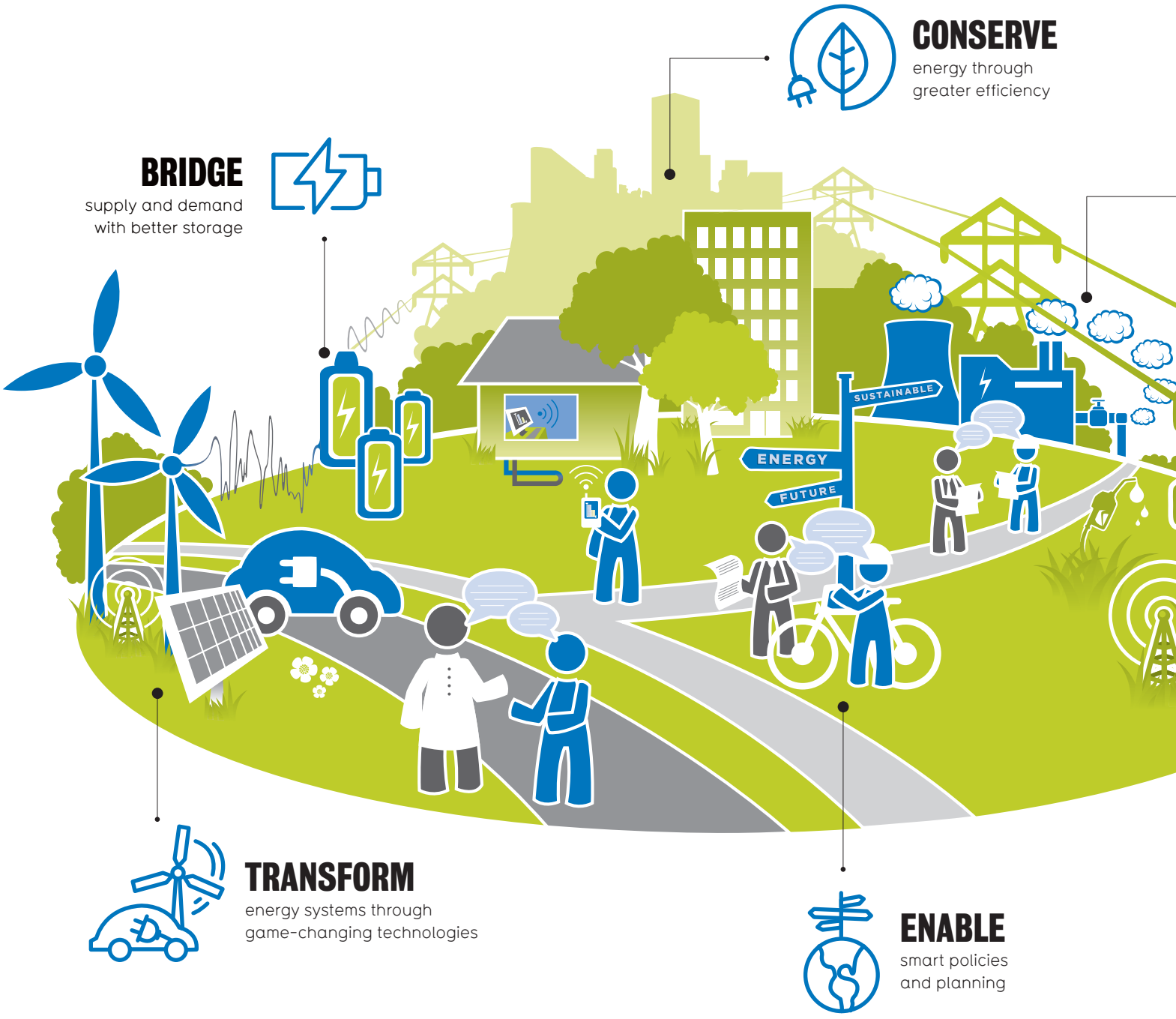
WISE annual report

Waterloo Institute for Sustainable Energy

2018–2019

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

I am pleased to present you our annual report 2018-2019 and confirm the renewal of the mandate of our institute by the university senate for the period 2019-2024.

Here, we recognize the achievements of our members who continue to make important contributions to the advancement of energy research nationally and internationally. Our work has a strong interdisciplinary focus and we remain committed to establishing partnerships for collaboration across faculties, departments and agencies and institutions external to the university.

Our efforts are directed at developing solutions to address the complex challenges of a global energy transition in harmony with emission scenarios consistent with global climate change targets. Mitigating the threat to climate change and providing access to energy that is clean and affordable for every global citizen put an enormous premium on our capacity for both technological and social innovations.

We are confident we will continue to build on our past success and our efforts will yield major global impacts through our research activities.

In the coming years, we will engage more deeply in crosscutting themes across social sciences, humanities, environment and STEM. We will explore linkages between energy, climate, water, health, education, economic inequities and work to integrate science into public policy.

JATIN NATHWANI, Executive Director

FROM THE VICE PRESIDENT, RESEARCH

The Waterloo Institute for Sustainable Energy (WISE) advances the global discussion on sustainable energy solutions. Through an interdisciplinary approach to research and innovative solutions, WISE researchers are transforming the energy system for long-term sustainability on a national and international scale. WISE researchers are at the forefront of alternative energy opportunities driving new knowledge and approaches that are shaping policy, technology and practice for a sustainable future.

I am delighted to share the stories of our researchers and students who are contributing to this critical discussion through the WISE 2018-2019 Annual report. These are the stories behind the research, technologies and solutions bringing affordable, reliable, sustainable energy to the world.

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

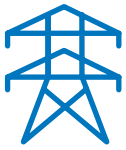
CONSERVE:

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 21 departments and encompasses every faculty at the University of Waterloo.

21 departments | **6** faculties


The Most Experienced
and Respected Name
in Geothermal.

FROM THE ASS
OF STRATEGIC
FACULTY OF ENVIRONMENT

Professor Paul Parker (WISE member and Associate Dean of Strategic Initiatives, Faculty of Environment) has been a significant research contributor to several WISE initiatives over the past decade. His research focuses on building sustainable communities by creating win-win opportunities for the environment and economy. He is particularly concerned with how local economic development strategies can achieve a sustainable future. Sustainable energy systems are an essential starting point, so he looks first at conservation and improving energy efficiency, then at renewable energy sources and smart grid networks as integral parts of community energy plans and net zero energy buildings and neighbourhoods. Professor Parker combines his strong research background with direct experience engaging local representatives from communities across Canada, and internationally, to envision and build local capacity, vitality and sustainability. Recently he has lead national economic development seminars in Edmonton, Iqaluit, Inuvik, Halifax, Saskatoon, Stratford, Sudbury, Thunder Bay, Quebec City and Whitehorse. Sustainable energy projects demand interdisciplinary teams and Paul works with many colleagues across campus, as well as those in his home Faculty.

For over 50 years the Faculty of Environment has been dedicated to having a positive impact. Faculty members in Geography & Environmental Management (GEM), Knowledge Integration (KI), School of Environment, Enterprise and Development (SEED), School of Environment, Resources and Sustainability (SERS), and School of Planning create knowledge, nurture learning and promote action to achieve sustainable energy futures in Canada and around the world. With interdisciplinary programs and research, our community of students, faculty, alumni, donors and staff make meaningful change happen in the classroom, the office, and in communities around the world. Our vision is to use our unique position

OCIATE DEAN INITIATIVES

as a leading teaching and research institute for the environment to create sustainable solutions needed to address the complex challenges facing our world.

Waterloo's Faculty of Environment hosts the Canadian chapter of the Sustainable Development Solutions Network (SDSN), an organization that has grown from the United Nations Sustainable Development Goals (SDGs) and the Paris Climate Agreement. It is "part of a global SDSN movement to build a network of universities, colleges, research centers, and knowledge institutions to promote practical solutions for sustainable development."

The Faculty also launched Entrepreneurship@Environment, in partnerships with Waterloo's Velocity and St. Paul's University College GreenHouse, to provide support for student entrepreneurship and ideation to solve SDG challenges. The initiative is supported by the Associate Dean of Strategic Initiatives and an Entrepreneur in Residence, and has facilitated numerous student and young alumni awards in pitch competitions.

With nearly 100 professors, 2,500 undergraduate students, 600 graduate students and high quality research programs, the Faculty attracts outstanding students from around the world. Together, they create innovative transdisciplinary research, education and training opportunities, including advanced understanding of the climate crisis and the rapidly approaching sustainable energy transition.

PROFESSOR PAUL PARKER,
Associate Dean of Strategic Initiatives, Faculty of Environment

EDUCATION AND TRAINING

7 FELLOWSHIPS TOTALING

$60,000 were awarded in 2018

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.

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 extend the analysis across the building stock market in North America in order to determine the potential environmental benefits in a typical city.

