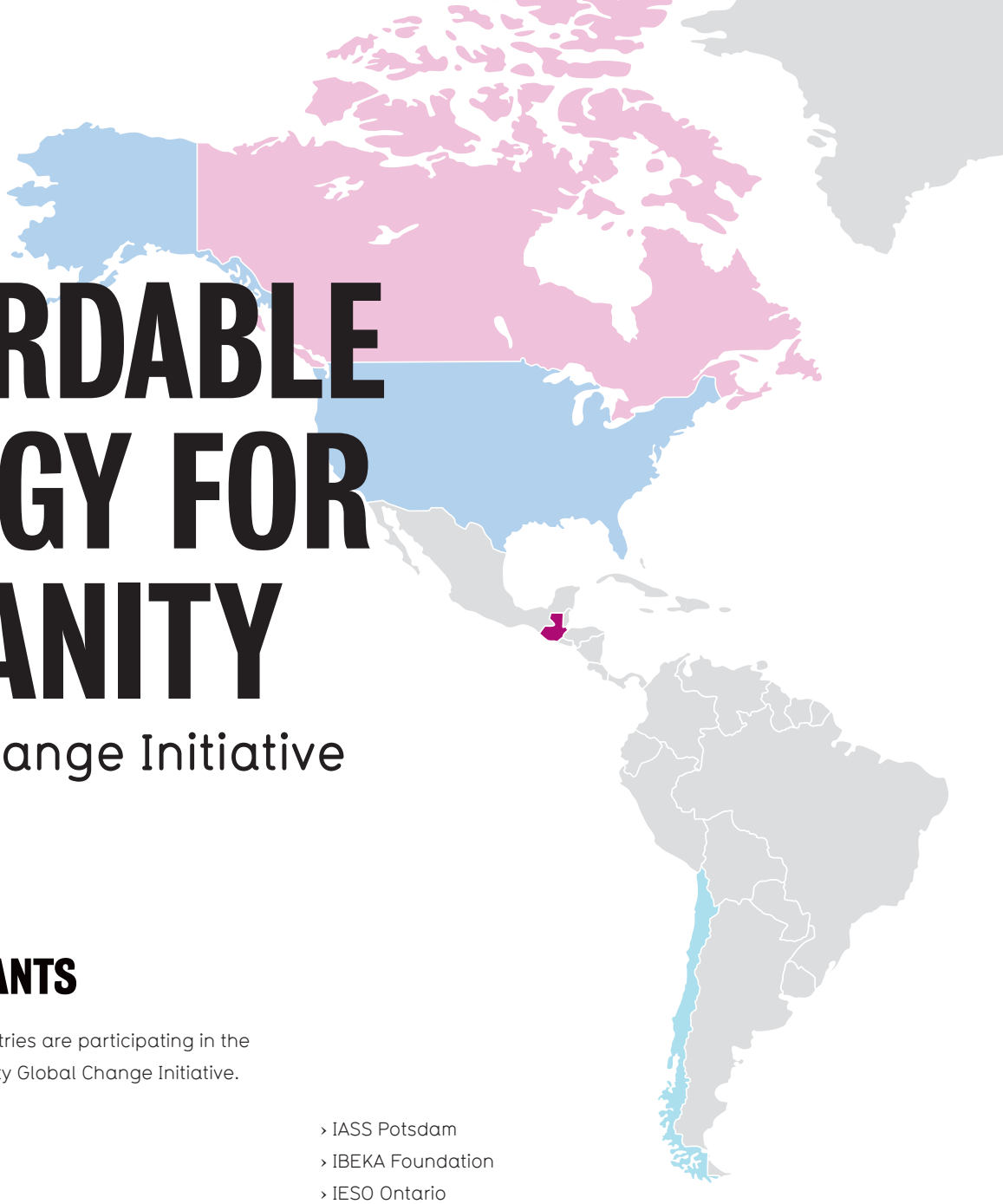
AFFORDABLE ENERGY FOR HUMANITY

A Global Change Initiative



AE4H PARTICIPANTS

50 organizations from 24 countries are participating in the Affordable Energy for Humanity Global Change Initiative.