SCOTT MORTON NINOMIYA

SUSTAINABILITY MANAGEMENT

Scott'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. His 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 renewable energy as a tool for community sustainability, particularly in Atlantic Canada, and in remote off-grid communities throughout Canada.

HSIU-CHUAN CHANG

MANAGEMENT SCIENCES

Hsiu-Chuan is working on the allocation of community energy storages for households focusing on the optimization of solar systems using machine learning. The goal is to develop a robust framework for effective utilization of diverse distributed energy resources to reduce the carbon emissions profile of the Canadian energy system.

NICHOLAS PALASCHUCK

SCIENCE, BIOSCIENCE, TECHNOLOGY AND PUBLIC POLICY

Nick's research seeks to integrate community based energy systems as an alternative to conventional energy systems by creating functional linkages between local energy production and consumption with an eye to understanding how local perspectives and values shape transition processes towards low-carbon futures.

NITIN PADMANABHAN

ELECTRICAL AND COMPUTER ENGINEERING

Nitin's objective is to develop frameworks and models that will allow energy storage systems to effectively participate in the electricity markets for flexibility provisions at the wholesale and retail level and to evaluate their system and market impacts.

TRUZAAR DORDI

SOCIAL AND ECOLOGICAL SUSTAINABILITY

Truzaar's research examines financial sector resiliency in response to rapid decarbonization. This research seeks to gain a better understanding of how climate related risks and opportunities affect asset pricing and portfolio allocation.

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).

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.

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

- Geothermal Energy
- Battery Science
- Fuel Cells
- Microgrids
- A Global Change Initiative – Affordable Energy for Humanity (AE4H)

1 GEOTHERMAL ENERGY

WISE has identified development of geothermal energy as a strategic priority for advancing a low-carbon source of energy, both for heat and electricity. Geothermal energy is an important resource to help meet growing energy demand in developed and developing countries. Recent advances in drilling and hydraulic fracturing technologies for flow enhancement and Enhanced Geothermal Systems (EGS) based on hot/warm fluids from deep geological formations have a significant potential for power and heat applications. Also, geothermal systems can be easily integrated with solar and wind resources to provide storage capabilities.

Geothermal heat as a local source of energy is a reliable, resilient, and environmentally sustainable energy option feasible in different geographic contexts. Geothermal energy has merit for different applications: heating and cooling of buildings, generating electricity, and greenhouses operations. Resource availability is not dependent on weather or climate and can be used for heat and electricity almost continuously throughout the year. It is also possible to use geothermal projects as "thermal batteries", wherein waste or collected heat is stored for future use, seasonal arbitrage, making geothermal energy a promising non-carbon source of energy on large scale.

WISE members Professors **Maurice Dusseault** and **Madjid Soltani** (Earth and Environmental Sciences) have done a comprehensive study of geothermal heating and cooling methods and the history of geothermal energy district systems in different parts of the world. It was concluded that the four main categories of ground source heat pump systems i.e. (1) Geothermal Water Heater Pump (GWHP), (2) Ground-Coupled Heat Pump (GCHP), (3) Surface Water Heat Pump (SWHP), and (4) Standing Column Well (SCW) are dependable technologies for residential and commercial use, with better performances than air source heat pumps (with coefficient of performance (COPs) up to 4.9). They can be improved significantly by using them as hybrid systems in combination with heat rejecters or heat absorbers, depending on the climate conditions (with COPs up to 6); accordingly, hybrid systems can further reduce the consumption of energy.

The cold, remote, northern regions of Canada constitute a challenging environment for the provision of reliable energy and food supply to communities. A transition from fossil fuels to renewables-based sources of energy is one positive step in reducing the greenhouse gases from the energy supply system, which currently requires long-distance transport of diesel for electricity and heating needs. Geothermal energy cannot only displace diesel for part of this energy need, it can provide a base-load source of local energy to support food production and mitigate adverse impacts of food insecurity on communities.

Professor Dusseault, Professor **Jatin Nathwani** (Management Sciences), and Professor **Roydon Fraser** (Mechanical and Mechatronics Engineering) have studied the challenge of food security in northern environments and evaluated the technical and economic feasibility of producing vegetables in a "controlled environment", using ground sources of heat for energy requirements at three remote locations —

Resolute Bay, Nunavut, as well as Moosonee and Pagwa in Ontario. The system is designed for geothermal district heating combined with efficient use of nutrients, water, and heat to yield a diverse crop of vegetables at an average cost up to 50 per cent lower than the current cost of these vegetables delivered to Resolute Bay. The estimates of thermal energy requirements vary by location (e.g., they are in the range of 41 to 44 kW of thermal energy for a single greenhouse in Resolute Bay). To attain adequate system size to support the operation of such greenhouses, it is expected that up to 15 per cent of the annually recommended servings of vegetables can be provided. Notwithstanding high capital costs, the study demonstrates the technical and economic feasibility of producing vegetables cost-effectively in the cold northern climate. Highlighting the promise of geothermal energy systems that can supply the heat needed for greenhouse applications in remote northern regions. Reliable and robust source of cost-competitive sustainable energy provides a strong basis for improved food security and economic empowerment of communities.

MAURICE DUSSEAULT
Professor, Earth and Environmental Science

JATIN NATHWANI
Professor, Management Sciences

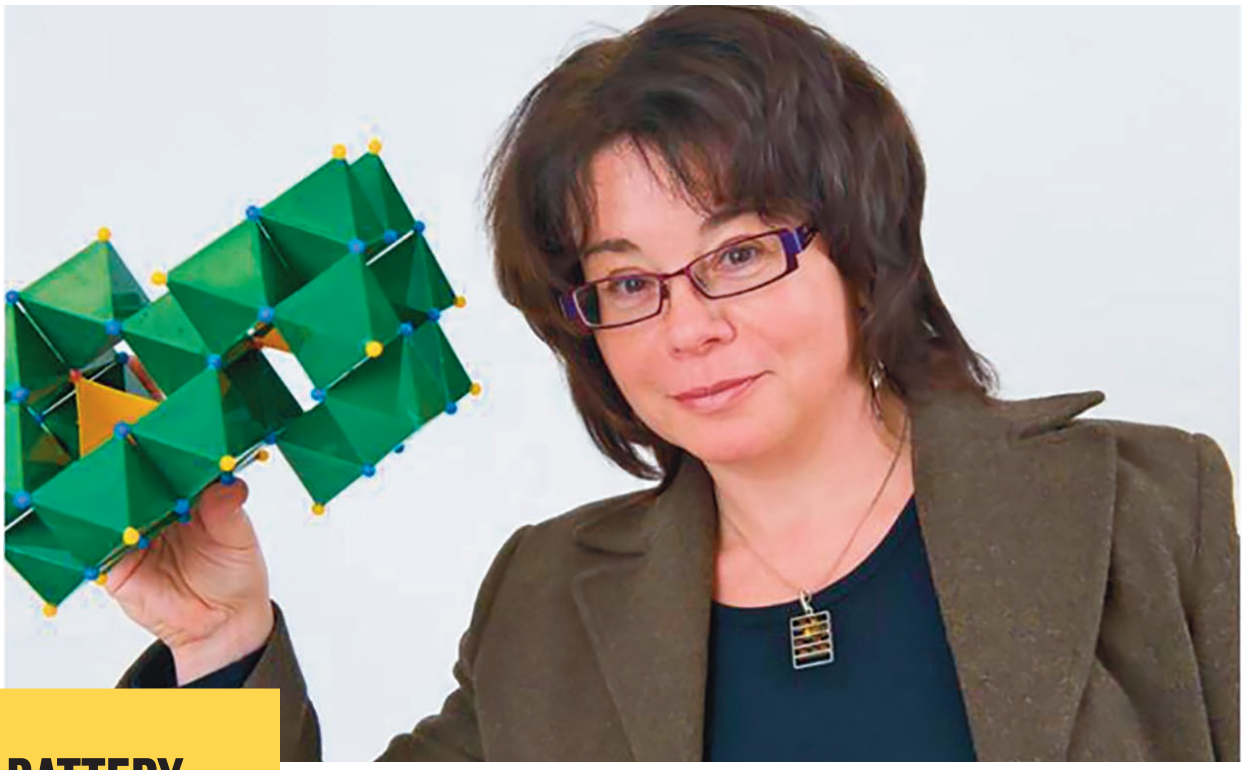
ROYDON FRASER
Professor. Mechanical and Mechatronics Engineering

Professor Dusseault and Professor Nathwani have also completed a first-order technical and economic feasibility study of the integration of different local energy sources (both renewable and non-renewable) with geothermal energy (deep and shallow) to establish a pathway for a more efficient, low-carbon, sustainable energy sources. The results of this analysis provide a strong basis for investment in modular small-scale integrated geothermal systems for seasonal heat storage and electricity services. The study provides a comprehensive evaluation of the needs and requirement for the provision of critical energy services to communities in Canada's northern region.

Professors Fraser and Dusseault have done a performance evaluation of an Enhanced Geothermal System (EGS) in the Western Canada Sedimentary Basin. In this study, a conceptual sedimentary EGS in the Williston Basin is investigated numerically. Thermo-hydraulic and hydro-mechanical coupled models are used to assess the thermal performance and stress evolution of a geothermal doublet system.

Using realistic properties of the target area, doublet spacing and recirculation flow rate are studied to evaluate the growth of the heat transfer volume. Introducing a more permeable zone (i.e., a fault or high permeability channel) across the flow path between wells does not shorten the useful reservoir lifetime; in fact, it delays cold front advancement by lateral broadening of the heat transfer domain.

As cold water is re-injected into the reservoir in a recirculation approach, large stress changes are generated, and the stress distribution and local stress gradients change with time through combined convective and conductive heat transfer. Although the rock model used represents an unfractured sandstone with negligible permeability sensitivity to effective stress changes, the authors note that for a naturally fractured reservoir the stress changes will have major impacts on flow paths (compressional versus extensional expansion) and hence temperature distributions and heat extraction behavior.



2 BATTERY SCIENCE

Advancements in battery science and storage has been identified as a critical enabler of an energy transition to a low-carbon energy system in light of rapid penetration of renewable energy sources (wind and solar) and parallel development of electric mobility in the transport sector.

WISE members are actively working on the technical aspects of battery design, manufacturing, and production to reduce the environmental footprint, minimize life-cycle cost and integrate smart materials for improved performances. The materials innovation is a central feature of the next generation battery technologies. Extensive R&D efforts address the challenges in the areas of energy density, drive cycles, battery management system (BMS), grid integration, frequency control in power systems with battery energy storage technologies and analysis of key operating parameters (voltage, temperature, charge rate, state of charge/discharge), and motor (tortque, speef, and temperature).

PU CHEN
Professor, Chemical Engineering

Professor Pu Chen (Chemical Engineering) and his team have demonstrated a promising ultrafast conversion reaction chemistry in an aqueous lithium energy storage system. The team has reported that a reversible conversion reaction can happen between Li+ and semicrystalline MnO_2 (scMO) prepared from a conventional $LiMn_2O_4$ (LMO) interaction material; as added benefits, this results in extreme fast charge/discharge rate and exceptional reversibility in aqueous lithium-ion batteries (ALiBs). In this study, the proposed mechanism, a crystalline LMO–semicrystalline MnO_2 (denoted as cLMO–scMO)/Zn rechargeable

hybrid aqueous battery (ReHAB) was constructed and shown to deliver a high cell-level power (5118 W kg^{-1}) and energy density (171 Wh kg^{-1}), with extraordinary long cycle life: 3,000 cycles without obvious fading in capacity. These parameters make cLMO–scMO based ReHAB a strong competitor for energy storage application where high power density is required, such as back-up supercapacitors in smart grids, start-stop batteries in automotive vehicles, as well as microcells in medical fields. This has the potential to meet the requirements of commercial electrical vehicles, such as Nissan Leaf and Tesla Model.

The battery industry anticipates the exploration of new electrochemistry beyond conventional lithium-ion intercalation technology to boost energy density and reduce the cost for electric vehicles. **Professor Linda Nazar** (Chemistry) and her team have built a model for a low E/S ratio Li–S battery by addressing the two central challenges i.e. (1) shuttling of the super-concentrated polysulfides, and (2) depletion of the electrolyte by the Li anode. They have demonstrated that by tuning the electrolyte structure they were able to optimize both electrodes synchronously, as opposed to solving problems on one aspect only. By using a diglyme electrolyte with a saturated LiTFSI salt, G2:LiTFSI (0.8:1), the team witnessed not only a transition in the sulfur speciation pathway from the conventional dissolution–precipitation to a quasi-solid state reaction, which thus inhibited polysulfide dissolution and shuttling, but also a greatly suppressed parasitic reaction with the Li anode, which delays electrolyte depletion at a low E/S ratio. Their approach relies on establishing a networked electrolyte structure – as proven by computational studies—that shows a reduced solvent activity, which leads to a sparing polysulfide solubility and low reactivity with Li. The group has showcased a significantly improved capacity retention for sulfur cells using a low E/S ratio of 5 µl mg^{-1} (720 mA h g^{-1} over 100 cycles, as opposed to 420 mA h g^{-1} over 20 cycles for the control electrolyte). This class of electrolytes also demonstrates reduced flammability and high safety, which is essential for electric vehicle applications.

Lithium-ion batteries are currently used extensively in modern devices and systems, including smartphones, electric vehicles, and grid-scale energy storage. Models of Lithium-ion batteries, that estimate their energy content after a series of charge and discharge operations, hence play a central role in the optimal design, analysis, and operation of these battery-based systems. To overcome the shortcomings of conventional models that have low fidelity at high C-rates (a measure of the rate at which a specific battery is discharged relative to its maximum capacity) and couldn't model the battery management system, **Professor Catherine Rosenberg** (Electrical and Computer Engineering) and **Professor Srinivasan Keshav** (Cheriton School of Computer Science) have proposed an alternative, called the Power-based Integrated model that is also completely spec-based, yet has much higher fidelity. Their team has performed two types of validation, the first one uses the voltage profiles in the spec while the other is based on laboratory experiments. Both validations confirm that their model, which they have publicly released as a Simulink system block, has a mean absolute voltage error of less than 0.1 V across a wide range of C-rates.

3 FUEL CELLS

Fuel cells utilizing hydrogen provide a promising alternate pathway for generating electricity with low environmental impacts. Fuel cells are a vital technology for multiple applications comprising on-site electric power for residential households and commercial buildings; supply auxiliary power to operate cars, trucks and aircrafts; power for other forms of transportation; and the integrated addition by power utility companies of new electrical generation customized to meet growth in power consumption.

Proton exchange membrane (PEM) fuel cells have unique characteristics, such as high energy-conversion efficiency, quick start-up and shut-down, fast response to instantaneous load changes, environmental benignity, and the ability to operate without moving parts.

Professor Xiangu Li and **Professor Feridun Hamdullahpur** (Mechanical and Mechatronics Engineering) have investigated the importance of membrane electrode assembly (MEA) conditioning for proton exchange membrane (PEM) fuel cells under various operating conditions, such as reactant flow and cell voltage-current combination by considering the impact of the cell hardware design. It has been shown that the MEAs conditioned with serpentine flow-field layouts on both the anode and cathode side have better performance than the MEAs conditioned with straight-parallel flow-field layouts, and that the peak power density can be increased from 0.83 W/cm^2 to 0.93 W/cm^2 (about 12 per cent increase) for the MEAs tested under the same operating condition using humidified hydrogen and air at atmospheric pressure. This performance improvement is mainly due to the under-rib convection of the reactant gases in serpentine flow-field layouts that provides more uniform conditioning of the entire MEAs.

4 MICRO-GRIDS

Microgrid systems that connect various distributed energy generation sources into a small network serving the needs of a small or rural community are an emerging technology that can deliver significant benefits, for example, low energy costs, maximize overall energy efficiency, local system resilience, stability and reliability, and improved environmental performance. Motivated by the evolution of modern electrical networks, hybrid AC/DC microgrids are gaining increasing attention, as they combine the benefits of both AC and DC distribution paradigms. On one hand, classic AC distribution networks can integrate both machine-based and electronically-interfaced distributed generation (DG) units, while providing conversion-free supply to AC loads such as induction motors and various home appliances. On the other hand, various renewable energy resources (RERs), energy storage systems (ESSs), and modern DC-based loads, such as variable speed drives (VSDs), plug-in electric vehicles (PEVs), and electronic devices can be integrated into DC networks, forming more efficient and economical distribution systems. Incorporating interlinking converters (ICs) permits power sharing between AC and DC subgrids in a hybrid microgrid architecture leading to potential improvements to overall system security and efficiency.

Professors Mehrdad Kazerani and **Ehab El-Saadany** (Electrical and Computer Engineering) have proposed a novel dynamic power routing (DPR) scheme for hybrid AC/DC microgrids operating in islanded mode, where unlike in grid-connected microgrids, local generation adequacy is crucial for proper system operation. The unbalanced nature of ac distribution networks limits the microgrid loadability in the sense that loads must be shed from heavily loaded phases, even if the connected distributed generators (DGs) have not reached their total three-phase capacity limits.

The main challenge is to exploit the available resources by routing the power between the ac subgrid phases, thereby minimizing load shedding. The proposed method utilizes the interlinking converters between the ac and dc sides of hybrid AC/DC microgrids to provide this functionality. A supervisory controller implements

a DPR-based optimal power flow (OPF) algorithm to allow full loadability of the islanded network. The formulated OPF problem is solved analytically using an interior point method that has proved to be computationally cost-effective. Many case studies are conducted to address the unbalance problem and to validate the effectiveness of the proposed strategy against conventional methods, which are based solely on optimal DG droop settings.