- Aalborg University
- Aalto University
- Arizona State University
- Ashesi University
- Carnegie Mellon University
- Centre for Global Equality
- Denmark Technical University
- E3 Analytics
- Earthspark International
- Ecobee
- Endeva
- ENERGIA
- ENFUSE
- Engineering for Change
- ENVenture
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- IBEKA Foundation
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- Infinite Potentials Consulting
- Karlsruhe Institute of Technology
- Kenya Power and Lighting Company
- Le Centre National de la Recherche Scientifique
- Lehigh University
- Massachusetts Institute of Technology
- ME SOLshare
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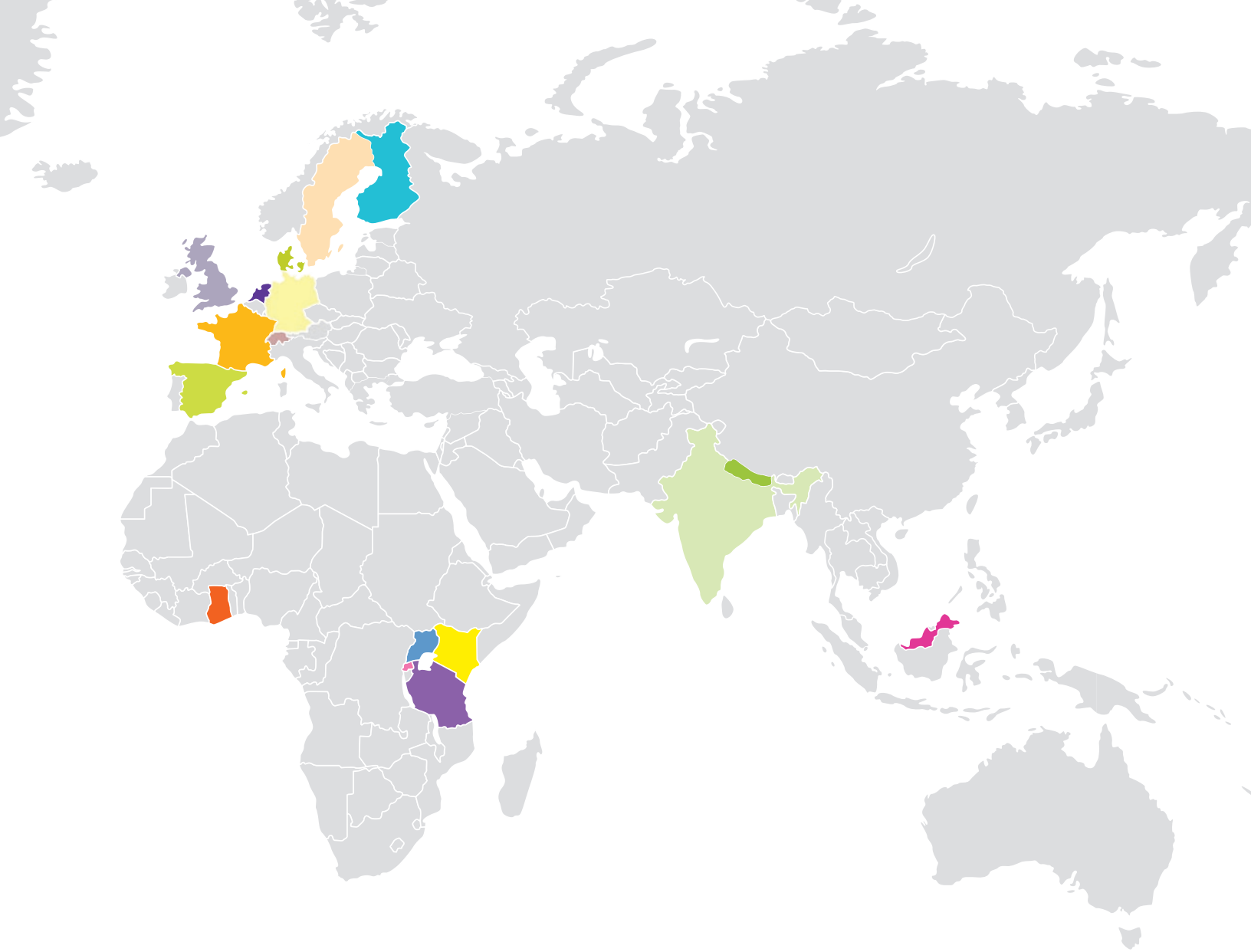

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