CLAUDIO CAÑIZARES
Professor, Electrical and Computer Engineering

In this study, it was suggested that the unbalanced nature of hybrid AC/DC microgrids restricts autonomous system operation under islanded mode. A higher layer of control is typically provided to coordinate the DGs' operation. Under heavy loading conditions, conventional supervisory controllers fail to adequately supply loads on heavily loaded phases even if the three-phase generation sufficiency criteria are satisfied. This study introduced a supervisory controller, implementing a novel dynamic power routing (DPR) technique that utilizes ICs to enable power routing among the ac subgrid's phases. The results demonstrate the ability of the proposed technique to better exploit the microgrid resources, thereby enhancing the system reliability. The results also prove the proposed scheme generic and effective for different microgrid sizes, configurations, and loading conditions.

Professor Claudio Cañizares (Electrical and Computer Engineering) has presented the mathematical formulation and architecture of a robust energy management system for isolated microgrids featuring renewable energy, energy storage, and interruptible loads. The proposed strategy addresses the challenges of renewable energy variability and forecast uncertainty using a two-stage decision process combined with a receding horizon approach. The first-stage decision variables are determined using a cutting-plane algorithm to solve a robust unit commitment; the second stage solves the final dispatch commands using a three-phase optimal power flow. This novel approach is tested on a modified International Council on Large Electric Systems (CIGRE) test system under different conditions. The proposed algorithm is able to produce reliable dispatch commands without considering probabilistic information from the forecasting system. These results are compared with deterministic and stochastic formulations. The benefits of the proposed control are demonstrated by a reduction in load interruption events and by increasing available reserves without an increase in overall costs.

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

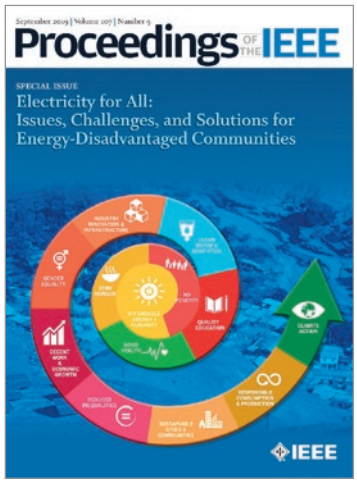
AE4H
Global Change Initiative

Since the establishment of the AE4H initiative by WISE in 2015, the consortium has grown to include more than 150 leading energy access researchers and practitioners from 59 organizations and 26 countries, focusing on the eradication of energy poverty. Scientific advisors representing the world's foremost post-secondary research institutions on the topic have also joined the initiative.

59 organizations

26 countries

We believe that it is not only a moral obligation but also a matter of global conscience that we expose the global community to technical, economic, policy, and social work and initiatives focused on addressing the plight of some 2.5 billion people in the world without reliable access to electricity or basic thermal energy services for cooking. Affordable energy is fundamentally connected to achieving development goals. Access to affordable energy is essential because of its direct role in water, food, and health security, as well as to social justice and equity. Increasing affordable energy access is also a transformative resource for those who live in extreme poverty (less than $1.25/day) and for the "proverbially" poor who survive on less than $2/day.



Building on the results of first AE4H Innovation Lab organized by WISE (at the Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany in 2017), Professors C. Cañizares and J. Nathwani (University of Waterloo) and Professor D. Kammen (University of California, Berkeley) have made a significant contribution as guest editors, to bring together and highlight the academic achievements of diverse researchers around the world in the Special Issue Publication of the Proceedings of IEEE (September, 2019).

PROCEEDINGS OF THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

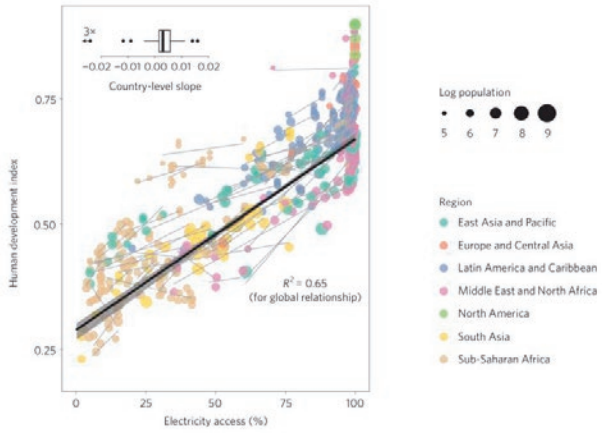
Energy access is a powerful multiplier of virtually all of the United Nations Sustainable Development Goals (SDGs). Energy services are intricately linked to the provision of adequate health and educational services that depend on a reliable infrastructure. Delivery of clean water and irrigation for agriculture, the capacity to transport produce to markets without spoilage, cooking with cleaner energy sources, reducing drudgery

and burden on women for critical household tasks, and economic empowerment of individuals through labor-saving devices all rely on affordable energy services. Universal energy access is now within reach but requires rapid diffusion of clean energy options.

The lead paper for this issue by Professor Nathwani and Professor Kammen identifies the need for a global movement to create an "Energy Access Extension Service for the Planet" as a powerful solution because of the need to focus coequally on knowledge creation, social and behavioral change, and both evolutionary and radical systems redesign.

The strategy for effective global change is to establish "energy access innovation centres" (EAICs) that bring into a sharp operational focus the creation and transfer of knowledge effectively and with urgency. The concept marks the transition from academic systems knowledge to practical implementation knowledge, based on robust and evidence-based empirical studies, direct feedback from end users, and deep engagement with communities to ensure adoption of solutions that meet the test of social and cultural acceptability.

Energy access is one key pathway for the reduction of endemic global inequality, but it will require radical progress in the development of scientific and technological solutions that can deliver aggressive cost reductions without compromising quality and significant improvements in performance. Low-cost energy becomes the driver of high-value impacts on life quality. The value of energy can be observed through many lenses, but certainly a simple and dramatic summary is how strongly and clearly across regions it correlates with the quality of life indicators, such as the human development index (HDI).



Lack of access is felt most acutely in regions of Sub-Saharan Africa (SSA) where 62.5 per cent of the population are without electricity, and Southeast Asia where 20 per cent of the population are without electricity. Within these energy-impoverished regions, a stark energy divide exists between urban and rural areas, with urban electrification at 97 per cent compared to rural electrification at 76 per cent. Despite recent progress, mainly in developing Asia, population growth continues to outpace electrification rates and future projections by the IEA suggest that by 2030 an estimated 670 million will still be without electricity (Ibid).

The basic aim here is to nurture and accelerate the "use-inspired basic research" for energy access on a global scale. To bridge the gap between leading research labs and impact-oriented organizations that work in the field, the research focus is to develop and test reliable and cost-effective strategies for reaching the goal of providing affordable, equitable, and clean access to energy supplies. Enhancing affordability through technological innovation is particularly important in meeting the needs of the most impoverished markets. For new technologies to be successful, they must be designed with a deep understanding of their use.

Leading university research labs around the world are engaged in the research on the topic of energy access – from technology to data analysis and modeling to policy, finance, community engagement, and so on. These research groups span the natural and social sciences' spectrum. They house a wealth of knowledge, resources, and capacity to develop new solutions, including those that can significantly reduce the costs of energy systems through breakthrough innovations.

Additional contribution in the Proceedings encapsulating the current global knowledge on this subject are as below:

Electricity for all: issues, challenges, and solutions for energy-disadvantaged communities

Edited by C. Cañizares, J. Nathwani, and D. Kammen

Affordable Energy for Humanity: A Global Movement to Support Universal Clean Energy Access

By J. Nathwani and D. M. Kammen

This article discusses and recommends a global network of Energy Access Innovation Centers (EAICs) dedicated to providing services that bolster solutions for energy-impoverished communities.

Data Standardization for Smart Infrastructure in First-Access Electricity Systems

By T. S. Ustun, S. M. S. Hussain, H. Kirchhoff, B. Ghaddar, K. Strunz, and I. Lestas

This article focuses on data standardization for electricity access and renewable-energy-based microgrids, since such data would play a significant role in the context of electricity access.

Review and Perspectives on Data Sharing and Privacy in Expanding Electricity Access

By J. T. Lee, J. Freitas, I. L. Ferrall, D. M. Kammen, E. Brewer, and D. S. Callaway

This article discusses the gathering and use of grid and end-user data, and examines how expanding access to data and data-sharing are likely to provide value and pose risks to key energy-access stakeholders.

Renewable Energy Integration in Alaska's Remote Islanded Microgrids: Economic Drivers, Technical Strategies, Technological Niche Development, and Policy Implications

By G. P. Holdmann, R. W. Wies, and J. B. Vandermeer

This article explores technical, socio-political, economic, and policy issues associated with the implementation of renewable-diesel hybrid microgrids in Alaska, including lessons learned.

Renewable Energy Integration in Diesel-Based Microgrids at the Canadian Arctic

By I. Das and C. A. Cañizares

This article presents planning models and studies that demonstrate the feasibility, impact, and benefits of introducing renewable energy together with variable speed generation technologies in remote microgrids in the Canadian Arctic.

Lowering Electricity Access Barriers by Means of Participative Processes Applied to Microgrid Solutions: The Chilean Case

By R. Palma-Behnke, G. A. Jiménez-Estévez, D. Sáez, M. Montedonico, P. Mendoza-Araya, R. Hernández, and C. Muñoz Poblete

This article discusses and illustrates a co-construction methodology for the development of sustainable energy supply solutions that exploit local renewable energy sources in actual energy-limited communities in Chile.

Optimal Electrification Planning Incorporating On- and Off-Grid Technologies: The Reference Electrification Model (REM)

By P. Ciller, D. Ellman, C. Vergara, A. González-García, S. J. Lee, C. Drouin, M. Brusnahan, Y. Borofsky, C. Mateo, R. Amatya, R. Palacios, R. Stoner, F. de Cuadra, and I. Pérez-Arriaga

This article describes and demonstrates an optimization model and program for electrification planning that identifies the lowest cost system designs for electricity access.

Distributed Resources Shift Paradigms on Power System Design, Planning, and Operation: An Application of the GAP Model

By J.-P. Carvallo, J. Taneja, D. Callaway, and D. M. Kammen

This article describes and demonstrates a capacity expansion model to assess the sequencing and pacing of centralized, distributed, and offgrid electrification strategies.

Least-Cost Electrification Modeling and Planning — A Case Study for Five Nigerian Federal States

By P. Blechinger, C. Cader, and P. Bertheau

This article presents a modeling process to derive a leastcost electrification plan for five states in Nigeria, combining energy system simulations with geospatial information system tools.

The Service Value Method for Design of Energy Access Systems in the Global South

By A. Clements, S. Wheeler, A. Mohr, and M. McCulloch

This article introduces and illustrates a novel method to gather and interpret end-user needs, aspirations, and contextual factors to improve engineering design practices for energy access in impoverished communities.

Electrical Minigrids for Development: Lessons from the Field

By A. S. Bahaj and P. A. B. James

This article describes and analyzes four identical capacity rural minigrid interventions undertaken in communities in Kenya and Uganda with differing socioeconomic characteristics and demographics.

Electrification Processes in Developing Countries: Grid Expansion, Microgrids, and Regulatory Framework

By A. Berizzi, M. Delfanti, D. Falabretti, S. Mandelli, and M. Merlo

This article presents a comprehensive review of the approaches and issues associated with microgrid electrification, discussing a “real-life” study case.

Microhybrid Electricity System for Energy Access, Livelihoods, and Empowerment

By M. Singh and P. Balachandra

This article reports a technoeconomic feasibility and sustainability analysis for a hybrid microgrid in India based on local solar PV and biomass resources.


AE4H
Global Change Initiative
AFFORDABLE ENERGY FOR HU
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IN PARTNERSHIP
WATERLOO
KIT
IASS
Mending Broken Lives Through Clean Energy Solutions
- Innovations for Humanitarian Chang
$100M
A Global Paradox
Our Values
We believe neither accident of birth, nor circ
beyond one's control - conflict, climate disasters -
should condemn our fellow citizens to a life of
despair and deprivation
Our Goals
Bring hope and opportunity to the displaced and the
Break the cycle of poverty
Create pathways for economic empowerment
Sustain the environment
Enhance healthy well-being
Our Plan
Accelerate adoption of
Solutions for global scalability
Build human capacity for positive change
Project Specifics
Refugee Camp
image here
Large-scale deployment of energy services
for clean water, cooking, education, health, mobility
Meet household needs at Tier 3 Level (1kWh, 200W 8hrs)
Integrate social, cultural and technological developmen
in concert
Micro-enterprises for income livelihood
Social innovations for skills development
all educational levels, genres or learning tools
Partnerships for Success
A Global Consortium of Partners
designed to amplify, animate
and advance UN SDGs - not as
a silo - but as an integrated whole
Nanitha
Image
Here
1 Billion

WISE EVENTS

ENERGY DAY 2018

MARCH 27, 2018

› Panel 1: Access to Clean Energy for All: Is Innovation the Problem?
› Panel 2: Getting to a Low Carbon World: Capture or Utilize?
› Panel 3: Block chain in the Energy Sector: Bust or Bonanza?

ONTARIO TESLA ASSOCIATION ANNUAL MEETING

May 1, 2018

› The Waterloo Institute for Sustainable Energy (WISE) hosted the Annual Conference for the Tesla Owners Club – Ontario association at University of Waterloo on May 1st, 2018.

› University of Waterloo has now become the first institution of higher learning to have installed a smart EV charging infrastructure in support of research to the energy and the auto sector.

› The event was intended to bring enthusiastic Tesla owners, researchers, innovators, and entrepreneurs to explore the advancements of electric vehicles (EVs) in Canada's transportation sector. Professor Nathwani, as a guest speaker, has highlighted the emerging innovations in the energy sector globally that would shape the future role of electric mobility as a key driver of decarbonization at the national level. He has provided a perspective on the scope and scale of transformation of the energy system required to reduce the threat to climate change arising from use of fossil fuels. The transport sector is a large contributor to greenhouse gas (GHG) emissions and a rapid transition to non-carbon form of energy for mobility services is part of the answer.

› Electric Mobility in all modes of transport will emerge as a key plank in the tool-kit for positive change. The arrival of electric cars coupled with widespread policy support at national levels including Canada is an indicator that a pivotal moment has arrived. Beyond electric cars displacing gasoline vehicles, new business models are emerging that recognize the value of the storage capacity in EVs as support for ancillary services to the grid. The car changing places with the grid-and the car owner as a grid operator-is not too farfetched from reality. Such a paradigm shift will have a profound impact on our ability to make a positive change for an energy transition that is in alignment with aspirational national targets for GHG reduction.

› The Tesla Owners Club of Ontario is comprised of friendly and enthusiastic Tesla owners and reservation holders. The club is a member of Tesla Motors' official Owners Club program.

RESOURCE RECOVERY PARTNERSHIP WORKSHOP 2018

June 21-22, 2018

› Circular economy: is there an integrated approach to sustainable energy and sustainable materials management?

› Competing philosophies of the sustainable economy: is there "one" right answer?

› Waste as feedstock – technology – end markets: can we close the loop to maximize resource efficiency?

› Exploring the versatility of recovery technologies: we can discover the many hidden methods and sources to achieve sustainable energy.

› Charting the path to a sustainable economy by: identifying the financial, legislative and market challenges, impediments and opportunities for advancing the "4th R".

BUILDING SCIENCE SYMPOSIUM INNOVATION IN BUILDING SCIENCE: TRANSITION TO LOW CARBON ENERGY BUILDINGS

October 31, 2018

› Panel 1: The Business of Future Low-Carbon Buildings
› Panel 2: Innovation in Achieving Low-Carbon Buildings
› Panel 3: Technologies for a low-carbon future Bust or Bonanza?

TECHNOLOGY INNOVATION AND POLICY FORUM 2018

November 7, 2018

Event title: *Unlocking Energy Innovation for a 'Low Cost-Low Carbon' Economy*

› Panel 1: The Promise and Perils of Technology Disruption
› Panel 2: Financing Energy Businesses: The Good, the Bad and the Ugly

THE AESTHETICS OF RENEWABLE ENERGY: DESIGNING A POST CARBON CULTURE

November 8, 2018

› The great global energy transition that is required to stem the tide of climate change will have an impact on our built environment and our visual landscapes like no other technical shift since the automobile.

› Rather than ask the public to sacrifice the aesthetic of our cities to a monoculture of solar panels and wind turbines, the Land Art Generator Initiative (LAGI) presents new energy infrastructures that are expressions of local culture and that strive to enhance the beauty of cities and landscapes.

THIRD AGE LEARNING KW: ENERGY ACCESS FOR HUMAN BETTERMENT

February 5, 2019

› Energy remains a fundamental enabler of human betterment. Affordable access is the key step on the ladder to an improved quality of life for billions without clean energy for heat, light, water, food or medical care. Solutions that are low cost, robust and scalable on a massive scale are required to deliver on the UN promise of sustainable energy for all.

› Professor Nathwani will highlight the foundational basis of scientific, technological and social innovations needed to drive an energy revolution to make energy poverty a footnote of history.

WISE PARTICIPATION

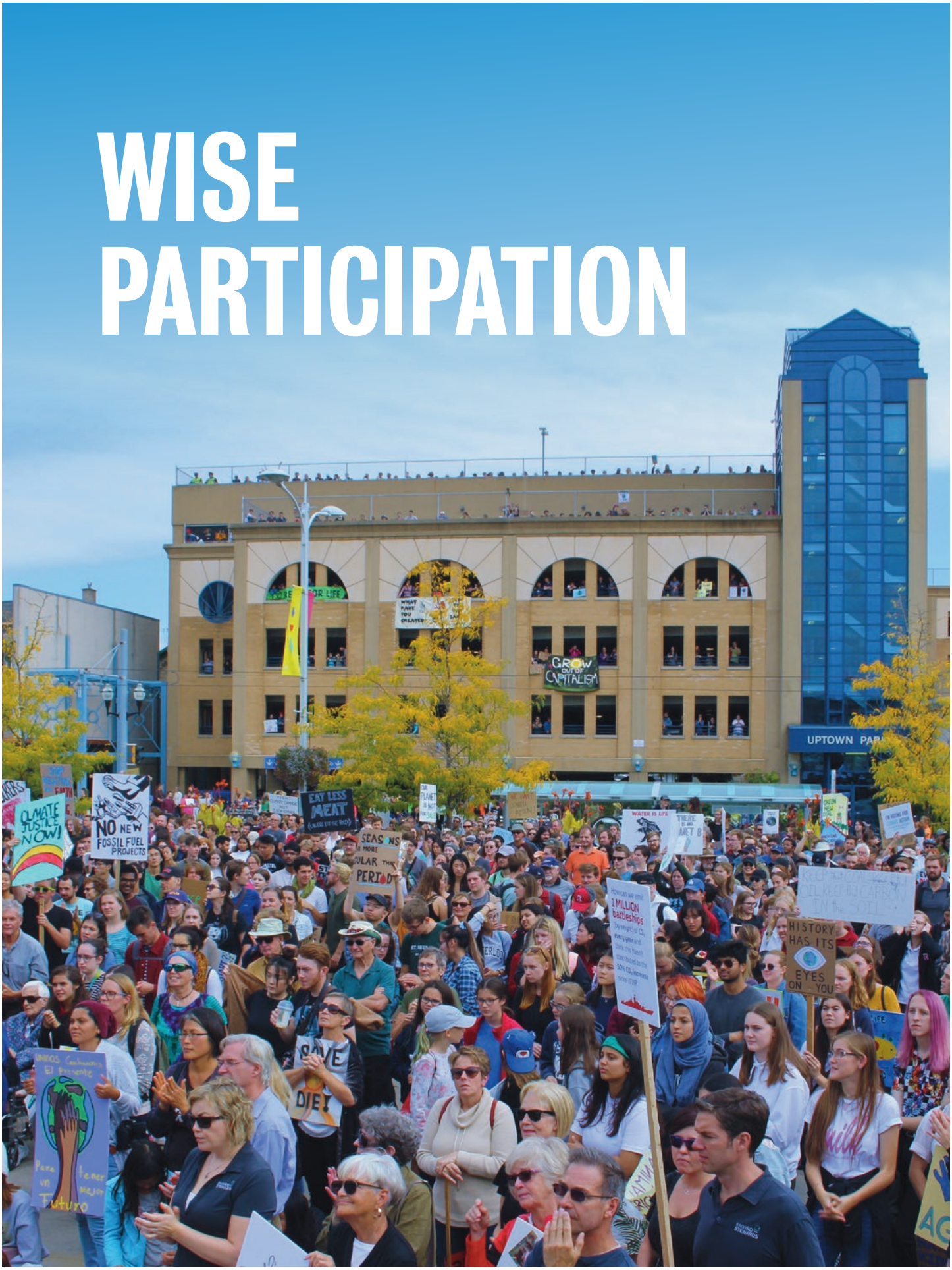


Photo Credit: Erin Perri

POWERING OUR FUTURE PLANET; GEOGRAPHY 2050 – ENERGY POLICIES AND ENERGY FUTURES

New York City, NY | November 15-18, 2018

WISE Executive Director **Jatin Nathwani** gave this invited talk at the American Geographical Society Plenary Session held in New York City.

NET ZERO EMISSIONS: A SUSTAINABLE STRATEGY FOR THE LONG FUTURE?

Kyoto, Japan | October 7-9, 2018

Professor **Jatin Nathwani** Chaired and was a Speaker at the STS Forum, 15th Annual Meeting of the Science and Technology in Society.

SUSTAINABLE DEVELOPMENT NETWORK (SDSN) CANADA NATIONAL LAUNCH

Waterloo, ON | May 7-8, 2018

WISE Member and University of Waterloo President **Feridun Hamdullahpur** and Vice President of Research **Charmaine Dean** participated at the Sustainable Development Network (SDSN) Canada National Launch. J.G. Hagey Hall of the Humanities, Humanities Theatre at University of Waterloo.

INTERNATIONAL WORKSHOP: GEOMECHANICS OF SHALE GAS AND ENERGY STORAGE

Wuhan, China | May 15-17, 2018

WISE Member **Maurice Dusseault** was part of the this workshop where he discussed grid-scale CAES facility and valuable ancillary services that could help to manage electrical grids, and rapid large changes in power inputs, allowing large increases in the percentages of renewable energy use.

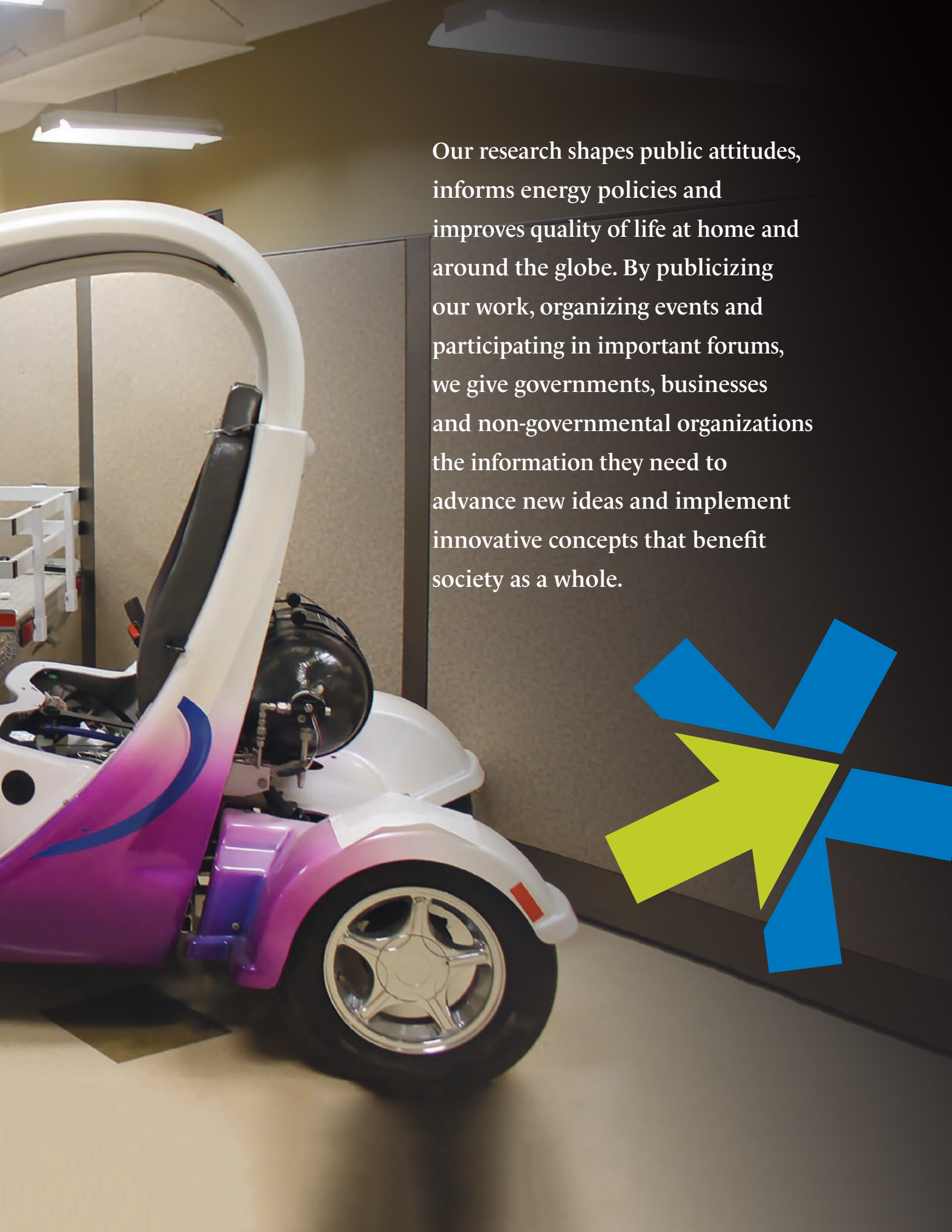
"SULPHUR WATER" AND THE LEGACY GAS WELLS OF SOUTHWESTERN ONTARIO

Waterloo, ON | April 4, 2019

WISE Member **Maurice Dusseault** gave a Water Institute public lecture presentation on the emission of methane and hydrogen sulphide gas from legacy gas wells in southwestern Ontario as an emerging public-health issue.

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

PUBLIC LECTURE SERIES

JUNE		
Dr. Sriram Narasimhan	Associate Professor, Canada Research Chair, Smart Infrastructure Civil and Environmental Engineering, Mechanical and Mechatronics Engineering	Actualizing Smart Infrastructure to Enable Data-Driven Asset Maintenance Decisions
Dr. Rebecca K. Saari	Assistant Professor, Civil and Environmental Engineering	Health Impacts of Climate Change and Climate Policy
JULY		
Sankaran Ramalingam	WISE Senior Research Fellow, University of Waterloo	Decoding the Energy Access Puzzle: An Overview of an Experiment at the Grassroots Level
David Thompson	Project Manager, Technical Services, Walker Environmental	Biogas - Resource Recovery and Clean Tech
AUGUST		
Professor Emeritus Jaan Timusk	Civil Engineering, University of Toronto	Can Building Science save the Day?
SEPTEMBER		
Dr. Jason Jonkman	Senior Engineer, NREL	The New FAST.Farm: Wind Farm Design and Analysis
Vikram Singh	Director of Advanced Planning, Alectra Utilities	Blockchain: A New Foundation for Distributed Energy Resources
OCTOBER		
Professor Pierre Pinson	Centre for Electric Power and Energy (CEE), Electrical Engineering, Technical University of Denmark	Show me your forecasts, I will show you mine! Are we moving towards energy data markets?
NOVEMBER		
Robert Ferry and Elizabeth Monoian	Co-Directors, Land Art Generator	The aesthetics of renewable energy: designing a post carbon culture
JANUARY		
Roydon Fraser	Teaching Chair and Professor, Mechanical and Mechatronics Engineering	Exergy Destruction Principle: Is the optimum thermodynamic system one that maximizes it's use of exergy?
MARCH		
Paul Doherty	Continuing Lecturer, Stratford School of Interaction Design and Business	Are Small Nuclear Reactors the Answer to Sustainable Energy for Canada?
APRIL		
Umar Waqas	P.ENG, CEM, Director, Engineering Services, Energy+ Inc.	Utility of the Future – Perspective from a Local Distribution Company

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.

SMART CHARGERS AMP UP ELECTRIC VEHICLE RESEARCH

RESEARCHERS: Roydon Fraser + WISE Team of 21 Faculty

MAY 2018

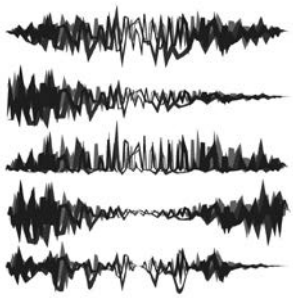
In April, Waterloo became the first Canadian university to install smart charging infrastructure for electric vehicles (EVs). That is good news for anyone on campus who wants to charge up for free. It's even better news for the 21 WISE faculty whose research focuses on EVs.

Unlike regular chargers, these units optimize charging patterns based on demand levels and time-of-use electricity costs. They also collect a wealth of detailed data to help investigators shed light on critical issues of grid management and next generation EV design.

SEPARATING THE NOISE FROM THE DATA IN NUCLEAR POWER PLANTS

RESEARCHERS: Mahesh D. Pandey, Bo Li

JUNE 2018

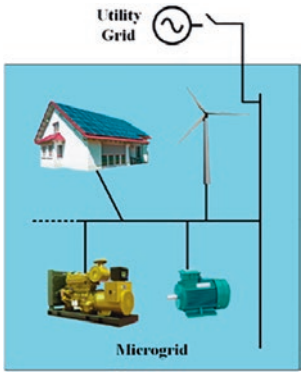


To ensure nuclear power plants are running safely, operators closely scrutinize a slew of different measurements, monitoring for any signs of wear-out. Take the example of the electro-hydraulic system controlling the plant's turbines. Operators collect weekly samples of the control fluid, looking for an uptick in acids that indicate the fluid is starting to break down.

The problem is deciphering what are the important, underlying trends and what is simply noise in the data — short-term fluctuations caused by variations in the chemical processes and environment.

Pandey and Li used simulations to test this approach and then applied it to real data taken from control fluids at a nuclear plant. The results gave plant operators a clear picture of acid levels in the fluid — and hence how well the plant's maintenance methods are working.

POWERFUL TOOLS FOR ANALYZING POWER FLOW OF MODERN MICROGRIDS



RESEARCHERS: Mehrdad Kazerani, Mahmoud A. Allam and Amr A. Hamad

JULY 2018

Microgrids integrate small-scale electrical energy sources and energy storage systems into local electrical distribution grids. This modern concept facilitates the integration of renewable energy sources, such as solar and wind energy, for greener energy generation. Microgrids are potentially more reliable than conventional electrical distribution networks because they can operate independently if disconnected from the main utility grid under any circumstance. As a result of their new and unique operational philosophy, the tools used to analyze power flow in traditional electricity grids simply cannot do the job for microgrids.

That is why WISE researcher, Mehrdad Kazerani and his PhD student set out to develop a robust algorithm capable of analyzing power flow in complex microgrids operating under a variety of conditions. Their goal was to develop an approach that would work with the two possible methods for controlling frequency and voltage within a microgrid: droop control and isochronous control.

RESEARCH SPOTLIGHTS

NO BATTERIES REQUIRED: SELF-POWERED SENSOR USES AMBIENT ENERGY

RESEARCHERS: Hassan Askari, Ehsan Asadi, Amir Khajepour, **Behrad Khamesee**

AUGUST 2018

The world is filled with ambient energy: stray heat, vibrations, electromagnetic fields and more that pulse all around us. Instead of letting those resources go to waste, WISE researchers are taking full advantage of them. In the case of a team led by Waterloo mechanical and mechatronics engineering professors Amir Khajepour and Behrad Khamesee, that means designing a self-powered sensor that taps into two different forms of freely available energy.

One is movement. Hassan Askari a PhD student of Khajepour and Khamesees' team used a coil and magnet to generate electricity from mechanical energy. When anything from vibrating machinery to a jogger's heel hitting the pavement compresses the coil, the magnetic field generates electrical current.

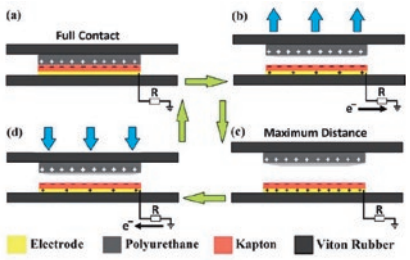


Fig. Mechanism of the TENG component of the self-powered sensor under one cycle of pressing and releasing

SELF-POWERED SENSORS COULD HELP AVOID BLACKOUTS

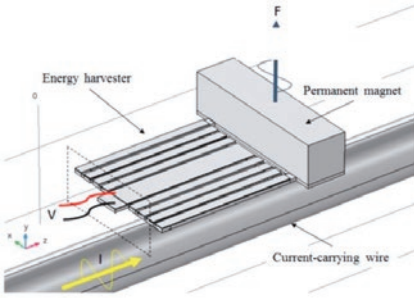
RESEARCHERS: Armaghan Salehian, David Nairn, Lan Wei, Hélène Debéda, Egon Fernandes, Blake Martin, Isabel Rua, and Sid Zarabi

SEPTEMBER 2018

As the electricity grid ages, blackouts become more likely. Placing sensors at strategic locations along transmission lines would allow grid managers to detect faults or fluctuations before they cause major headaches. However, powering those sensors with batteries would require replacing the batteries every couple of years — an expensive proposition when you consider the labor involved.

That makes the idea of self-powered sensors very attractive. Once installed, they would keep working, year after year, without human intervention.

Now, WISE researchers have developed the technology to make that possible. A team led by Professor Armaghan Salehian (Director of Waterloo's Energy Harvesting and Vibrations Lab), Professor David Nairn and Professor Lan Wei (Electrical and Computer Engineering), have designed a system that takes advantage of the alternating magnetic fields created by the A/C electricity that flows through power lines.



DETECTING FAULTS IN SUPERHIGHWAYS

RESEARCHERS: Sahar Pirooz Azad and Dirk Van Hertem

OCTOBER 2018

Electricity is often generated hundreds of kilometers from where it's consumed. (Think offshore wind farms and remote hydroelectric dams.) The most efficient and economical way to move electricity over those kinds of distances is through high-voltage direct current (HVDC) transmission lines — so-called "power superhighways."

However, addressing faults like voltage or current spikes and short circuits is far more difficult in an HVDC grid than in a standard AC grid, because they travel so much faster. WISE researcher Sahar Pirooz Azad is tackling that issue. Together with Belgian collaborator Dirk Van Hertem, Azad has developed a relaying algorithm that can detect an HVDC fault and identify its location in a fraction of a millisecond, making it possible to contain the problem quickly.

BLOCKCHAIN BOOSTS GREEN POWER MARKETS

RESEARCHERS: Srinivasan Keshav

NOVEMBER 2018

Block chain can do more than drive cryptocurrency transactions, according to WISE researcher Srinivasan Keshav. The computer science professor also sees opportunity to let small-scale energy producers sell green electricity to the highest bidder.

Currently, a homeowner with a dozen photovoltaic panels on her roof has only one option for selling the electricity she produces: to the local utility at a price established by government.

But as Keshav points out, lots of companies are keen to prove their eco-credentials by buying renewable energy certificates (RECs) to offset the carbon-intensive electricity they use. Unfortunately, certifying RECs is cumbersome and expensive, putting it beyond the reach of smaller producers.

DRY IDEAS: DESIGNING BUILDINGS WITH MOISTURE IN MIND

RESEARCHERS: John Straube

DECEMBER 2018

When the three little pigs built their houses, their top priority was protection from a huffing, puffing wolf. But according to WISE member and civil engineer John Straube, the biggest concern when it comes to building performance is actually water.

In every climate zone on Earth, houses must be designed to handle moisture, whether it's rain on the outside, condensation on the inside or leaks in the plumbing system. In August, Straube shared the latest research on moisture physics at the 2018 Westford Symposium on Building Science — an annual event that attracts some of the best and brightest researchers and practitioners in the field.

RESEARCH SPOTLIGHTS

A NANO-SIZED SOLUTION TO GLOBAL WARMING

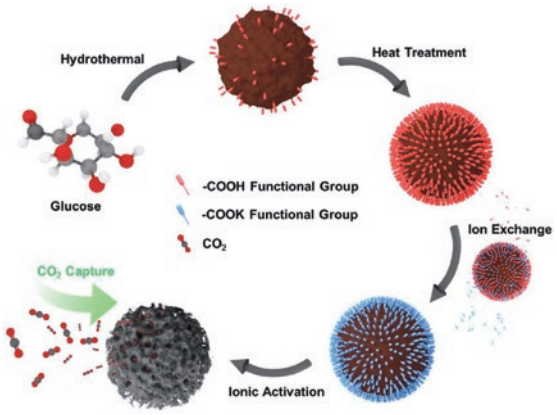
RESEARCHERS: Zhongwei Chen, Zhen Zhang, Dan Luo, Gregory Lui, Gaoran Li, Gaopeng Jiang, Zachary Paul Cano, Ya-Ping Deng, Xiaojuan Du, Song Yin, Yifei Chen, Minhua Zhang, Zifeng YaN

JANUARY 2019

To prevent global warming from reaching catastrophic proportions, we need to slash greenhouse gas emissions. The question is how. WISE researchers have a nano-sized solution: tiny balls that trap CO_2 emissions within smokestacks before they wreak climate havoc.

For a number of years, investigators have recognized that porous carbon can adsorb CO_2. Now a team led by Waterloo's Zhongwei Chen has developed a way to maximize that useful property.

This powerful carbon-capture technology could play a big role in limiting climate change. However, the applications do not stop there. Chen and his colleagues see potential to use the nanospheres in water purification, energy storage and more.



A BETTER MODEL FOR EV BATTERY PERFORMANCE

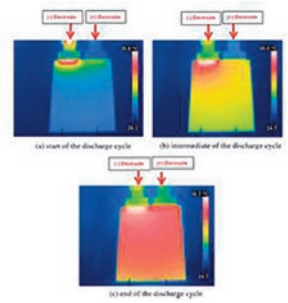
RESEARCHERS: Roydon Fraser, **Michael Fowler**, S. Panchal, M. Mathew, I. Dincer, M. Agelin-Chaab

MARCH 2019

An electric vehicle (EV) is only as good as the battery that powers it. Battery performance drives vehicle performance and reliability — and ultimately the willingness of consumers to trade their conventional car for an electric version.

Various numerical models have been developed to predict the behavior of batteries. However, to be useful to EV designers, they have to reflect real-world conditions as accurately as possible. That is where WISE researchers come in.

A team headed up by mechanical engineering professor Roydon Fraser and chemical engineering professor Michael Fowler started by collecting road data from an electric vehicle. They drove the car under a variety of conditions: aggressive highway driving, stop-and-go traffic around town and outdoor temperatures ranging from two to 17 degrees Celsius.



PUBLICATIONS

SELECTED MEMBER PUBLICATIONS

Tamimi, B., and **Cañizares, C.** (2018). Modeling and Application of Hybrid Power Flow Controller in Distribution Systems. *IEEE Transactions on Power Delivery*, 33 (6), 8424044, 2673-2682.

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Leterme, W., **Azad, S.**, and Van Hertem, D. (2018). HVDC grid protection algorithm design in phase and modal domains. *IET Renewable Power Generation*, 12 (13), 1538-1546.

Todescato, M., **Simpson-Porco, J.**, Dorfler, F., Carli, R., and Bullo, F. (2018). Online distributed voltage stress minimization by optimal feedback reactive power control. *IEEE Transactions on Control of Network Systems*, 5 (3), 7967778, 1467-1478.

Allam, M., Hamad, A., **Kazerani, M.**, and **El-Saadany, E.** (2018). A novel dynamic power routing scheme to maximize loadability of islanded hybrid AC/DC microgrids under unbalanced AC loading. *IEEE Transactions on Smart Grid*, 9 (6), 7907166, 5798-5809.

Yilmaz, M., and **El-Shatshat, R.** (2018). State-based Volt/VAR control strategies for active distribution networks. *International Journal of Electrical Power and Energy Systems*, 100, 411-421.

Malik, M., Mathew, M., Dincer, I., Rosen, M., McGrory, J., and **Fowler, M.** (2018). Experimental investigation and thermal modelling of a series connected LiFePO4 battery pack. *International Journal of Thermal Sciences*, 132, 466-477.

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AWARDS AND RECOGNITION

CANADIAN ACADEMY OF ENGINEERING (CAE) FELLOWS

Professor Susan Tighe (Civil and Environmental Engineering)

Waterloo Engineering professors and graduates were inducted into the Canadian Academy of Engineering (CAE) on June 18. One of the fellows were a WISE member Professor Susan Tighe from the Department of Civil and Environmental Engineering. The CAE is the national institution through which Canada's most distinguished and experienced engineers provide strategic advice on matters of critical importance to Canada. She is currently the Deputy Provost and Associate Vice-President, Integrated Planning and Budgeting at University of Waterloo. She is a member of several committees and councils, including Senior Vice President of the Canadian Society of Civil Engineering, Chair of the American Society of Civil Engineering Infrastructure Systems Committee, Member of the Transportation Association of Canada Chief Engineers Council and Past Chair of the Transportation Association of Canada Soils and Materials Standing Committee, and Transportation Foundation Scholarship Committee. She has been involved with research projects both in Canada and abroad. Her research interests include: solar PV based roads, climate change, smart infrastructure, pavement design and management, asphalt pavements, material characterization; life cycle cost analysis, airport engineering, sustainability, concrete pavements, pavement performance modelling, infrastructure management, maintenance, and advanced manufacturing.

ROYAL SOCIETY OF CANADA (RSC)

Feridun Hamdullahpur, Waterloo's president and vice-chancellor, is named a Specially Elected Fellow, a designation that recognizes individuals who have made exceptionally valuable contributions to promoting the objectives of the RSC in ways that contribute significantly to Canadian society. Hamdullahpur is named for advancing equity in higher education including as a United Nations HeForShe Impact Champion and for his leading work with co-operative education and entrepreneurial programming. Waterloo's reputation nationally and internationally is furthered by his work and commitment to research excellence, equity, and education. His visionary leadership continues to be a hallmark of the University's success as a premier research university. This recognition from the prestigious Royal Society of Canada is truly an honour. Feridun Hamdullahpur is an engineer, educator and leader with a career in research and higher education spanning more than 35 years. A professor of mechanical engineering, Hamdullahpur has served in various academic and administrative roles. His research expertise comprises of energy conversion systems, fluidized beds: hydrodynamics and combustion, hydrodynamics of gas-solid two-phase flow systems, cyclone modeling, fluidized bed drying, fluidized bed gasification of bio-mass, and solid oxide fuel cells.

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59 organizations

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